SOME ASPECTS OF BUILDING CONSTRUCTION
IN EARTHQUAKE PRONE ZONES

by

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SUMMARY

Proper designing of earthquake-resistant buildings and formulation of realistic building code are the essential prerequisite for mitigating the risk of earthquake hazard. Due to inadequate data of earthquake parameters like the seismicity and the corresponding seismic coefficients, ground acceleration and ground response there is a tendency to overdesign the buildings resulting increased cost of construction. It is suggested that the vulnerability of smaller areas within different seismic zones based on more accurate seismic, geologic and ground motion data along with availability of local building materials, building tradition and economic condition of the people should be considered while devising realistic building code.

INTRODUCTION

The optimum design of an earthquake resistant building or a structure is a complicated problem because of uncertainty in the magnitude of any future shock in the area. The primary data usually utilised are the past history of earthquakes in the area in question, the probability of future earthquakes, their magnitude and return period, location of nearby fault zones and the geological condition between the site and the epicentral location. But it is to be realised that earthquake usually generates random ground motion causing the buildings and structures vibrate in all directions, making it more difficult to analyse the response of structures. In the absence of actual ground motion data from the places of earthquake the ground motions are often estimated from the expected magnitude of the future shock and the geologic condition. From the expected return period decision is taken whether the structure should remain within elastic limit in the case of small shocks which are more frequent and also whether the structures should be able to dissipate energy through inelastic deformations in the case of larger shocks that are expected once or twice during lifetime of the structure. But the real problem is about the accuracy in the estimation of ground motion which causes sometimes underestimation or overestimation in the requirement of strengthening of buildings and structures. Instrumental records of peak ground acceleration during some of the large shocks are now available along with analysis of structural response but the same cannot faithfully be used for earthquakes of varying magnitude under varying geographical and geological condition.

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Past experience showed that the major victims of earthquakes are masonry construction, which are most common and popular all over the world. These buildings are usually made of brick, stone, mud, timber or a combination thereof. In a survey after 1960 Chilean earthquake it was observed that of the total damage of 45,000 dwellings about 83% were unreinforced brick masonry construction. In India the construction varies from sundried brick walls with thatch roof on bamboo frames to burnt brick or stone walls or reinforced bricks or concrete slate roofs. From the survey of earthquake devastated areas it was found that the larger loss of human lives are mainly due to collapse of dwellings. It was therefore reasonable to expect that if the buildings in the earthquake prone areas are properly strengthened, the risk of damage during an earthquake would be greatly reduced. With a view to introduce different degrees of strengthening in public and private dwellings and other structure, the earthquake prone areas are normally divided into different seismic zones on the basis of prevailing seismicity condition and building codes have been devised as applicable to these zones. Introduction of such a code is no doubt feasible in the case of government buildings and public places but as it involves additional cost of construction which the common man, especially of the developing countries, cannot easily afford the building code remains mostly un-implemented. It is therefore necessary that while suggesting building code particularly for the common man's dwellings care should be taken to avoid prescribing any over-design involving infructuous expenditure so that the code is easily acceptable to the common people. Some aspects which need to be considered in doing so are discussed below.

PEAK GROUND ACCELERATION

Estimation of peak ground acceleration from any impending earthquake in the region is one important pre-requisite to design any earthquake-resistant building or structure. For this purpose information of depth of focus are necessary because it has been found that generally the shallow focus earthquakes produce larger ground acceleration while larger shocks are generally associated with deep focus earthquake. There are of course many exceptions like the one in Assam in 1950 in which case the magnitude of shock was 8.5 whereas the estimated depth of focus was about 15 km. The other consideration is how far is the site of structure from the epicentral location of earthquake which will give the predominant period of ground motion and also the amount of peak ground acceleration. Gutenberg and Richter (1956) gave an empirical formula for calculating the magnitude of peak ground acceleration at various distances from the epicenter under certain fixed depth of focus. Many other workers also suggested different formulae for calculating peak ground acceleration at different distances from the epicenter. These calculations showed that while near the epicentral region the magnitude of peak ground acceleration varied from 0.28 to 0.63 g the same at a distance of 60 km varied from 0.5 to 1.5 g.

The maximum acceleration recorded so far by accelerographs during actual earthquake ranged between 0.5 to 2.0 g. The discrepancies in the calculated values of g might be due to consideration of varying ground condition like firm rock or hard ground as the soil conditions upto the ground surface play important role in the propagation of seismic waves. Epicentral maps of earthquake prone regions are now available but to these the information of depth of foci are required to be included for their greater use for the calculation of associated peak ground acceleration.

SEISMIC ZONING AND BUILDING CODE

The essential requirement for applying any earthquake protection rule in an earthquake prone area is the preparation of a detailed seismic zoning map taking into account the past earthquake data of epicenters and maximum observed earthquake intensity. Such zoning map together with information of isoseismals of past earthquakes and associated tectonic features are normally utilised to divide a region into areas liable to different degrees of shaking during an earthquake and to devise codes for earthquake resistant design of structures and buildings. However, such a building code appears to have limited use due to the actual situation that strongest seismic activity, though persists in the same region generally, they vary regionally or locally as new foci of earthquakes do not generally remain the same and very frequently it has been found that they occur at new new places. The other limitation is that though the variation of earthquake intensities may remain within the same range, occasionally, at large intervals of time the intensity exceeds appreciably. To study this aspect the frequency-magnitude characteristics of earthquakes in our north India were examined in the context of its applicability towards the prescribed building code as described below.

As in other countries, our country (India), where at least 55% of the land is earthquake prone, has been divided into five seismic zones liable to different degrees of shaking during an earthquake and building codes have been devised for earthquake resistant design of structures and buildings. To study the applicability of the code the frequency-magnitude of all past earthquakes were studied by dividing the high seismic zones III to V into four distinct areas as Northeast India, Nepal-Himalayan foot-hills of north India, Indo-Gangetic plane and Kashmir-Western Himalayas (Fig. 1). For this study earthquake data of magnitude $M \geqslant 5.0$ during the period 1820-1970 as compiled by Tandon and Srivastava (1974) were used. It may be mentioned that though data from 1820 was considered for the study, systematic instrumental records were available only from 1910 or so. It could be seen that over north-east India while majority of earthquakes was between magnitude 5.5 - 7.0, a sizeable number of earthquake also struck this area with magnitude 7.0 - 8.0 at an average time interval of 5-6 years (Fig. 2). The area also experienced two major earthquake of mag. more than 8.0 at an interval of about 50 years, the last one having struck in 1950. A different situation arises in the case of earthquake in Kashmir and Western Himalayas where majority of earthquakes were of magnitude 5.5 - 6.0. A few earthquake, much less in number, had mag more than 6.0 with a single earthquake exceeding 7.0. In the case of Nepal-Himalayan foot hills of north India though majority of earthquakes were of mag 6.0 a good number had mag greater than 6.0. Three earthquakes were of mag. greater than 7.0 of which one in 1934 was more than 8.0. In the case of Indo-Gangetic Plane, the earthquakes were of lesser magnitude generally below mag 6.0 with one isolated earthquake with mag 6.7.

The above analysis of earthquake frequency-magnitude distribution showed that though Kashmir-Western Himalayas, Nepal-Himalayan foot-hills of northern India and Indo-Gangetic planes lie mostly in seismic zones III and IV there were occasions when earthquakes of mag greater than 7.0 had occurred. A still more complicated situation arises in the case of North-east India (Seismic Zone V), where a large number of earthquakes had magnitude 5.5 - 7.0 and a fairly large number had magnitude greater than 7.0. The question therefore arises upto what seismic force should we take into consideration for designing earthquake resistant structures in each of these broad areas.

TYPE OF CONSTRUCTION

Code of practices for earthquake resistant construction of buildings have been devised in many countries so that buildings can withstand shocks of moderate intensity and will not collapse totally during heavy shocks. Varying seismic co-efficients have been suggested to take into account while designing any construction in the different seismic zones but experience showed that it is rather difficult to determine the realistic seismic co-efficient due to lack of precise information of past earthquakes, their magnitude and the depth of foci. Moreover it is not certain that the limits of seismic intensity and the corresponding seismic co-efficient suggested for different zones for the purpose of design will not exceed at times. It may be possible that in some zones of lesser seismicity we have an earthquake of severe intensity while in the zone of high seismicity we may not encounter any severe earthquake at all. Again earthquake of severe intensity may also occur in an area totally unpredicted. It has been suggested vide Indian Standard (1976) - Criteria for earthquake resistant design of structures, that in highly seismic areas, buildings of mud masonry or rubble masonry should be avoided and instead construction in light weight materials and well braced timber-framed structure should be resorted to. This may be applicable to some extent for North East India but not in other areas like Indo-Gangetic plane with lesser seismicity but having maximum human concentration with correspondingly increased demand for constructing taller buildings.

VULNERABILITY ANALYSIS & PHYSICAL PLANNING

Building codes prepared for designing buildings or structures in different seismic zones suffer from large deficiency as the maximum intensity of earthquake assigned to respective seismiz zone occasionally vary widely. Moreover, earthquakes of same intensity at two different places having identical human activity and buildings within the same seismic zone may have effect of different dimension because of different soil composition, ground response and resonance of ground vibration with the natural frequency of tall structures. In order to obviate this difficulty in making realistic design of buildings UNDRO (1978) suggested a vulnerability index for Metro Manila based on ground response, categorised as weak, strong, very strong and violent and ground resonance categorised as short, medium and long so as to optimise the design of buildings both as regards their heights and strengths. In view of limited use of broad seismic zoning maps, it is felt that a vulnerability map prepared taking into account the frequency and magnitude of past earthquakes and the respective soil condition and fault location within each seismic zone will be more useful for designing earthquake resistant structure and buildings and also for physical planning of future location of development activities.

The above concept of introducing physical planning for locating future human settlement away from the earthquake prone areas to avoid loss of life and property was introduced by UNDRO (1978). But considering that 55% of land area in India is earthquake-prone and highest density of population and maximum number of development projects lie in high seismic zones of the country the author (1978) made an analysis of the risk and categorised the earthquake prone areas into different degree of earthquake vulnerability and suggested to take the vulnerability aspect into account for making the building code more realistic and also for locating costly projects and future human settlements.

It is to be realised that the main purpose of introducing building code is to ensure sufficiently small number of collapse of special buildings of public utility. It has been suggested that the private dwellings and industrial buildings must be able to withstand an earthquake of intensity which, in the concerned area, will have a return period equal to the normal life of the buildings. The above hypothesis will have two problems. First, the return period of large earthquakes may be sufficiently large of the order of 50-100 years, the same for smaller earthquakes but of damaging size may be much shorter of the order of 5-10 years. Secondly, the construction of particular building may have taken place in between two consecutive earthquakes and the intensity of next earthquake may exceed the previous earthquakes

CONCLUSIONS

The cost of construction of a building according to code of practices is high and varies widely depending on the methods utilised and the degree of risk against which the protection is considered. Considering that the common people, especially in a developing country cannot easily afford to invest much additional expenditure it is considered necessary that optimum seismic force should be found out by actual measurement of seismic parameters during earthquake and realistic design is made taking into consideration the vulnerability of the place, the local building materials and traditional means of constructing houses so that the building code can be easily acceptable to the common man. It is suggested that before suggesting a rigid building code the cost-benefit ratio should also be worked out for each human locality taking into account the cost acceptable to the concerned society for protecting their buildings against earthquake, the expected cost of damage to the building and the number of victims during a damaging earthquake.

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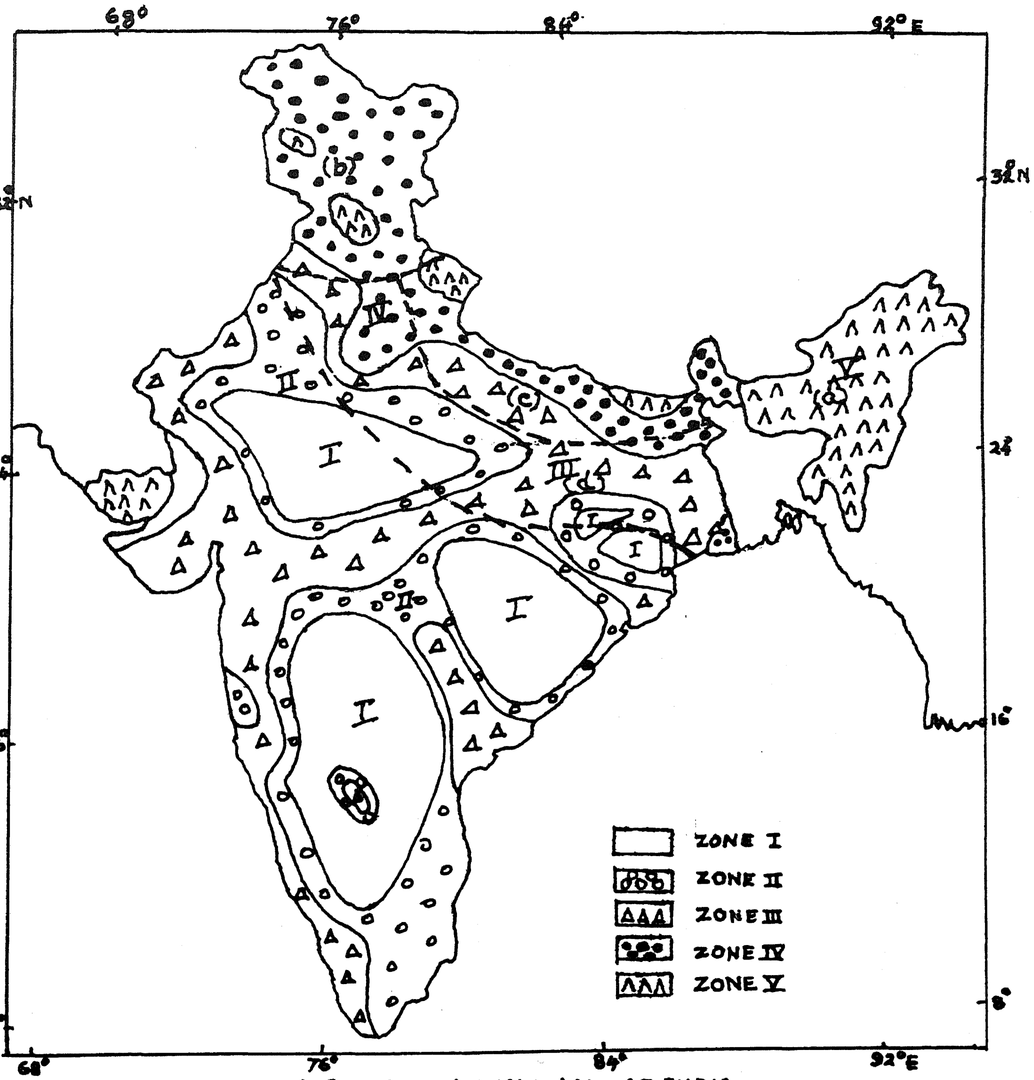

Fig.1 SEISMIC ZONING MAP OF INDIA
(Reproduced from IS:1893-1975)

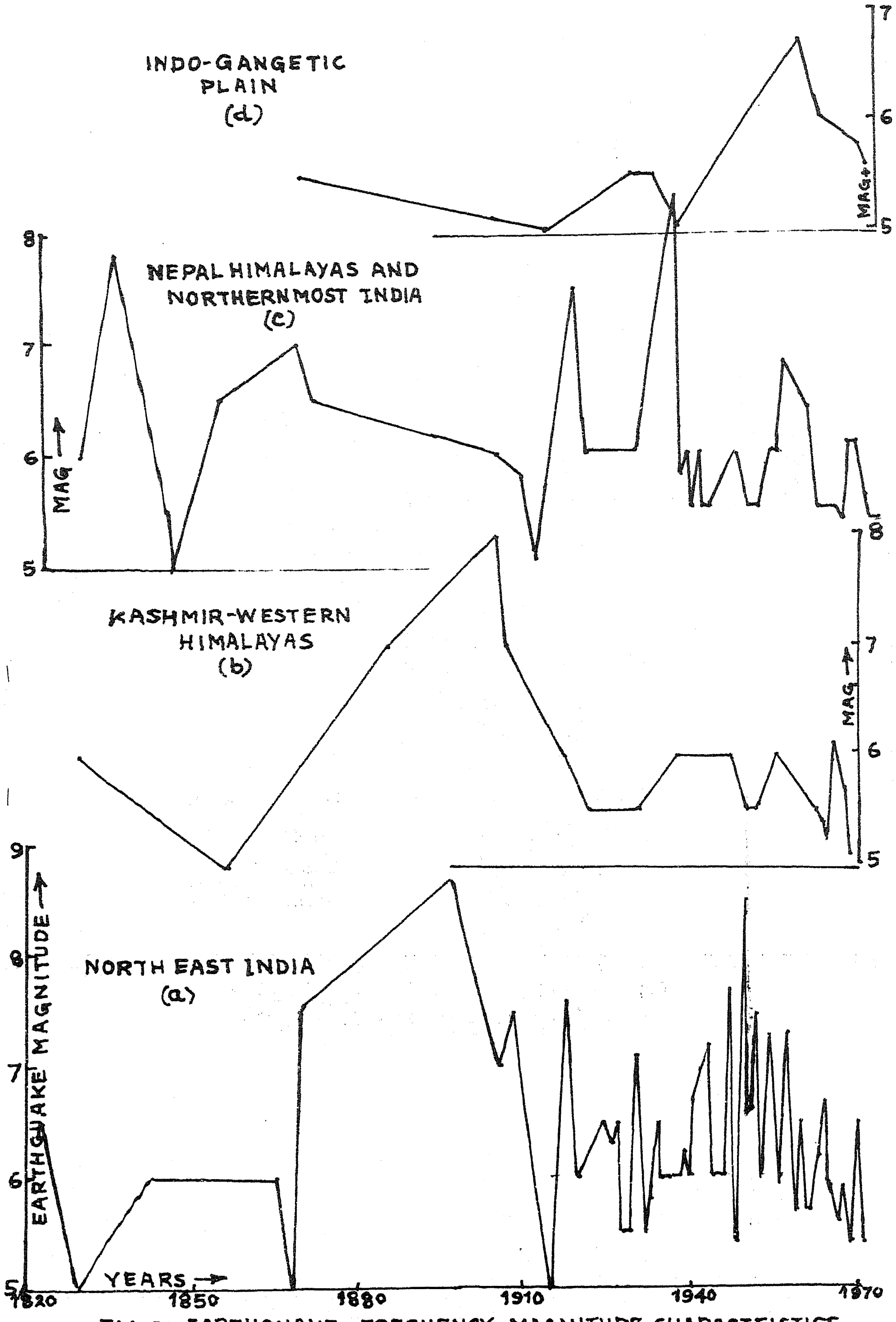

FIG. 2 - EARTHQUAKE FREQUENCY-MAGNITUDE CHARACTEISTICS