Provisions for Geotechnical Aspects and Soil Classification in Indian Seismic Design Code IS-1893

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Abstract
Seismic codes are important guidelines for urban planning and infrastructure development. Seismic codes are mainly used for earthquake resistant design of new structures and retrofitting existing structures. The geotechnical aspects play a crucial role in the development of response spectra for a site/region which is the basis for any earthquake resistant designs. In this study an attempt has been made to study the geotechnical provisions in the Indian earthquake code of "Criteria for earthquake resistant design of structures"[17]. The first version of this code was released by the Bureau of Indian Standards in the year 1962 and followed by many revisions soon after major earthquakes in the country. The modification in the zonation map of India with occurrence of significant earthquakes shows that the assessment of hazard on a regional scale is not consistent with local variation. India has diverse geology and geotechnical material (soil and rock) properties with typical borelogs from different parts of India. Seismic code groups the geology/geotechnical variation in three categories i.e. hard, medium and soft soil in order to account site and induced effects of earthquakes.

In IS 1893, soil types are classified based on the standard penetration test (SPT) N-value and soil classification using grain size distribution. It is mentioned to take the N- value but the depth option for which the SPT must be considered is not clearly mentioned. Many international standards have soil shear wave velocity as the main factor to categorize the subsurface materials missing in the Indian standard. This paper also presents a comparison of design response spectra, as per Indian standard and modern international seismic standards like International Building Code (IBC) and Eurocode for similar earthquake, site and building conditions. Design spectral values given in the Indian code do not match with modern codes for similar seismicity, building type and site condition.

Keywords: Site classification, response spectrum, amplification, PGA.

Introduction

Increasing population leads to agglomeration in the cities which results in rapid and unplanned constructions. The Asian cities are more hazardous and high risk areas, even for moderate earthquakes. Earthquakes in and around India are as inevitable as the autumnal fall of fruit from a tree[4]. As the earthquakes are not precisely predictable, the only way to reduce damages is to design or retrofit the structures against earthquake forces in urban centers where risk level is more due to agglomeration. Seismic codes have become popular in the last few years due to frequent earthquakes around the world. Site effects represent seismic ground response characteristics and are inevitably reflected in seismic code provisions. The selection of appropriate elastic response/design spectra according to soil categories and seismic intensity is the simplest way to account for site effects both for engineering projects and for general purposes like microzonation study[38].

Recent modern seismic codes in America, Europe, Japan and worldwide (IBC 2009, UBC 97, NEHRP and EC8) have produced numerous valuable data and have incorporated the site effects based on most important experimental and theoretical results. The accurate soil categorization is introduced based on a better description of soil profiles using standard geotechnical parameters like plasticity index (PI), undrained shear strength (Su) and average shear wave velocity (SWV) values. A special attention is given to incorporate amplification factors of spectral values and field conditions in the modern seismic codes.

In general the important parameters describing site effects in seismic codes are expressed through (a) soil categorization and (b) spectral amplification factors and shapes. Seismic codes should always reflect the basic knowledge and technology of the present time, keeping in mind that they must be simple and realistic, having an acceptable level of accuracy, compatible among others, with the tools used for the seismic design of the structures[38].

The design of an earthquake resistant structure mainly in urban centers is very important as the populations of the occupants in the building are high. The Indian seismic code IS 1893[21] is the standard prescribed by the Bureau of Indian Standards (BIS). This standard gives seismicity of locations in India with other factors to calculate forces for design of earthquake resistant structures. The seismic zonation of the country was updated in every revision of the code soon after the major earthquakes in the country. In this paper an attempt has been made to review geotechnical provisions in Indian standard (IS) 1893[21] by comparing geotechnical provisions and design spectrum with international modern seismic codes. The site sub soil classification in the Indian Standard is based on the soil classification considering the grain size distribution and the SPT N value. Design spectral values arrived from Indian code is not comparable to the modern codes of IBC and Eurocode.

Seismic Zonation Map of India

The first version of the Indian code[17] was released by the Bureau of Indian Standards (BIS) in the year 1962 and followed by many revisions soon after major earthquakes in the country, specific second revision in 1966, the third revision in 1970, the fourth revision in 1984 and the fifth revision in 2002[18-21]. In the first version, the Seismic Zonation map was presented based on the earthquake epicenters and an isoseismal map published by Geographic Survey of India in 1935. In this revision the whole country was divided into seven zones (0, I, II, III, IV, V, VI). The hazard level of zero was given to the Deccan Plateau as it was considered more or less a safe zone. Koyna was placed in zone 0 in the 1965 release. Second revision published after the 1967 Koyna earthquake incorporated the map showing the epicenters along with the five seismic zones (I, II, III, IV and V) and adding a more rational approach to the design of buildings and the substructure of bridges etc.

In the third revision, the zone factors were incorporated instead of multiplication factors for each zone which were given in the second revision. Other changes were also made like introducing the importance factor for buildings, the introduction of new clauses for determination of hydrodynamic pressures in elevated tanks and clauses on concrete and masonry dams were modified. In the fourth version, the zonation map was modified where the regions of different seismogenic potential were identified on the basis of past earthquakes and the regional tectonic features. The fifth revision was made after the occurrence of the 1993 Latur earthquake, 1997 Jabalpur earthquake and the 2001 Bhuj earthquake, the Zones I and II were merged and there are now four Zones (II, III, IV and V) in the country.

Seismic zonation maps of country with seismic details of each revision of the code with maps are presented by Walling and Mohanty[48]. The modifications in the seismic zonation map of India were done soon after the occurrence of significant earthquakes. But the assessment of seismic hazard is not uniform; particularly less importance is given on a regional scale with local variation. Indian standard in its current form does not provide a quantified seismic hazard for each region but lumps large parts of the country into unstructured regions of equal hazard[10,39]. The zonation in India also is not appropriate as the country was divided into four zones with four zonation factors (hazard factor) only.

Many recent studies have highlighted that macro level zonation factor (peak ground acceleration) map given in Indian code is lesser or higher than that of the micro level seismic hazard studies.[6,11,33] This problem may be resolved if the code gives the hazard factor/PGA contours maps based on detailed deterministic and probabilistic approach rather than one map with a deterministic approach for the whole country considering probable future earthquake zone based holistic approach[11], so that the correct value of the places can be assessed and interpolation can be also possible in the places in between these contour lines. These may be due to lack of good earthquake recording, earthquake source modeling and limited attenuation characteristic of Indian plateau.

Most of the countries publish their hazard maps based on probabilistic approach but the Indian hazard map is not probable. These show that there is a need for updating the seismic zonation/hazard map of the country. Recently NDMA (National Disaster Management Authority, 2010)[36], Government of India presented a probabilistic seismic hazard map of India based on available data and Ground Motion Prediction Equations from simulated ground motion data. The first author has highlighted the merits and demerits of NDMA[36] map based review invitation from the NDMA for a future revision (unpublished report).

Geology Information of India

Surface materials play a very important role in modifying the seismic waves from seismic bedrock and cause damage to the structure and/or to fail surface materials. Geology is used as reference to show change in seismic wave amplitude, duration and frequency in the beginning stages of Engineering Seismology. Surface design spectrum was obtained by modifying rock spectrum by considering the surface geology of the region. The geology of India started with the geological evolution of the rest of the Earth i.e. 4.57 Ga (billion years ago)[23]. India is not only diverse in geography, people and culture but also in geology and soil deposits. Geology contains rocks covering almost the entire spectrum of the Geological Time Scale.

Different regions in India contain rock of all types belonging to different geologic periods. Some of the rocks are badly deformed and transmuted while others are recently deposited alluvium yet to undergo diagenesis. Generally India can be naturally divided into three geological provinces, namely, the Himalayas, the Indo-Gangetic Plain and the Indian Shield. Geologically India can be divided as 20 geological provinces and detailed geological reports with maps are published by the Geological Survey of India (GSI). Figure 1 shows the distribution of Geological Provinces in India.

The southern boundary of the Himalayas is defined as Siwalik range which contains sediments deposited by ancient Himalayan Rivers. The lesser Himalaya lies in between Main Boundary Thrust (MBT) and the Main

Central Thrust (MCT) and consists of mostly Palaeozoic sedimentary rocks. The Great Himalaya, which is the most northerly sub-province comprises of crystalline metamorphic and igneous rocks. The Indo-Gangetic region consists of the vast alluvial plains. The sagging of the basement in this part is attributed to the collision of the Indian and the Eurasian plates. The Indo-Gangetic region is filled with sediments flowing from the Himalayas and parts of the peninsular shield region. The thickness of the alluvial deposits in the Indo-Gangetic Plains is of the order of 1.5-6 km. This conceals the solid nature of its basement.

The peninsular shield consists of a complex system of folds and faults in the basement rock, attributed to the intense tectonic activity during its evolution. This region contains the majority of the rock formations and stratigraphical units in India. The rocks of the oldest Archean era known as Dharwars occupy more than half of the India shield. This discussion gives an overview of rock and geological deposits in India and detailed geological reports with maps can be accessed in Geological Survey of India. Here it can be clearly seen that geologically rock type and surface deposit are not uniform in India.

Recent studies have highlighted that geology has limited application for representing earthquake site effects and induced effects for the purpose of seismic zonation.[12,45] In addition, Wills and Silva[49] suggested the use of shear wave velocities rather than geological units, despite the extensive field investigations required to determine the shear wave velocities. Geology can be used as purpose to determine the boundaries and the characteristics of the geological formation, cross validate geotechnical data and rough seismic zonation. This shows inevitably properties of soil and rock layers above bedrock (geotechnical materials) are very important to represent seismic effects.

Indian Soil and Rock Information

Geology generally discusses broadly about the materials in the surface, its depositional character and age with more emphasis on rock. But most of the engineering structures require surface and subsurface material engineering properties for the design. Geology may provide a rough idea about the materials but limited details about strength. Engineering properties of surface and subsurface materials such as soil and rock are studied in detail in geotechnical engineering or soil mechanics and foundation engineering. Soil and rock have different behavior based on loading type and its application. Behavior of soil and rock completely change after some type of load, for example, saturated sandy soil will liquefy during dynamic loads and properties of liquefied soil will be different from initial conditions.

Soil is also capable of changing dynamic (earthquake) loading amplitude, duration and frequency. Change of wave characters depends on soil types, thickness, dynamic properties and its relative variation spatial and depth to respective rock/hard materials. These have been well recognized by structural, earthquake geotechnical engineers and engineering seismologist and incorporated in developing design spectrums in most of the developed countries based on detailed analysis of soil behavior for different earthquakes in their region. Design spectrum is region specific where unique character of regional earthquakes, soil and rock has to be accounted. Many modern seismic codes in America, Europe, Japan and worldwide (IBC 2009, UBC 97, NEHRP and EC8) have developed design/response spectrum considering detailed regional parameters.

Before reviewing geotechnical provision in Indian seismic code response spectrum, let us see the soil and rock information in India based on available drilled boreholes. It is attempted to compile soil/geotechnical properties variations in India by collecting available borehole information with standard penetration test (SPT) N values. Drilling or boreholes up to hard rock or required depth, logging soil information with a collection of in-situ samples for laboratory experiments and measuring the strength by SPT N values is a classical step before designing any geotechnical structures. Many geotechnical tests of SPT, cone penetration test (CPT) (Piezocone-CPTu and Seismic Piezocone – SCPTu), Full Flow Penetrometers, Flat Plate Dilatometer Test (DMT) and non destructive Crosshole seismic method, Downhole and uphole method (with a seismic CPT or a substitute device), Surface wave reflection or refraction, Suspension logging (also known as P-S logging or Oyo logging), Spectral analysis of surface waves (SASW), Modal Analysis of Surface waves (MASW), Reflection microtremor (ReMi) and Ground Penetration Radar (GPR) are widely used for geotechnical investigations.

Most of the methods give information at the point (1-D properties with depth) and last four methods can also give information with depth and distance (2-D and 3-D). Among these methods SPT, an age old method is widely used in many parts of the world. Many SPT tests are being carried out in India to measure engineering properties of surface and subsurface layers in depth and distance. But very limited attempted has been made to show the soil engineering properties variation in distance and depth for whole India. Few maps are available to show spatial variation of soil in surface which is not much useful for engineering application and mostly used for agricultural purposes. Even from the agricultural point of view, soils are diverse and differ from area to area.

Sixteen major types of soils have been recognized in India. Summary of these soils is given by Misri[34] and these are red loamy soils (eastern Himalaya, eastern Ghats, Tamil Nadu uplands), red and lateritic soils (eastern plateau, north-eastern hills, western Ghats), red and yellow soils (eastern plateau adjoining central highlands), shallow and medium black soils (Deccan plateau, central Maharashtra and Karnataka plateau), medium and deep black soils (central highlands, Narmada Valley, Malwa plateau, Bundelkhand and Kathiawar peninsula), mixed red and black soils (parts of Deccan plateau, Telangana, Bellary and Anantpur regions of Karnatka plateau), coastal alluvium - derived soils (eastern and western coastal plains), alluvium - derived soils (western, northern and eastern plains), desert soils (southwestern Punjab, Haryana plains, Rajasthan, Marusthali and Kachchh peninsula), Tarai soils (foothills of central and western Himalaya), brown and red hill soils (eastern Himalaya), saline and alkali soils (Kathiawar peninsula, alluvial plains of Uttar Pradesh, Haryana, Punjab and Rajasthan), shallow and skeletal soils (Ladakh and Kashmir). Grey brown soils (foothills of Aravallis), brown forest and podzolic soil (north-western Himalaya), sandy and littoral soils (Lakashdweep and coastal areas of Andaman and Nicobar islands).

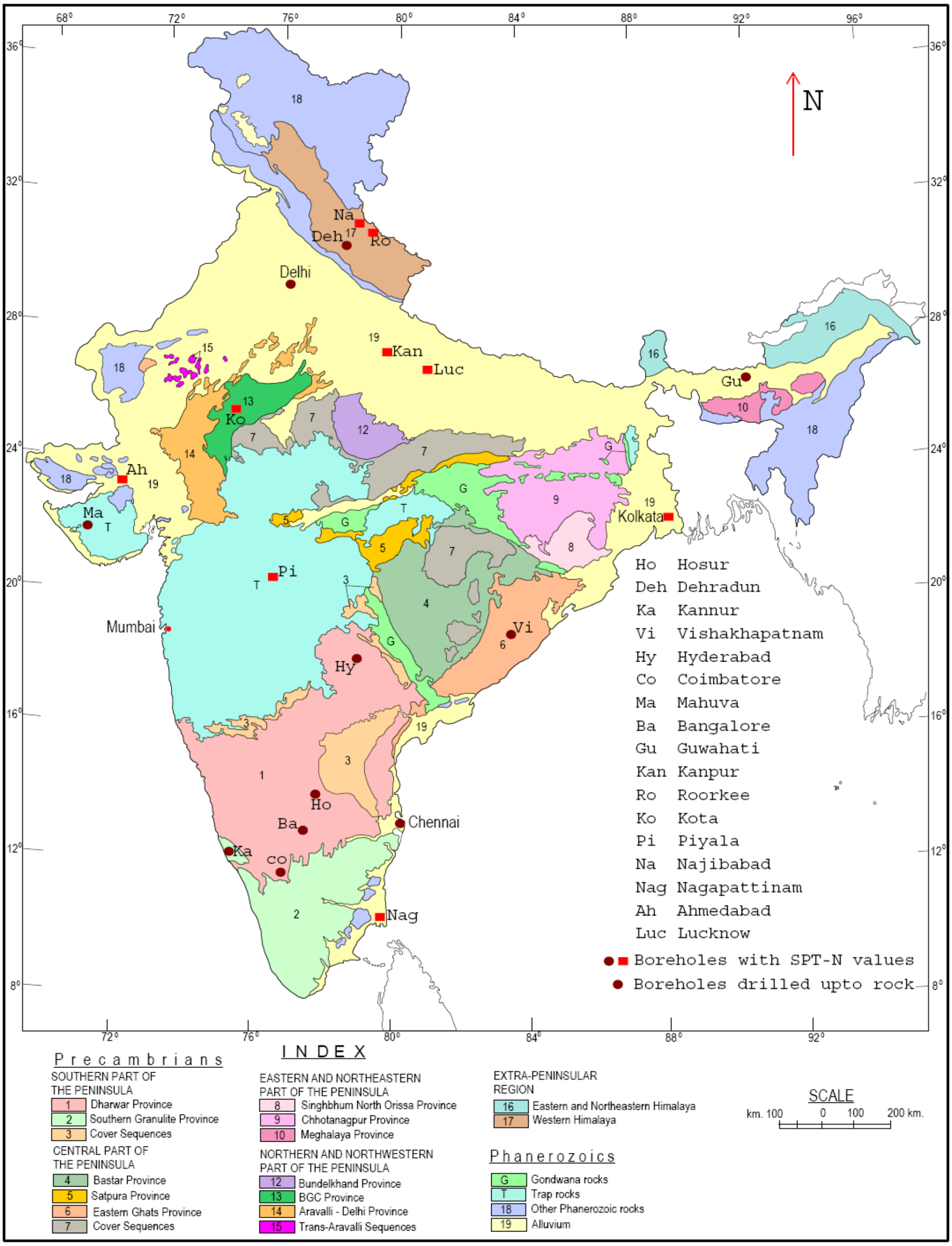
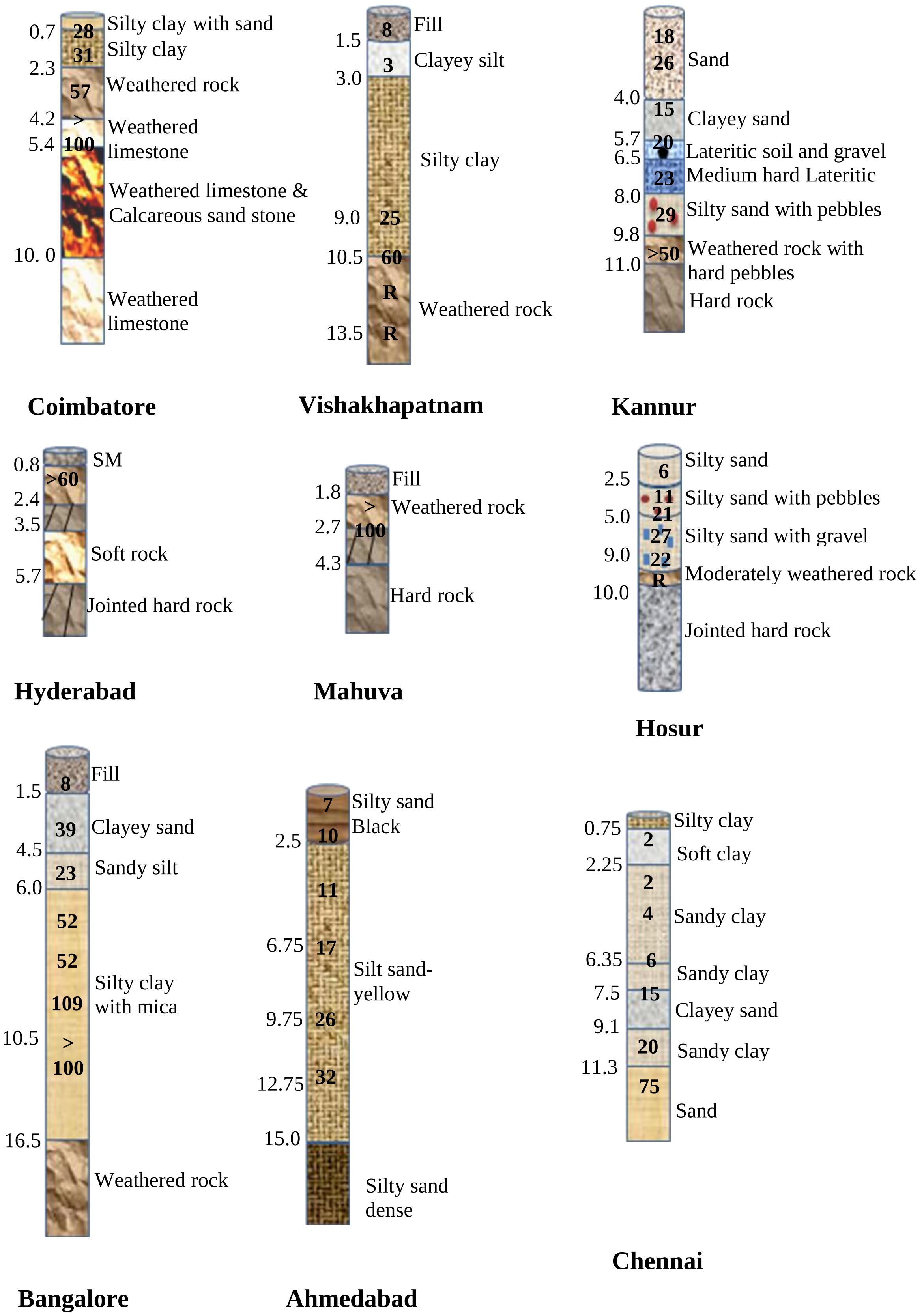


Figure 1: Geological Provinces in India (Modified after NDMA[36])



0.7
28
Silty clay with sand
2.3
31
Silty clay
57
Weathered rock
4.2
>
5.4
100
Weathered limestone
Weathered limestone & Calcareous sand stone
10. 0
Weathered limestone
Coimbatore
1.5
8
Fill
3.0
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Clayey silt
Silty clay
9.0
25
10.5
60
R
Weathered rock
13.5
R
Vishakhapatnam
18
26
Sand
4.0
15
Clayey sand
5.7
6.5
20
Lateritic soil and gravel
23
Medium hard Lateritic
8.0
29
Silty sand with pebbles
9.8
>50
Weathered rock with hard pebbles
11.0
Hard rock
Kannur
0.8
SM
>60
2.4
3.5
Soft rock
5.7
Jointed hard rock
Hyderabad
1.8
Fill
>
Weathered rock
2.7
100
4.3
Hard rock
Mahuva
2.5
6
Silty sand
11
Silty sand with pebbles
5.0
21
27
Silty sand with gravel
9.0
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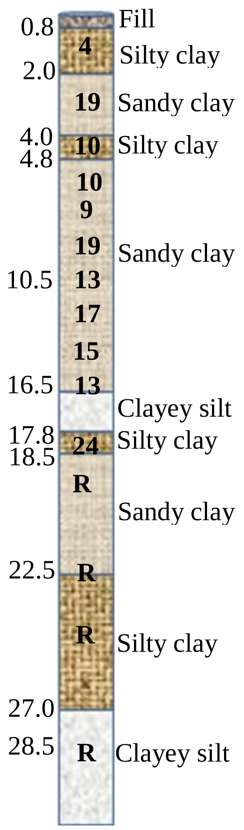
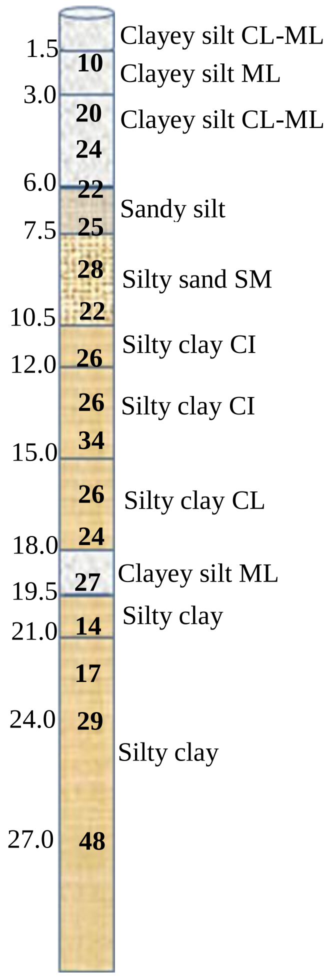
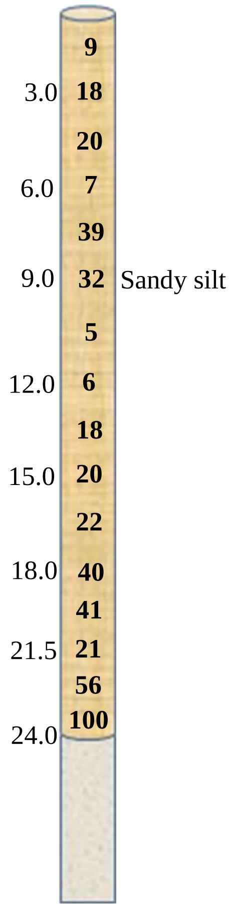
Moderately weathered rock
10.0
Jointed hard rock
Hosur
1.5
8
Fill
39
Clayey sand
4.5
23
Sandy silt
6.0
52
52
Silty clay with mica
109
10.5
>
100
16.5
Weathered rock
Bangalore
7
Silty sand
2.5
10
Black
11
6.75
17
Silt sand-yellow
9.75
26
12.75
32
15.0
Silty sand dense
Ahmedabad
0.75
Silty clay
2
Soft clay
2.25
2
4
Sandy clay
6.35
6
Sandy clay
7.5
15
Clayey sand
9.1
20
Sandy clay
11.3
75
Sand
Chennai



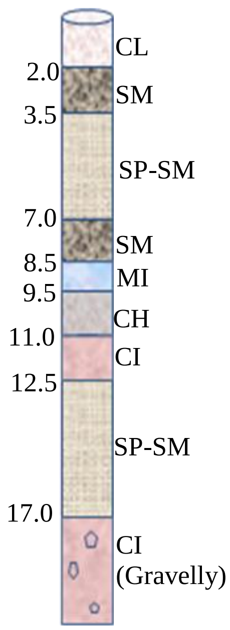
Guwahati



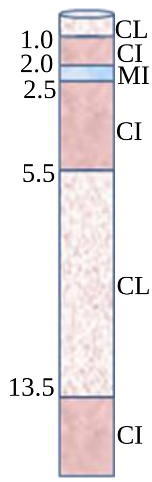
Lucknow



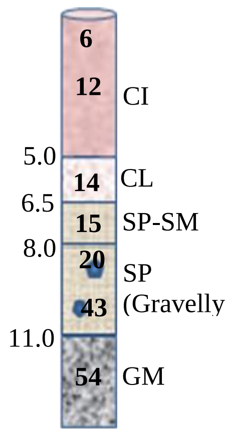
Delhi



Roorkee



Kanpur



Dehradun

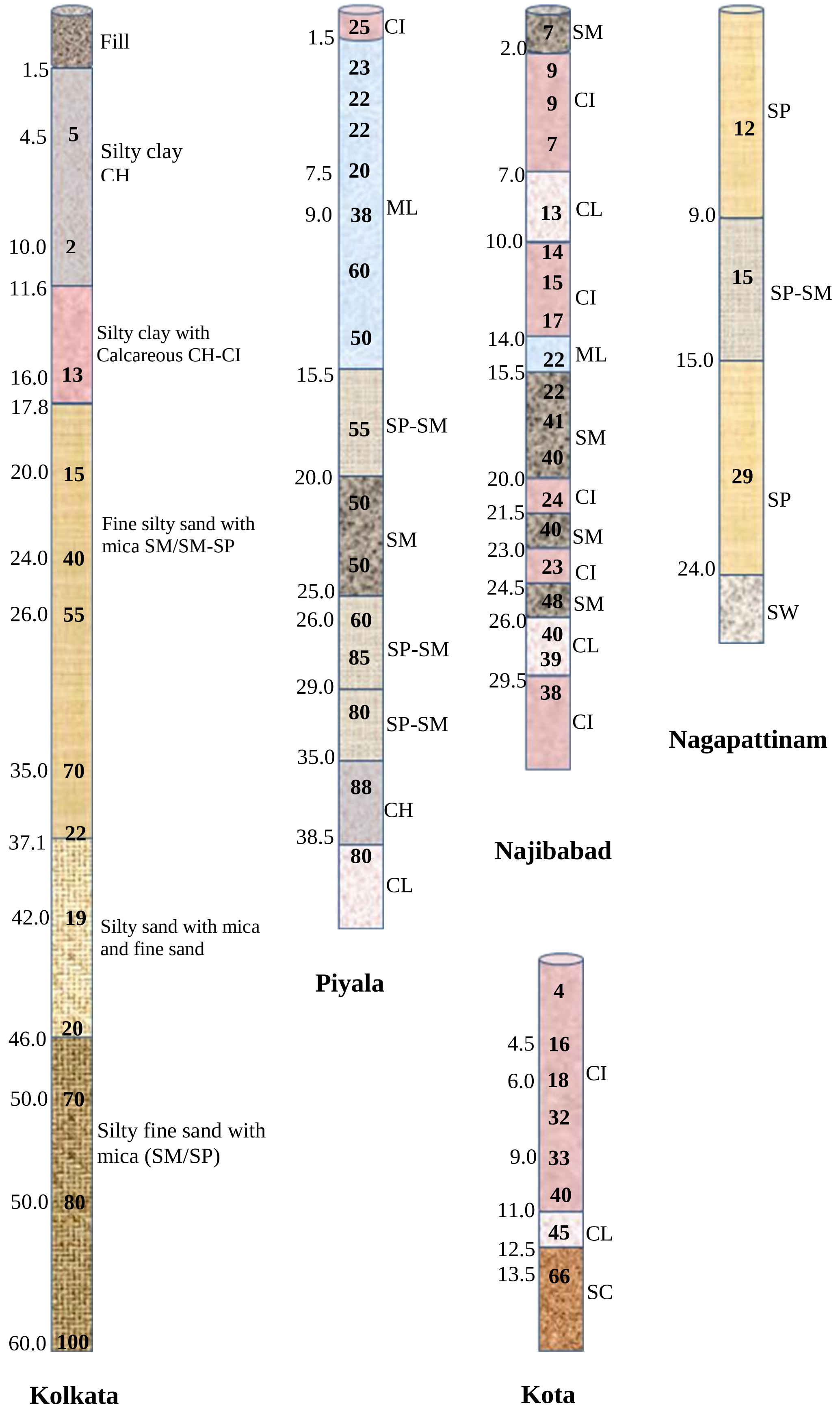


Figure 2a-c: Typical borehole information with standard penetration test (SPT) N values from selected locations (For soil classification refer table 1)

In order to show spatial variation of soil engineering properties, bore logs with SPT N values are collected and presented here. Borehole locations are shown in figure 1 and soil layers with SPT N values are given in figure 2a-c. Many of these boreholes are drilled for different important projects and collected from reputed geotechnical firms. It can be observed that most regions in India have shallow soil deposits (less than 100 m) except few locations like Ganga basin and river deposits. Each location has different layers of soil from filled up soil to hard rock. Strength wise these soils can be classified as very loose soil to hard rock as given in borelogs. Variations of SPT N values can be observed in each location which mean that soil layer are heterogeneous in depth.

Due to limited data of bore logs, mapping of spatial variation is not attempted, but one can easily visualize heterogeneous soil distribution in the country for each meter of depth from the ground surface. These materials can create different earthquake geotechnical hazard with respective specific properties of soil. Following simple way to account them in present form without considering the variation in geology and geotechnical properties may not be appropriate for entire country.

Site subsoil Classification in IS 1893[21]

In order to account site effects due to soils in the construction site, site sub classification was introduced in the Indian code IS 1893. These provisions are consistent right from the first version of the seismic code. The subsurface materials i.e. foundation soil can be broadly categorized into three types according to code, namely Type I - Rock or Hard Soil, Type II - Medium Soil and Type III - Soft Soil.

Type I - Rock or Hard Soil is defined as well graded gravel and sand gravel and sand gravel mixtures with or without clay binder and clayey sands poorly graded or sand clay mixtures (GB, CW, SB, SW, and SC) having N above 30 where N is the standard penetration value.

Type II – Medium Soil is defined as all soils with N between 10 and 30 and poorly graded sands or gravelly sands with little or no fines (SP) with N>15.

Type III - Soft Soil is defined as all soils other than SP, with N<10.

The soil classification GB, CW, SB, SW, SC and SP should be carried out based on grain size distribution according to IS 1498[19]. It is interesting to note that the soil types GB, CW and SB are not specified in the code IS 1498. In the IS 1498, the prefixes and suffixes used in Indian Standard soil classification are given in table 1. First symbol indicates soil type and second symbol indicates subgroup of soil based on gradation and Atterberg's limits. Here it can be observed that "SB" given in BIS[21] but suffix B is not described in IS 1498. "CW" is given in IS 1893 which means well graded clay, but according to IS 1498 clay cannot be classified based on gradation and hence CW, which should mean 'well graded clay', is of no meaning[35].

Nagaraj et al[35] proposed few modifications in the existing description for soil type which are inadequate when compared to modern seismic codes' site classification. These modifications might be arrived considering National Earthquake Hazards Reduction Program (NEHRP)[24]. It is noted that soil profile is classified in Indian code based on the N-value of the standard penetration test (SPT) and soil classification using grain size distribution. SPT N values are measured as per IS 2131 and this test is very common and very widely used method in India and hence it may be adopted by the IS 1893[21]. When the soil profile is layered and there are different types of soils present in different layers (Figure 2), then the procedure for adopting the N-value is not mentioned in the code. It is mentioned to take the N-value but the depth upto which the SPT N values must be considered is not clearly mentioned.

Many international standards are using soil shear wave velocity as main factor to categorize subsurface materials missing in the Indian standard[35]. It is worth to note that N value based site classification given in modern seismic code results in similar site class for medium to dense soil irrespective of the rock depth in shallow bedrock region[5]. Direct application of modern seismic code site classification system developed elsewhere to Asian cities, particularly to India is not appropriate.[7,8,10]

Modern Site Classification System

Wide spread destructions caused by many earthquakes particularly Guerrero earthquake (1985) in Mexico city, Spitak earthquake (1988) in Leninakan, Loma Prieta earthquake (1989) in San Francisco Bay area, Kobe earthquake (1995), Kocaeli earthquake (1999) in Adapazari are important examples of site specific amplification of ground motion, even at locations far away (100-300 km) from the epicenter[12]. The recent 2001 Gujarat-Bhuj earthquake in India is another example with notable damage at a distance of 250 km from the epicenter. These failures are the result of the effect of soil condition on ground motion that translate to higher amplitude which also modifies the spectral content and duration of ground motion[5]. Site specific ground response analysis aims in determining these effects by considering local soil conditions.

Seismic codes describe the site effects in simplest way in the form of elastic response spectra considering soil categories and seismic intensity. Seismic identities are evaluated with respect to regional parameters. Soil categories are taken into account by means of seismic site characterization. Seismic site characterization is a process of classifying region/site based on average soil properties. Ground classification of individual sites based on soil boring or SWV is a more direct indicator of local site effects.

Studies on site effects require knowledge of shear stiffness of the soil column, expressed in terms of SWV[22]. The site classes are defined in terms of SWV upto a depth of 30 m, denoted by Vs^{30}. If no measurement of SWV up to 30 m is feasible, standard penetration resistance (N_{30}) and undrained shear strength (S_u^{30}) could be used[22]. SWV can be directly measured in field tests or can be estimated from existing correlations between SPT blow-counts (SPT-N) and SWV[29]. The site classes based on Vs^{30} are useful for future zonation studies because site amplification factors were defined as a function of Vs^{30} such that the effect of site conditions on ground shaking can be taken into account.

In the initial stage of seismic site classification, surface geology was used for site classification but later it was proved that considering the geological units as the only criteria for seismic site characterization is not appropriate[12]. Seismic site characteristics are inevitably incorporated in modern seismic code provisions in many countries. Table 2 shows the summary of site classes adopted in National Earthquake Hazards Reduction Program (NEHRP)[24], International Building Code[30] or Uniform Building Code and Eurocode 8[26]. In order to avoid confusion of detailed specifications, only key information is given in table 2 for direct comparison. In this study, the site classification using SPT-N and SWV is considered. The equivalent shear stiffness values of soil based on SPT-N or SWV over 30 m depth can be calculated by:

$$N_{30}\ or\ Vs^{30} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n}\left(\frac{d_i}{N_i\ or Vs_i}\right)} \quad (1)$$

The international standards like NEHRP, IBC and Eurocode are using average soil shear wave velocity and SPT N up to 30 m as the criteria for site classification. But using 30 m approach for site classification system in all areas is not appropriate.[4,8,9] Indian code does not give any information on depth for site classifications, soil categories given in Indian code poorly match with modern seismic codes of IBC and Eurocode. Soil grouping i.e. site class based on SPT N value in IS 1893[21] is formless.

Design Response Spectrum

Design response spectra are very much useful in designing infrastructural components of any structure against earthquake forces. Important role of seismic code is to narrate seismic design parameter for a maximum possible accuracy so that designed structures are safe against earthquake and also cost is controlled. Obtaining the response spectrum of an earthquake at a location is the first step in the designing of any earthquake resistant structure. In Indian Standard (IS 1893), the procedure to develop the response spectrum for an earthquake is given in section 6.4. To find the horizontal seismic coefficient (A_h) for which a structure has to be designed, one must know the Zone factor (Z) of the area in which the structure is to be built, the importance factor (I) of the structure which depends on the functional use of the structure and hazardous consequences of its failure, the response reduction factor (R) which depends on the perceived seismic damage performance of the structure and the average spectral acceleration coefficient (S_a/g) which depends on the period of vibration and the coefficient of damping of the structure.

The spectral acceleration coefficient (S_a/g) is obtained based on the soil type and the period of the undamped free vibration. The site sub soil is classified into three types based on the SPT N-values. The spectral acceleration coefficient is given for the 5% damping and for other damping factors it is multiplied with corresponding coefficients. The normalized spectrum (S_a/g) given in IS 1893[21] is shown in figure 3. Using the S_a/g equations given in IS 1893, the response spectrum for maximum credible earthquake can be obtained by multiplying with the zonation factors given in code for different places in India. India is broadly divided as four zones based on seismic history, seismotectonic data and geology. The zonation factor for Zone II is 0.10, Zone III is 0.16, Zone IV is 0.24 and Zone V is 0.36. Design spectrum can be obtained by multiplying normalized response spectral values by half of the zonation factors.

Similar to IS 1893, IBC and Eurocode also gave steps to generate design spectrum. Modern seismic codes [IBC 2009 and Eurocode 8][26,30] are accounting site effects in design spectrum in the form of modified spectral acceleration considering different site classes given in table 2. The design spectrum in IBC is obtained based on the mapped spectral acceleration values at 0.2 s (short) and at 1 s (long) period. These mapped values are determined based on the seismic hazard maps given in the code for site class B i.e. at rock level. These spectral values can be used to find the maximum considered earthquake spectral acceleration and design spectral acceleration as mentioned in the code.

In the Eurocode 8[26], the earthquake motion at a given point on the surface is represented as elastic ground acceleration response spectrum called an “elastic response spectrum”. The design ground acceleration (a_g) is defined as the product of importance factor and peak ground acceleration (a_{gR}). The shape of response spectrum is taken considering two levels of seismic actions of no-collapse requirement and damage limitation requirement mentioned in the Eurocode. There are two types of spectra given in the code and the selection of the type of spectrum is to be done as per the earthquake magnitude. The detailed procedures and formulae to develop site specific design spectrum are presented in the respective codes.

Table 1
Prefixes and Suffixes given in IS 1498 (BIS 1959), to classify soils.

Soil Type	Prefix	Sub-Group	Suffix
Gravel	G	Well graded	W
Sand	S	Poorly graded	P
Silt	M	Silty	M
Clay	C	Clayey	C
Organic	O	w_{L^*}<35%	L
Peat	Pt	35%<w_L<50%	I
		w_L>50%	H

* w_L- liquid limit of soil

Table 2
Site classification system given in modern seismic codes with Indian Standards

Site Class	Generalized Description	NEHRP (BSSC,2001)		IBC 2009/ UBC1997		Eurocode 8 (2007)$		Indian Standards IS 1893 (BIS 2002)	
		N_{30}	Vs^{30}	N_{30}	Vs^{30}	N_{30}	Vs^{30}	N	Vs^{30}
A	Hard rock	N/A	>1500	N/A	>1524	N/A	N/A	*	*
B	Rock	N/A	760-1500	N/A	762-1524		>800	*	*
C	Very dense soil and soft rock	> 50	360-760	> 50	366-762	>50	360-800	>30	*
D	Dense to medium soils	15-50	180-360	15-50	183-366	15 - 50	180 - 360	All the soil 10 to 30 or Sand with little fines N>15	*
E	Medium to soft soil	< 15	< 180	< 15	< 183	<15	<180	<10	*

N/A-Not applicable, * Not mentioned, $The site classes B, C, D and E in this table correspond to site classes A, B, C and D as per Eurocode 8

Site Specific Indian Design Spectrum and Rock Motion

Indian code has four seismic zones, zone II and III are low to moderate seismic zones and zone IV and V are high seismic zones. Two cities are selected where rock level spectral values are available. Bangalore is in the low seismic zone i.e. zone II and Chamoli is in the high seismic zone i.e. zone V. These two cities are selected to compare design spectrum based on IS 1893 and intentional standards of IBC and Eurocode. In IS 1893[21], limited earthquake acceleration time history is available for low to medium seismic regions in India. Hence synthetic ground motion developed for low seismicity region of Bangalore is considered for the study.

Recent study by Sitharam and Anbazhagan[44] recommends upgrading of Bangalore from Zone II to Zone III. Synthesized response spectrum presented at rock level with PGA of 0.16 g for maximum credible earthquake (MCE) by Sitharam and Anbazhagan[44] is considered in this study. This synthetic spectrum is generated for moment magnitude of 5.1 and is a representative of an intra-plate earthquake event in South India. Figure 4 shows response spectrum for zone II and III (zonation factor for zone II is 0.1 and zone III is 0.16) as per IS 1893[21] with synthesized response spectrum by Sitharam and Anbazhagan[44].

Zone II response spectrum is much lower than synthesized response spectrum. Response spectrum given in IS 1893 (2002) for Bangalore (zone II) does not represent complete seismicity in a micro level. Seismicity of Bangalore city is relatively higher, but in IS 1893 the city is placed in lower zone. Rock level synthesized spectrum is very well matching with the response spectrum for zone III in IS 1893, however spectral acceleration for longer periods is much more than synthesized spectral values for same rock level condition.

Response spectrum of Chamoli is arrived from recorded inter plate earthquake of Chamoli published in Atlas of Indian Strong Motion Records[41]. The Chamoli earthquake occurred on 29 March 1999 at north of Chamoli in the Lesser Himalayas. This event has moment magnitude of 6.6 and peak ground acceleration of 0.19 g recorded at rock level. Even though eleven records are available for Chamoli earthquake, one rock motion is considered in this study for comparison demonstration. Figure 5 shows response spectrum corresponding to zone V as per IS 1893[21] and recorded response spectrum of Chamoli earthquake. Response spectrum very well matches with recorded data for long periods but is higher for short periods.

Spectral values as per IS 1893[21] given in figures 4 and 5 correspond to maximum credible earthquake and these values should be reduced to half for design based earthquake. Even though this is not mentioned explicitly in IS 1893, the DBE has been likened to ground motion with a 475 yr return period.[25,33] The code-prescribed elastic design spectra for the DBE and the MCE are in a 1:2 proportion, as in many contemporary seismic codes worldwide, the MCE can be associated to ground motion with a 2475 yr return period[33].

Moderate and minor seismic regions (zone II and III as per IS 1893) have higher spectral values at short period and lower spectral values at long period for same site condition which is vice versa for high seismic regions (zone IV and V as per IS 1893). This has been very well accounted in the modern seismic codes of NEHRP, IBC and Eurocode. But Indian code does not differentiate response spectra for lower seismicity and higher seismicity regions.

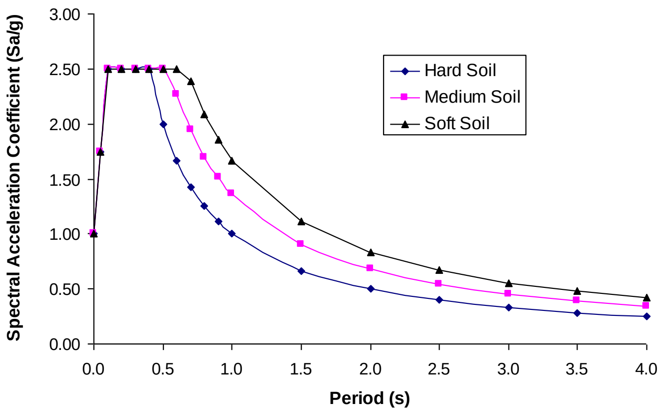


Figure 3: Normalized response spectrum given in IS 1893[21].

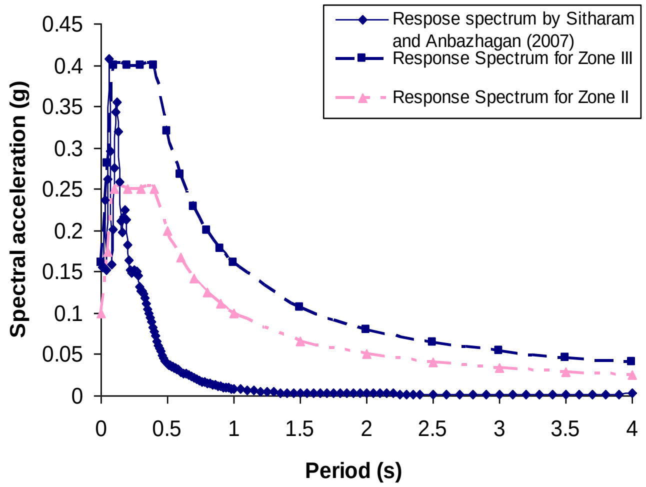


Figure 4: Comparison of response spectra at the rock level for Bangalore city as per IS code zone II and Zone III for MCE and synthesized response spectrum at the rock level by Sitharam and Anbazhagan[44]

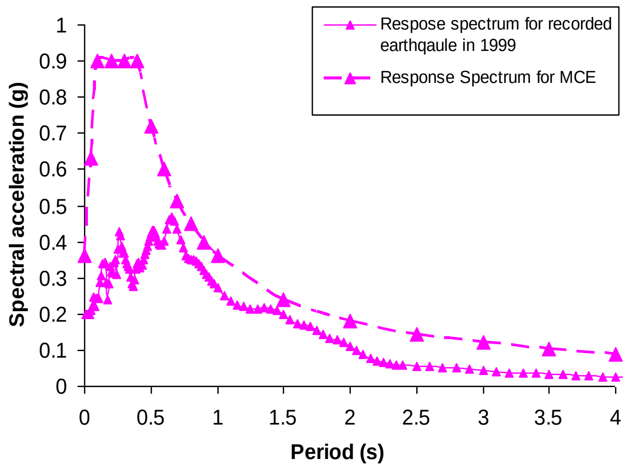


Figure 5: Comparison of response spectra at the rock level for Chamoli as per IS code Zone V for MCE and recorded earthquake of M_W 6.6 in 1999.

Indian Standards and International Building Code

IBC[30] has six site classes to account site effects for different soils. Site effects of the last group (site class F) need to be assessed by a site specific study and rest five classes can be accounted by site classification and spectral coefficients. IS 1893[21] has three classification of soil and type I in IS 1893 is close to the site class C in IBC (Table 2). Design spectrum for Bangalore and Chamoli has been arrived and compared with design spectrum for similar seismic condition. IBC design spectral values are estimated considering spectral values in Bangalore synthetic response spectrum for zone II and III.

Figure 6 shows comparison of design spectra for a rocky site i.e. site class A, B and C in IBC and type I in IS 1893. These response spectra show that the spectral acceleration values based on Indian Standard are much higher than IBC. Short period design spectrum values correspond to IS 1893

Zone II type I and are comparable to IBC site class C values. For similar seismic intensity and building condition IS 1893[21] gives higher design spectral acceleration when compared to IBC.

The definition of site class D in IBC is comparable to type II or medium soils in Indian Standard. Figure 7 shows comparison of design spectra for site class D in IBC and type II in IS 1893 Zone II and Zone III. Short period spectral values of IBC site class D matches well with IS 1893 Zone III short period values but Indian code marked Bangalore in seismic zone II in IS 1893[21]. Long period spectral values in Indian code are higher than IBC. In IBC site class D spectral values are higher than site class C (Figure 6 and 7) due to site effects. But in Indian code short period spectral values are not changed (Figure 6 and 7), which means that site effects for low to moderate earthquake (zone II and III) are not accounted. Definition of type III - Soft Soil in Indian Standard corresponds to IBC site class E. Figure 8 shows comparison of design spectrum for site class E in IBC and type III in IS 1893 Zone II and Zone III. Short period spectral values of IBC site class E do not match with any of design spectra in IS 1893. In Indian code spectral values increased for long period to account site effects, but for moderate earthquake short period spectral values have to be increased, which are not reflected in IS 1893[21].

Similar comparison has been made for high seismic region of Chamoli. IBC design spectral values are calculated considering recorded Chamoli earthquake spectrum as discussed earlier. Figure 9 shows comparison of design spectra for site class A, B and C as per IBC and type I as per IS 1893. Indian code- design spectral values are more than two times of IBC values up to the period of 1 second (short period). Spectral values for long period from IS 1893 are matching with IBC site class B spectral values. Comparison of spectral values of IS 1893 Type II soil with IBC site class D for high seismicity region is shown in figure 10. Design spectrum given in IS 1893 over estimates spectral values for short period and under estimates for long period. Figure 11 show comparison of design spectrum for soft soils i.e. type III in IS 1893 and site class E in IBC. Design spectral values are underestimated in IS 1893 when compared to IBC for similar site conditions.

This study shows that design spectral values given in Indian code IS 1893[21] for rock poorly match with IBC rock level spectrum. Spectral values are over estimated for low to moderate seismic regions. Indian code short period design spectral values are over estimated in type I and type II soils. Similarly IS 1893 type III design spectral values are under estimated for long period in IS 1893. This clearly shows inadequate provision for site effects when compared to IBC. In IBC, special provision is given for sites having shear wave velocity of around 100 m/s (called as site class F). These sites may be subjected to another geotechnical problem of liquefaction, it is recommended to carry out liquefaction assessment. In Indian code there is no indication of liquefaction, even though many Indian cities have experienced liquefaction from historic times[6].

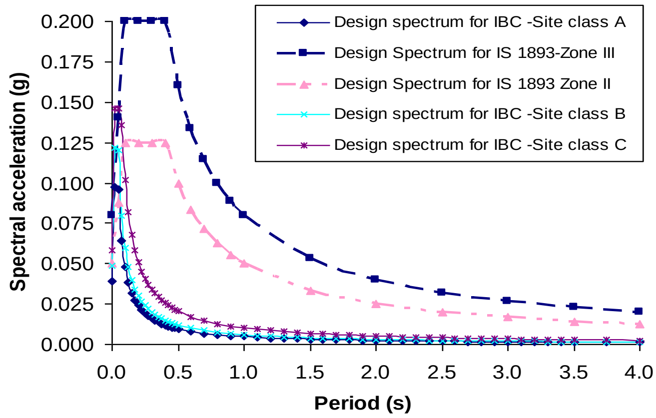


Figure 6: Comparison of the design spectrum from IS 1893 for zone II and III for type I soil with IBC site class A, B and C for moderate earthquake

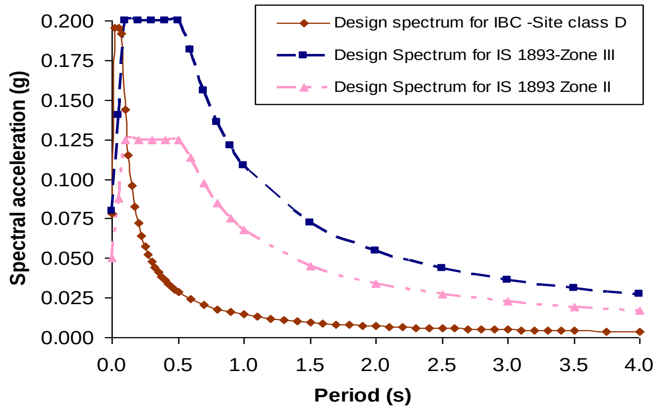


Figure 7: Comparison of design spectrum of IS 1893 type II for zone II and III with IBC site class D design spectrum for moderate earthquake

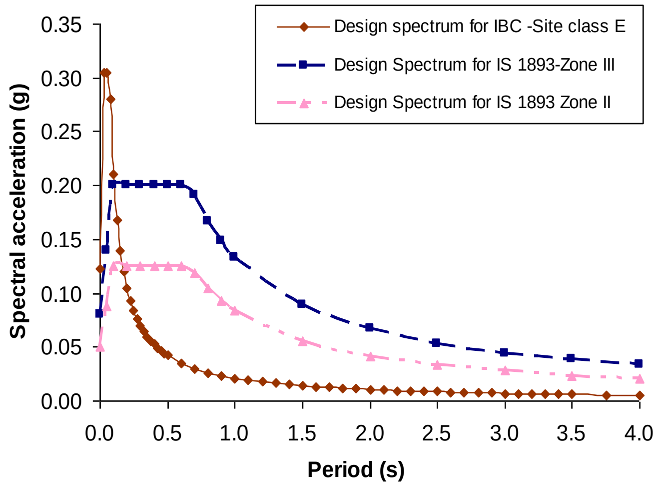


Figure 8: Comparison of design spectrum of IS 1893 type III for zone II and III with IBC site class E design spectrum for moderate earthquake

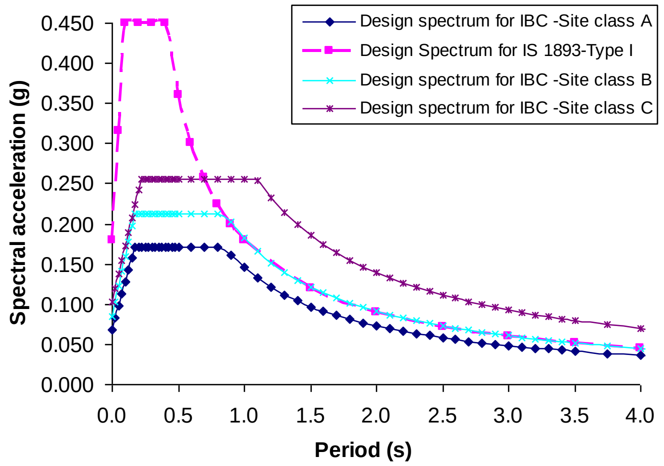


Figure 9: Comparison of the design spectrum for the major earthquake region as per IS 1893 for type I and IBC site class A, B and C

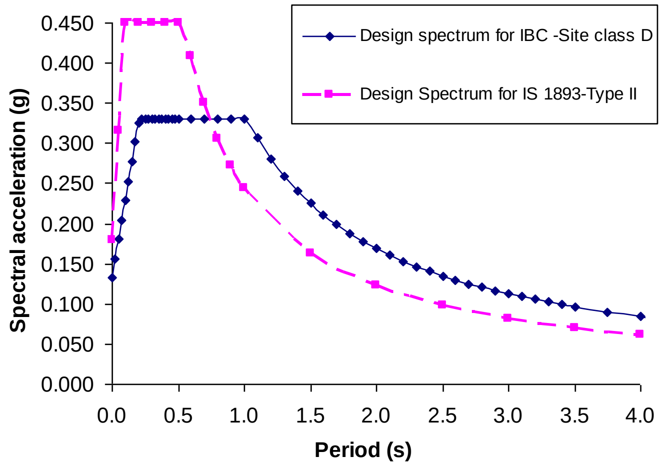


Figure 10: Comparison of the design spectrum for the major earthquake region as per IS 1893 for type II and IBC site class D

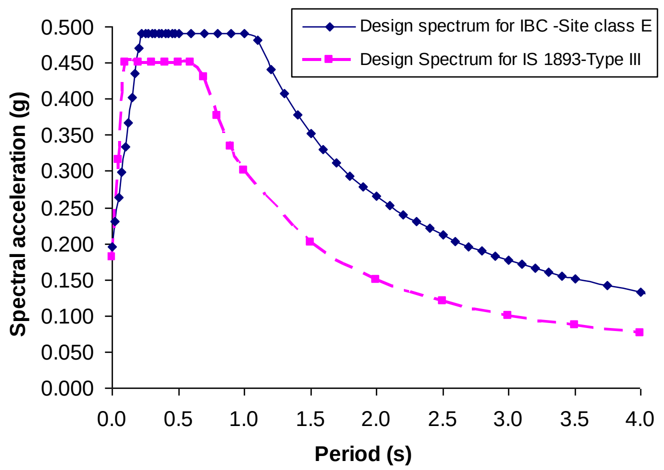


Figure 11: Comparison of the design spectrum for the major earthquake region as per IS 1893 for type III and IBC site class E

Indian Standards and Eurocode

In Eurocode, the site subsoil is classified into different ground types A, B, C, D, E and S_1 and S_2. First five classes are described by the stratigraphic profiles and parameters given in the table 2. Last two classes (S_1 and S_2) are special subsoil classes, for these classes, special studies are required for the definition of the seismic action[38]. Eurocode class A is defined as all rocky formations including at most 5 m of weaker material at the top, with average shear wave velocity in the top 30 m of the soil profile greater than 800 m/s. Eurocode site class A corresponds to IBC site class B, there is no separate site class that corresponds to IBC site class A in Eurocode. Rock having SWV of more than 760 m/s is the engineering bedrock[6] where amplification is unity. Rock harder than engineering bedrock (Vs^{30}>1500 m/s) is usually not found in engineering geotechnical investigations and spectral amplification is also less than that of engineering bedrock. Eurocode recommended two types of spectrum based on seismicity of region. Type I spectrum is recommended for earthquake of magnitude which is more than 5.5 and type II spectrum is recommended for earthquake of magnitude which is less than 5.5.

Type I soils defined by Indian Standard correspond to site class B in Eurocode. Bangalore comes under low to moderate seismic region and synthetic spectrum was also developed for moment magnitude of 5.1 which is less than M_W of 5.5. Hence Type II design spectrum of Eurocode has been developed and compared with Indian design spectrum. A comparison of design response spectra based on Indian Standard (Type I) and European Standards (site class B and A) is shown in the figure 12. Figure 12 clearly shows that the spectral acceleration values based on IS – 1893 are very low when compared to Eurocode for Zone II and Zone III. Indian code Type II soil corresponds to Eurocode site class C.

Figure 13 shows the comparison of the design spectra for Indian Standards type II for zone II and III with European standards site class C. It is observed that the spectral values by IS 1893 are underestimated even when compared to the site class C of Eurocode. Eurocode has defined two site classes for soft and loose soil i.e. site class D and E. These site classes are comparable to Indian Standards type III soils. Figure 14 shows the comparison of spectra of Indian code type III soil for zone II and III and Eurocode site class D and E. Eurocode spectral acceleration values are much higher than the Indian code spectral acceleration values for these sites. Low to moderate seismic regions design spectral values given in Indian standard are much less than Eurocode for short and long periods.

Similarly, spectral values for high seismicity region are also compared. Design spectrum from Indian code for zone V and Type I soil is compared to design spectrum type I in the Eurocode for site class A and B. Figure 15 shows comparison of spectra from Indian code and Eurocode.

Type I soil in Indian code corresponds to site class B in Eurocode but design spectral values are matching and comparable to Eurocode site class A. Figure 16 shows comparison of design spectra for Indian code zone V Type II soil and Eurocode site class C. Design spectral values of Indian code match with Eurocode upto a period of 0.1 s and after 2.5 s.

Soft soil type III given in Indian code corresponds to site class D and E in Eurocode. Figure 17 shows comparison of design spectra for these sites for high seismic region. Short period spectral values in Indian code are matching with Eurocode both site classes upto a period of 0.1s. Indian code spectral values after 0.7 s are comparable to Eurocode site class E and not with site class D.

In all types of soils, it is observed that the Indian Standards design spectral values are much lower than the European standards for similar seismic condition and building type. In low to moderate seismic regions, design spectral values of Indian standards are less for all the periods. For high seismic regions Indian spectral values are relatively matching with part of spectrum (upto 0.1s), rest of the spectral values are not matching. This shows that the geotechnical provisions in the Indian Standard are insufficient and are not properly accounted. The values of design spectral acceleration seem to be lower bound when compared to Eurocode.

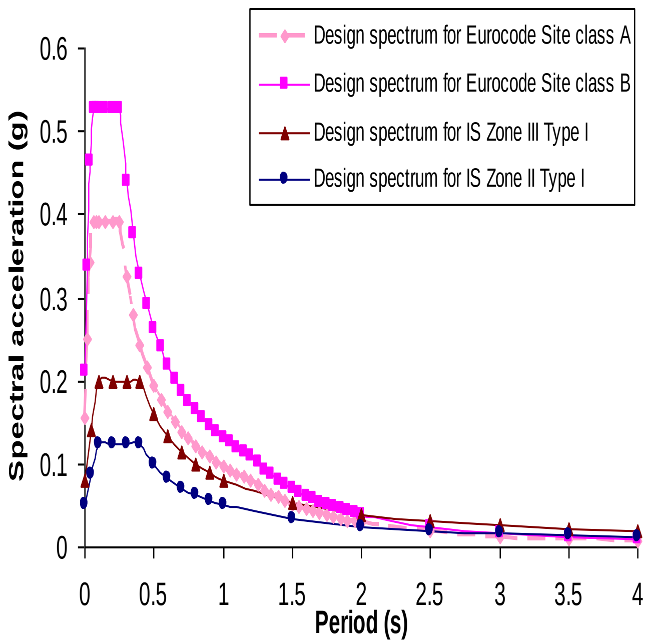


Figure 12: Comparison of the design spectrum of IS 1893 type I sail for zone II and Zone III with Eurocode 8 site class A and B for minor to moderate seismic region.

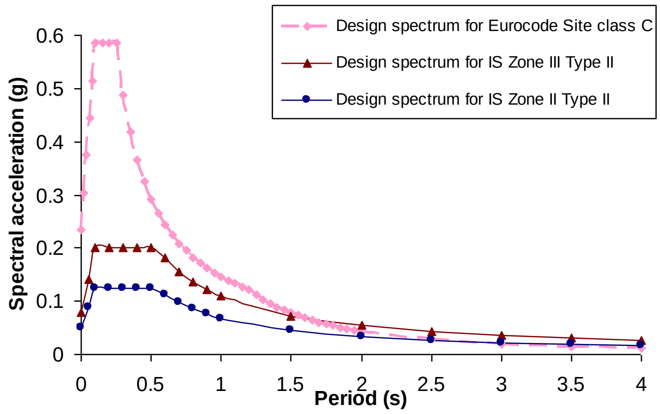


Figure 13: Comparison of the design spectrum of IS 1893 type II soil for zone II and Zone III with Eurocode site class C for minor to moderate seismic region.

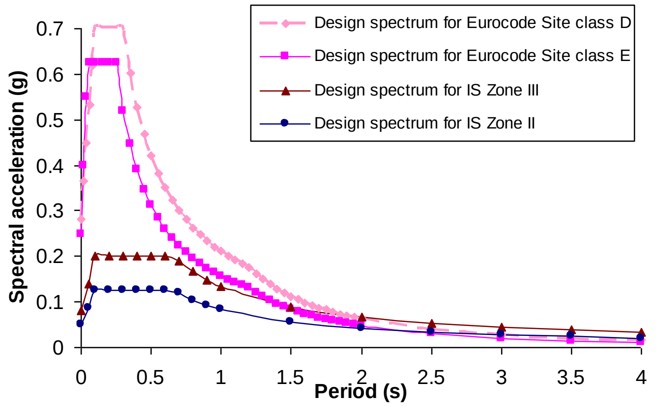


Figure 14: Comparison of the design spectrum of IS 1893 type III soil for zone II and Zone III with Eurocode 8 Site class D and E for minor to moderate seismic region.

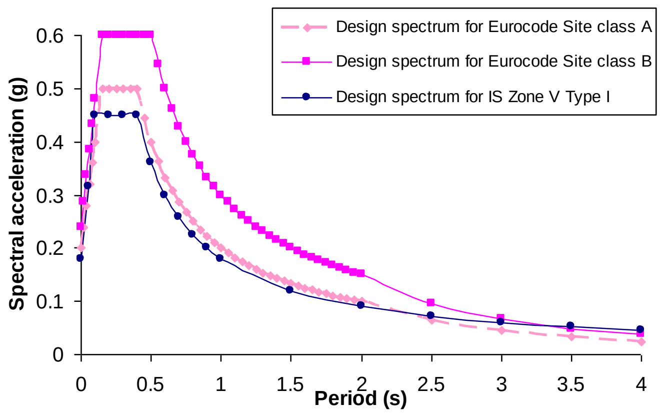


Figure 15: Comparison of the design spectrum of IS 1893 type I soil for zone V with Eurocode 8 Site class A and B for the high seismic region.

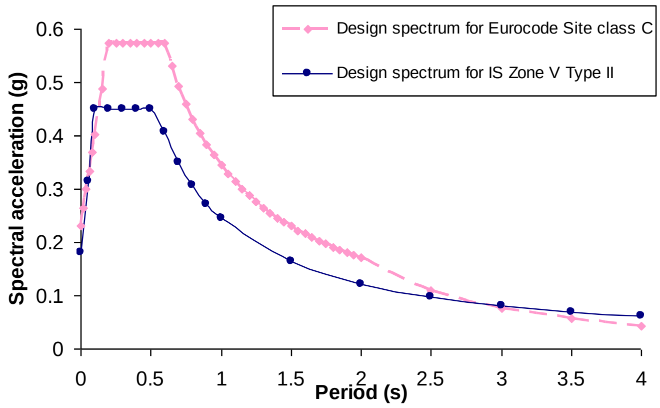


Figure 16: Comparison of the design spectrum of IS 1893 type II soil for zone V with Eurocode 8 Site class C for the high seismic region.

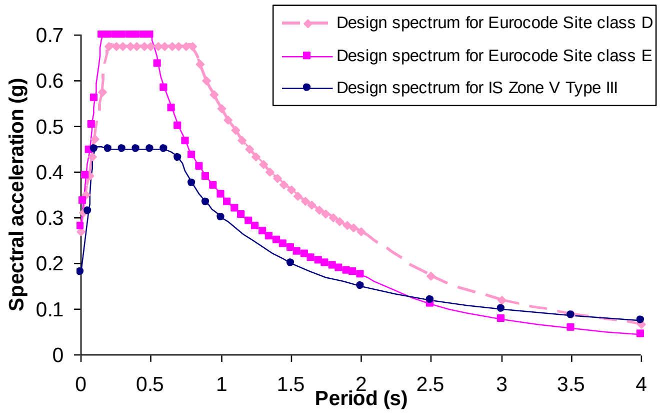


Figure 17: Comparison of the design spectrum of IS 1893 type III soil for zone V with Eurocode 8 Site class D and E for the high seismic region.

Results and Discussion

Seismic zonation map of India is based on a deterministic approach and it was revised soon after major earthquake in the country. As seismic codes are playing very important role in urban design, planning and construction of infrastructures, many countries have understood the importance and role of geotechnical aspects in modification of seismic waves and have incorporated in their seismic standards. Geology and subsurface data collection show that India has diverse geology, soil and rock properties. Soil and rock properties play very important role in seismic site effects and induced effects. Site specific variations in soil and rock properties are accounted in modern seismic code by seismic site classification/geotechnical provision.

In Indian seismic code, subsurface materials are grouped into three classes to account site and induced effect i.e. hard, medium and soft for entire India. These groupings may be based on experience and there is no scientific definition and guide line to define each group in engineering point of view which clearly shows that geotechnical provisions are not properly incorporated in Indian standard of IS 1893[21], even though India has long history of earthquake damages. Soon after 2001 Bhuj earthquake many site specific response analysis and microzonation studies are being carried out in India to generate representative response spectra and surface level hazard map. Seismology division of Ministry of Earth Science and National Disaster Management Authority are working towards to produce representative seismic hazard map at rock level and surface level.[13,36]

Some of the completed and ongoing seismic microzonation works are summarized in Sitharam et al[43] with role of geotechnical aspects. Many of the studies are based on seismological method of experimental-empirical approach where dominant period or frequencies are mapped. These studies are usually carried out by scientists from the area of geology, geophysics and seismology. Few site specific response studies are also carried out in selected locations in India by considering detailed geotechnical properties of subsurface materials and suitable earthquake for the specific region. These studies are carried out by engineering seismologist or civil engineers. Scientists concentrate more on earthquake wave in large scale but engineers concentrate on response of buildings/structures by taking account of source, path and site specific soil conditions.

Site specific response studies were carried out by Govindaraju et al[27] and Sitharam and Govindaraju[42] for Bhuj, Anbazhagan and Sitharam[2] for Bangalore, Iyengar and Ghosh[31]; Rao and Neelima Satyam[40]; Hanumantha Rao and Ramana[28] for Delhi, Suganthi and Boominathan[46]; Uma Maheswari[47] for Chennai, Mahajan et al[32] for Dehradun, Govindaraju et al[27] for Kolkata, Anbazhagan et al[7] for Lucknow and Phanikanth et al[37] for Mumbai. These studies have shown that surface peak ground acceleration or spectral acceleration estimated for study area is different from the seismic code provision attributed to the detailed consideration of site specific subsurface soil and rock properties. Even though these authors have not explicitly compared site specific response spectrum of their region with IS 1893[21] spectrum, but difference can be easily identified.

Comparison analysis shows that design spectral acceleration of Indian standards is not comparable to the modern seismic codes for similar building, seismic and site conditions. Based on these studies, it is recommended that the Indian Seismic Design Code, IS 1893 has to be updated in its hazard mapping and geotechnical provisions which is very important for obtaining the correct earthquake resistant design of structures. Site classifications followed in the developed countries are based on detailed regional study and local soil type. Modern seismic code site classification system is widely used in Indian cities particularly in seismic microzonation studies without checking its validity and applicability. Following modern seismic site classification systems in India are resulting in stiffer site class and lower spectral values, particularly when rock depth is less than 25 m[8,10,11]. There is a warrant to develop our own site classification system and incorporate proper geotechnical aspects in the Indian standard.

Conclusion

The first step in any earthquake resistant design is the development of the response spectrum considering site specific subsoil and then finding the horizontal acceleration that is acting on the structure. Hence, there is need for updating and modifying the code in order to avoid the damage of structures and casualties. Many countries' seismic codes serve for disaster management planning during earthquakes. In Indian seismic code, seismic hazard factors were grouped as four zones with respective zonation factors based macro level study. Many recent studies show that micro level hazard values are lesser or more than seismic hazard values in the Indian code. India has diverse geology and subsurface lithology. Three site classes defined in Indian seismic code are insufficient to account soil distributions in India to account earthquake geotechnical hazards. Few definitions given for soil classification in Indian seismic code do not match with Indian soil classification standard.

Modern seismic codes used shear wave velocity as a prime factor to group the soils but Indian code uses only N values. These N values are not also clearly defined when compared to modern seismic codes. Design spectra have been developed for low to moderate seismicity region of Bangalore and high seismicity region of Chamoli. These spectra are compared to modern seismic codes. This study shows that design spectral values given in Indian code are higher for short period and lower for long period when compared to international building code for low to moderate seismic regions.

The spectral response curves based on Indian Standard gave very higher values of spectral acceleration for short periods in the case of Chamoli earthquake and long periods in Bangalore earthquake. Design spectral values obtained from Indian code are lower than Eurocode for low to moderate seismic regions. Design spectral values from Indian code for high seismic regions are matching with Eurocode upto period of 0.1 s, beyond this, these values are lower. Geotechnical provision in Indian code is formless when compared to modern seismic codes like International building code and Eurocode.

This study shows that there is some inaccuracy in the geotechnical provision in Indian code. Further detailed analysis may be carried out by considering Indian specific soil conditions and these results can be incorporated in the seismic code to account geotechnical earthquake hazards in the design requirements.

Acknowledgement

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