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SEISMIC EVALUATION OF EXISTING NUCLEAR FACILITIES

LATUR EARTHQUAKE AND ITS IMPACT ON THE ASEISMIC DESIGN OF STRUCTURES IN INDIA

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ABSTRACT : The Latur earthquake occurred on September 30, 1995. The epicentre was located near the Killari village of Latur District which is situated in the stable continental region of Southern Peninsular India. The earthquake caused a wide range of damage though its magnitude (MS) was 6.4. Intensive damage survey was carried out and a number of geophysical and seismological studies had been undertaken. It was been concluded from the results, available so far from these studies, that the hypocentre of the earthquake was on the lineament dipping NW-SE. The rock matrix in the hypocentral region was weakened due to the presence of fluid and rupture of this weak region caused the event. The ground motion produced by the earthquake was of complex nature comprising of horizontal and vertical component. The ground acceleration in the epicentral region was estimated as 0.2 g. Latur earthquake raised several issues with respect to aseismic design of structures in India which need further deliberation. These issues are related to seismic zoning of India, determination of design basis ground motion, design/ detailing of structures, etc.

INTRODUCTION

Latur Earthquake occurred in the early morning of 30th September, 1993. The epicenter of the earthquake is located in the Latur District of Maharashtra State, India. The epicentral area falls in the Southern Peninsular India known to be seismically stable. The event was preceded by several foreshocks and followed by a number of aftershocks.

Field studies and damage surveys were carried out by a number of organizations following the earthquake. The Latur earthquake would go down in the history as the deadliest earthquake to strike a stable continental region (SCR).

No significant past earthquake incidents are known in the region surrounding Latur and as such no earthquake instruments were installed in this area before this earthquake. However, a number of geological, geophysical as well as seismological studies have been undertaken in the earthquake affected regions following the event. All these studies are yet to be completed but results from some of these studies, have been published.

The purpose of present paper is two fold. Firstly, to present an account of the event of Latur earthquake on the basis of data/information collected from the published literature and the interview/discussion with people. Secondly, to deliberate on the impact of this event with respect to the practice followed in India for aseismic design of the structures.

THE EVENT OF LATUR EARTHQUAKE

Main Shock [1 TO 6] *

Origin time	:	22:25:53 GMT, September 29, 1993. 00:03:53 IST, September 30, 1993
Epicentral location	:	18.07^{o}N, 76.62^{o}E Near Killari Village of Latur District of Maharashtra State in India.
Hypocentral Depth	:	< 10 Km (5-10 km)
Magnitude	:	Body wave (Mb) = 6.3 Surface wave (Ms) = 6.4 Richter (Mw) = 6.1
Duration	:	30 to 40 seconds
Seismic Moment	:	In order of 10^{25} dyne.cm. (This is about 20% of annual seismic energy released by stable continental region earthquake)

(Different values for the above parameters have been published in different literatures)

Epicentral Track [5, 14]

The topology of the affected area is mildly undulated. The bed rock is covered by black cotton soil mantle having average thickness of 300 mm. There are number of flat topped mounds. The rivers Terana, Manjra and Bhema flow through the affected area. The village Killari which is nearest to the epicentre is near to tributary of river Terana . Fig.2 depicts the epicentral track of the earthquake.

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* **Note:** Numerical value inside the square bracket indicates reference number.

Foreshocks [1, 6, 7]

A number of foreshocks during October-November, 1992 were reported. An earthquake of magnitude 4.0 occurred on 18th October, 1992 in the vicinity of Killari causing minor damages. There were about 25 felt earthquakes in the following week. On November 1 and 2, 1992, four (4) earthquakes of magnitude 2.2 to 3.8 occurred. Felt tremors were also reported in 1962, 1967, 1983 and 1984.

Aftershocks [6, 7]

The main shock was followed by 187 (one hundred and eighty seven) aftershocks, largest being magnitude 4.4 occurred on 30the September, 1993. The aftershock activities decreased rapidly but a shock exceeding magnitude 4.0 occurred on November 12, 1993. The aftershock zone is clustered near the point of confluence of the two tributaries of the Terana river south of Killari village (see Fig. 1). A detail account of the foreshocks and aftershocks are given in reference - 7.

Probable cause of earthquake [3,6,7,8,9,10]

Indian plate is moving north word direction [9]. Cluster of earthquakes have been observed due to this movement along the main thrust zone below the Himalayan mountain range on the boundary of this plate. Peninsular India is a stable continental region on the Indian plate within which the epicentral area of Latur earthquake falls. The region comprising of the Deccan volcanic province (DVP) and a craton. Eight (8) major earthquakes occurred in the stable continental region of India. Fig.1 shows the tectonic map of this stable continental region and the locations of these eight earthquakes. However, no major earthquake event was recorded in the epicentral region of Latur during the historical past.

A number of geological, geophysical, seismological studies were started following the earthquake [11]. In some literatures [1&2], question was raised whether the Latur earthquake was induced by reservoir, because of the presence of Terana river in the epicentral track. Rastogi examined this aspects from various considerations and concluded that the Latur earthquake is not a reservoir triggered one [12]. Chetty and Rao studied the lineament pattern of Latur - Osmanabad area [13] and summarised that the area is confluenced by the lineament system as shown in Fig. 3. The results so far obtained from the geophysical studies indicate the presence of fluid in the hypocentral region [10]. It has also been revealed from these investigations that the hypocentre of the Latur earthquake falls on the lineaments dipping NW-SE and passing around the tributaries of Terana river near Killari village; and due to the presence of fluid in the hypocentral region, the rock matrix was weakened and rupture of this weak region caused the event. It also appears from these studies that the event occurred on the plane striking at about 45° NE-SW on fault dipping at about 135° NW-SE.

Damage Survey

The area within 6 km radius of epicenter on either side of the river Terana was almost completely destroyed. The most affected villages were Killari, Talni, Mangrul, Sastur, Hulli, Rajegaon and Yekundi. The extent of damage was gradually lessened with the distance from epicentre. Iyengar et al generated damage intensity map (see Fig.4) in UN scale [5]. The earthquake completely damaged about 19,000 houses and partially damaged 200,000 houses in 67 villages killing about 11,000 persons [4].

No major failure associated with land-mass such as liquefaction, landslides, subsidence, uplift, etc. except a surface rupturing of about 30 mm wide and 3 km long near Killari was reported. Jain [1] and Chetty et al [13] mapped this rupture [see Figs. 5&6]. Strange incidences like smell, sound/noise, unusual behaviour of animals, phenomena associated with the variation of ground water level, etc. were reported [14]. The outcome of the examinations on these incidences are given in references - 15 & 16. The preliminary data obtained from the field reconnaissance of ground water indicates that there was no visible impact of the earthquake on the ground water regime. The gas emanation was reported upto a distance of 200 km. The onset of volcanic activities as reason for this gas emanation has been ruled out. The gas emanation in all probability were due to release of trapped gases as a result of earthquake. Subterranean sounds/micro earthquakes and ground cracks were reported in nearby regions within about one month of the main shock. This could be attributed to the stress re-distribution caused by main shock which triggered micro earthquakes. As such, the earthquake did not create significant environment disorder.

The structures (buildings, public utilities, industrial facilities, etc.) behaved in expected way during earthquake [4, 5, 14 & 18]. Non-engineered conventional buildings suffered complete collapse to very severe damage making them non-usable. Almost all the conventional buildings of stone wall with mud mortar collapsed in the epicentral area as their resistance against lateral force was very little (see Fig.7). Though the stone wall buildings with sand cement mortar (see Fig.8) or those with wooden frame to support roof (see Fig.9) responded in a better way than the stone wall with mud mortar but they also became unusable. The engineered structures responded in expected way and suffered generally acceptable pattern of damage. Performance of reinforced structures, in general, was good except one water tank (see Fig.10). It was reported that the reinforcement detailing of this tank might not be in accordance with the accepted practice.

Iyengar et al observed that the earthquake was felt more widely and severely to the South of epicentre than to the North [5]. They developed the damage intensity map (UN Scale) based on damage survey. An intensity of VIII has been assigned to the mizoseismic area. Another interesting feature is that intensity VII had also been observed in Unrani and Bhosgak which are at a large distance from the epicentral area (see Fig.4). This may be due to the local geological and sub surface condition.

Ground Motion

The Latur earthquake was reported to be felt in large area, even at a distance of about 800 km from the epicentral region. This is an interesting feature of an earthquake of magnitude in the range 6.4 and is attributed to two reasons; firstly, the focal depth is shallow and second one is the efficient wave propagation characteristics of the rock strata of the shield region.

No strong motion records are available of this earthquake. Based on field survey, interviews of local residents, Sinval et al reported that the ground motion generated by the earthquake was of complex type [14]. The possibility of vertical and torsional component alongwith the horizontal component, generated by the earthquake, was inferred from the information obtained from the field survey, the pattern of damage and deformation suffered by the structures, etc. Sliding of heavy objects were also reported [5,14]. Iyengar et al estimated ground acceleration near the epicentral area as about 0.2g based on the information regarding sliding, tilting and toppling of objects (see Table-1).

IMPACT ON ASEISMIC DESIGN OF STRUCTURES

The Latur earthquake reveals a good deal of information regarding the earthquake potential of the stable continental regions of Peninsular India. The event has raised a number of issues related to the aseismic design of structures in India. These are related to the seismic zoning of India, method to determine the design basis ground motion (DBGM) and design of structures. Some of the present practice related to these activities are examined in the following sections vis-a-vis the various data/information obtained from the field study and other investigation carried out following the Latur earthquake.

Present Practice of Aseismic Design in India

1. General Buildings/Structures

In India, earthquake resistant design of general buildings/structures are carried out as per "Indian Standard, Criteria for Earthquake Resistant Design of Structures", IS:1893-1984 [17]. In the standard, it has been endeavored to ensure that, as far as possible, structures are able to respond, without structural damage to shocks of moderate intensities and without total collapse to shocks of high intensities. The structures, which are designed as per this standard, are expected to experience more severe ground motion than the one envisaged in design during its life time. In view of this, the standard advocates to adopt the ductile design considerations.

The standard divides entire India in five (5) seismic zones based on the probable earthquake intensity (see Fig.11). Table-2 contains the assigned intensity and earthquake potential of these zones. The standard principally deals with the horizontal motion in the detail. However, vertical motion needs to be considered when the stability is main criteria in the design. The standard specifies that the seismic coefficient for vertical motion should be 50% of that for horizontal motion.

As per IS-1893, the horizontal seismic coefficient (a_h), the design parameter of earthquake excitation for which structure is to be designed, is determined from the following expression :

$$a_h = \beta I . a \qquad (1)$$

where, the values of β depend on soil foundation systems and varies from 1.5 to 1.0, while the range of I (importance factor) is given in IS1893 as 1.0 to 3. The value of ground motion factor, 'a', varies with seismic zones.

(i) Seismic Coefficient Method

In this method, 'a' is the basic horizontal seismic coefficient (a_o), the values of which for different seismic zones are given in Table-2.

(ii) Response Spectrum Method

In this method, the structural response is determined by dynamic analysis using response spectrum method based on modal super position technique. The standard provides an average spectra (see Fig. 12) and the horizontal seismic coefficient is calculated from equation (1) for which 'a' is given by

$$a = Fo\ Sa/g \qquad (2)$$

Where, Fo and 'Sa/g' are the seismic zone factor for average spectra (see Table-2) and average spectral ordinate (ref. Fig. 15) respectively.

2. Nuclear Power Plants (NPP)

In India, the nuclear safety related structures are designed presently for site specific DBGM. The DBGM are evaluated for two levels of severity. The severe earthquake level is termed as S1 (OBE) and the extreme level is designated as S2 (SSE). The DBGM of a given site is determined following the guidelines laid done in "Safety Guide on Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites", AERB/SG/S11 [18].

In general, peak ground acceleration (PGA) of a site is calculated following deterministic approach and considering the geological, geophysical and seismological information of the region within 300 km radius from the site. This region is divided into a number of seismotectonic provinces. The maximum earthquake potential of each fault in a province is evaluated. The maximum earthquake potential of a fault can be determined either from historical earthquake data (adding one intensity to the estimated/recorded intensity of reported earthquake) or by evaluating the maximum earthquake capability of the fault considering its tectonic characteristics. However, the peak ground accelerations of S1 and S2 level earthquake in horizontal direction should not be less than 0.05g and 0.1g respectively. Ground acceleration in vertical direction is desirable to be determined following the same procedure as used for determination of the acceleration in horizontal direction. In lieu of this, AERB/SG/S-11 also allows to consider the vertical excitation as 67% of the horizontal excitation.

The design response spectrum is derived from an ensemble of acclearograms recorded on similar sites and covering broad range of source and transmission path characteristics. Design time history is generated from this design response spectra ensuring that the time history is compatible to it.

Seismic zoning

1. General Buildings/Structures

The seismic zone map of IS:1893 has been developed primarily on the basis of available strong motion seismic data/information. The seismic zone number of a region is the representation of the size of earthquakes (magnitude or intensity) which could occur in that region. Potential of earthquake primarily depends on the strain of rock. The work of Gaur and others [9] indicates that strain is accumulated in the crust of peninsular India at a slow rate. For rupture of rock, threshold value of strain is in the order of 10^{-3}. If the rate of strain accumulation is in the order of 10^{-6} to 10^{-7} (as in the case of Southern part of peninsular India; see ref.9), the return period of a typical moderate to higher size earthquake in this region may be taken in the order of 10^3 to 10^4 years. Therefore, current potential of earthquake in any area of this region depends on the value of accumulated strain till date. Again, if there is any weak spot due to the presence of fluid or due to any other reason in a lineament, the rock mass could rupture at lower threshold value.

Bureau of Indian Standard (BIS) has taken up a programme to revise the seismic zoning map of India. The seismic zoning map would be revised considering the earthquake potential of different regions in India and taking into account the geological, geophysical and seismological features of these regions alongwith strong motion as well as micro earthquake data.

2. Nuclear Power Plants

Incidentally, no Indian NPP or sites of ongoing nuclear power projects are situated within 300 km radius from the epicentral area of Latur earthquake. Since, the site specific DBGM of NPP-Site is determined conservatively from the maximum earthquake potential of all causative faults (falling on the area within 300 km radius from the site), change in seismic zonation of India will not have any impact in the engineering of Indian NPP.

Ground Motion

1.0 General Buildings and Structures

It has been inferred from the field survey that the ground motion generated by Latur earthquake contained horizontal, vertical and possibly torsional component [7, 14]. It may not be possible to infer the existence of torsional motion just on the basis of deformation/damages of structure, but possibility of vertical motion could be inferred with reasonable certainties from these information. IS:1893, principally, deals with horizontal motion in detail and apparently attaches less importance to the vertical motion. The information revealed from Latur earthquake clearly indicates that both of vertical and horizontal motion should be treated with equal importance in aseismic design.

The range of ground acceleration (horizontal) calculated is 0.023g to 0.006g considering different values of ß and I for regions falling in seismic zone-I. The ground acceleration in epicentral area of Latur earthquake has been estimated as 0.2g using the information collected after the event. Therefore, if a structure is designed for earthquake excitation as per IS1893 in the epicentral area of Latur earthquake, then it needs to have ductility factor 8.69 to 33.33 (corresponding to PGA 0.023g to 0.006g) to withstand 0.2g ground acceleration.

It is presumed that when a structure is designed and detailed following the codal criteria of ductile design [21] and good engineering practice, the ductility factor of about 5 could be achieved. Demand of ductility factor 8.69 may be acceptable with a view that structure could be allowed to suffer certain level of damage. But demand of ductibility factor 33.33 is too high. It indicates that there exists possibility of underestimation of the design value of seismic effects by IS1893 in some cases and there is a need to re-examine this respect.

2.0 Nuclear Power Plants

The PGA values are calculated for the areas around Killari village from maximum reported magnitude of earthquake as per AERB/SG/S-11. The maximum magnitude earthquake occurred before the September 30, 1994 event was felt 4.0. For various combinations of epicentral distance and hypocentral depth, PGA values are calculated with this information and are found to be less than 0.2g. The maximum value is 0.104g when epicentral distance of 5 km and hypocentral depth of 5 km are considered. For other combination of epicentral distance and the hypocentral depth, the values are less than 0.1g. For the epicentral distance and the hypocentral depth both taken upto 10 km, the calculated PGA values are even less than 0.05 g in some cases. The PGA values were also calculated for different combinations of epicentral distance (upto 20 km) and hypocentral depth (20 km) for magnitude upto 7.5. It is found in number of cases the PGA value works out to be less than 0.2g and in a few cases it is even less than

0.1g when magnitude is taken less than or equal to 6.5. In this context, it may be noted, out of eight major earthquakes occurred in the region of peninsular India, magnitude of seven earthquakes were less than 6.5. The magnitude of the largest one was 7.79 which occurred in 1819 at Kutch region.

The above results indicate that it may not always be conservative to determine the PGA only on the basis of past earthquake data only, specially, for the site falling in a stable continental region.

Design and Detailing of Structure

The principal failure modes of concrete structures which are generally addressed in the design of a reinforced concrete structure are flexure, shear and bond, while for steel structure they are flexure, shear, buckling. The joints are also very important aspect for steel structures or pre-fabricated structures for efficient aseismic design. Except flexure, all other failure modes are non-ductile for concrete structures. Structural design should eliminate the possibility of non-ductile failure modes. For this purpose, ductility should be implemented in all design implicitly and when this is warranted, explicit implementation should be made [22].

The behaviour of different engineered brick masonry buildings and RCC structure with aseismic design feature during Latur earthquake again confirms that present state of aseismic design of structure can attribute them the capability to withstand the effect of earthquakes in intended way even if the seismic excitation is more than the one accounted in the design.

SUMMARY

1. The Latur earthquake occurred in the stable continental region of peninsular India comprising of the Deccan Volcanic Province (DVP) and a craton. According to seismologist, this earthquake of magnitude above 6.0 in a stable continental region associated with craton is a rare event.

2. The earthquake had shallow focus and while the damage area was comparatively small but the felt area was very large. This is attributed to efficient propagation of seismic wave in the shield region. High number of death toll was due to the fact that the earthquake occurred in the early morning hours when people were fast asleep. Moreover, large damage of buildings is also responsible for this. The buildings/structures

responded in expected manner. Most of the buildings in the affected areas were of conventional type construction and were poor in resisting lateral forces and thus suffered severe damage or collapsed. Appropriately engineered structures with earthquake resistant capability withstood the earthquake in intended way.

3. The ground motion produced by the earthquake was of complex nature comprising of horizontal and vertical component. Presence of torsional component in the ground motion was also reported. The ground acceleration in the epicentral region has been estimated as 0.2g.

4. *Following conclusions are drawn from the* examination of some of the aspects of present methodology of aseismic design followed in India.

   i) The revision of seismic zoning map needs to be based on the geological, geophysical and seismological information along with the strong motion as well as micro earthquake data.

   ii) The present methodology of IS1893 to determine the design parameters of earthquake ground motion for aseismic design of structure may underestimate the value of design ground motion parameter which may not be the intent of IS1893. The method needs to be re-examined.

   iii) Ductility should be implemented in all design implicitly. When required explicit implementation of ductility is to be made through design methodology.

   iv) A minimum level of ductile detailing should be specified for the all buildings/structures irrespective of their location of construction with respect to seismic zone.

   v) Appropriate detailing needs to be adopted, as a first step, to cater for possible torsional motion generated by earthquake.

   vi) Both the vertical and horizontal excitation needs to be taken care in the design assigning equal importance to each.

   vii) Evaluation of maximum earthquake potential of faults only on the basis of past earthquake data may not give conservative design basis ground motion of a NPP site in a stable continental crust region. The maximum potential shall also be evaluated considering the capability of the fault from geological, geophysical and seismological information/ data.

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TABLE - 1 Field Observations of Overturned/Tilted Object [5]

Place	Distance Killari (km)	District and Taluk	Description	Horizontal acceleration to initiate tilting (g)
Killari	-	Latur	Roadside boundary stone near post office	0.18
		Ausa	Roadside marking stone near main square	0.24
Kavatha	<5	Osmanabad	Idol in Hanuman temple on 2m high platform	0.16
		Umerga	Surya idol kept on pedestal in Vishnu temple	0.17
			Vishnu idol kept on ground	0.14
Sarwadi	7	Latur Nilanga	Idol in Vishnu temple on 1.5 m high platform	0.13
Sirur-G	30	Gulbarga	Idol in Hanuman temple on 1m high platform	0.16
		Aland	Idol in Hanuman temple on 1m high platform	0.24
Thair	50	Osmanabad Osmanabad	Idol in Laxmi temple on 1.5 m high platform	0.1
Umerga	25	Osmanabad Umerga	Steel cupboard in 3rd floor of MSEB quarters	0.25
Kohinoor Pahad	50	Basavakalyan Bidar	Stone block in graveyard on 1m high platform	0.12

TABLE-2 Assigned Intensity and Estimated Earthquake Potential of Different Seismic Zone (IS:1893) of India.

Seismic zone	Assigned Intensity (MM)	Maximum Earthquake Potential (Magnitude)	Basic horizontal seismic coeff. (a_o)	Seismic zone Fo
I	V	5.7	0.01	0.05
II	VI	6.3	0.02	0.10
III	VII	7.0	0.04	0.20
IV	VIII	7.7	0.05	0.25
V	IX	9.0	0.08	0.40

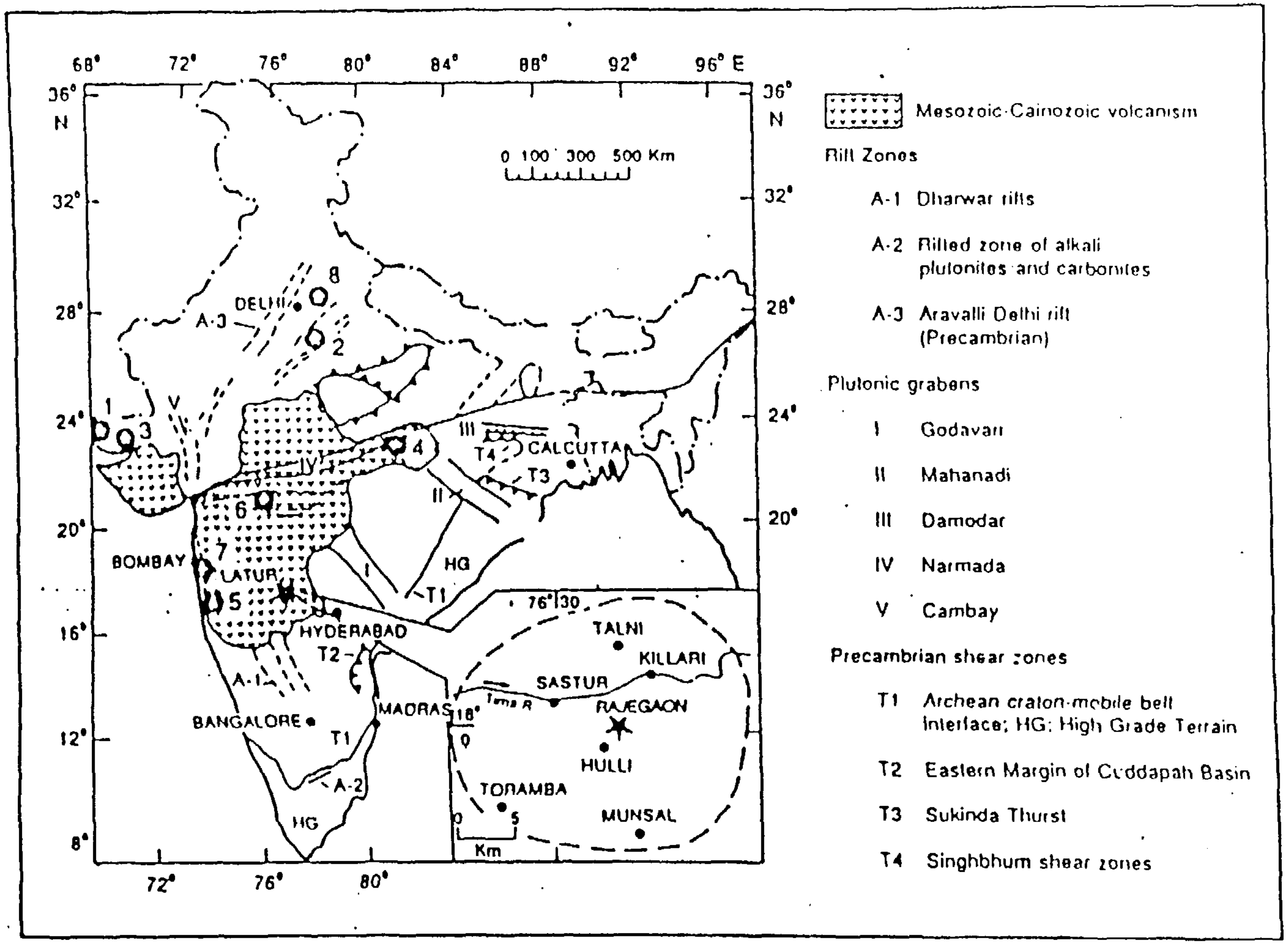

Fig. 1 Generalized tectonic map of the stable continental region of India.
The big star is the epicenter of the Latur earthquake of September 30, 1993. Open star enclosed in solid circles are previous eight largest earthquakes (after Johnston (1993)): 1: 1819, M = 7.79; 2: 1803, M = 6.65; 3: 1956, M = 6.48; 4: 1927 M = 6.40; 5: 1967, M = 6.3; 6: 1938, M = 6.26; 7: 1918, M = 6.24; 8: 1956, M = 6.05.
Inset is the mejzoseismal area of Latur earthquake.

(Ref-10)

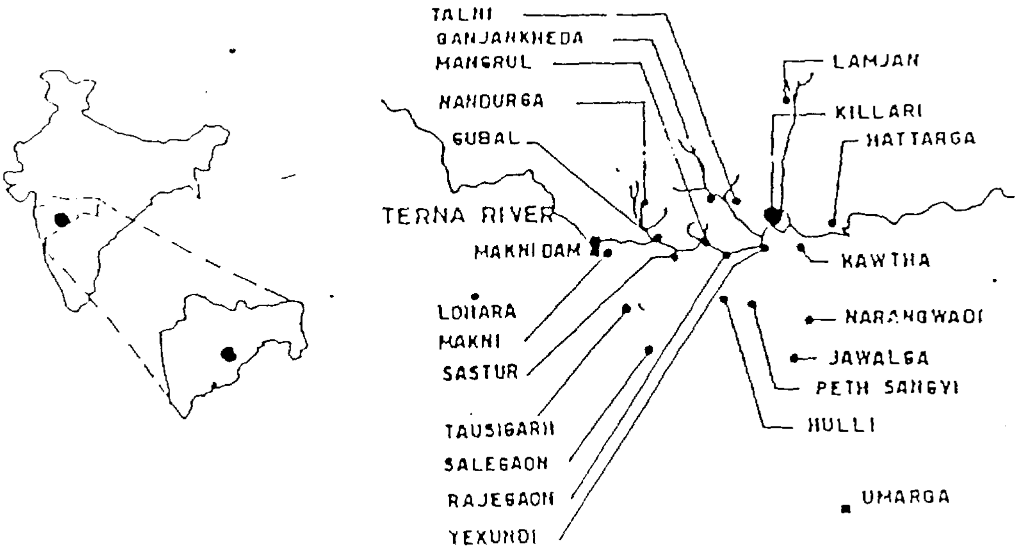

Fig 2 *Location of some of the worst affected villages devastated by the Latur - Osmanabad earthquake of September 30, 1993. (Modified after Survey of India Toposheet 56 B). Inset shows epicentre of the earthquake on map of India.*

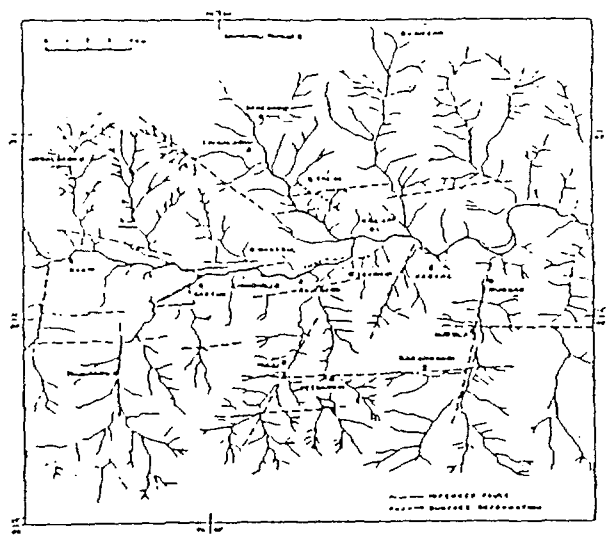

Fig-3 Drainage Pattern Around Killari Village and Inferred Subsurface Faults (Ref-14)

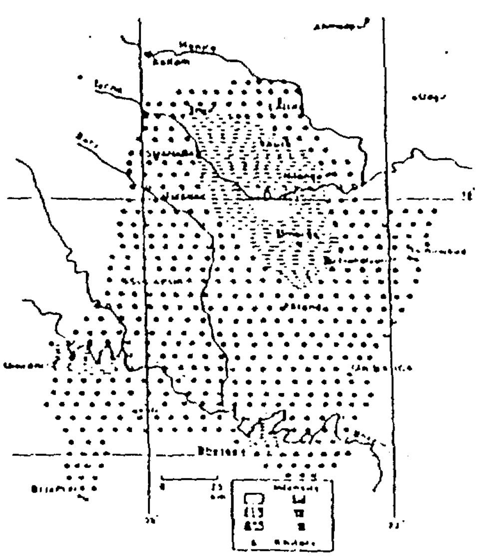

Fig-4 Damage Intensity Map in UN Scale (Ref-5)

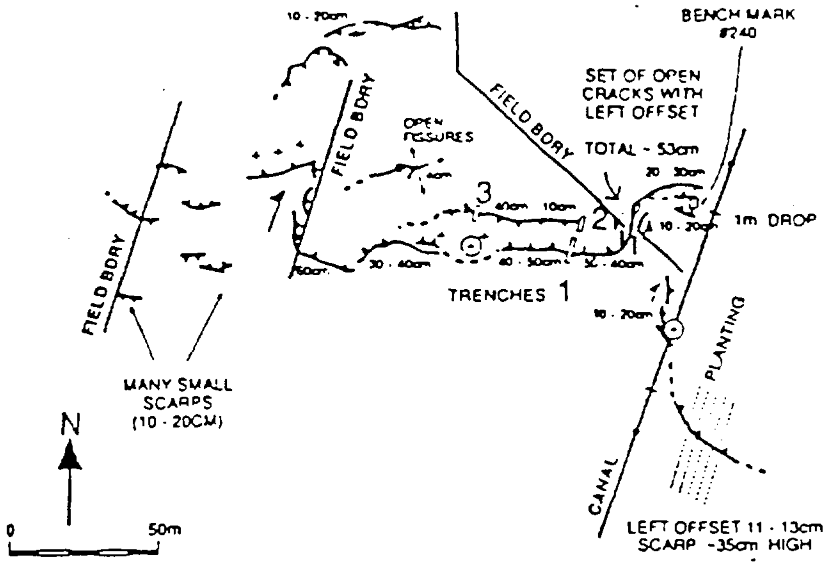

Figure 5 · Portion of the surface rupture associated with the 1993 Killari earthquake. This rupture was mapped discontinuously in an east-west zone over a distance of about 1 km. Barbs indicate the uplifted side of the scarps; the approximate height of the scarps is also indicated. Plus signs indicate uplifted area, circled when localized. Note that a "transform" fault connects a south-facing scarp in the center of the map with a north-facing scarp on the right. This "transform" offsets a field boundary by 53 cm left laterally, which is a minimum measure of the shortening. The strike of this and other "transforms" in this map is north-northeast, the inferred direction of shortening.

(Ref-1)

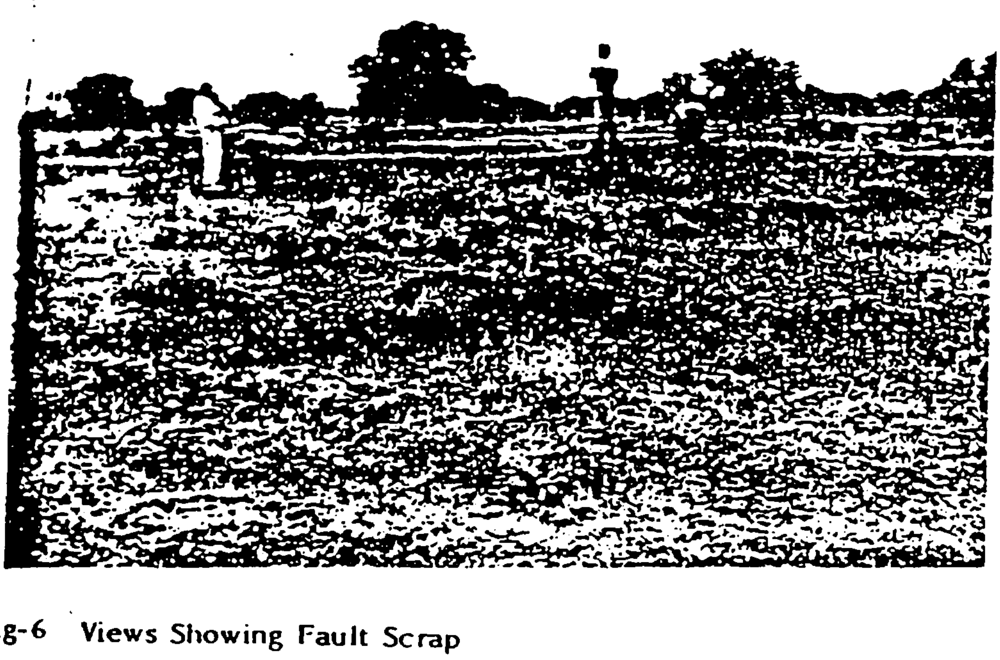

Fig-6 Views Showing Fault Scrap

(Courtesy Dr. S.K. Jain, IIT, Kanpur, India)

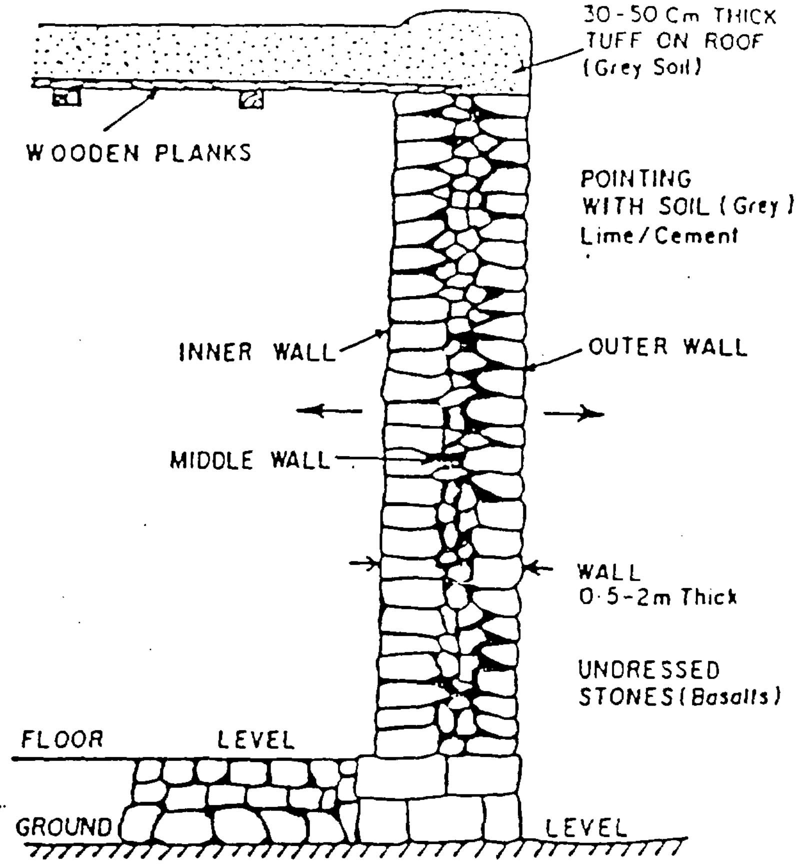

Fig-7 Typical Detail of Conventional Buildings with Stone Wall (Ref-4)

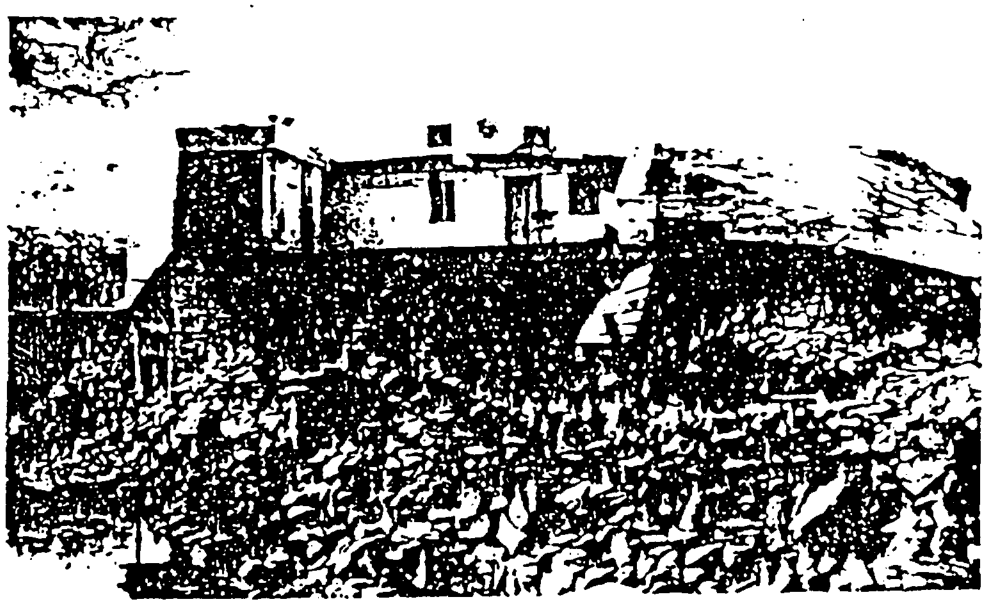

Fig-8 Damage of Conventional Stone Wall Building (Courtesy : Dr. S.K. Jain, IIT, Kanpur, India)

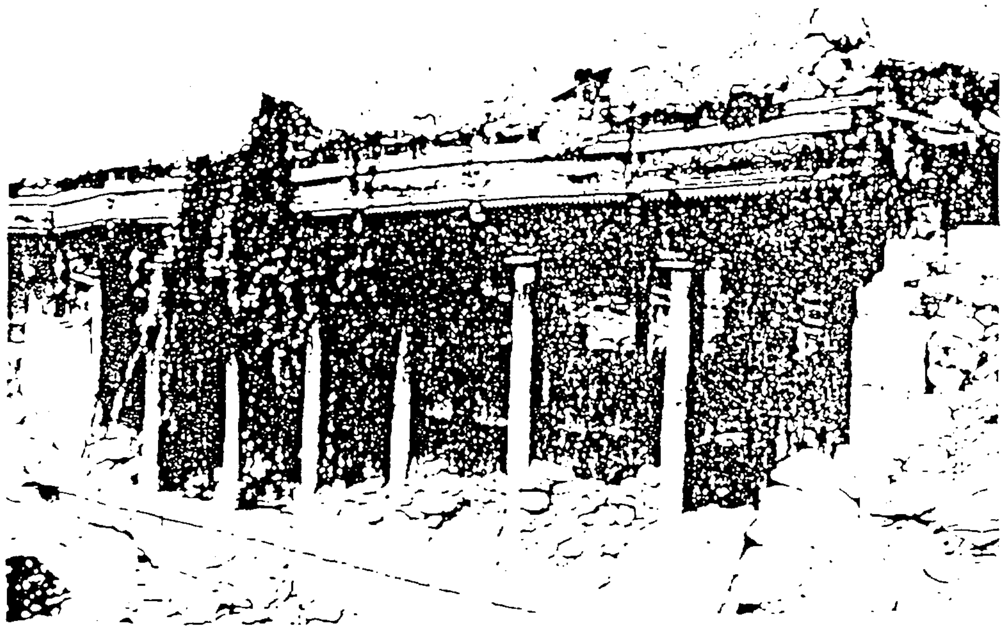

Fig-9 Damage of Building with Wooden Frame
(Courtesy : Dr. S.K. Jain, IIT, Kanpur, India)

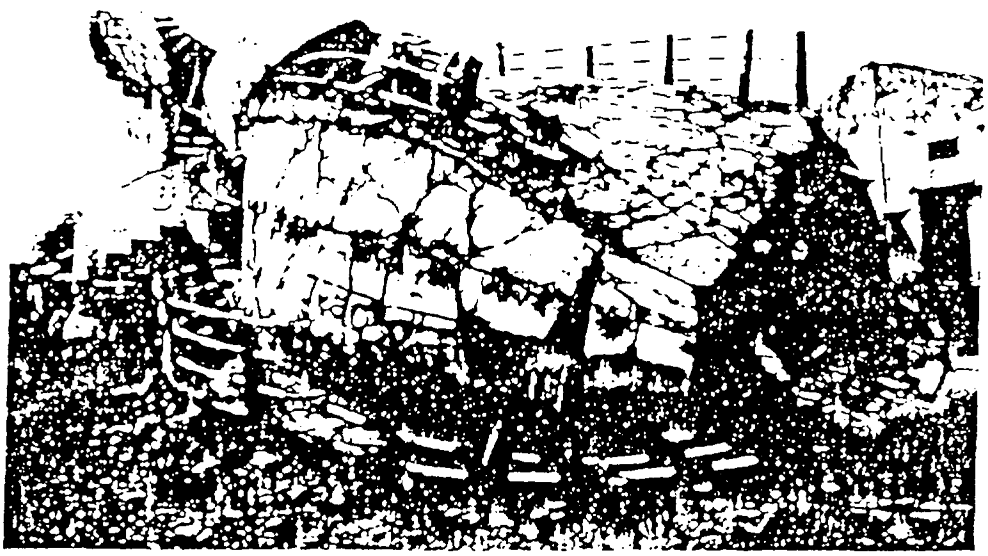

Fig-10 Views Showing Failure of RCC Circular Water Tank
(Courtesy : Dr. S.K. Jain, IIT, Kanpur, India)

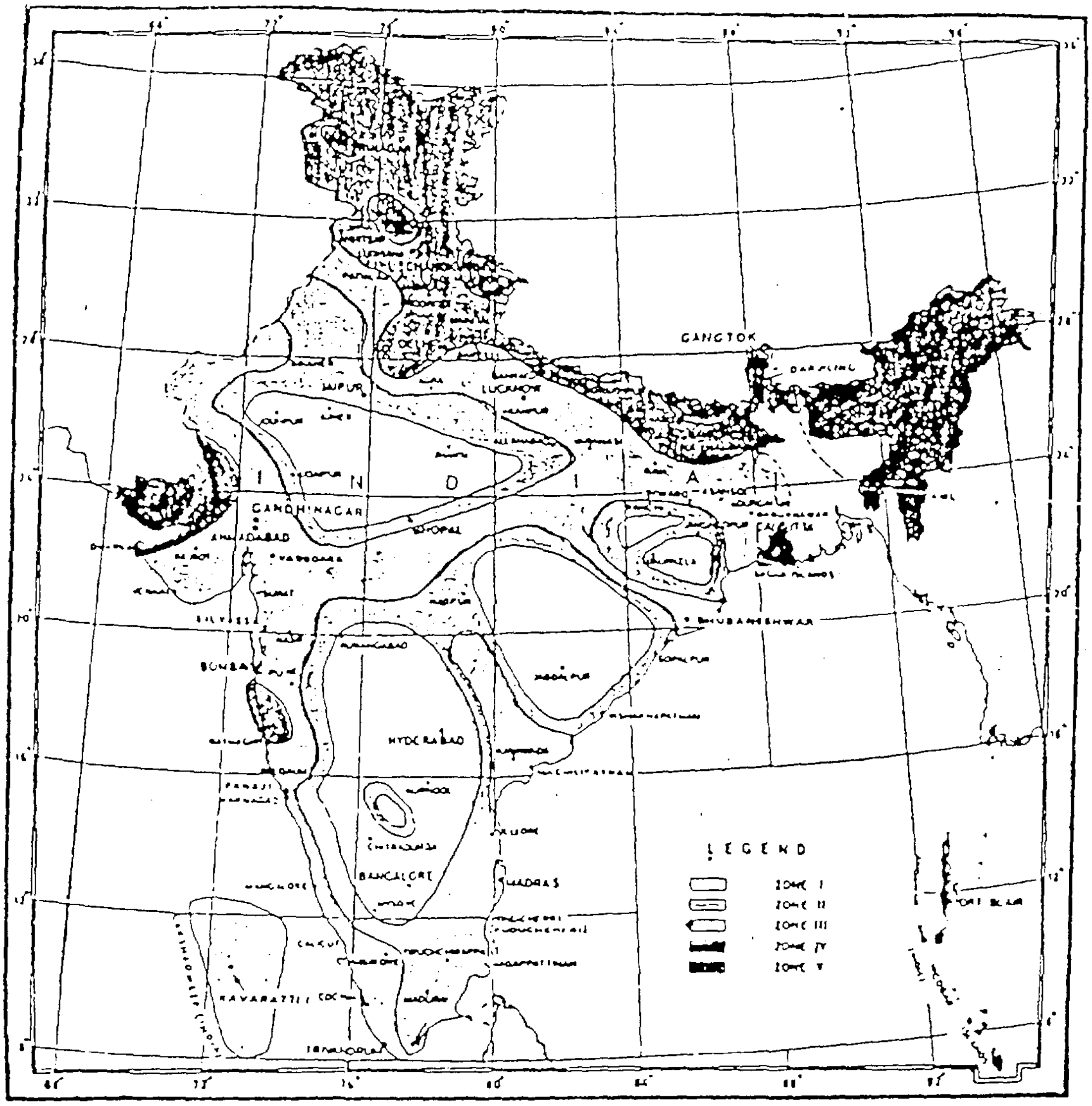

Fig- 11 Earthquake Zoning Map of India
(Ref. IS 1893)

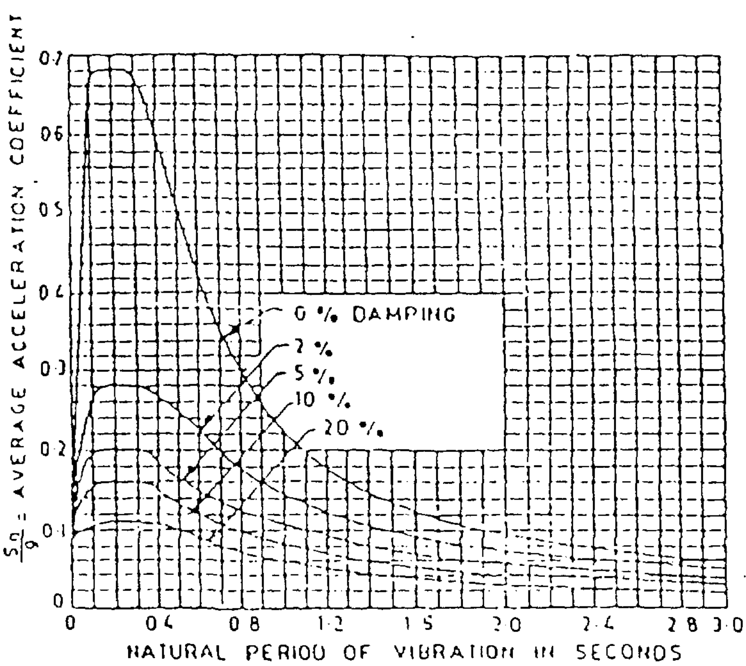

Fig-12 Average Response Spectra (IS 1893)