A NOTE ON THE ACCURACY OF SEISMIC HAZARD IN PENINSULAR INDIA

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ABSTRACT:

This study was conducted in order to compute the deviations in the Peak Ground Acceleration (PGA) values as specified in the IS 1893:2002 for different regions from the values obtained from modern empirical attenuation formulae. For this purpose, earthquake events catalogue was prepared for various earthquakes that occurred from year 1984 to 2003 in Peninsular India (PI). The data was obtained from Seismotectonic Atlas of India (GSI). Sizes of these earthquakes for most of the sites are defined in terms of Surface wave Magnitude (M_s) and the Body wave Magnitude (m_b). These values of magnitude were converted into uniform moment magnitude (M_w). By using moment magnitude and hypocentral radius, PGA values were computed using Iyengar & Raghukanth's attenuation relationships. From the study it is found that large portions of PI regions are over estimated. In this regard, it is recommended to study macro seismotectonics of Indian plate before taking up microzonation in a big way.

KEYWORDS: Seismic zonation, Attenuation relationship, Moment Magnitude (M_w), Peak ground acceleration (PGA)

INTRODUCTION: Figure 1 shows the seismic trend of India for a period of around 500 years[1)] from 1594 to 1998. From the figure, it is apparent that there is a noticeable increment in the number of earthquakes over a period of time, especially after 1950 or there is a void in records taken before 1950. When we look at the number of fatal earthquakes over a period, it suggests that the recent rate of fatal earthquakes in India is 5 per decade which is much higher than at any time in the past 400 years. In last 2 decades, India has witnessed several moderate earthquakes (Bihar-Nepal border (M6.4) in 1988, Uttarkashi, Uttaranchal (M6.6) in 1991, Latur, Maharashtra (M6.3) in 1993, Jabalpur, Madhya Pradesh (M6.0) in 1997, Chamoli, Uttaranchal (M6.8) in 1999, Bhuj, Gujarat (M6.9) in 2001 and Muzafarrabad,Kashmir (M7.6) in 2005) causing over 1 lakh casualties due to collapse of structures. This shift towards more frequent occurrence of fatal earthquakes has posed Indian researchers in a situation to rethink over the measures suitable for an appropriate disaster management. The first step in this direction is to classify India into various seismic zones based on the criteria crucial for causing maximum loss (considering loss is in terms of both property and life).

Current seismic zonation map as per IS 1893-2002[2)] says that around 60% (Zone V= 12%, Zone IV=18%, Zone III = 26% and Zone II 44%) of India is prone to moderate to major earthquakes. Accordingly, zone factors (z) are defined for each zone to arrive at the design seismic force acting on the structure. As per table 1[3)], zone II corresponds to intensity VI or lower and zone V corresponds to intensity IX or higher. From the horizontal peak ground acceleration as a function of earthquake intensity given by various researchers[4)] it can be seen that zone

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factor for zone II and zone III is largely over estimated especially when we see the PI region. In order to support the above statement, we have conducted a study using the data of several earthquakes occurred in PI region and computed PGA as per attenuation relationship given by Iyengar & Raghukanth[5)] and the same are compared with the values given in IS 1893-2002.

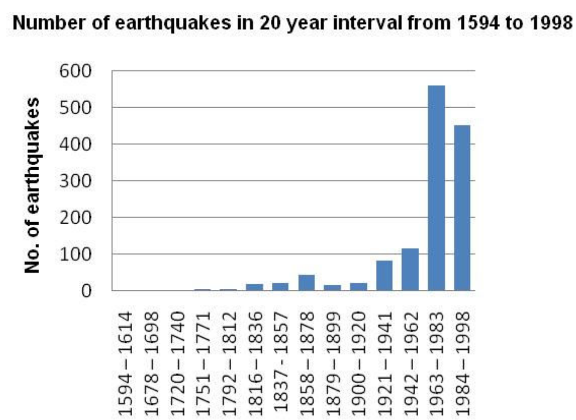

Fig 1: Number of earthquakes in 20 year interval from 1594-1998

SEISMOTECTONIC SETUP AND SEISMIC ZONATION OF INDIA

According to the Bird's model for plates across the globe, whole world is divided into 14 major plates and 38 minor plates[6)]. Out of these plates, Indian subcontinent is composed of 3 major plates viz., Indian plate, Eurasian plate and Australian plate and many minor plates like Burma plate, Sunda plate etc. Distinct physical and kinematic properties of these plates lead to a diversified seismicity from one region to another in Indian subcontinent. On the basis of historic seismic trend, Indian shield can be easily classified as seismically active at the Himalayan, Karakoram, and Tibetan plateau belt stretching in approx 2500 km line and somewhat seismically moderate in the peninsular shield (see fig 2). Various regions were identified and classified on the basis of their seismic activeness. Since these seismic activities are random in nature, classification merely on the basis of major seismic activities is always been a topic of debate among the researchers.

Seismicity trend of India classifies it as a highly varied country in terms of seismic activities. Figure 3 shows the seismicity of India. This map was prepared using the ISC data and Google map. From this map it can be seen that there is a broad variation in seismic hazard levels in terms of the intensity of ground motion and the frequency of occurrence. These variations divided India into different zones with respect to the severity of expected ground motion. All these changes were incorporated in various zonation maps. Different zonation map reviews have taken place so far and different criteria were considered for these revisions. The first seismic hazard map of India was compiled by the Geological Survey of India (GSI) in 1935. This was the only map proposed by GSI, after this, all maps were prepared and proposed by India Standard Institution (ISI).

The second map was released in 1962 (see fig 4(a)) by the Indian Standards Institution (ISI) presently called as Bureau of Indian Standards (BIS). This map was published in Indian Seismic Design Code IS 1893:1962[7)]. The map divided India into 7 seismic zones from zone 0 (no damage) to zone VI (extensive damage). This division was based upon the Maximum Mercalli Intensities (MMI). In this map, peninsular India is shown as stable region. It assumes that if at all there is an earthquake in PI region it will not affect structures. The third map was published in 1966[8)] (see fig 4(b)); four years after the 2nd map got published. This map again divided India into 7 seismic zones from zone 0 to zone VI. This map also used geological information of earthquake activity and tectonic maps that delineated fault system. Some portion of peninsular India was upgraded from zone 0 to zone I.

The next map revision took place in the year 1970[9]. Koyna earthquake (1967, M 6.5) made this revision mandatory. This map divided India into 5 seismic zones from zone I to zone V based upon Comprehensive Intensity Scale (CIS–64) historically observed or expected in those zones. Concept of zone 0 was abolished in support to the fact that there is no region in India with probability of an earthquake equal to zero. For the first time a seismic hazard map was based upon Comprehensive Intensity Scale (CIS-64).

Again in 1984[10] major revision took place (see fig 4(c)). Number of zones was 5. In this revision, irrational shape is assigned to some higher zones because attenuation can't be so small. Again two moderate events took place in peninsular India. First one was in Latur in 1993 and second was in Jabalpur in 1997. These events demanded the attention of researchers towards comprehensive study of peninsular region. Fifth revision of IS 1893:2002 took place immediately after the devastating earthquake in Bhuj. In this revision, only 4 zones were adopted viz., zone II, III, IV & V. Zone II being low damage risk zone and Zone V being high damage risk zone. Also, most of peninsular region is upgraded to zone II and III. Zone I is completely discarded in this revision. Moreover in this revision around 60% of Indian region was considered in zone III or above. In this regard, large portion of PI was upgraded.

The latest revision in code IS 1893:2002 uses CIS-64 scale for its ground shaking Intensity (I) considerations. Both MMI and CIS-64 scales are considered for zonation due to the absence of instrumentally recorded data. Current zonation does not consider the probability of occurrence of earthquake in a given region and moreover, the classifications based on Intensity scales are not up to mark as they are related to damage observations that are always liable to human error. The present study has been conducted to show that most of the PI region is over estimated.

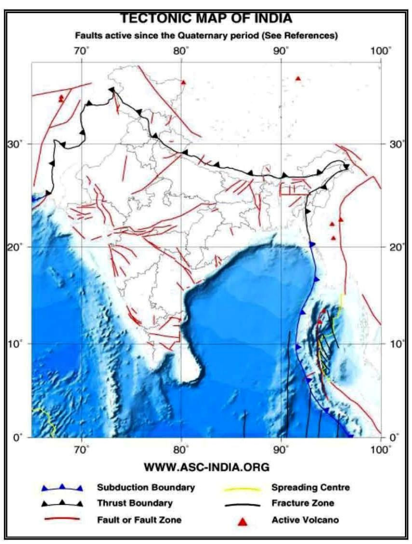

Fig 2 Tectonic Map of India

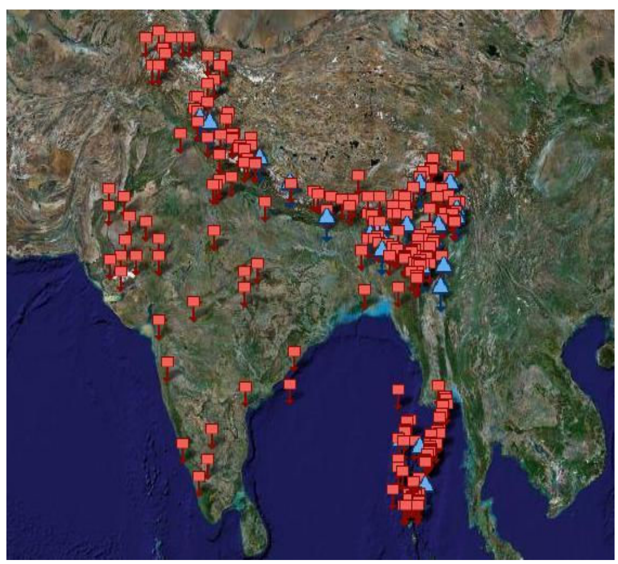

Fig 3 Seismicity of India

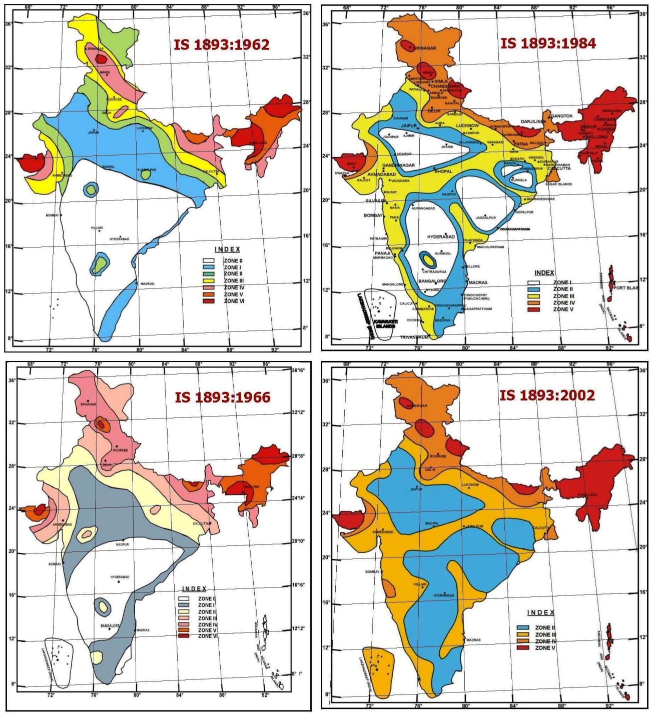

Fig 4 Zonation maps of India

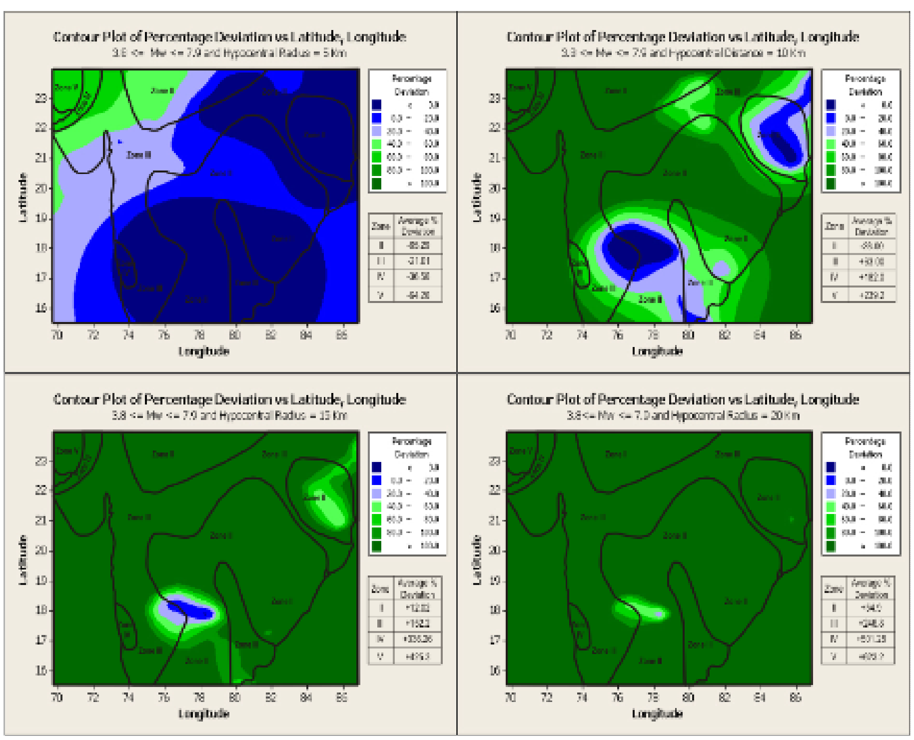

Fig 5 Average Percentage deviation in PGA values for different Hypocentral Radius

ACCURACY OF SEISMIC HAZARD IN PENINSULAR REGION

For estimating the deviations of PGA assigned for various zones in PI region, data has been collected from Seismotectonic Atlas of India and its environs[1)] and later all the magnitudes values were converted to uniform moment magnitude values using Scordilis formula and attenuation relation of Iyengar[5)] were used to estimate the PGA values. Estimated PGA values were used to compute the deviation with respect to assigned PGA values for various regions according to IS 1893:2002.

Data Collection

For given ranges of latitudes and longitudes, earthquake catalogue was prepared for peninsular region (PI) region. For this the data was collected from a uniform resource viz. Seismotectonic Atlas of India and its environs. Data was collected from a uniform source in order to maintain the uniformity in computation

Earthquake Size Computation

Size of the earthquake was computed using Scordilis[11)] formula. This formula makes use of m_{bw} and M_{sw}. In case of both m_b and M_s values available for an event in a record, we have used the conversion relations proposed by Scordilis and then we have estimated the weighted average of the converted magnitudes using as weight the $1/\sigma$ of each conversion formula. We called the corresponding M_w values computed based upon m_b and M_s as m_{bw} and M_{sw} respectively and the final magnitude (M_w) was computed as:

Where corresponding values of σ_1 and σ_2 are as shown below:

For $3<=M_s<=6.1$, $\sigma_2 = 0.17$

For $6.2 <=M_s<=8.2$, $\sigma_2 = 0.20$

For $3.5<=m_b<=6.2$, $\sigma_1 = 0.29$

Moreover at the places in record where only m_b or M_s values were given M_w was computed directly on the basis of whatever source value (either m_b or M_w) is given.

$$M_{sw} = 0.67(\pm 0.005)\, M_s + 2.07(\pm 0.03),\quad 3.0 \le M_s \le 6.1,\ R_2 = 0.77,\ \sigma_2 = 0.17,\ n = 23{,}921 \qquad (2)$$

$$M_{sw} = 0.99(\pm 0.02)\, M_s + 0.08(\pm 0.13),\ 6.2 \le M_s \le 8.2,\ R_2 = 0.81,\ \sigma_2 = 0.20,\ n = 2{,}382 \qquad (3)$$

$$m_{bw} = 0.85(\pm 0.04) m_b + 1.03(\pm 0.23),\ 3.5 \le m_b \le 6.2,\ R^2 = 0.53,\ \sigma_1 = 0.29,\ n = 39{,}784 \qquad (4)$$

Computation of PGA for Peninsular India or PI region

Peak ground acceleration (PGA) can be evaluated using empirical attenuation relationships proposed for different seismic regions (Interplate, Intraplate, and Subduction). Every attenuation relationship is different from another in terms of applicability that is limited depending upon certain factors like the type of soil (Hard/rock, medium or soft), type of region (interplate, Intraplate or subduction), type of fault (Normal, reverse, strike-slip) and so on. Since the actual values of all these parameters were not present, empirical relationships and few logical assumptions were made in the computation of PGA.

For this study, we mainly focused on earthquakes that occurred in Peninsular India (PI) region, which is taken as south of 24° N latitude. Iyengar and Raghukanth[11)] proposed attenuation formulas for the peninsular Indian (PI) regions in their work "Attenuation of strong ground motion in peninsular India". A general attenuation relationship was proposed and its different parameters were defined for three different regions (Koyna – Warna, Western Central region and Southern region) within the PI region. Iyengar and Raghukanth proposed following attenuation formula to compute the PGA of PI region that is again subdivided into 3 main regions. Various parameters and corresponding attenuation equation for these regions are as follow:

$$\ln y = c_1 + c_2(M-6) + c_3(M-6)^2 - \ln R - c_4 R + \ln \varepsilon \quad (5)$$

Where y, M and R refer to PGA, moment magnitude and hypocentral distance respectively. Coefficients of this equation were also defined differently for different regions as given in Table 3.

Table 1 Percentage PGA deviation for PI

Date	Latitud-e	Longitud-e	Hypoce-ntral Radius	Moment Magnitude (Mw)	Peak Ground Acceleration (PGA Iyenger)	Seismic Zone (IS 1893:2002)	Zone basis PGA	Percentage Deviation
6/30/1983	17.9295	78.5429	10	5.2	0.263037	II	0.1	-61.9825
6/30/1983	17.9295	78.5429	15	5.2	0.172316	II	0.1	-41.9671
4/18/1987	22.5279	79.2405	5	5.1	0.436682	III	0.16	-63.3601
4/18/1987	22.5279	79.2405	10	5.1	0.211465	III	0.16	-24.3374
8/24/1993	20.6973	71.4408	10	5.2	0.235373	III	0.16	-32.0227
8/24/1993	20.6973	71.4408	15	5.2	0.151973	III	0.16	5.281627
9/29/1993	18.1054	76.6408	5	5.2	0.505542	II	0.1	-80.2192
9/29/1993	18.0898	76.473	5	6.2	1.340088	II	0.1	-92.5378
9/29/1993	18.1054	76.6408	10	5.2	0.242132	II	0.1	-58.7002
9/29/1993	18.0898	76.473	10	6.2	0.641843	II	0.1	-84.4199
9/29/1993	18.1054	76.6408	15	5.2	0.154627	II	0.1	-35.3282
9/29/1993	18.0898	76.473	15	6.2	0.409886	II	0.1	-75.603
6/21/1995	21.7637	85.286	5	5	0.391747	II	0.1	-74.4733
6/21/1995	21.7637	85.286	10	5	0.189705	II	0.1	-47.2866
6/21/1995	21.7637	85.286	15	5	0.122487	II	0.1	-18.3587
5/21/1997	23.0911	80.0818	10	5.9	0.477946	II	0.1	-79.0771
1/26/2001	23.369	70.563	5	5	0.391747	V	0.36	-8.10406
1/26/2001	23.506	70.517	5	5.1	0.436683	V	0.36	-17.5603
1/26/2001	23.424	70.847	5	5.2	0.486053	V	0.36	-25.934
1/26/2001	23.348	70.441	5	5.3	0.540204	V	0.36	-33.3585
1/26/2001	23.431	70.216	5	5.3	0.540204	V	0.36	-33.3585
1/26/2001	23.246	69.947	5	5.3	0.540204	V	0.36	-33.3585
1/26/2001	23.522	70.076	5	5.5	0.664322	V	0.36	-45.8094
1/26/2001	23.425	70.096	5	5.6	0.735064	V	0.36	-51.0247
1/26/2001	23.421	70.119	5	5.9	0.986978	V	0.36	-63.525
1/26/2001	23.442	70.31	5	7.9	5.008278	V	0.36	-92.8119
1/26/2001	23.369	70.563	10	5	0.189705	V	0.36	89.76833
1/26/2001	23.424	70.847	10	5.2	0.235373	V	0.36	52.94892
1/26/2001	23.348	70.441	10	5.3	0.261596	V	0.36	37.61694
1/26/2001	23.431	70.216	10	5.3	0.261596	V	0.36	37.61694
1/26/2001	23.246	69.947	10	5.3	0.261596	V	0.36	37.61694
1/26/2001	23.522	70.076	10	5.5	0.3217	V	0.36	11.90542
1/26/2001	23.442	70.31	10	7.9	2.425275	V	0.36	-85.1563
1/26/2001	23.369	70.563	15	5	0.122487	V	0.36	193.9087

Finally a computer program was developed in C programming language to compute the PGA(y) for different values of M_w and R corresponding to earthquakes belonging to different classifications within PI region. The code was developed in such a manner that by reading the latitude and longitude of the earthquake it assesses the region (koyna-warna, western central or south region) in which this earthquake has occurred and suitable constants will be used to compute the PGA value. A total of around 250 earthquake records occurred PI region were considered in this study. A sample table (Table 4) of few records has been prepared showing the event date, latitude and longitude, assumed hypocentral radius, computed moment magnitude, PGA using attenuation relationship, zone & zone based PGA and %deviation.

Table 2 Coefficients for Iyengar - Raghukanth attenuation formula for PI

Region	c1	c2	c3	c4	ε
Koyna - Warna Region	1.7615	0.9325	-0.0706	0.0086	0.3292
Western - Central Region	1.7236	0.9453	-0.074	0.0064	0.3439
Southern Region	1.7816	0.9205	-0.0673	0.0035	0.3136

Equations used for computing M_{sw} and m_{bw}
$M_{sw} = 0.67(\pm 0.005)\ M_s + 2.07(\pm 0.03)$,
$3.0 \le M_s \le 6.1$,
$R_2 = 0.77$, $\sigma_2 = 0.17$, $n = 23{,}921$
$M_{sw} = 0.99(\pm 0.02)\ M_s + 0.08(\pm 0.13)$,
$6.2 \le M_s \le 8.2$,
$R_2 = 0.81$, $\sigma_2 = 0.20$, $n = 2{,}382$
$m_{bw} = 0.85(\pm 0.04) m_b + 1.03(\pm 0.23)$,
$3.5 \le m_b \le 6.2$,
$R^2 = 0.53$, $\sigma_1 = 0.29$, $n = 39{,}784$

RESULTS & DISCUSSION

In this study the major concern was to compute the average percentage deviation in the values of PGA assigned to various seismic zones in India. Region considered for this study lies in between 16-23 latitude and 70-86 longitude. The percentage deviation was classified into 7 different levels (see figure 5) viz., less than 0, 0-20%, 20-40%, 40-60%, 60-80% 80-100% and greater than 100%. These percentage deviations were then studied with respect to different zones in which the region under study is classified. Percentage deviation was computed considering the following equation:

$$Deviation(\%) = \frac{PGA_{zone} - PGA_{computed}}{PGA_{computed}} x100$$

Hence, negative values of deviation indicate computed PGA to be more as compared to zone based PGA value defined as per code and hence indicating the underestimated values of PGA in our design code of practice. On the other hand, positive values of deviation indicate computed PGA to be less as compared to PGA by zone value defined and hence indicating the overestimated values of PGA in our design code of practice.

It was observed that for hypocentral radius=10 km as shown in Fig 5(b) much wider spectrum of percentage deviations were obtained. This signifies the uneven trend of seismicity in the region and more rigid definition of PGA for an area with hypocentral radius equals to 10. Moreover for this range of radius most of the zone II region was qualified as underestimated region. It means that the PGA value estimated using attenuation formula was greater than the PGA value proposed by the code. The overall average deviation for zone II was estimated to be

-28%. Similarly for zone III it is +63%, zone IV it is +182% and for zone V it is +239%.

In the same manner, average % deviations were estimated for other ranges of hypocentral radius as well. In case of 15 km (fig 5 (c)) and 20 km (fig 5 (d)) all the zone II, III, IV and V were evaluated with all positive values of average % deviations, indicating overestimated values of PGA for different zones. Moreover overall deviation towards overestimated rate was obtained to be more for higher hypocentral radius. For zone II, III, IV and V and radius =15 km values were obtained to be all positive. While for radius 20 km these deviations are much higher. These differences in values clearly indicate the average deviation to be biased more towards overestimated scenarios for higher hypocentral radii. Contour map and percentage deviation for radius 5 km was not considered much into this discussion as this value is too small to consider for deviation calculations. 5 km of hypocentral distance makes epicentral distance too small to be considered for such deviation. This was concluded when diverse ranges of deviation were covered for the region within this epicentral limit.

CONCLUSIONS

In this study we estimated the deviation of PGA mentioned in IS 1893:2002 from the computed PGA values using attenuation relations proposed by Iyengar & Raghukanth for peninsular region. From the results it is found that PGA values are over estimated in lower zones especially zone II and III for hypocentral radius ranging from 10 km to 20 km. For higher values of hypocentral radius it is found that PGA values of all the zones are over estimated. In this regard, it is recommended that serious attention is required for understanding macro seismotectonics of Indian plate for arriving at the macro hazard map.

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