New acceleration design response spectra for deep and shallow sites – Application to India

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ABSTRACT

In the present study, acceleration design-response spectra (ADRS) for deep and shallow sites have been proposed for different seismic site classification as per NEHRP. Nonlinear site response analysis has been performed at different subsurface profiles and surface spectra have been derived. The site factors in terms of short period or 0.2 s (F_a) and long period or 1.0 s (F_v) for both the regions has been estimated. Finally, using these site factors, ADRS for both the regions have been proposed. This is the first time such extensive study has been done for developing the ADRS for the deep and shallow sites of India or Asia for different seismic site class.

Keywords: ADRS, Seismic site class, site response analysis, site factors, deep and shallow sites

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. Anbazhagan et al. (2010) highlighted that local site effect is the major factor that causes the damage due to an earthquake. 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. Boominathan et al. 2008; Anbazhagan and Sitharam, 2008; Naik and Choudhury, 2013 etc.) have studied the local site effect and estimated amplification factors considering shallow sites for the Indian subcontinent 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. Till today there are no comprehensive studies available for estimating and differentiating the local site effect for the deep and shallow deposits of IGB and SI considering the measured Shear wave velocity (V_S) profiles for more than 100 m depth.

In this study, the site factors at zero period (F_{PGA}), at short period or 0.2 s (F_a) and long period or 1.0 s (F_v) as adopted by the American Society of Civil Engineer's Standard ASCE 7-10 (ASCE 2010), the International Building Code (ICC 2012), and the AASHTO guide (AASHTO 2011) have been derived for both the deep and shallow regions by carrying out detailed field experiments and analysis considering regional parameters. Further, the subsurface profiles have been classified based on NEHRP (BSSC, 2003) seismic site classification. For each site class, surface spectra for both the regions have been determined using the non-linear site response analysis. Finally, the obtained surface response spectra for different site class has been used in deriving the respective site factors.

2 STUDY AREA

The Indo Gangetic Basin (IGB) 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 upto ~ 5 to 6 kms in the northernmost part. High neotectonic activity and reactivation of tectonic features and lineaments are acknowledges by various researchers (e.g. Singh, 1996 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. V_S at 275 locations in the IGB is measured for the study.

Southern India (SI) 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. Ramaswamy, 2006) 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 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 Figure 1 (b).

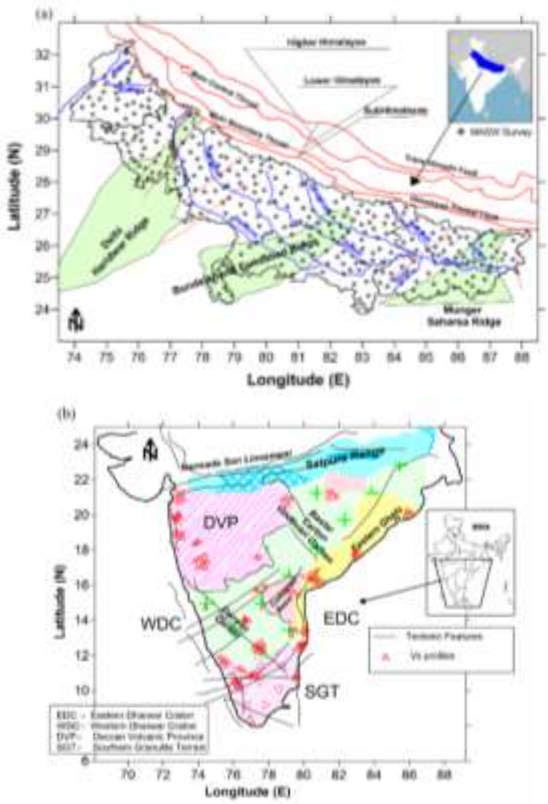

Fig. 1. Study area and the location of subsurface profile used in the present study

3 SITE RESPONSE ANALYSIS

As IGB and SI lack in recorded ground motion data corresponding to different soil sites. Hence to develop the surface spectra corresponding to different soil types, detailed site response analysis has been carried out at sites with different V_S subsurface profiles, measured in IGB and SI. To obtain the deep V_S in the IGB, both active and passive multichannel analysis of surface wave (MASW) survey has been carried out at 275 V_S profiles (See Figure 1a). In SI, both MASW and also site-specific $\mathrm{V_S}$ and SPT-N relation has been used to get 125 shallow V_S profiles (See Figure 1 b). The detail information regarding the MASW survey and processing of the recorded raw data can be referred from Bajaj and Anbazhagan (2019 a) for IGB and Anbazhagan et al (2016) for SI. For the first 10 m the average $\mathrm{V_S}$ varies from 150 to 800 m/s and it increased to 160 to 1206 m/s at a depth of 30 m. Out of 275 profiles, more than 60 % of the profiles have average shear wave velocity upto 30m depth ($\mathrm{V_{S30}}$) between 183 to 357 m/s. The details about the variation of V_S in the entire IGB can be referred from Bajaj and Anbazhagan (2019 a). The depth of soil column varies from 4 to 34 m in the SI. The minimum and maximum shear wave velocity at a depth more than 30 m is 456 and 2157 m/s respectively, in case of SI. More detail about the V_S profiles in the SI can be referred from Anbazhagan et al. (2016).

Shear modulus $(\mathrm{G/G_{max}})$ and damping curve, and input ground motion are another critical parameter for any site response study. For rock, gravel, sand and clay predominate profiles, EPRI (1993), Menq (2003), Zhang et al. (2005) and Darendelli (2001) $\mathrm{G/G_{max}}$ and damping ratio respectively has been used as per suggestion by Bajaj and Anbazhagan, (2019 b).

For selecting the ground motion preliminary, the seismic hazard map for return period of 475 years at bedrock level for the IGB and SI has been used. The PGA for IGB and SI respectively vary from 0.03 to 0.24 g and 0.01 to 0.48 g respectively. The entire PGA variation of the IGB has been divided into four bins as (a) 0.03 to 0.08 g, (b) 0.08 to 0.13 g, (c) 0.13 to 0.18 g, and (d) 0.18 to 0.24 g. These are further referred as group 1 (GI1), group 2 (GI2), group 3 (GI3) and group 4 (GI4). Similarly, for the SI, PGA variation has been categorized into four bins as (a) 0.01 to 0.05 g, (b) 0.05 to 0.13 g, (c) 0.13 to 0.2 g, and (d) 0.2 to 0.48 g. These four groups are referred as group 1 (GS1), group 2 (GS2), group 3 (GS3) and group 4 (GS4). As the recorded ground motions could not cover the entire range of PGA required for site response study. Both simulated and recorded ground motion at bed rock have been used for site response.

One-dimension non-linear site response analysis has been performed using DEEPSOIL. Each ground motion is inputted at the bottommost layer having V_S equal to 1500 m/s. For each site, 10 input ground motion has been selected based considering the PGA value at bedrock. Hence in total 275 × 10 = 2750 and 125 × 10 = 1250 nonlinear analysis have been carried out to comprehend the site response characteristics of the IGB and SI respectively. Spectral parameters at surface have been estimated and further used for determining the surface response factor and site amplification factors.

4 SITE AMPLIFICATION FACTORS

Amplification of a ground motion at different spectral periods can be effectively expressed as amplification factor or site coefficient. IBC (2003) proposed the site coefficients for short period (0.2 s spectral period) $\mathrm{F_a}$ and long period (1s spectral period) $\mathrm{F_v}$. $\mathrm{F_a}$ defined in the IBC are the average value and $\mathrm{F_v}$ are approximately the average +1σ amplification values (Dobry et al., 1999). In IBC, $\mathrm{F_a}$ is estimated for the short-period band 0.1–0.5 sec, whereas, $\mathrm{F_v}$ is defined over the long-period band 0.4–2.0 sec. In the present study, different bins of F_a and F_v are analyzed for better match of the surface spectra for the corresponding case and site. The range of spectral period that resulted in the best match is 0.01-0.35 s for F_a and 0.35-1.25 s for F_v in case of the IGB. The spectral period range of 0.01-0.15 s and 0.15-1.0 s for F_a and F_v respectively resulted in the best match of surface spectral spectrum in case of the SI. The detail calculation for F_a and F_v can be referred from Dobry et al. (1999). The calculated F_a and F_v for the IGB and SI are respectively given as Table 1 and 2.

F_a and F_v calculated in this study is higher than NEHRP in case of the IGB and SI. For site class C, for PGA between 0.13 to 0.18 g (i.e. GI3), F_a and F_v calculated in this study is 1.61 and 2.48 respectively, however as per NEHRP estimated F_a and F_v 1.2 and 1.68 respectively. For site class C, for PGA between 0.13 to 0.22 g (i.e. GS3), F_a and F_v calculated in this study is 2.537 and 1.442 respectively, however as per NEHRP estimated F_a and F_v 1.2 and 1.64 respectively. F_v calculated in this study is less than NEHRP for seismic site class C and higher for seismic site class D.

The site factors derived in this study is recommended only for constructing ADRS for the IGB and SI. The F_{PGA}, F_a and F_v values derived in this study is different from previous study may be due to (1) difference in input layer; (2) region-specific ground motions data; and (3) representative region-specific input parameters.

5 PROPOSED ACCELEARTION DESIGN RESPONSE SPECTRA

The site coefficients determined in this study has been further used for developing the ADRS for any site in the IGB and SI with known seismic site class. The procedure outlines in AASHTO (2011) can be briefed in four steps: (1) identify the seismic site class as per NEHRP; (2) calculated the PGA at bedrock (PGA_{BR}), SA at 0.2 sec (S_S) and SA at 1.0 sec (S_1) for return period of 475 years from probabilistic seismic hazard maps; (3) for site-specific PGA, S_S and S_1 calculate the corresponding F_{PGA}, F_a and F_v values; (4) three points of acceleration design response spectra (ADRS) can be derived as

$$PGA = PGA_{BR} \times F_{PGA} \tag{1}$$

$$S_{DS} = F_a S_S \tag{2}$$

$$S_{D1} = F_v S_1 \tag{3}$$

where, S_{DS} and S_{D1} are the design short period (0.2 s) and design long period (1.0 s) spectral response acceleration at ground surface. Fig. 2 shows the comparison of acceleration design response spectra (ADRS) for site class C constructed using F_{PGA}, F_a and F_v derived in this study for IGB. The PGA value used in comparison for group GI1, GI2, GI3 and GI4 respectively is 0.07, 0.1, 0.16 and 0.23 g. ADRS for site C is compared with the ADRS of medium soil for IS-1893 (2016) respectively. It has observed that for the same PGA value, ADRS constructed using IS-1893 is underestimating the spectral acceleration values. Fig 3 shows the comparison of ADRS for site class C developed using F_{PGA}, F_a and F_v defined in the present study. The PGA value used in comparison for group G2, G3 and G4 respectively is 0.07, 0.13, and 0.22 g. ADRS for site class C is compared with the ADRS of medium soil for IS-1893 (2016) respectively. It has observed that for the same PGA value, ADRS constructed using IS-1893 is underestimating the spectral acceleration values at short period and overestimating at long period.

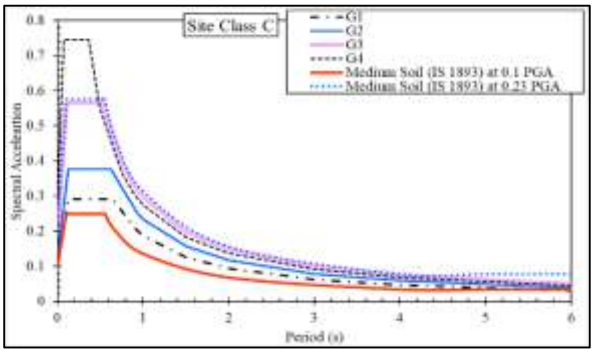

Fig. 2. Typical ADRS for seismic site class C with BIS:1893 (2016) for IGB

6 CONCLUSION

In the present study, non-linear site response analysis has been carried out for deep and shallow profiles in the IGB and SI. The input ground motions are selected based on seismic hazard map developed considering return period of 475 at bedrock. The bedrock PGA of 0.03-0.24 g increased to 0.1-0.75 g at surface in case of the IGB. The average surface amplification of 1.04 to 4.32 has been observed in the SI. The site factors F_{PGA}, F_a and F_v factors have been estimated by classifying sites based on NEHRP for the IGB and SI. F_a and F_v have been calculated for period range 0.01-0.35 s and 0.35-1.25 s respectively. The range of spectral period that has been used for F_a and F_v respectively is 0.01-0.15 s, and 0.15-1.0 s in case of SI. The newly derived site factors for IGB and SI is more representative for deep and shallow sites. PGA value, ADRS constructed using IS-1893 is underestimating the spectral acceleration values as compared to present study for deep and shallow basins. This is the first time such an extensive study has been done for determining the F_{PGA}, F_a and F_v and ADRS for deep sites in the IGB and SI.

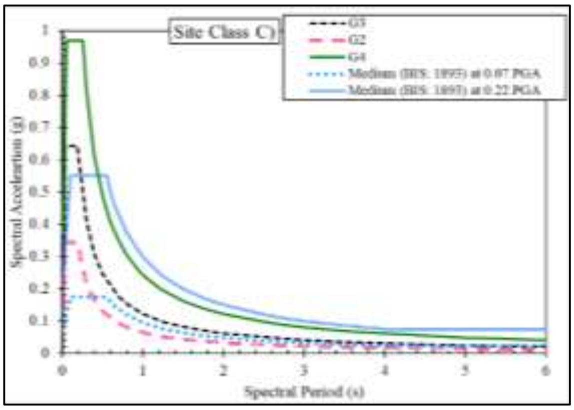

Fig. 3. Typical ADRS for seismic site class C with BIS:1893 (2016) for IGB

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO) (2011). LRFD Bridge Design Specifications, 2nd edition, Washington, D.C, 286.

American Society of Civil Engineers (ASCE) (2010). Minimum Design Loads for Buildings and Other Structures, ASCE Standard 7–10, Reston, VA. 650.

Anbazhagan, P. and Sitharam, T.G. (2008). Site characterization and site response studies using shear wave velocity. J Seism Earthq Eng.,10(2), 53–67

Anbazhagan, P., Kumar, A., and Sitharam, T.G. (2010). Site response of Deep soil sites in Indo Gangetic plain for different historic earthquakes. In: Proceedings of the 5th international conference on recent advances in geotechnical earthquake engineering and soil dynamics. San Diego, California 3.21b: 12

Anbazhagan, P., Bajaj, K., Reddy, G.R. et al. (2016) Indian Geotech J 46, 381. https://doi.org/10.1007/s40098-016-0181-y

Bajaj, K. & Anbazhagan, P. (2019 a). Seismic site classification and correlation between V_S and SPT-N for deep soil sites in Indo-Gangetic Basin. Journal of Applied Geophysics (First Review completed).

Bajaj K and Anbazhagan P (2019 b). Identification of Shear Modulus Reduction and Damping Curve for Deep and Shallow Sites: Kik-Net Data. J Earthquake Eng. (First Review completed)

BIS 1893 (Part 1) (2016). Indian standard criteria for earthquake resistant design of structures, Sixth Revision, Bureau of Indian Standards, New Delhi, 2016.

Boominathan, A., Dodagoudar, G.R., Suganthi, A, and Maheshwari, R.U. (2008). Seismic hazard assessment of Chennai city considering local site effects. J Earth Syst Sci., 117(S2), 853–863.

Building Seismic Safety Council (BSSC). NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures—Part 1: Provisions, FEMA-368; Part 2: Commentary, FEMA-369, Federal Emergency Management Agency, 2003, Washington D.C.

Darendeli, M.B. (2011). Development of a new family of normalized modulus reduction and material damping curves. Ph.D. dissertation, University of Texas at Austin, Austin, Texas.

Dorby, R., Ramos, R., and Power, M.S. (1999). Site factors and site categories in seismic coded, Report MCEER-99-0010, Multidisciplinary Centre for Earthquake Engineering Research, Buffalo, NY, April.

Electric Power Research Institute (EPRI) (1993). Guidelines for Site specific ground motions, Palo Alto, California, November, TR-102293.

International Code Council (ICC) (2012). International Building Code (IBC), Falls Church, VA, 328.

Menq, F.Y. (2003). Dynamic properties of sandy and gravelly soils. Ph.D. thesis, Department of Civil Engineering, University of Texas, Austin, TX.

Naik, N., and Choudhury, D. (2013). Site specific ground response analysis for typical sites in Panjim city, Goa. In: Proceedings of Indian geotechnical conference, Roorkee, India

Ramasamy, S.M. (2006). Remote sensing and active tectonics of south India. Int. J. Rem. Sens. 27(20), 4397–4431.

Singh, I.B. (1996). Geological evolution of Ganga plain – an overview. Jour. Paleont. Soc. India. 41, 99–137

Zhang, J., Andrus, R., and Juang, C.H. (2005). Normalized shear modulus and material damping ratio relationships. J Geotech Geoenviron Eng ASCE. 131, 453–464.

Table 1 Proposed site coefficients for all the four groups with respect to sites for the IGB.

	Class E			Class D			Class C			Class B		
	F_{PGA}	F_a	F_v	F_{PGA}	F_a	F_v	F_{PGA}	F_a	F_v	F_{PGA}	F_a	F_v
GI1	3.013	3.063	4.159	1.869	2.310	3.287	1.422	1.938	2.887	1.015	1.305	1.933
GI2	2.710	2.749	3.839	1.680	2.184	2.894	1.354	1.793	2.609	1.013	1.305	1.765
GI3	2.595	2.521	3.206	1.572	2.092	3.023	1.314	1.609	2.483	1.010	1.261	1.561
GI4	2.321	1.586	2.765	1.362	1.324	2.161	1.290	1.022	1.246	1.001	1.016	1.048

Table 2 Proposed site coefficients for all the four groups with respect to sites for the SI.

	Class D			Class C			Class B		
	F_{PGA}	F_a	F_v	F_{PGA}	F_a	F_v	F_{PGA}	F_a	F_v
GS1	-	-	-	-	-	-	2.084	2.183	1.285
GS2	2.314	3.045	3.106	2.147	2.264	1.507	2.012	1.985	1.202
GS3	2.014	2.607	2.223	1.945	2.057	1.442	1.878	1.855	1.138
GS4	1.847	1.822	1.957	1.745	1.656	1.352	1.592	1.557	1.141