A need to review the current official seismic zoning map of India

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The Indian subcontinent has experienced a number of devastating earthquakes in the last fourteen years, repeatedly reminding us about the high level of seismic hazard and risk prevailing in the country. Two of these were in the Himalayas – Uttarkashi in 1991, Chamoli in 1999, and three in peninsular India – Killari in 1993, Jabalpur in 1997 and Bhuj in 2001. Now the November 2005 Mujafarabad earthquake in Kashmir Himalaya is the latest disaster that has claimed 80,000 lives. The grave hazard and risk the earthquakes pose to the region are once again restated by the above event.

Defensive measures against seismic destruction are based on seismic hazard, which are estimated on the basis of seismological, geodetic and geological studies. Depending on the severity of seismic hazard, the region is segmented into zones which cover defined ranges of seismic hazard, i.e. often in terms of ground motion peak acceleration. For each seismic zone, a construction code is defined to provide buildings with enough strength to survive up to a certain extent, the expected shaking in future earthquakes. Seismic zoning can be done on a macro or on a micro scale depending on the size of the area (a whole region or a whole country versus a metropolitan area, for example). Over the years seismic zoning maps for India as a whole have evolved. The first attempt was made by GSI in 1935, when the Indian territory was delineated into three regions on a qualitative basis, defining regions with low to no damage, moderate and high damage. Subsequently, other maps have been made and the seismic zoning map of India in IS1893 (1962) utilized intensity as the main parameter and was dominated by the past large magnitude events, as the factor of greatest influence used in mapping was the observed intensities of the past major earthquakes. This led to meizoseismal areas of the past great earthquakes being the places defining the zones of highest risk in northern India. The map was progressively revised in 1966, 1970, 1984 and 2002 by giving some weights to the known tectonic features, while retaining the earlier concept of using the intensities of large earthquakes as the main determining factor. However, this progressive evolution fell quite short of utilizing the available state-of-the-art knowledge base, in particular a model to represent the earthquake occurrence process and continued to be beset with the bias caused due to using the past earthquakes as such in the zoning procedures. The currently adopted Indian seismic zoning map defines four seismic zones – II to V, zone V being the one with most severe hazard. Figure 1 shows the seismic zoning map of the Himalayan region taken from the currently adopted seismic zoning map of India. It is noticed that the seismic hazard along Uttaranchal, Himachal and Kashmir Himalayas is characterized by small 'islands' depicting zone V (the highest risk, shown in red colour), with areas depicted as zone IV (the next lower risk shown in green colour) intervening in between. Similarly, in the eastern sector a region of lower seismic risk is identified. The 'islands' of zone V fall essentially over the meizoseismal areas of the past major or great earthquakes. Thus this map is flawed, as it does not provide a proper estimate of future earthquake risk in areas between the 'islands' of zone V. Further, in this approach estimation of risk in terms of probabilities is not available. Availability of probabilities of seismic hazard in seismic zoning allows taking informed decisions, including cost-benefit ratio of implementing a hazard reduction strategy.

Scientific pursuit usually takes a course in which observations or empirical data are used to develop a suitable scientific model of phenomena under study, which has a proper predictive power of the phenomena, wherein lies its usefulness. Also, this is where the power and utility of science lies. In the late sixties–early seventies, significant development took place in the field of seismic hazard estimation and a probabilistic representation of earthquake occurrence was used as a basis of seismic hazard analysis. In order to take into account the unpredictability of earthquake occurrences, a stochastic model was adopted that has the capability of probabilistically predicting the occurrence of future earthquakes. Thus, taking this as a basis, the probabilistic seismic hazard analysis (PSHA) model was developed that has been found to be adequate for probabilistically predicting the future ground shaking-parameters from earthquakes. Not only does this model take into account several source zones that may be affecting a site and estimate the sum total of their individual contributions to the hazard, it has the flexibility to estimate the contributions of the individual source zones to the sites as well. PSHA has been done for the Himalayas[1,2], consistently showing that there is a sustained high level of hazard all along the Himalayas (Figure 2; map adapted from Bhatia *et al.*[2]). As is known, such maps give expected peak ground accelerations in hard rock within a user definable time window, as well as the level of probability of occurrence of the strong ground motion. Any deviations, such as soft sediments at a site causing amplification of the ground motion, have to be applied onto the hard rock values. What is relevant here is that the PSHA maps show more or less uniformly high level of expected accelerations throughout the length of the Himalayas, disregarding which the zoning map shows globules of highest risk zones in those areas where in the past one hundred years or so, a great earthquake has occurred. This is precisely the lacuna, i.e. the physical process of earthquake occurrence, which is now quite well understood and constrained, has not been taken into account so that the map depends on spot values (occurrence of a great earthquake in the historical data, which incidentally has been scientifically shown to be incomplete) that do not possess any systematic and scientific predictive

Figure 1. Adapted from seismic zoning map of India. After IS1893 (part I) 2002. Green areas are assigned a pga of 2.4 and red areas of 3.6 m/s^2.

capacity of the phenomena, and therefore are deficient and are often misleading in several places.

A number of recent studies of a fundamental nature that include GPS, palaeoseismological studies, seismic moment deficit, etc. have found correlating and convergent findings. These studies show that the entire Himalayan plate boundary currently is a veritable storehouse of high level of strain energy that is capable of generating great earthquakes[3] (see Figure 3). On the basis of Shimazaki time predictable model of earthquake recurrence and the concept of characteristic earthquakes, Khattri[4] estimated a rather significant value of 0.89 for the probability of a great earthquake in the Himalayan region in a 100-year time window (with effect from 1999). A host of other studies also have been made which complement seismological and GPS investigations. For example, palaeo-seismological studies[5,6] have independently corroborated findings from other facets of the earthquake process, about the occurrence of great earthquakes in sectors not visited by such an earthquake in historic time. There is a dire need to integrate all the recent advances in our knowledge into producing a state-of-the-art zoning map, both on large as well as micro scales on which the public can depend.

As already mentioned, in the Indian seismic zoning map four zones are defined depending upon expected severity of earthquake-generated ground motions, with zone V being the most severe, PSHA maps define a continuously changing (w.r.t. ground location) ground shaking parameter such as the PGA and the zoning maps define zones where the ground-shaking parameters have a specified range. This is because it is impractical to define the building codes on a continually varying basis; hence zoning is adopted where the same codes apply in the one zone. In the Indian zoning map, zone V is defined as one that has an average expected PGA of 3.6 m/s^2 and zone IV that has an average expected PGA of 2.4 m/s^2. However, the entire Himalayan belt has a PGA of 3.5 to 4.8 m/s^2 on hard rock, as shown in Figure 2. A comparison with the PSHA map shows that the characterization in the zoning map is not consistent with the seismic hazard for regions lying between the 'islands' showing zone V classification. Other studies cited above also correlate and converge to indicate a high level of seismic hazard and risk for the entire region. Thus the presently adopted seismic zoning map of the country is basically flawed for the Himalayas and adjoining regions.

As noted above, the amplitude of strong ground motion can be substantially modified by local site conditions such as near-surface low velocity layers, by the presence of thick sediments, focussing effects of heterogeneity, variation in exposed rock types, valley edge effects, topography, etc. Often maps are prepared representing various types of information and are sometimes called *n* level zone maps. However, these *n* level maps, though rich in information of local site conditions, by themselves do not constitute seismic zone maps. Seismic micro zoning takes information from such maps and factors the same into estimating seismic hazard. It is an approach that makes zoning more detailed and site-specific. Yet, preparation of micro seismic zone maps must primarily use information on the occurrence of strong ground motion per se, as it is the causative factor of damage to begin with. Micro zoning is often confined to cover areas of relatively restricted size, such as cities with high density of population and other economic units.

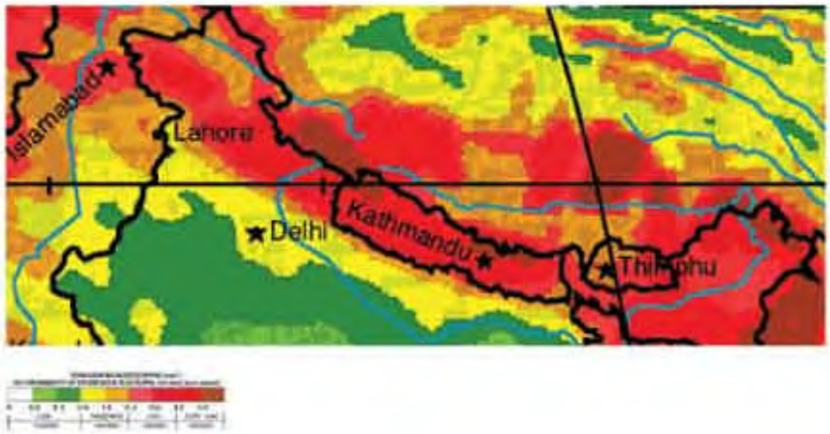

Figure 2. Probabilistic seismic hazard map of North India showing contours of peak accelerations with 10% probability of exceeding in 50 years (adapted from Bhatia *et al.*[2]).

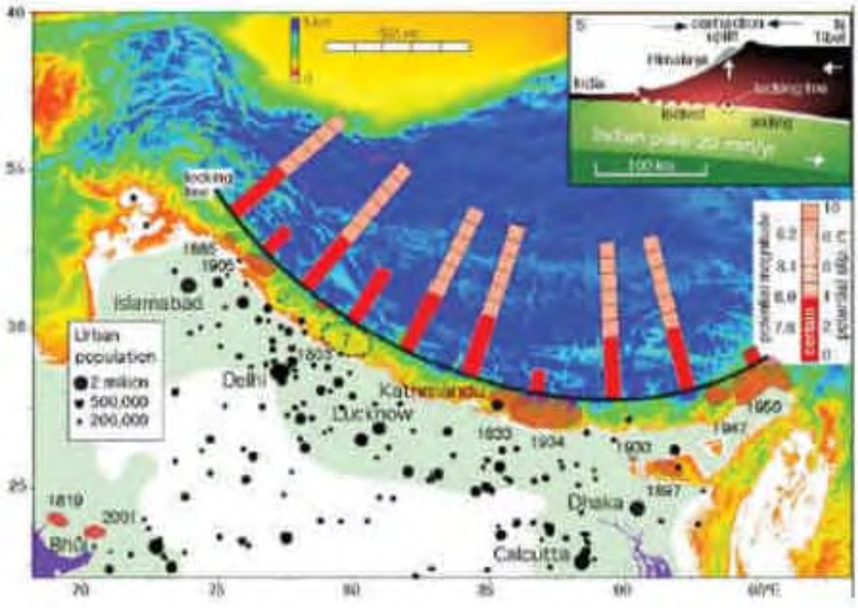

Figure 3. Estimates of potential magnitudes of future earthquakes in the Himalayan region (after Bilham *et al.*[3]).

It is important to appreciate that a microzonation map expresses the relative susceptibility of different areas of a locality, and unless coupled with ground acceleration at the bed rock, provides little information about the actual ground motion at a site that may be generated by a damaging earthquake.

On the other hand, India is a large country with over 70% population (over 74 crore) living in rural areas. There are over 600,000 villages and over 6000 small towns. Thus it will be a daunting task, to say the least, to prepare micro-zoning maps for all these habitat units within a reasonable time-frame. Utilization of richly defined micro-seismic zones by rural populations will also pose its own problems because of lack of sufficient training and know-how by the rural population as well as its administration. Yet people of villages and small towns also have to be provided adequate protection, without undue delays, from earthquake hazard on the basis of a sound scientific analysis.

A way to do this efficiently is to have a compliment of large-scale national seismic zoning map and small-scale micro zoning maps of important localities. A few questions that need to be addressed are noted next. How can we profitably weave into the fabric of seismic zoning at all scales, new evidences from diverse fields such as GPS, palaeo-seismology, etc. as noted above, in preparing a state-of-the-art zoning map? What should be the smallest size of an area for attempting micro zoning? This also relates to the question as to how fine a scale the knowledge of geological properties needs to be for the stated end-objective of micro zoning. For geology can be studied from microscopic to megascopic scales. Moreover, often the boundaries of geological units are not sharp. How can one exploit the formalism of fuzzy logic to our advantage in defining the zones, etc. in such situations? How can one take into account the effect of thinning wedge-like sediments of the Ganga valley on the areas (major cities) at its southern edge? Then again, there is the question of low seismicity rate regions such as peninsular India. What methods can be developed to appropriately define seismic hazard there? We need to open up this field of remarkably rich complexity to specialists from other fields and take advantage of their expertise for our purposes. What can be better than to pose the problem in an open forum like *Current Science*, so that a wide range of exposure and participation is ensured?

A matter of grave concern is the use of the current building codes devised on the basis of flawed national seismic zone map, that are becoming a means to create unsafe buildings in large sectors of the country. Hence, there is an urgency to produce scientifically correct national seismic zoning maps, both in the large and the micro scales (i.e. micro-zoning maps for large cities and other significant units) on the basis of which appropriate building codes can be defined. All future construction and retrofitting activity may be done on such a properly defined basis.

There is also dire need to promote wider implementation of earthquake-resistant building codes and ways to achieve this need to be discussed. A possibility is to introduce incentives to those who follow the codes for new constructions as well as for those who do retrofitting.

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