SEISMIC ZONING MAPS OF INDIA

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ABSTRACT – *The paper describes the history of preparing seismic zoning map of India including the limitations on its use. Recent strong motion observations round the world have revolutionized thinking on the design of engineering structures indicating that the designs have not only to take into account the seismic status of a locality based on geological and seismological observations but also the foundation characteristics and the properties of structures themselves. So far zoning has not incorporated these findings into maps, but this indicates the direction of future work. Such observations also point out that the ground motion intensity at a location does not go on increasing with the magnitude of an earthquake beyond a certain size. This points to the necessity of decreasing the number of zones to 3 or so.*

INTRODUCTION

Earthquakes have been occurring in India from times immemorial leaving their tell-tales in the form of shear zones, faults, and other tectonic features. Some regions get big shocks, others moderate ones and some have no known history of their occurrence. Some areas get them frequently and others at long intervals of time. No location, however, could be described as "not susceptible" to earthquake occurrence.

Considering that there is a wide variation in the seismic hazard in terms of intensity of ground motion and frequency of occurrence it would be uneconomical to construct all man-made structures everywhere to stand very strong earthquakes. An effort is, therefore, made in most countries to divide them into zones with respect to the severity of expected ground motion so that the margin of safety of all similar constructions everywhere is as evenly distributed as possible. This is an ideal, aimed to be achieved in preparing zoning maps, but a map is only a representation of current knowledge about seismicity at any point of time. They are reviewed and revised periodically as more data becomes available.

Inspite of continuous effort to up-date them, maps are only a guide and, for any important construction, detailed study of the site and its surroundings is essential for a more precise estimate of seismic hazard.

It is proposed to discuss here the parameters that influence seismic zoning with particular reference to India. Here "magnitude M" would mean "Richter's Magnitude" and "Intensity I" would mean "Modified Mercalli Scale Intensity (MM)". The paper also explains the limitations of a zoning map, and direction of future effort.

PARAMETERS AFFECTING ZONING

Historical Data

In zoning, it is assumed that the regions that have experienced earthquakes in the past, will also do so in the future during the expected life time of man-made constructions. It is, however, unfortunate that the historical records of India have been destroyed to a great extent by the invading armies, past earthquakes and floods, so that the past history of earthquakes available for even the severely seismic regions of north India is very sketchy. The reliable records are available only for about 200 years and that is a short period of time for earthquake hazard estimation. In South India earthquakes occur very infrequently. Thus statistical indications are reliable only for North-East India where a large number of earthquakes have occurred in the last 200 years and continue to do so at present. For other areas, other factors besides historical records must play an important role in estimating seismic hazard.

Historical records of the 19th Century are newspaper descriptions of what happened at different places during a particular earthquake. For the first quarter of the present century, the instrumental data for very strong earthquakes only is available from instruments in other countries. Seismological stations have been set up in India only in the last 65 years, so that more data is available. Some countries like Japan, China, Italy, USSR, etc. have records for much longer periods.

Figure 1 shows the epicentral locations from the instrumental data available from stations in India and outside. It would be seen that most of the earthquakes have occurred in North East India, Tibet and adjoining areas. Rest of the Himalayas also experienced quite a few shocks. Other areas have suffered only a few moderate size earthquakes, and this fact has influenced the seismologists in zoning India to a great extent. In the beginning of the zoning exercise (1959–1962), it was thought that since a map is being presented to the general public as an Indian standard for the first time, it should conform to historical indications only so that people rely on the map and get used to using it. Later, other factors, which are not so apparent to the general public, should be introduced to make the map more scientific in the hope that people once accustomed to using a zoning map for aseismic design, will continue to do so inspite of such changes. This psychological aspect cannot be ignored particularly when the Indian Standards Recommendations for zoning are based on judgement for which the historical data is inadequate, and they are not precise enough to be legally enforceable. The first zoning map, published by the ISI[1] and shown as figure 2, should be viewed in this light. This map had taken advantage of the map published by the Geological Survey of India in 1935.

It may be relevant to state that a particular zone may have, more or less, the same order of susceptibility for earthquake "intensity" yet the seismic "hazard" for the whole zone may not be the same spread over a long period of time. Some areas like North East India are expected to suffer large shocks every couple of years somewhere or the other, but, even though the western and Central Himalayan regions could experience a strong shock of the same intensity as the North East, the frequency of occurrence of such a shock may be once in many decades. Thus the "severely" seismic zone also need not be classed as one on economic grounds. At the same time, it is essential to ensure that important constructions such as "dams", "Nuclear Power stations"

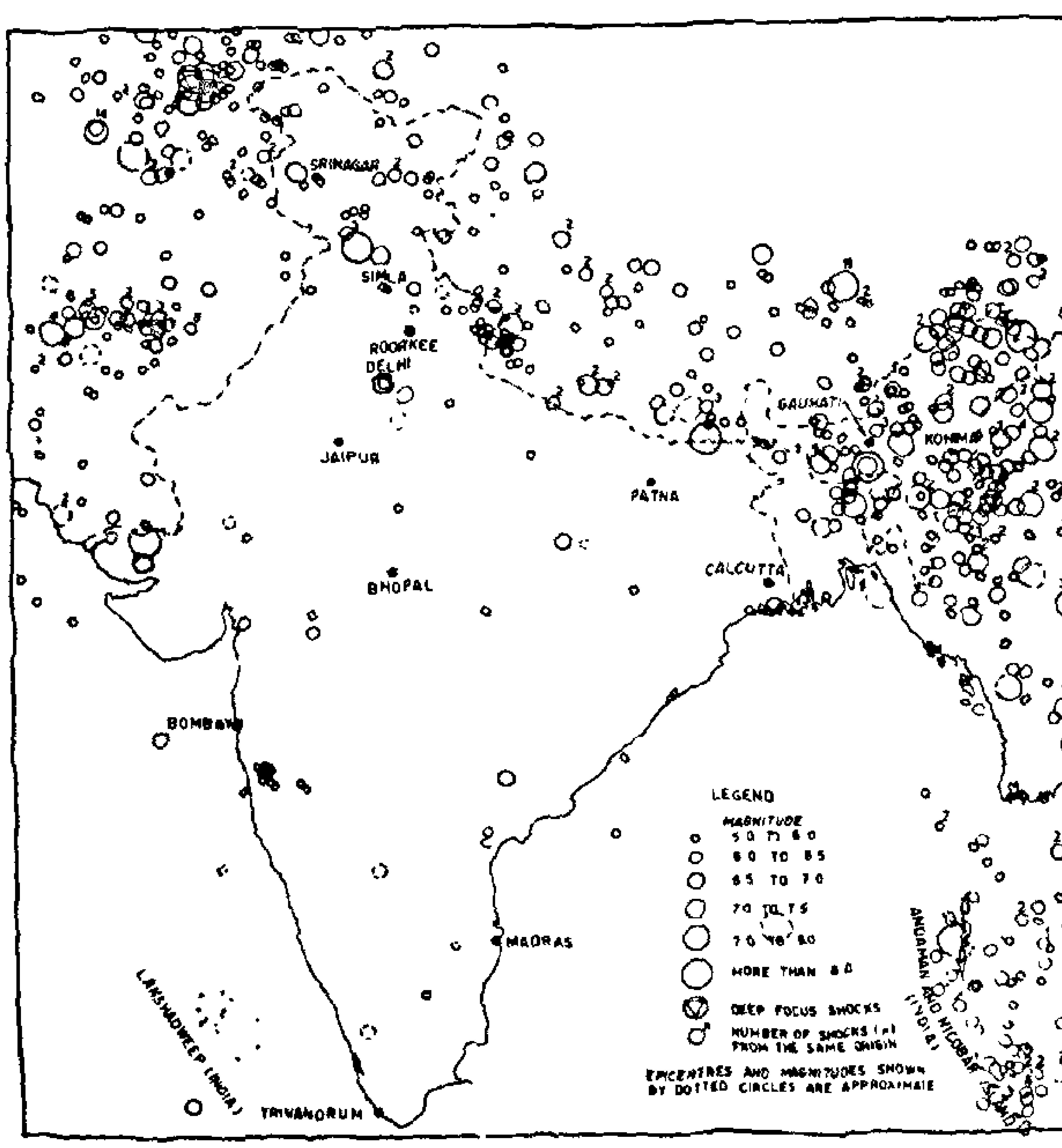

FIGURE 1. Map showing epicentres of earthquakes in and around India.

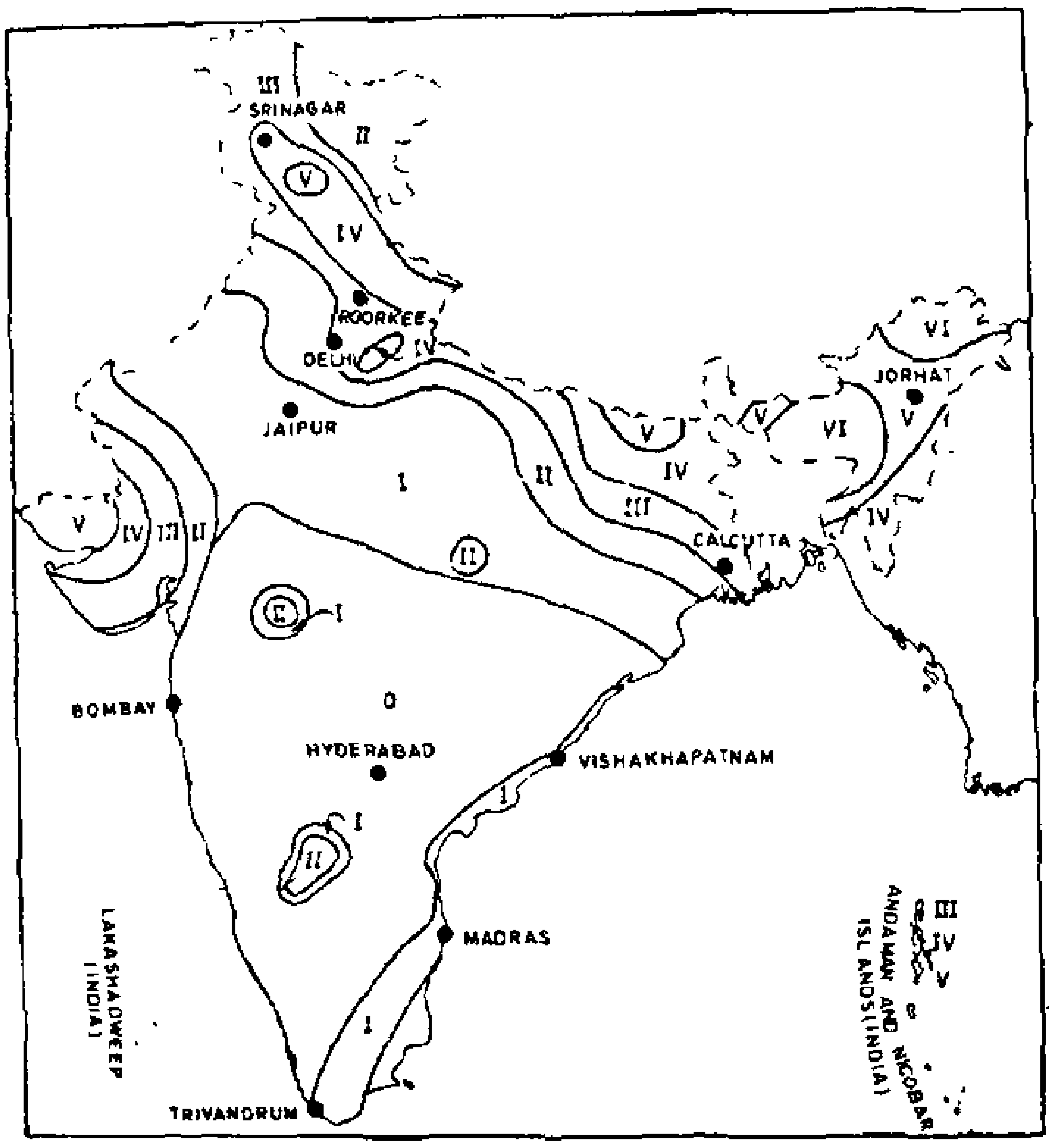

FIGURE 2 Seismic zoning map of India (on lines of IS:1893–1962).

etc. should be designed to stand the strongest shock even though it may occur at their site rarely.

Thus "seismic potential" has to take into account not only the historical data but also economic factors and importance of a structure. All three factors cannot be represented on a map simultaneously and only the historical "potential" and to some extent "economics" are accounted for. The "severe" zone is then divided into two – one getting frequent shocks and the other less frequently.

Other zones were also divided similarly and "importance" factor was left to be accounted for separately.

In considering the epicentral map, it has to be kept in mind that the one point representation for an earthquake is only a convenient method of preparing an epicentral map. It is not a scientifically sound representation of the location of the rock mass that ruptured to cause an earthquake. The point marked on this map is projection on surface of the earth just above the point from where the first seismic wave originated to be recorded on the seismograph. This origin may be anywhere in the rock mass which ruptured. In any shock of substantial size this mass is 50–250 kms long and is of the order of thousands of cubic kilometers in volume and thus these points could be quite misleading about the location of the ruptured mass. They are not necessarily at the centre of the mass. This is the reason why an 'epicenter' does not quite often lie in the isoseismal region of the highest intensity for an earthquake. Figure 3 indicates an approximate relationship between magnitude of earthquake and fault length or length of ruptured mass[2].

Sometimes a "gap" in the epicentral map is taken to be an area where strain energy is accumulating so that the next earthquake is predicted to have its epicenter in this gap. This is erroneous. This need not always be so. The "gap" should be located by plotting ruptured masses for all recent earthquakes, and the uncovered mass of rock may be treated as "gap" where rupture may be expected next.

In spite of the shortcomings of an epicentral map, it is a useful historical picture of the severity of seismicity of a region and is universally used as a guide for preparing a zoning map.

The first zoning map 1962 (figure 2) was based primarily on the epicentral map and on the data presented by the isoseismal maps published by the Geological Survey of India for some strong earthquakes, and GSI's 1935 Zoning map. Epicentres of earthquakes of magnitude 5 and above were plotted and "MM intensities" of some strong earthquakes ranging form V to IX were superimposed on it to give the zones. Minor modifications were made to account for local features such as indicated by Delhi earthquake

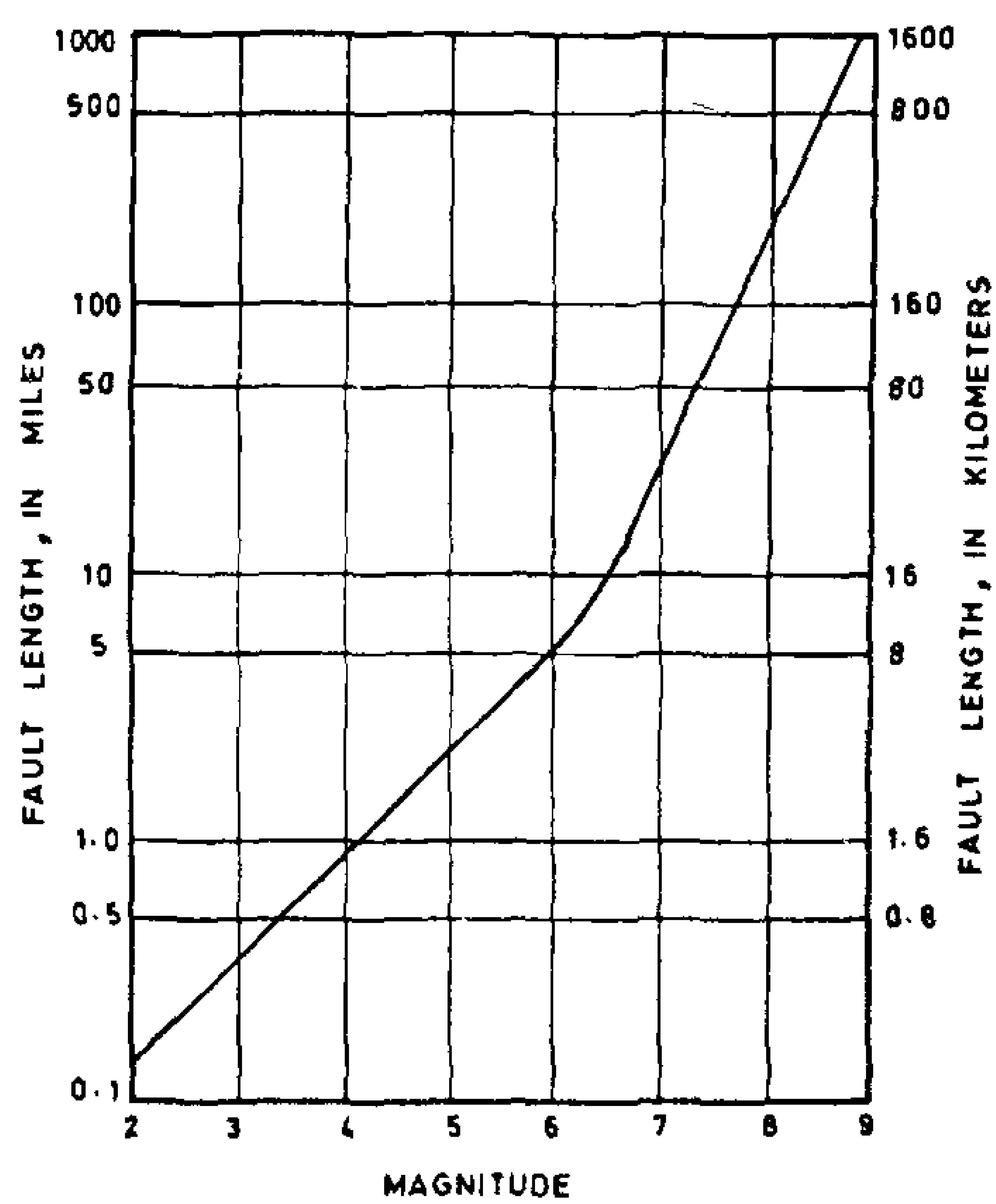

FIGURE 3 Idealised curve showing approximate relation between earthquake magnitude and length of slipped fault.

along Aravalli axis. Bellary earthquake, and minor tremors extending from Trivandrum to Madras. At the same time, Narmada feature was not fully accounted for except for local areas that had experienced an earthquake in the living memory.

Geological and Geophysical Data

While preparing the map on historical data alone, it was realised that there are several areas for which earthquake data was not available, but geologically the possibility of strong earthquakes occurring in such areas could not be ruled out. For example, before the Koyna earthquake of 1967, the whole of the Deccan plateau was marked as, more or less, a "safe" zone although a few earthquakes had been known to have occurred in the plateau, e.g. Coimbatore etc. This point has been elaborated later.

The occurrence of Koyna shock surprised geologists and seismologists and necessitated a review of the philosophy for zoning India. It was considered essential that the geological and geophysical data should be superimposed on the historical one. A tectonic map had been prepared by the Geological Survey of India and was the main source for geological data. Advantage was also taken of the aero-magnetic and gravity surveys undertaken by the Oil and Natural Gas Commission in locating magnetic and gravity anomalies to draw inference on "discontinuities" and possibility of the presence of Oil. Since this information had a bearing on seismic activity also it was used along with the tectonic map.

While zoning, one consideration that prevents the upgrading of the seismicity of a region is the economic impact of doing so. In areas where earthquakes occur frequently, people are willing to invest in earthquake resistance of their construction, but in regions where they occur very rarely, upgrading of seismicity, inspite of scientific indications, becomes difficult. That was the reason why minor earthquakes were ignored and Deccan Plateau was marked as "Safe" zone that is Zone Zero or One in the first map.

In the 1966 revision (figure 4) the fact that zoning map had begun to be used and more important construction had begun coming up with industrial development, played a role[3]. It was considered necessary to provide better protection to what we build even in less seismic regions. The tectonic features, even though not recently active frequently, were accounted for in modifying the zoning lines. Notice was also taken of the philosophy that earthquake forces and distance from tectonic features have a relationship that permits downgrading of the seismic status with distance from such features as proposed by the author in 1959[4] and is represented[2] as shown in figure 5. Thus the main zones in the north were made more or less parallel to the Himalayan tectonic trends.

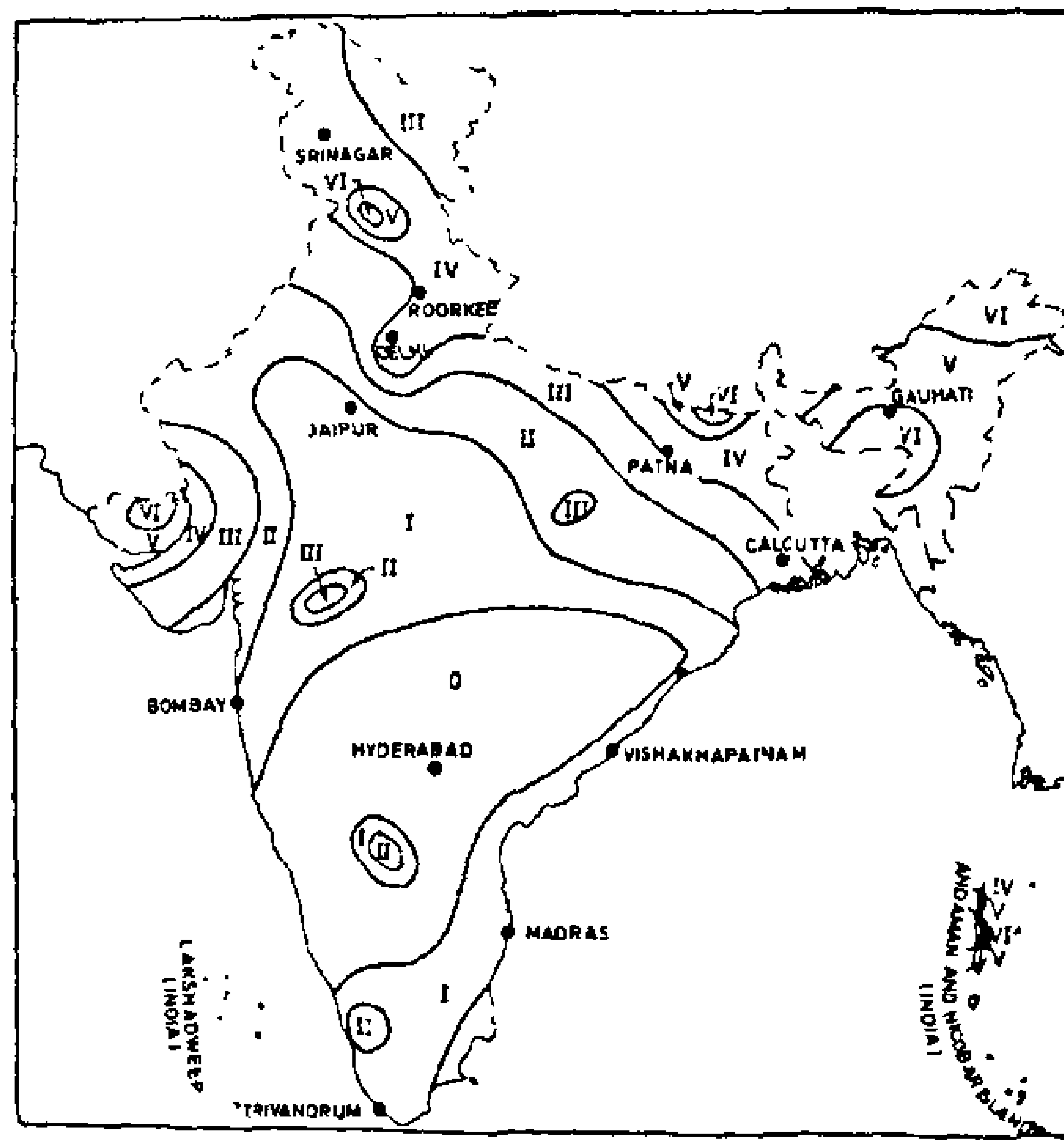

FIGURE 4 Seismic zoning map of India (on lines of IS: 1893–1966).

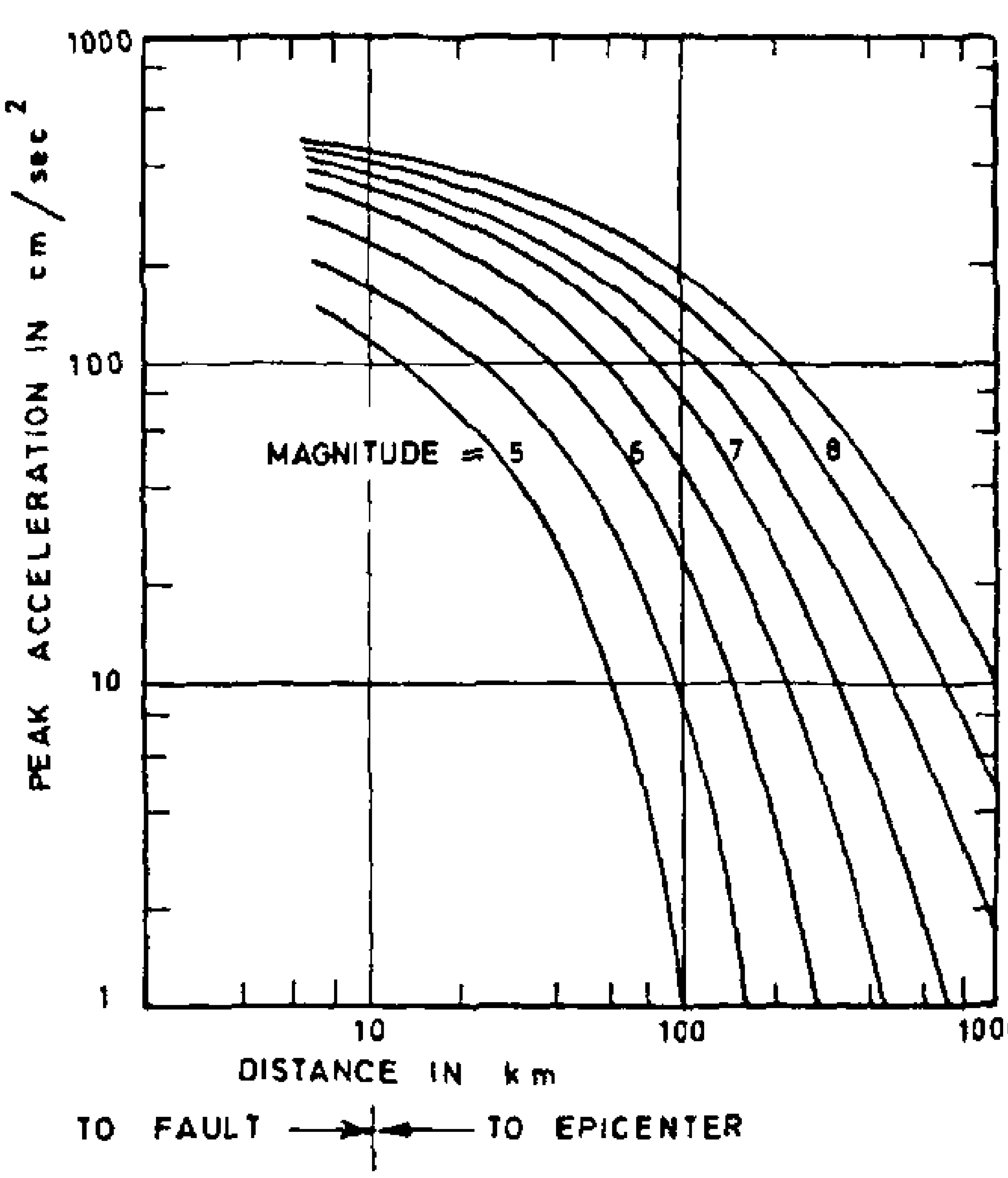

FIGURE 5 Idealised curves showing reduction in intensity of ground shaking with distance from causative fault.

After the earthquake at Koyna in 1967 necessity arose to review the zoning particularly in the Deccan Plateau. Where Oldham's hypothesis of faulted west coast, occurrence of earthquakes at Coimbatore, Bellary, Koyna and Broach, and existence of hot springs along the western ghats were considered to upgrade the seismic status. Narmada region was upgraded and some rationale introduced in Kangra. Kashmir, North-East regions and Andaman, Nicobar Islands, taking into account the susceptibility of these areas to suffer a strong shock causing heavy damage over a big area. Zone zero was reduced in size in the Deccan plateau in 1966 map. Revised maps were prepared and published in 1966 and 1970 publications of ISI 1893[3,5].

The revised zoning map represented more closely the seismotectonic features without sacrificing the information obtained seismologically and from the magnitude-distance-acceleration relationship philosophically. This map was published by ISI in 1966.

Another attempt to rationalise the zoning map was made in 1970 (figure 6). One of the significant changes was to abolish zone zero recognizing the fact that it was not scientfically appropriate to declare any region where the possibility of earthquake shock is zero or that such a shock need not be taken notice of in designing even important structures.

Another change here is the merging of most of the zones V and VI into one zone, in view of the fact that the whole region had a potential of high risk even though the known history may not have recorded a strong shock. Thus the total number of zones were reduced from 7 to 5.

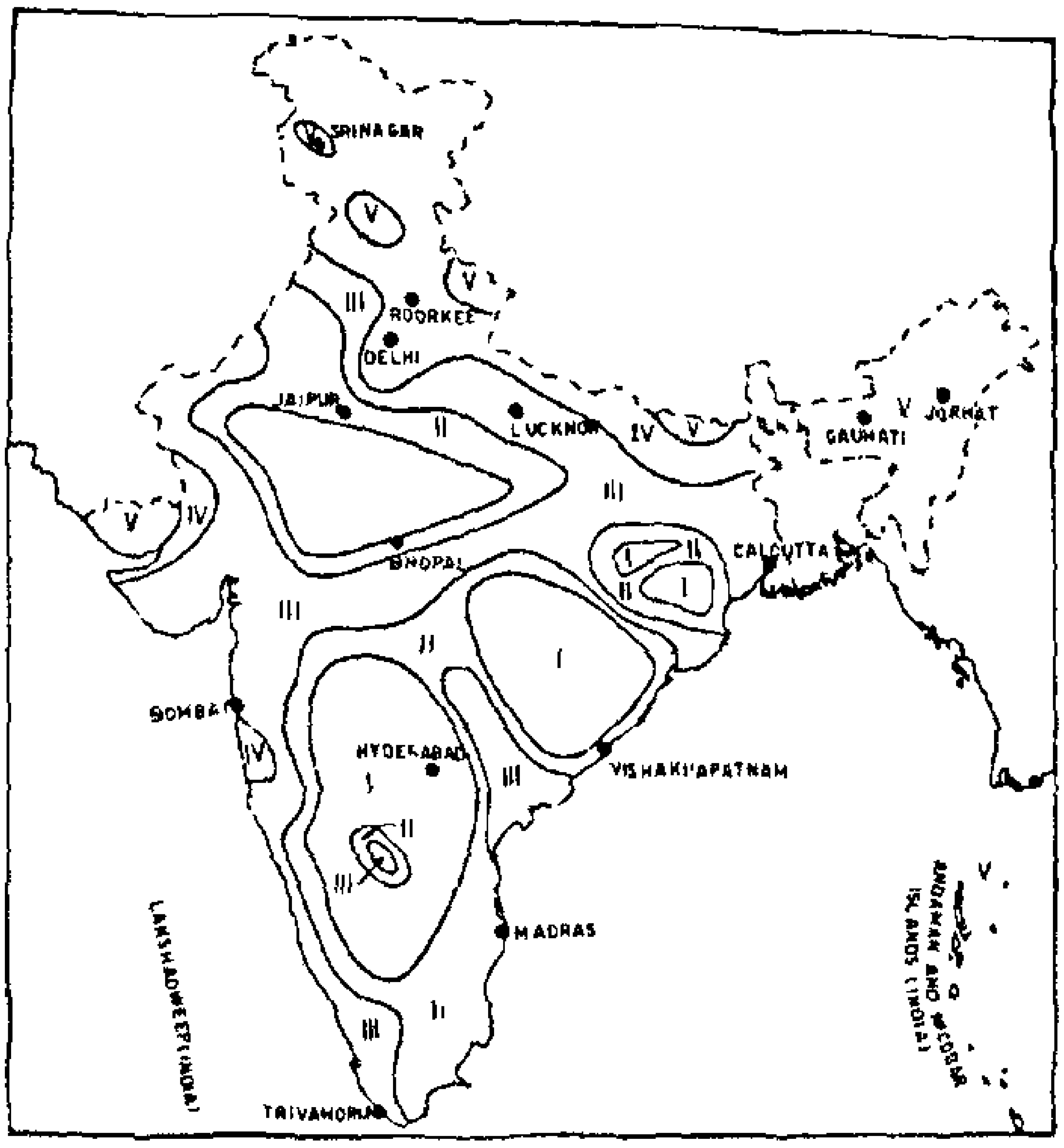

FIGURE 6 Seismic zoning map of India (on lines of IS: 1893-1970)

Statistical Methods

Some attempts have been made at statistical methods for zoning, but the reliability of such methods depends upon the amount of data available. It must be emphasized that there is nothing to beat the ground data presented through occurrence of earthquakes and observed seismotectonic and geological information aided by Remote Sensing Imagery. These are the methods adopted in most other countries for zoning. The same have been used here although, as stated earlier, judgement and local experience played some part in drawing the zoning lines. Statistical methods have not been formally introduced in this process yet. Informally the historical information represented by an epicentral map is the basis of zoning from the very beginning. In future, more data is expected with instrumentation in the regions having multiplied several fold and that would enable taking a closer look at these methods in due course.

In some countries, risk maps have been prepared since a good deal of data was available, but, by and large, they are being used for insurance purposes and not for design of engineering structures.

MICROZONING AND FUTURE WORK

Sometimes it is thought that a broad seismic zone marked on the bases described earlier may be divided into smaller zones depending upon local geological and foundation conditions. Whereas it is recognized that an engineer, when choosing a site for constructing an important structure, examines the foundation material through boreholes, it is difficult to corelate this with the seismicity of the site. Seismicity is a regional parameter, although its effect on the safety of construction at a site greatly depends upon the foundation material through which seismic waves pass before reaching the structure. These waves get filtered so that short period waves get absorbed in comparatively soft material although the amplitude of ground motion gets enlarged, and only longer period waves reach the structure. The properties of ground motion get modified by the strata through which they pass but there is a large variation in the properties of material of different strata and at different points in the same stratum. Extreme examples may be the records of the recent Mexico earthquake (1985) in which waves recorded in Mexico had about 1 to 2 sec. period, having filtered away short and medium period waves, whereas 1967 Koyna[7] earthquake recorded in

Koyna dam indicated very short period waves (about 1/10 to 1/12 of a second). This large variation arises from the nature of strata through which the waves pass and prevents any standardised classification of microzoning. This can happen even in regions of similar seismic status or susceptibility. Each site thus requires special study. Microzoning should only attempt to equalise seismic hazard depending upon the foundation condition and for a particular type of structure.

The structural properties that are important in microzoning are the natural period and damping characteristics of the structure to be constructed at a site. Figure 7, shows the comparison of the spectra for 1985 Mexico and 1967 Koyna earthquakes[6,7]. It will be seen that the response of different structures characterised by their properties like natural period and damping differs widely during the same earthquake, the same site, and at the same time. The structures affected most in the earthquakes of similar size differ widely and the wave characteristics conditioned by foundation properties determine which structures, even though designed equally strong will stand the shock better. Microzoning, therefore, is a function of the properties of the structure to be built besides those of foundation material and the properties of the seismic waves expected at the site.

It is well known that the wide scatter in the properties of ■ seismic waves, ■ foundation material and ■ structures to be built, when combined for a particular construction, will result in a very low confidence level for microzoning puposes. Every case, however, can be studied in detail and confidence level with respect to seismic effect on constructions at a site increased considerably.

As an example, it may be stated that quite often tall buildings escape damage close to the source of ground motion, while short stiff structures get damaged

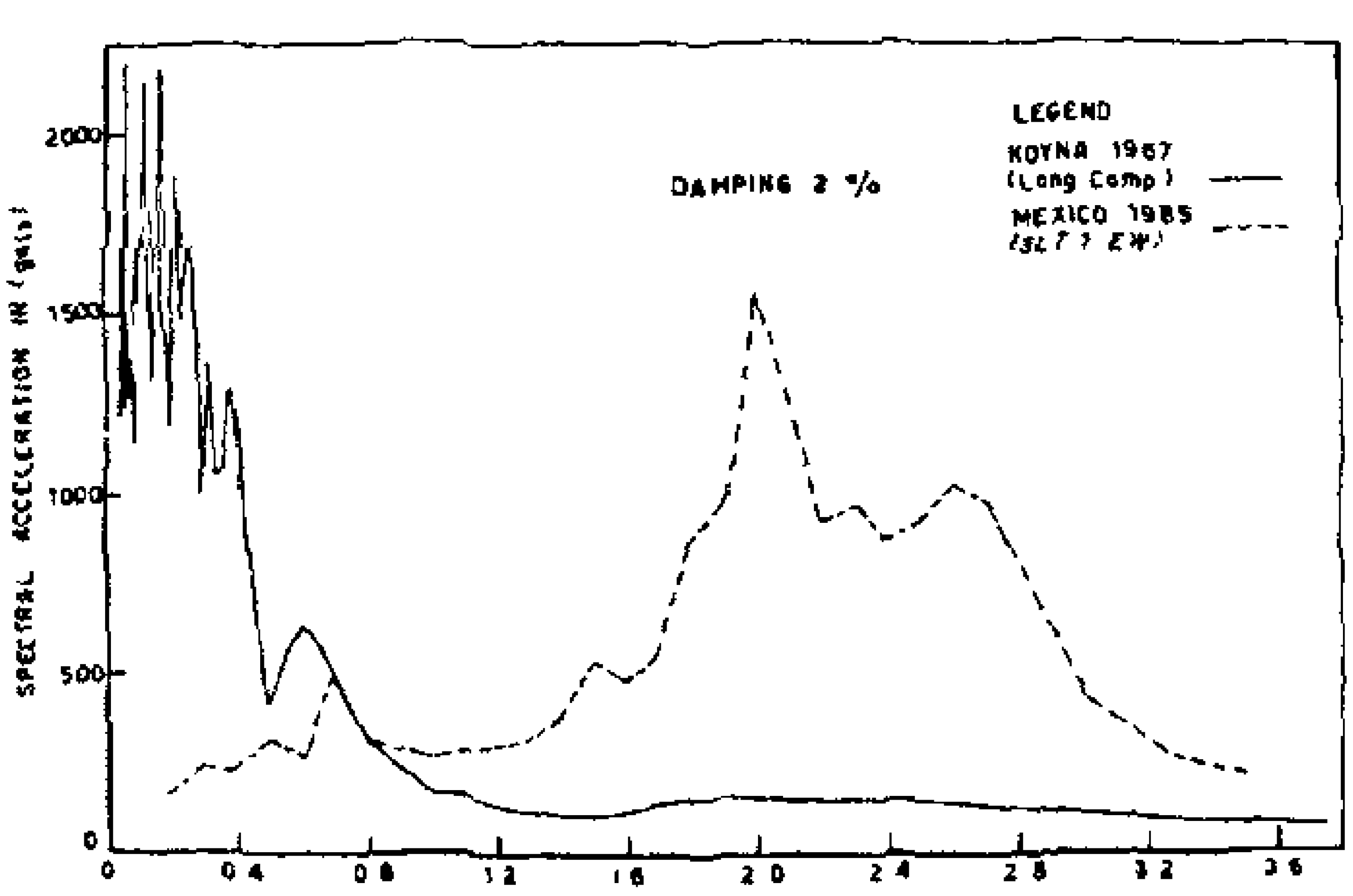

FIGURE 7 Comparison of spectral accelerations for 1967 Koyna and 1985 Mexico earthquakes.

badly. Similarly, say 100 kms away, short structures, even though not strongly built, stand a strong shock, while tall structures suffer badly. A zone is thus meant to indicate the seismic status of a region, i.e. seismic hazard to the same type of structures at different sites in that region provided that the foundation conditions are also similar, and is useful only to the extent of estimating the ground motion due to earthquakes. The actual design of a structure should be based on the response spectrum drawn for the expected ground motion depending upon the properties of foundation soil, and the structure itself. A spectrum indicates the natural period of the structures which could quasi-resonate at the site at which a particular earthquake has been recorded. This would indicate that the microzonation will have to be structure-wise (or natural period-wise) to be really useful. This aspect of zoning needs further research work and intensive observations.

There are two significant observations made in the last 20–30 years, which needs to be worked upon more intensively to review the zoning. One of them flows from the large number of reconnaissance surveys carried out after earthquakes. It has been seen that, even in small-size earthquakes of magnitude about 4.5, considerable damage is caused to stiff structures around the epicenter. The question therefore arises whether zone one should be retained separately or merged with zone two so that the lowest design coefficients are raised. In most cases the intrinsic strength of well-built structures will be adequate to stand the higher forces, but this will emphasize the need to build the weak ones stronger so that they do not suffer badly in small size local earthquakes. The economic impact of this change may not be excessive, since provisions to absorb energy could be made at a small additional cost.

Another result, that has flown from the strong ground motion recording over the last 50 years and more particularly in the last 20–30 years, is the fact that the maximum intensity or ground motion does not go on increasing *indefinitely* with the magnitude of an earthquake[8]. See figure 8. Beyond a certain size of shock, the maximum intensity of ground motion remains more or less the same, which is a very vital fact for the design of structures. Since zoning is basically aimed at designing, this point needs to be taken into account. The author and other workers have pointed this out for more than 20 years but the impact of this fact on zoning has been felt only recently. In the light of this, are we justified in having so many zones even in the higher intensity range particularly for important structures like Nuclear Power Plants, Dams etc.? If there is a possibility of a site experiencing a shock of magnitude 7 or so, the designs should be as strong as they would be where 8.5 is expected. The higher magnitude only indicates that a much larger area will

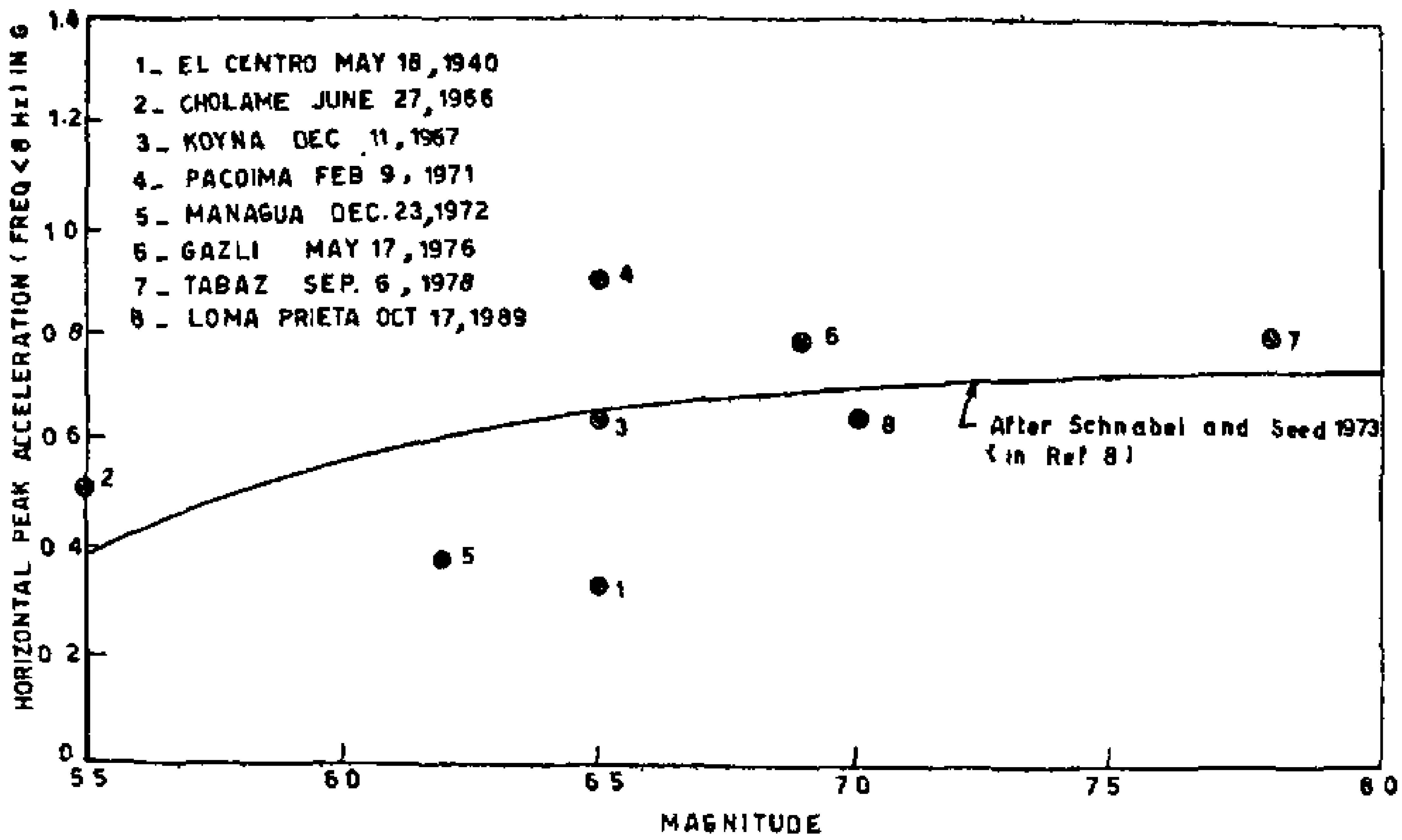

FIGURE 8 Relationship between maximum horizontal acceleration (recorded within 5 km of causative fault) and magnitude.

experience a high intensity of ground motion compared with that in an earthquake of magnitude 7, but designs are effected only by the intensity of motion and not by the area over which it is felt.

Therefore the division of the severe zone should only be on grounds of economy taking into account the frequency of occurrence of strong shocks. This indicates the possibility of reducing the total number of zones to three or at most four.

CONCLUSION

Seismic Zoning Map of a country is a guide to the seismic status and susceptibility of a region. It has limitations in its use for designing engineering structures since design is governed also by the type of a structure and its foundation. Further, a zoning map should be reviewed periodically as more data becomes available, and recent information indicates the possibility of reducing the number of zones.

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