Elastic Seismic Design Response Spectra for Deep and Shallow Basin of the Indian Subcontinent

Ketan Bajaj and P. Anbazhagan

Abstract In the present study, new elastic design response spectra (EDRS) for the deep and shallow region of the Indian subcontinent has been proposed for rock and soil site. For determining the EDRS for bedrock, 50 each rock recorded ground motions have been used for Intra and Interplate region. For determining the EDRS for soil sites, 250 and 178 ground motion for deep and shallow sites has been used, respectively. For SI, only few ground motions are available, hence for developing EDRS for shallow sites, ground motions recorded at similar tectonics have been used in the present study. Further, EDRS is derived based on Eurocode, i.e. normalized elastic design response spectra which is based on one parameter, i.e. effective ground acceleration at rock.

Keywords Response spectra · Ground motion · Deep and shallow basin · Seismic site classification

1 Introduction

Local site conditions have great influence on ground surface motion and structural damage caused by an earthquake event. The Indian Subcontinent (IS) has one of the most diverse seismotectonic and seismicity. The high level of seismicity is associated with the Himalaya tectonic province will result in site amplification in the contiguous deep alluvial deposits named Indo-Gangetic Basin (IGB), due to any major earthquake in future. Whereas, low to moderate level of seismicity in the Southern India (SI) causing high amplification due to shallow thin layers. Evidence from past earthquakes suggested that soft soil sites tend to amplify at low frequency, whereas rock sites have significant intensity at high frequencies. Anbazhagan et al. [1] highlighted that local site effect is the major factor that causes the damage due to an earthquake.

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2001 Bhuj (7.7 M_w), 1999 Chamoli (6.8 M_w), 2011 Sikkim (6.9 M_w), and 2015 Nepal (7.8 M_w) earthquakes are the recent examples that explained the effect of thick deposits on site-specific damage in the IS. Various researchers [e.g. 2–4] have studied the local site effect and estimated amplification factors using the 1D site response study but most of these studies are limited to soil column of 30 m depth. Moreover, in the previous site response studies, the input ground motions were either selected randomly from global database or simulated based on the occurred earthquake scenario. In India very limited attempts have been made to drive the design spectrum with different damping level considering regional recorded data.

In most of the modern seismic design, the estimation of seismic force of a typical structure is based on the 5% damped design response spectrum of recorded data in the region. In India limited attempts have been made to the drive design spectrum with different damping level considering regional recorded data, some attempt has been made by Anbazhagan et al. [5]. Generally, the design spectra of a given site are obtained by modifying the uniform hazard spectrum by considering site factors corresponding to a particular seismic site. Conventionally, the design force is specified via. response spectrum amplitude. However, with the increased complexity of the modern structure and understanding the seismic performance of structure demands, it is now essential to define the amplitude and shape of the design spectra.

This paper aims at the development of new elastic design response spectra for Intra and Interplate region of the Indian subcontinent considering region-specific seismic data. Further, EDRS is derived based on Eurocode, i.e. normalized elastic design response spectra which is based on one parameter, i.e. effective ground acceleration at rock.

2 Study Area

The Indo-Gangetic Basin is the foredeep depression that is situated between the Indian Peninsular shield and the Himalayan region. IGB lies roughly between longitude 74° E, and 88° E and latitude 24° N and 32° N (Fig. 1a). The sediment depth varies from few tens of meter in the south part of the IGB and progressively increasing up to ~5–6 kms in the northernmost part. High neotectonic activity and reactivation of tectonic features and lineaments are acknowledged by various researchers [e.g. 6 etc.]. IGB is contiguous to the most seismically active Himalayan region and experiencing the strong compressional stress conditions. Any large to moderate earthquake in the Himalayan region may result in massive destruction in the IGB due to site amplification and liquefaction.

Southern India is considered as one of the oldest geologically evolved and tectonically stable continental crust of the IS. The seismotectonic of the SI is majorly consist of various faults, ridges, shear zones, and tectonic lineaments. Various researches [e.g. 7, etc.] defined the tectonic feature of the SI and many authors reported the reactivation of fault along the western part of the Peninsular India. Additionally, SI

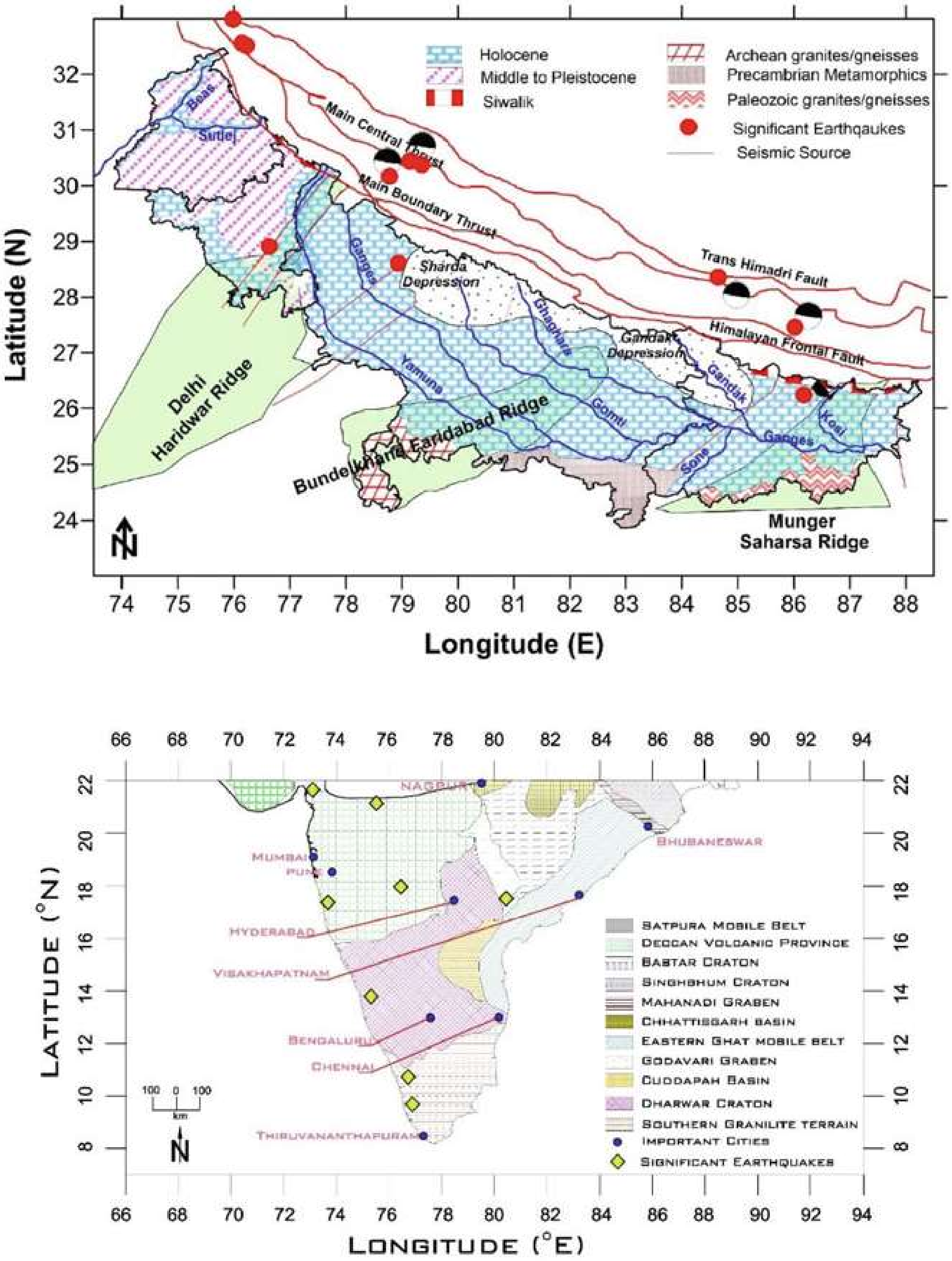

Fig. 1 Study area used in the present study

is having an irregular seismicity. As micro-seismicity is reported in the South Granulite Terrain, Eastern Dharwar craton is surrounded by intermediate seismicity, and Koyna-Warna region and Deccan Volcanic Province has high seismicity. The SI is also marked in Fig. 1b.

3 Methodology

Malhotra [8] concluded that the response of the structure derived using acceleration time history does not correspond to the velocity and displacement time histories. Response of the flexible structures (long period) can be contradictory if computed only using processed acceleration time history [8]. Based on that, Malhotra [8] proposed a methodology to compute elastic response spectra for incompatible acceleration, velocity, and displacement time histories. The following is the procedure recommended by Malhotra [8] for deriving the normalized response spectra and used in the present study. For determining the EDRS for bedrock, 50 each rock recorded ground motions have been used for Intra and Interplate region. For determining the EDRS for soil sites, 250 and 178 ground motion for deep and shallow sites has been used, respectively. For SI, only few ground motions are available, hence for developing EDRS for shallow sites, ground motions recorded at similar tectonics have been used in the present study. After smoothening the recorded ground motion, the elastic design response spectra have been defined considering the following equations

$$0 \leq T \leq T_B : \frac{S_a(T)}{PGA_{rock}} = s.\left[1 + \frac{T}{T_B}.(\beta - 1)\right] \tag{1}$$

$$T_B \leq T \leq T_C : \frac{S_a(T)}{PGA_{rock}} = s.\beta \tag{2}$$

$$T_C \leq T \leq T_D : \frac{S_a(T)}{PGA_{rock}} = s.\beta \frac{T_C}{T} \tag{3}$$

$$T_D \leq T : \frac{S_a(T)}{PGA_{rock}} = s.\beta.T_C \frac{T_D}{T^2} \tag{4}$$

Here, PGA_{rock} is the design ground acceleration at rock-site conditions, S and β are the soil amplification and spectral amplification factors. T_B and T_C are the limits of constant acceleration branch and T_D is the beginning of the constant displacement range of the spectrum. Distributing the spectra into two regions helps in better representation of the shape of the response spectra. β, T_B, T_C, and T_D are determined based on the shape of the normalized response spectra. S and β have been determined considering the methodology proposed by Pitilakis et al. [9]. Typical EDRS is given as Fig. 2. The amplification factor corresponding to acceleration, velocity, and displacement is denoted as α_A, α_V, and α_D. T_1, T_2, T_3, T_4, T_5, and T_6 in Fig. 7.2 is denoted as control periods (where the straight-line segments meet).

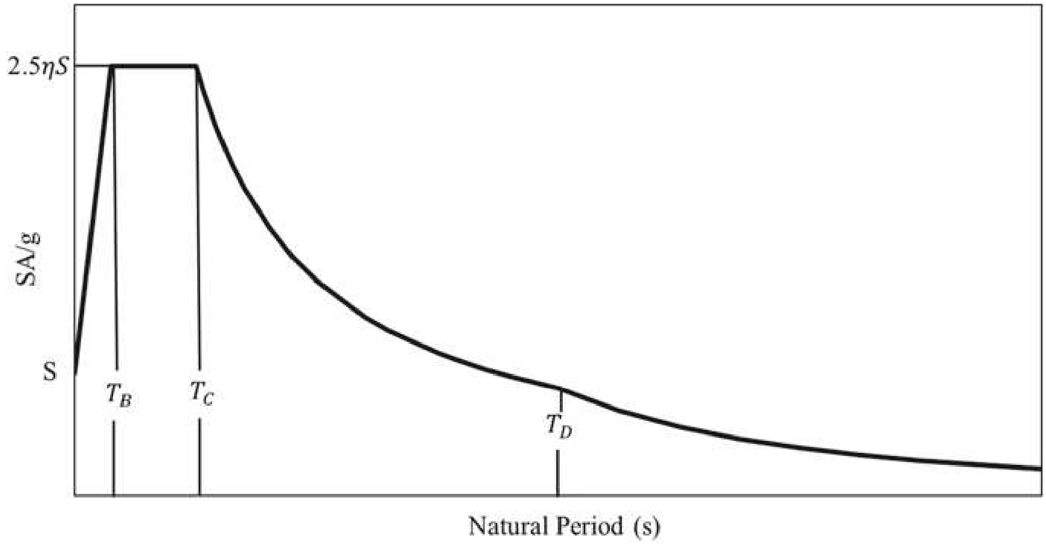

Fig. 2 Typical EDRS derived in this study

4 Result and Discussion

Pitilakis et al. [9] defined different approaches in determining the soil amplification (S). In this study, it is calculated considering the period-independent amplification factor with respect to rock site. The period-independent amplification factor for soil site and different magnitude at an interval of 0.5 with respect to rock is calculated as

$$S = (I_{soil}/I_{rock}).(1/SR) \tag{5}$$

here, SR is the spectral ratio, I_{soil} and I_{rock} are the spectral intensities for soil and rock, respectively. Housner [10] defined the response spectrum intensity as

$$I = \int_{0.05}^{2.5} PSV(\xi, T)dT \tag{6}$$

i.e. the area under the pseudo velocity response spectrum between periods 0.05 to 2.5 s. To compute the I_{rock} for IGB and SI, the area under the PSV curve has been determined. Similarly, the area under the PSV curve for soil site is computed and I_{soil}/I_{rock} has been determined. SR reflects the difference in shape of soil spectra with respect to rock spectra, when all the spectra are normalized and have the same ordinate at starting period. The spectral amplification factor (β) is analogues to α_A (see Fig. 3) is also determined for both the regions and given as Table 1. From Table 1, it has been observed that S is 1.22 in case of IGB and 1.13 in case of SI for soil site. Similarly, β is 2.91 in case of IGB and 2.21 in case of SI, for soil.

The parameters β, T_B, T_C, and T_D have been determined using the normalized spectrum. These factors are the result of fitting the smooth spectrum to the median

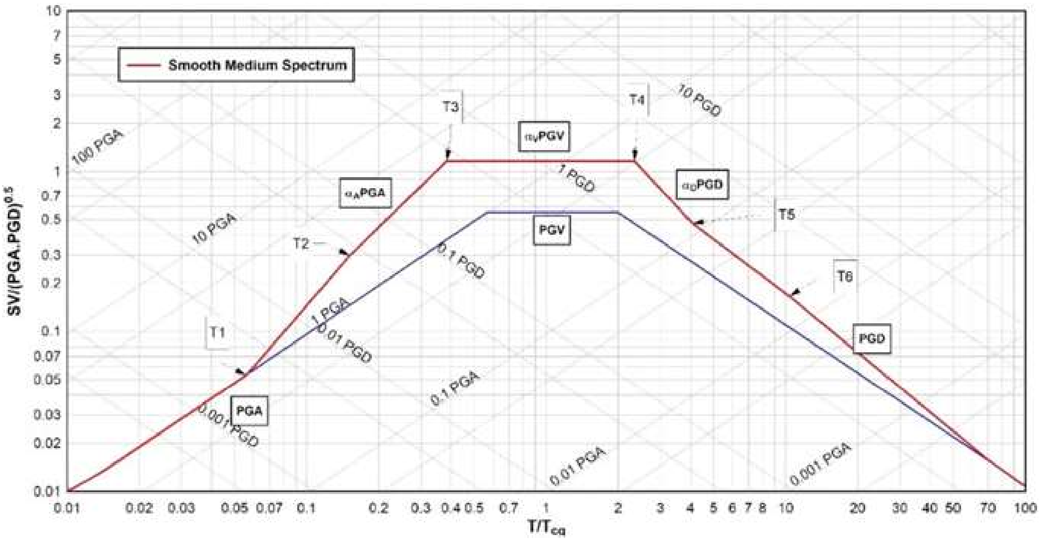

Fig. 3 Typical smooth medium response spectrum considering

Table 1 Parameters of the proposed design response spectrum for 5% damping

Parameters	Soil		Rock	
	IGB	SI	IGB	SI
T_B	0.16	0.12	0.15	0.08
T_C	0.52	0.29	0.38	0.28
T_D	1.90	1.41	2.33	1.52
S	1.22	1.13	1.00	1.00
β	2.91	2.21	2.29	2.81

normalized spectrum (see Fig. 3). The values are given in Table 1. The derived spectrum for the IGB and SI is given as Fig. 4a, b, respectively. The proposed spectra in this case depend on the effective ground acceleration at rock sites (i.e. PGA) and soil amplification factors (S, β), whereas control periods remain constant for the corresponding site class. The derived EDRS is also compared with design spectrum given in Indian standard code (IS:1893) and given in Fig. 4.

5 Conclusion

In the present study, new elastic design response spectra for the deep and shallow soil sites in Inter and Intraplate regions of the Indian subcontinent have been proposed. EDRS for bedrock is determined by considering 50 each rock recorded ground motions for Intra and Interplate region. For determining the EDRS for soil sites, 250 and 178 ground motion for deep and shallow sites has been used, respectively.

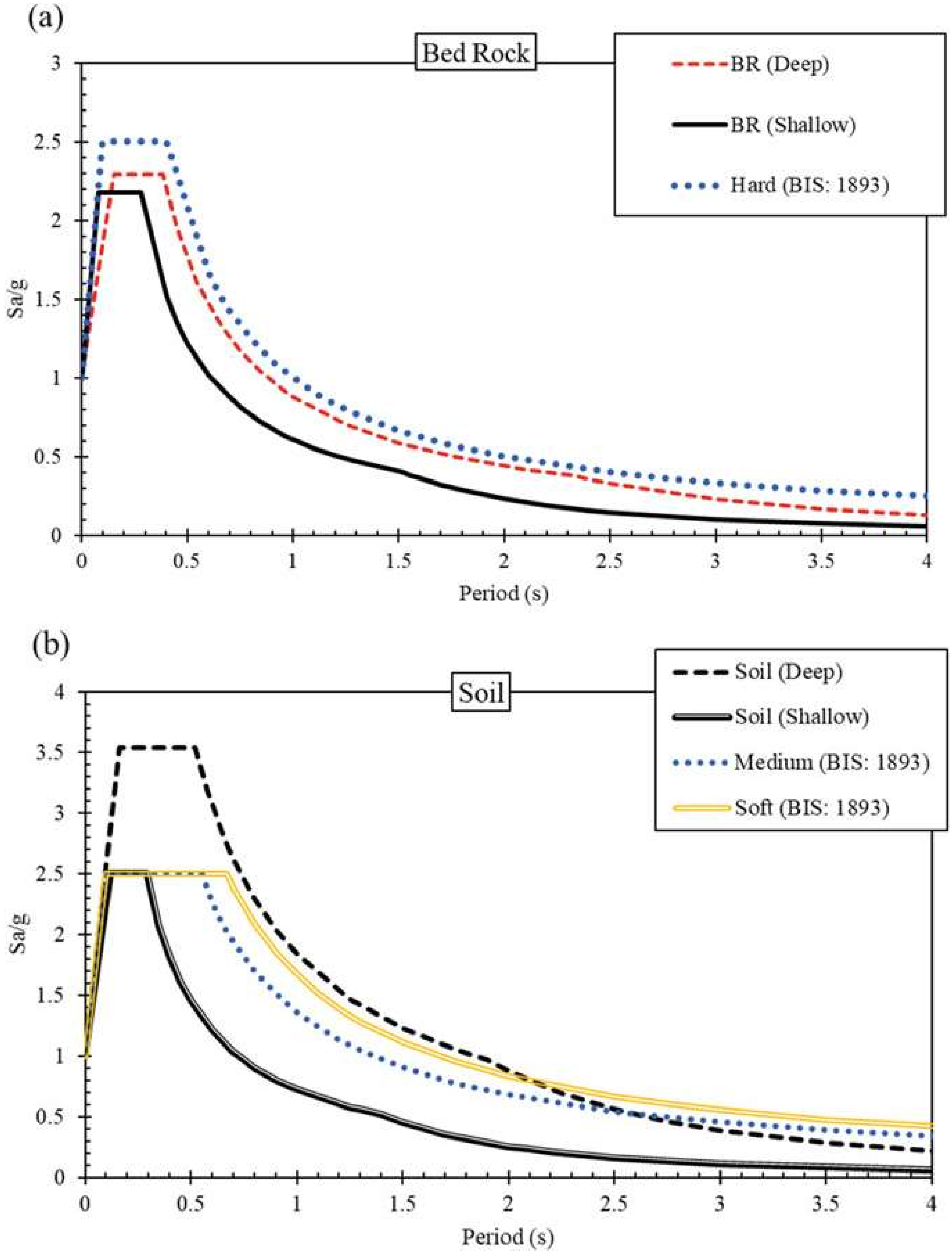

Fig. 4 Design response spectra for deep and shallow basin of India for bedrock and soil sites

EDRS is derived based on Eurocode, i.e. normalized elastic design response spectra which is based on one parameter, i.e. effective ground acceleration at rock. Response spectra for IS:1893 are underestimating the spectral values at long and short periods.

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