Abstract

Among all-natural hazards, earthquakes are the most damaging in terms of loss of lives and damage to infrastructure. Amplification and liquefaction are the major effects of earthquake that cause massive damages to infrastructures and loss of lives. Subsurface soil layers play a very important role in ground shaking modification. These ground shaking modifications when a seismic wave passes through soil are estimated by understanding of site effects. Site effects are the combination of soil and topographical effects, which can modify (amplify and deamplify) the characteristics (amplitude, frequency content and duration) of the incoming wave field. There are two stages of site effect evaluation. First is site characterization which is done by classifying the site based on soil properties. Next step is to estimate amplification of possible motions through these site classes. This is done by amplification factors or site coefficients in various provisions. Widely it has been agreed that site effects/amplification are different for deep and shallow soil deposits.

Classifying the sites based on 30 m average shear wave velocity (V_S^{30}) is useful for zonation studies because site amplification factor was defined as a function of Vs^{30} such that the effect of site conditions on the ground shaking can be taken into account. However, the definitions of site classes in different codes are not consistent. Seismic site classification and amplification for seismic micro zonation are obtained on basis of V_S^{30} irrespective of bedrock depth in Asia. As shear stiffness and the time period of soil column affect soil response most, parameters representing them are used for classification worldwide. Various codes use shear velocity $(V_S)^{30}$ and SPT-N as defining parameter for the purpose. Despite their wide use, the seismic site classification schemes considering top 30-m soil layers are being applied to dissimilar bedrock profile and are under significant research scrutiny. In this study, an attempt has been made to estimate amplification of shallow bedrock sites in Bangalore, Chennai, Coimbatore, and Vizag city in the Intraplate region using most appropriate input parameters. Initially dynamic properties of shallow bedrock sites are estimated by carrying out experimental studies of Multichannel Analysis of Surface Wave and Standard Penetration Test (SPT). Then new shear modulus (G_{max}) versus SPT N correlation has been developed to overcome limitations in the existing similar correlations. Further for response calculation purpose, input layer, dynamic model curves and suitable G_{max} correlations for different soil types have been identified by parametric study. Finally, a nonlinear site response has been carried out and amplification factors for shallow bedrock sites are estimated and presented in this thesis.

In the first part of this work, preliminary site response analysis of hypothetical shallow bedrock sites has been carried out and mismatching of site classification and amplification factor is highlighted. Further, limitation of routinely used shear modulus correlation for stiffness estimation, dynamic models (shear modulus and damping curves), the input level of site response has been highlighted. Characterization of the subsurface and estimation of dynamic properties requires understanding of site effects and amplification. Even though several destructive earthquakes have caused extensive damages in shallow bedrock sites in Peninsular India, which is part of intraplate region, very limited systematic attempt has been made to estimate the dynamic properties of several sites in these regions. Soil dynamic properties in the form of shear wave velocity or shear modulus are required to estimate site effects and amplification. Experimental studies are carried out in shallow bedrock regions of South Peninsular India to obtain shear velocity and SPT N profiles. For these profiles, average 30 m values as per NEHRP and average till soil column, are estimated. It is observed that these values are different than average values up to rock because of inclusion of rock shear wave velocity values of the soil average values in shallow bedrock sites. Hence, 30 m average concept results in stiffer site class than soil average values. Misinterpretation of site class and following NEHRP provisions in shallow bedrock sites can lead to incorrect site coefficients and hence incorrect design force parameters.

Literature review shows that several site response studies are being carried out by estimating shear modulus of soil layers considering SPT N values. Even though SPT N data are widely used for site response and seismic micro zonation, very few studies are available for in situ correlation between shear modulus versus standard penetration test (SPT) N values using field experiments. It is found in this study that many of the currently used G_{max} correlations are not suitable for a particular soil type. Hence, in this study available correlations between SPT N and shear modulus are compiled and reviewed. New correlations are proposed by combining author's data with available old data from each researcher separately in two ways (a) using all the data and (b) eliminating assumed and extrapolated data i.e. measured data. This study shows that correlations using measured data are better than correlations using all the data (including extrapolated). Further, another set of correlations is developed by combining three and more data sets by considering all the data and measured data separately. Three and more data combinations give the best correlation when compared to the original independent correlations and two data combined correlations. A new correlation has been developed considering measured, old and new, data from Japan and India, where N values are measured with hammer energy of 78%. Modification factors for old and new correlations are suggested for the other regions, where SPT N values are measured with different hammer energy.

Representative evaluation of soil response requires the input parameters to be close to the physical behavior of soil column in the site. Several site response studies are carried out in South India considering limited representative parameters such as intraplate recorded earthquake data, soil specific shear modulus correlation, best soil dynamic model and input layer. Several site response analyses are being carried out using existing few shear modulus reduction and damping curves without knowing their suitability. Similarly, input ground motion for site response is being given at the depth of rock layer or borehole termination depth or 30 m. As per our knowledge, there is no clear cut guideline regarding the use of suitable G_{max} correlation for the specific soil column, best shear modulus reduction and damping curves for typical soil and appropriate input layer in the site response study of shallow bedrock sites. As part of this study, an attempt has been made to identify suitable G_{max} correlation for different types of soil column such as sand, clay and gravel alone or the mixture of all (sand, clay, gravel, sandy soil). Sites with earthquake data recorded at the surface, soil profiles along with SPT N values and shear wave velocity are selected from K-NET (Japanese website) data set for this study. Collected earthquake data consist of moment magnitude (M_w) of 5.0 to 9.0, which are recorded at different epicentral distances. Site response analysis has been carried out by considering earthquake data recorded at a rock site as an input ground motion to the soil profiles published in K-NET data site. Surface ground motion and response spectrum are obtained from different G_{max} correlations. The results obtained are compared with surface recorded earthquake same event. The study shows that peak ground acceleration (PGA), response spectrums (RS) and amplification factor (AF) obtained from very few G_{max} correlations are comparable with the recorded PGA, response spectrum and amplification factor.

Over the years, several researchers have presented a variation of shear modulus and damping ratio with shear strain for different materials. Of several modulus and damping curves available for different soil type from existing literature, set of curves are selected such that only few input parameters are required to use this curve in site response analysis. Selected curves are then used for representing corresponding soil type in the evaluation of soil response. Soil profiles of sites having a surface and bedrock motion recordings are selected from the Kiban-Kyoshin Network data (KiK-net, http://www.kyoshin.bosai.go.jp/). Site response study has been carried by giving rock recorded data as input and surface response is evaluated for each site by changing modulus and damping curves. The evaluated surface response is compared with recorded data for different soil types. Comparison concentrated to identify the best match regards the shape of spectral curve and PGA value. Based on analysis, appropriate dynamic model curves for each soil type has been identified.

Further an attempt is made to identify the input layer shear wave velocity beyond which change in response is insignificant. For the purpose, soil density and modulus and damping curves were kept constant by a parametric study by giving input at recorded level. Using same Kik-net data, site response analysis is carried out by considering constant properties and changing input level. Estimated response by giving input at different depth is compared with original response, the layer in which response changes are considerable is considered as cutoff layer. Shear wave velocity of cut off layer is almost similar in most of profiles considered in the study. This study shows that the input given below the soil layer of having shear wave velocity 500 (±100) m/s and above is predicting response close to recorded data irrespective of the soil type. Parametric study results obtained in this chapter are used as an input / guideline for site response studies of shallow bedrock sites.

Shear stiffness of the column above the input level has been estimated using shear wave velocity profiles discussed previously. It is found that few locations do not have Vs profiles, hence few SPT N profiles are selected and added. In total 64 shallow bedrock sites are considered for analysis. In previous studies on subject, for most of the site response analyses was carried out in the intraplate shallow bedrock sites, considering synthetic data or active region ground motion data were considered. In this study, for first time available intraplate data are compiled and acceleration time histories are selected based on regional seismicity. A total of 13 intraplate motions recorded in stable continental regions is selected and baseline corrected. These motions have PGA varying between 0.05-0.17g and is in accordance with the hazard maps suggested for these regions by various researchers. Site response calculations are done using a one-dimensional non-linear approach in DEEPSOIL v5.1 software. Water table information and Index properties in the study are obtained from soil reports for the corresponding bore logs. In total, 832 analysis has been carried out and surface spectral values are compiled. Amplification factors are calculated using Ratio of Response Spectra (RRS) method from the spectral results for different time period ranges. Initially amplification factors are evaluated considering the period ranges 0.1-0.5 and 0.4-2.0 s which are similar to the International Building Code (IBC) and compared. The study shows that IBC period range does capture variation of the spectrum of intraplate shallow bedrock sites. Hence the new period range has been derived by considering spectral signatures of input and surface response spectrum. Amplification factors are calculated for new period range 0.01-0.06 s and 0.05-1.0 s. Significant amplification is observed in 0.05-1.0 s period range and amplification factor corresponding to this range is proposed as a final result.

Soil profiles used in the study are grouped as five groups based on the stiffness of the soil column above input based on similarity in spectral signatures. The five groups are G1 with shear modulus <50 MPa, G2: 50-100 MPa, G3: 100-150 MPa, G4: 150-250 MPa and G5: >250 MPa. Average amplification for each group has been estimated and compared with previous studies. This study shows that amplification of short period range is comparable with PGA ratio amplification factor estimated in the region. Spectral amplification for the period range 0.05-1.0 s is less than short period amplification and IBC values. These values are calculated for each stiffness group and are decreasing with an increase in stiffness, with 3.24 for the group with modulus less than 50 MPa to 1.84 for the group with modulus greater than 250 MPa.