Paper No. 81

Bulletin of the Indian Society of Earthquake Technology, Vol. 6, No. 4, pp. 185-194, Dec. 1969

A NOTE ON THE SEISMIC ZONING MAP OF INDIA*

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Abstract

The paper describes the basis and procedure adopted in the preparation and revisions of the Seismic Zoning Maps of India adopted for use in Indian Standard Recommendations/ Criteria for Earthquake Resistant Design of Structures and Code of Practice for Earthquake Resistant Construction.

Introduction

Based on the available data on geology, tectonics and past earthquake occurances, various attempts have been made to prepare earthquake zoning maps of India. In these maps the country was divided into three to four zones indicating, probable occurrence of the earthquakes (frequent, occassional, few) or probable accelerations (10 to 30 percent gravity, less than 10 percent gravity, ete.,) or likely intensity of damage (heavy, moderate, slight, etc.) or factor of safety to be adopted in the design of structures etc. These maps thus served limited purpose. With the development of earthquake engineering studies in the country, a systematic study of the various aspects of the earthquake problems was initiated and it was felt that standard recommendations for the earthquake resistant design of structures be prepared and the seismic risks involved in various parts of the country be indicated. The Indian Standards Institution, which was entrusted with this problem, brought out the first Indian Standard Recommendations for Earthquake Resistant Design of Structuees (IS:1893-1962) in 1962. This note describes in brief the basis which appears to have been followed in the preparation of the seismic zoning maps of India incorporated in this standard and its subsequent revisions.

1962 Seismic Zoing Map

In the formulation of the Indian Standard Recommendations for Earthquake Resistant Design of Structures it was considered necessary to have a seismic zoning map to indicate broadly the seismic coefficients that could generally be adopted for design in different parts of the country, though it was noted that the seismic coefficients used in the design of any structure is dependent on many variable factors and a rigorous analysis considering all the factors involved has got to be made in the case of all important projects in order to arrive at suitable seismic coefficients for design. With this in view a seismic zoning map dividing the country into various zones was prepared giving for each zone a reasonable estimate of the intensity of earthquake which will occur in the event of a future earthquake. The map prepared had seven zones and was prepared considering that a rational approach to the problem would be to arrive at a zoning map which show the maximum intensity (M.M. Intensity scale) of earthquakes likely to occur at each point based on data of the known earthquakes, assuming all other conditions as being average, and to modify such an average idealised isoseismal map in the light of tectonics, geology, soil conditions and the maximum intensities as recorded from damage surveys.

The following procedure appears to have been followed in preparing 1962 seismic zoning map shown in figure 1 : (1) the epicentres of all known earthquakes of magnitude 5

* Detailed comments on this note are solicited.

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and above and Maximum intersities at various points were plotted from the isoseismals of major earthquakes for which records were available. Since the 1819 Kutch Earthquake, 1897 and 1950 Assam Earthquakes, 1905 Kangra Earthquake, and 1934 Bihar Nepal Earthquake were of very high magnitudes, they adequately encompassed the effects of the lesser magnitude earthquakes occurring in the different regions. In addition to the great earthquakes of the country, other earthquakes taken into consideration were a few smaller earthquakes in the Himalayas, Delhi Earthquakes, Satpura and Rewa Earthquakes, Bellary Earthquake and the zone of minor tremors from Trivandrum to Madras and East Coast regions. (2) After plotting the idealised isoseismals for the earthquakes, enveloping lines for the different M.M. Intensities were drawn. These lines were modified where necessary, taking into account the magnitude of intervening earthquakes, local ground conditions, principal tectonic trends as portrayed in the preliminary Tectonic Map of India prepared by the Geological Survey of India in 1962, basement configuration of the Indo-Gangetic Plains and other alluvial basins as revealed by geophysical surveys of the Oil and Natural Gas Commission and the likely trend of the Gango-Brahamputra rift postulated by Mithal and Srivatava (1959). Thus in modifying the isoseismals of the Delhi Earthquake these were elongated in the direction of the trend of Aravallis, a higher elliptical zone was made following the Moradabad fault, and the isoseismals east of Barielly following Uttar Pradesh–Nepal Border were made along the likely trend of the Gango-Brahamputra rift. The isoseismals for the Satpura Earthquake were drawn as circular as its connection with the Narbada rift was not surmised. The Bellary Earthquake isoseismals were elongated roughly parallel to the zone of minor tremors from Trivandrum to Madras, which itself was tentatively delineated parallel to east coast lineament in the absence of other definite data. (3) After drawing the modified isoseismals, the zones with M.M. Intensity, V, VI, VII, VIII, IX and "X and above" were designated as seismic zones I, II, III, IV, V and VI and the region with M M. Intensity less than V was designatad as seismic zone 0. This "zero zone" was not a zone of "zero earthquakes", but the designation was given to suggest that no earthquake problems of any significance may occur in this region.

1966 Seismic Zoning Map

During the revision of the IS : 1893–1952, it was felt that the additional knowledge of geology, tectonics and earthquakes, made available in subsequent years. requires modifications in the 1962 zoning map. This revision took into account the detailed Tectonic Map of India (1963) and additional data on earthquakes for which instrumental records were not available and for which the magnitude values were evaluated by the India Meteorological Department on the basis of the felt area. The 1966 seismic zoning map also followed the same general approach as for the 1962 map, except that a greater recognition was given to the tectonic features. Figure 2 shows the 1966 Seismic Zoning Map (IS : 1893–1966). The following major modifications were affected in this revision ; (1) The marked embayment in zone II and III in Uttar Pradesh was reduced and was kept parallel to the prevailling tectonic trend of the Himalaya and marginal depression of the shield. (2) The seismic status of the Delhi and surrounding regions was increased from III with an elliptical eyelet of zone IV to zone IV in general on the basis of the earthquake frequency studies carried out by the India Meteorological Department and recent earthquake activity related to the hidden Moradabad fault in the basement of the Gangetic plains, and the Sohna and other faults in the Delhi quartzites. (3) The location of the Kangra Earthquake was corrected and the isoseismal of M.M. Intensity. "X and above" was demarcated similar to that actually observed during the earthquake. This area of high intensity was given the designation of zone VI and seismic status of the region was thus enhanced. A region surrounding this high zone was demarcated as zone V on magnitude-intensity-distance relationship. (4) The seismic status of the north-west part of Kashmir

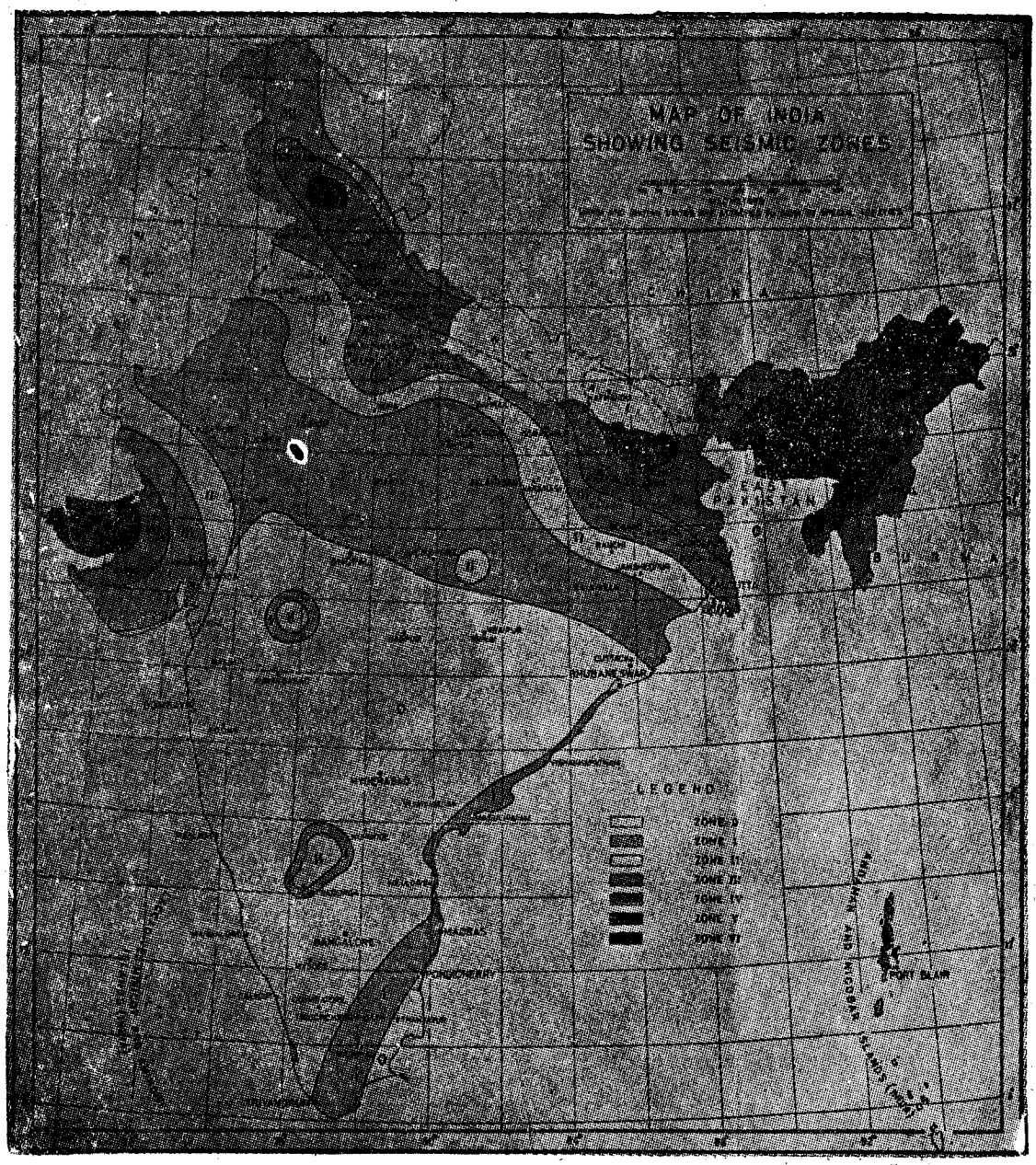

Fig. 1 Map of India Showing Seismic Zones as per IS:1897–1962

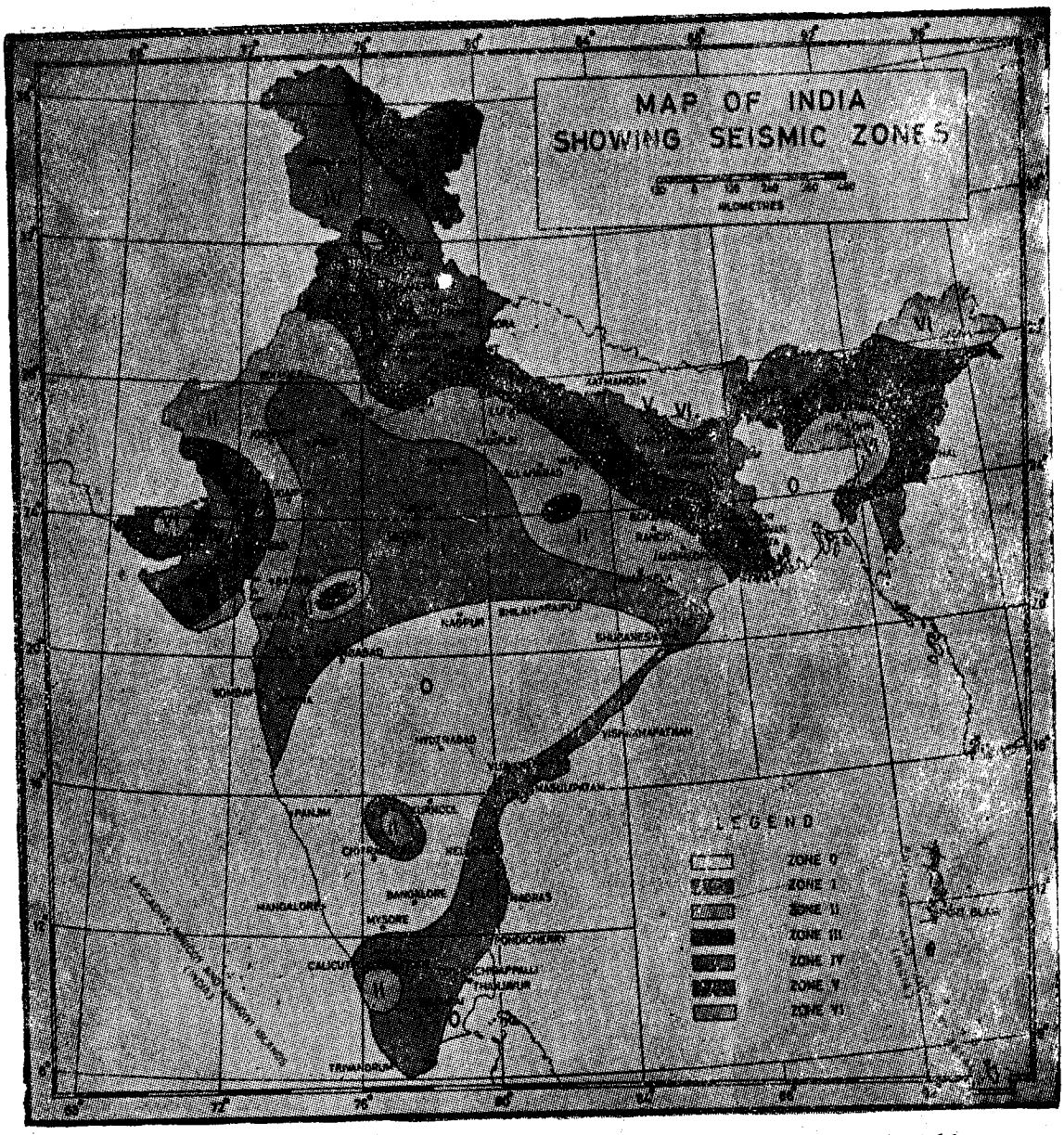

Fig. 2 Map of India Showing Seismic Zones as per IS:1897–1966.

was enhanced from zone III to zone IV in recognition of the activity related to the Himalayan thrusts, which has shown higher seismicity in other parts, and in the north-east part of Kashmir from zone II to zone III. (5) In north eastern part of the country zone V was readjusted to have a better accord with new data on tectonics and earthquakes. Zone III in Manipur and Tripura region was removed as the tectonics indicated higher activity. (6) In Andaman Islands the seismis status was upgraded on earthquake data from zone V to zone VI and other lesser zones were demarcated accordingly, (7) Earthquakes in the Satpura belt were replotted on the basis of revised data and the isoseismals of the Satpura and Rewa Earthquakes were elongated in the direction of the Narbada rift as this tectonic feature was taken to be their causative lineament. These eyelets were not joined to form a single zone along the Narbada rift due to lack of evidence of earthquake occurrences in the intervening area. The area in which these earthquakes were felt indicated higher magnitude of the earthquakes and the eyelets were marked from zone I and II to zone II and III. (8) Keeping in view the modification of zones in Satpura region and straightening out of the embayment in the isoseismals in Uttar Pradesh, the limits of zone I to III in the northern and eastern part of Peninsular were redrawn as asymptotic envelopes around the higher isoseismals on magnitude-intensity-distance relationship from probable earthquake occurrences from their borders. (9) The Kutch region was given a higher seismic status as the 1819 Cutch Earthquake was of similar magnitude as other great earthquakes of the country and zone VI was added. The trend of the zones was elongated in east-west-direction following the major faults. (10) In Gujarat region the sudden discountiuity from seismic zone II to seismic zone 0 east of Baroda and Surat was removed; and based on the tectonic set-up and occurrence of earthquakes in the region it was considered desirable to indicate the seismogenic nature of the western coast. However, as considerable data on earthquake occurrence along the entire coast line were not available, the probable marginal depression forming a mobile belt in the Maharashtra underlying the Deccan Traps was marked as zone I. (11) The causative tectonic lineaments related to the Bellary Earthquake were re-examined and it was considered that the same appear to be related to the Dharwarian strike and thus the isoseismals were re-oriented to correspond with the Dharwarian trend in NW-SE direction. (12) Based on the data of 1901 Coimbatore Earthquake isoseismals were drawn in Kerala and surrounding region so as to correspond to the trend of the Western Ghat, as it was felt that they are probably related to the seismogenic faulted western coast and related lineaments. (13) The extent of zone 0 in southern part of the Peninsula was thus curtailed taking into account the modifications due to Coimbatore earthquake and minor earthquakes along the east coast region.

Revision of 1966 Seismic Zoning Map

Shortly after the publication of the 1966 Seismic Zoning Map a large earthquake occurred at Koynanagar (District Satara) at the boundary of the probable marginal depression in the Maharashtra region. This earthquake indicated that the comparatively low seismic status, which was till then considered adequate for the marginal and other parts of the Peninsular shield requires modification with greater emphasis on the geological history and tectonic features present in different areas and the seismogenic nature of mapped or hidden tectonic features there in. The general approach to be followed to give greater recognition to geologic history and tectonic features was to divide the country into various tectonic units, each having characteristic geologic and tectonic history and seismic activity. With this in view Krishnaswamy (1969) proposed that in the seismic zoning of the country it would be desirable to take into account the varying magnitude of seismic activity of the various tectonic units (Table 1), with a decreasing magnitude and frequency of earthquake occurrences, and define the seismic zones so as to be in general consonance with the areal extent of these units, with local departures, as may be considered necessary or where adequate data are not available. It was also considered desirable to reduce the number

of zones from seven zones in 1966 map to five zones in the revised map, as the earthquake effects below MM Intensity VI (zone 0 and I of 1966 Map) are insignificant in terms of design, to call for separation. Likewise the zone VI of 1966 map includes M M. Intensity "X and above", and as M.M. Intensity IX encompasses destruction of well designed buildings, this separation was considered to be of little practical utility, and hence this zone could be omitted.

For evaluation of the distribution of earthquake intensity in different tectonic units data on magnitudes and focal depths was considered. Though a reasonable estimate of the magnitude of the earthquakes in various tectonic units can be had, little reliable information, is available on focal depths, and it is difficult to establish definite associations of earthquake occurrences with the tectonic features. Thus the delineation of the various tectonic feature as originating or causasive lineaments, movements along which could produce earthquakes, is mostly tentative, till the movements and crustal deformations along them can be confirmed by actual measurements by geodimeters, tiltmeters and other suitable instruments. Thus for the present the probable seismic intensities around the various tectonic features can be arrived at from known seismic data and assuming continuous and similar activity in homologous and adjacent tectonic features in other parts. The following describes in brief the earthquake intensies and delineation of the seismic zones (figure 3) in the various tectonic units.

1. Orogenic Unit—The regian east of Longitude 90° East consisting of Assam Himalayas, Belt of Schupen, Brahamputra valley, Shillong plateau, Mizo Hills, Tripura and other parts has shown the maximum earthquake activity in the country, and the intensities observed in various parts likely to occur in future are M. M. intensity "IX and above". The whole region thus has been kept as seismic zone V, though the tectonic features show dissimilarities with each other, and homologous and comparable tectonic features in other parts of the country show different seismic activity. This higher seismic status for this region is considered justified on the basis of the seismic data. Zone IV shown in 1966 map in the Mizo Hills and Tripura Region has been removed and the area has been included in zone V.

In the Kashmir, Himachal Pradesh. Uttar Pradesh and Bihar Himalayas a number of eyelets of M.M. Intensity" IX and bove" corresponding to zone V have been marked. Though these probably could form parts of a linearly elongated belt of higher seismicity related to the Himalayan thrusts and their extensions towards north along the dips, the marked comparatively less pronounced earthquake activity in the intervening regions and lack of data, inhibit marking the whole belt as zone V. Thus tentatively four centres of of higher activity, with M.M. intensity "IX and above", have been delineated-region surrounding Srinagar with major earthquakes probably related to the down-dip extension of the Panjal thrust, the epicentral tract of the 1905 Kangra Earthquake around Dharamshala related with the downward extension of the Satlitta thrust, the area near Pithoragarh and West Nepal boundary with major earthquakes with possible associations with downward extension of the Central Himalayan thrust and other thrusts in the outer Himalayas, and area of the epicentral tract of the 1934 Bihar-Nepal Earthquake. The Srinagar and Pithoragarh zones were not demarcated in 1966 map and are new zones. In view of the presence of Karewa lake sediments in the Kashmir valley and as earthquake of magnitude 7 have occurred in the past a higher zone in Srinagar is considered justified. Similarly the Pithoragarh region, where major shocks have occurred recently, demarcation of zone V is also considered justified. The north-eastern part of Kashmir was delineated as zone III in the 1966 map, but as this region shows numerous hot springs which may be related to active faults, and as the adjacent region in the USSR and Tibet show higher earthquake activity, the seismic status of this region has been enhanced to zone IV.

TABLE NO. 1

Generalised Tectonic Units of India with Decreasing Magnitude and Frequency of Earthquake Occurrences (After V. S. Krishnaswamy, 1969)

Tectonic Unit		Earthquake Occurrence	Seismic Zones
Name	Description		
Orogenic Unit	Orogenic unit of Cainozoic folding and faulting. The Shillong massif, which has been greatly affected by this faulting, has been includcd in this zone.	Common shocks of mag 5–6·5 with a number of shocks of mag 6.5-7·5 a few shocks of mag 7.5-8 and occassional shocks greater than 8 originating on some of the major Himalayan thrust and faults (Satlitta thrust, Panjal thrust, Central Himalayan thrust, Dauki faults etc.)	V and I
Foredeep and Marginal depression Unit.	Unit of Himalayan Foredeep and Marginal depression (where the boundary is not positively established, some of the marginal parts of the Shield may really be included in this zone. The Tectonic Map provisionally defines the boundary at 200 to 1000 m. contour of the basement at margin of the Shield).	Common shocks of mag 5-6 which a few shocks of mag 6-7 and occassional shocks of mag 7.5-8 originating along active faults in the basement (Patna fault ? or other basement faults, Kutch faults).	IV & II will islet of V.
West Coast & Narbada Tapti Unit.	Unit of Shield with Tertiary-Quarternary fault movemet including the West Coast seismogenic zone, the Narmada-Son rift zone, the Tapti rift zone and their postulated extensions.	Common shocks of mag 5-6 with few shocks of mag 6–7 in the Narmada and Tapti rifts. Past epicentres can be related to extensions of partly mapped faults. Maximum recorded mag. on West Coast Zone : 6.6-7, on Narbada rift 6.5, Tapti rift 6.25.	III with islets of IV.
Gondwana Rifts Unit.	Unit of Shield with Mesozoic fault movements and later adjustments, includes the Gondwana rift zone and adjacent parts of the Shield, marginal parts of the Peninsular Shield to the east and north with platform cover of Mesozoic Cainozoic sediments.	Occassional shocks of mag 5-6 with few centres which may have mag 6-6.5 and may be related to the boundary faults of the Gondwana basin and faults of limited extent in the Mesozoic-Cainozoic cover on the platform.	III
Shield Unit.	Generally aseismogenic and partitioned areas of the Peninsular Shield with ancient faults and with localised seismogenic features.	Occassional shocks of mag 5-6 with exceptional activity along local faults in the Archaeans with mag 6-6.5.	I and II with islests of III.

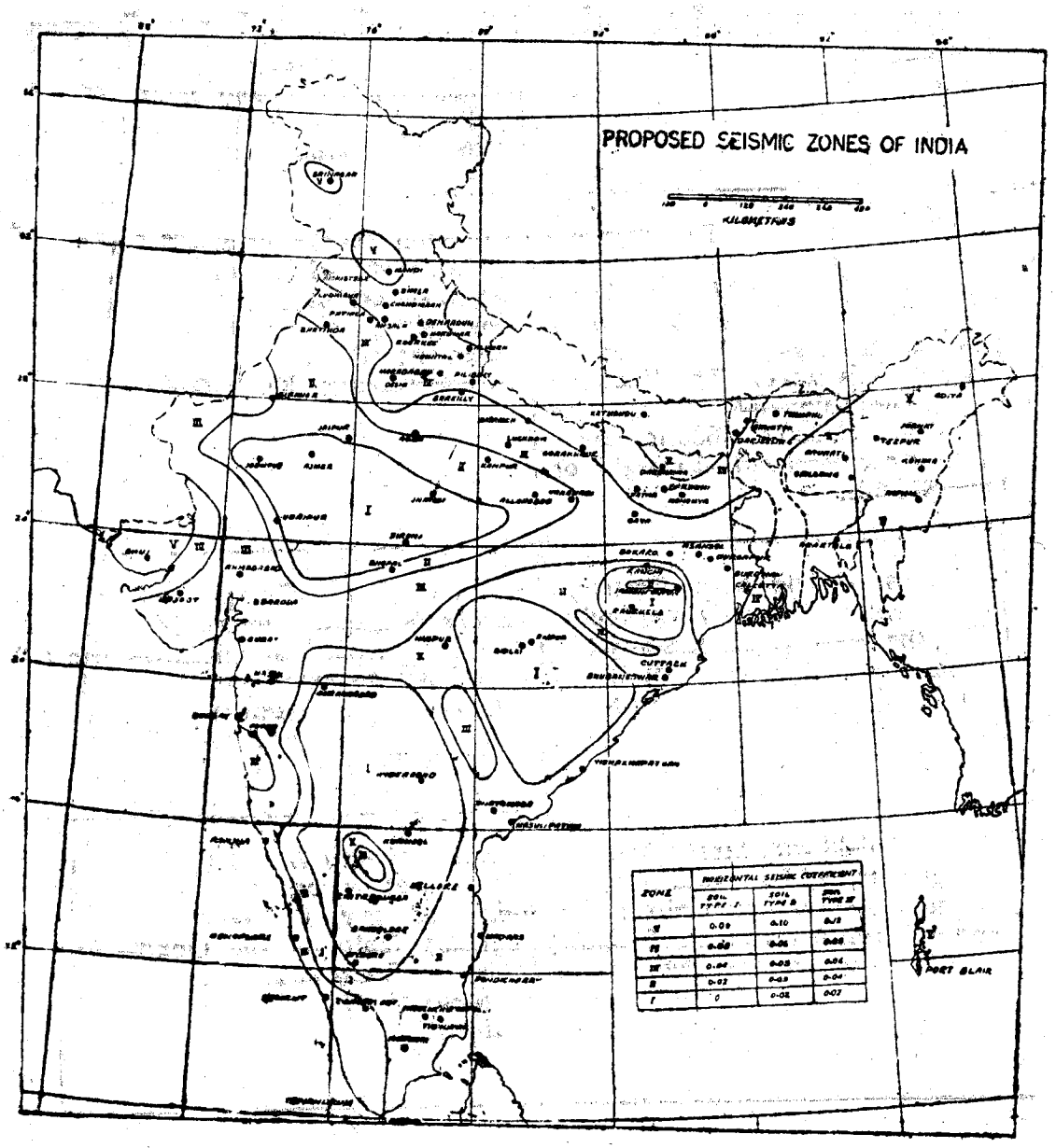

Fig. 3. Proposed Seismic Zones of India.

The Andaman-Nicobar islands, which form part of the Orogenic Unit, has been rated as zone V, and the various zones made earlier on magnitude-intensity-distance relationship have been removed as the whole belt shows similar seismic potentialities.

2. *Foredeep and Marginal Depression Unit*—In the fordeep paralleling the Himalaya and the marginal depression of the Peninsula which feel the effects of the large earthquakes emanating in the orogenic unit as well as earthquake originating along its edges and the basement faults, the boundaries of the M.M. Intensity VIII and VII were redemarcated such that the outer boundary of seismic zone III roughly follows the boundary of the marginal depressions of the Peninsular shield and the distribution of the corresponding isoseimals of the 1934 Bihar Nepal Earthquake and the 1819 Kutch Earthquake. A new seismic zone III following the marginal depresion has been demarcated in Rajasthan in this unit.

3. *West Coast and Narbada Tapti Unit*—The Tectonic Map of India (1963) shows a marginal depression, south of Cutch-Kathiawar-Cambay region along the West Coast extending for a distance of 150 kms from the coast. This mobile belt, postulated on the basis of gravity anomalies, lies burried below the Deccan traps and its exact demarcation and trend is not fully known However, in this belt a number of earthquakes have occurred in the past and the 1967 Koyna Earthquake occurred along its postulated border with the shield. In 1966 it was considered that, though earthquakes occur in this region, the intensity of earthquakes has not exceeded M.M Intensity V and the mobile belt in this part be kept as seismic zone I. The Koyna earthquake has thus focussed the necessity of reassesment of the seismicity of this belt. The two major seismotectonic features of this belt are the West Coast Fault and the West Coast Rift. The latter has been postulated by Tipnis and Srivastava (1968) and is considered to follow the West Coast in the Deccan Trap region, with its southern extensions off-setted towards west off the coast line. The region north of Panjim thus is susceptible to a wider belt of seismogenic features. The coastal belt between Panjim and Calicut is considered to be associated with only the West Coast Fault and a narrow belt along the coast would thus be seismogenic. South of Calicut the Coimbatore Earthquake, with its epicentre about 150 kms from the coast, appears to be related to hidden faults, following the local prevalent Pre-Cambrian orogenic trend and associated with the West Coast Fault. M.M. Intensity VII has been observed in the Maharashtra and Coimbatore region and the whole coastal belt is thus considered to have potentialities to produce similar intensities. This belt therefore, is marked as seismic zone III of varying width following the coast line with an islet of seismic zode IV in the Koyna region where higher intensities have been observed. The trend of the zone IV has been aligned in NNW–SSW direction along the likely trend of the Dharwarian strike below the Deccan trap which also appears to have controlled the trend of the postulated West Coast Rift resulting from the cymatogenic warping of this part of the Peninsular shield.

The Satpura Rift system along Narbada, Son and Tapti has indicated higher seismicity and extend across the shield from Saurashtra in the west to Bihar in the east, with possible extensions in Bengal. This belt of rifts and troughs, along with the plateau in between Narbada and Tapti, which may have hidden faults in the underlying basement, is considered to have seismic potential of producing an earthquakes similar to the Satpura Earthquake all along its bounding faults and thus the region encompassing distances upto 30 kms from the bounding faults and the areas within the troughs and the plateau between the Narbada and Tapti rivers has been marked as seismic zone III. This seismic zone III has been merged towards east with the seismic zone III of the Damodar valley and that marked due to the observed effects of the 1934 Bihar-Nepal Earthquake.

4. *Gondwana Rift Unit*—In the earlier preparation of seismic zoning maps the Gondwana rifts were considered to be stable with no earthquake activity associated with them. Such as assumptions has been proved to be fallacious by the 6.5 magnitude 1969

Bhadrachalam Earthquake. A study of old records show evidences of earthquake activity along Gondwana Rifts in earlier times also. With this in view the Gondwana rifts along the Godawari, Mahanadi and Damodar valleys have been classed as regions of seismic zone III. In the Godawari and Mahanadi valleys these have been shown as elongated belts of seismic zone III and the Damodar valley has been merged with seismic zone III of Satpura belt.

5. Shield Unit—The delineation of the various zones along various tectonic units leaves those parts of the Peninsular India which have shown comparatively much lower seismicity. Earthquakes have been felt in its various parts, but exact correlations with known or hidden tectonic features are not known. The eastern coast of India has been marked as zone II. The region east of the Chotangpur Plateau bordering West Bengal has been kept in zone III in continuation of the Damodar rift zone and the Bengal Basin of higher seismicity. The Singhbum Copper Belt Thrust and associated thrusts have shown earthquake activity during the last several years and the region thus has been delineated as seismic zone II along this belt. The isoseismals associated with Bellary earthquake have been drawn as before, but a higher zone III has been introduced on reassesment of the effect of this earthquake. In other parts of the shield unit deliniation have been made to conform with the distribution of the seismic zones in other tectonic units and occurrence of earthquakes, which are in general are of low magnitude.

From the foregoing description it would be evident that the proposed modifications in the 1966 seismic zoining map give greater recognition to tectonic features of the various parts of the country. But as considerable amount of data on earthquake occurrences and their associated tectonic features is not available and large scale maps showing orogenic-structural-stratigraphic belts have not been prepared for many parts of the country, only tentative modifications can be adopted in the different seismic zones. The revision of the seismic zones of the country is a long term continuous process and periodical revisions can be made as more data is obtained.

Acknowledgement

The author is thankful to Dr. Jai Krishna, Professor and Director, School of Research and Training in Earthquake Eengineering University of Roorkee, Roorkee, and Chairman Earthquake Engineering Sectional Committee, BDC 39, Indian Standrds Institution, New Delhi, Shri V S. Krishnaswamy, Director (E.G. Division). Northern Region, Geological Survey of India, Lucknow, and Convener, Maps Panel BDC 39:Pl, Indian Standards Institution, New Delhi, Dr. A.N. Tandon, Deputy Director General of Observatories, India Meteorological Department, New Delhi, Dr. S K. Guha, Chief Research Offices (Earthquake Engineering), Central Water and Power Research Station, Poona, and other members of the Maps Panel for their various discussions on the preparation and revision of the seismic maps of the country, which has helped in the preparation of this paper.

References

1. I.S: 1893–1962, "Indian Standard Recommendations for Earthquake Resistant Design of Structures" Indian Standards Institution, New Delhi, Nov. 1962.
2. I.S : 1893–1966, "Indian Standard Criteria for Earthquake Resistant Design of Structures", Indian Standards Institution, New Delhi, Nov. 1967.
3. Krishnaswamy, V.S., "Note on the Preparation of the Seismic Zoning Map of India", unpublished note, 1969.
4. Mithal, R.S. and L.S. Srivastava, "Geotectonic Position and Earthquakes of Gango-Brahamputra Region". Proc. First Symp. on Earthq. Engg., University of Roorkee, Roorkee, 1959.
5. Tectonic Map of India, GeologicalSurvey of India, Calcutta. First Edition, 1963.