Ground Response Analysis: A comprehensive review

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ABSTRACT

Ground response analyses is a notable way used to assess ground surface motions for development of design response spectra, to evaluate dynamic stresses and strains for evaluation of liquefaction hazards, and to determine the earthquake-induced forces that can lead to instability of earth and structures. In this paper, a comprehensive review of assessing ground response from different papers is being performed. The pros and cons of different techniques are being discussed in this study and the best possible method found so far is of obtaining shear wave velocity profiles from the SPT N value using the empirical correlations and non-linear site response carried out using the computer program SHAKE and EERA as this method seems to be more precise and less tedious. It is also seen that methods other than these are costly as well complicated. Also other methods such as H/V method comes to action where data obtained from SPT/CPT are not available. Also it is useful in places where boring is restricted or area is inaccessible. However, objective of this review is to know the various methods available for use and to identify a suitable one for further studies.

Keywords: site effects, amplification, PGA, period, spectra, SPT, CPT, shear wave.

INTRODUCTION

Ground response studies have got a very important role to play in the present day world in various fields. Civil engineering works such as construction as well as preservation of structures nowadays requires such kind of study in order to survive seismic effects. Local soil condition plays a notable role in amplifying the ground motion parameters during an earthquake. The amplification of the seismic waves is mainly due to the trapping of waves in the transition zone between sedimentary layers and bedrock. Site effect is mainly associated with the amplification in ground shaking of sedimentary deposits inducing liquefaction in many cases. Ground response studies deals with various works such as calculation of site natural period, amplification of ground motions, evaluation of response spectra to be used for structural design, evaluation of liquefaction potential etc. Factors effecting ground response analysis includes mainly the source effects, path effects and site effects. Source effect attributes to the magnitude and rupture mechanism which are at the source of an earthquake. Path effect comprises of the distance of travel path from the source to site and depends upon the crustal velocity and material property. Site effect can be defined as the modification in the ground motion parameters such as amplitude, frequency content and duration of ground motion due to the effects of local geology, when seismic waves propagate through a soil range. Therefore it is of outmost importance to analyze this topic in order to quantify seismic hazards of the site as well as for earthquake resistant design of structures.
In this paper effort has been made to review and analyze various ways of calculation of site response with the help of different methodologies suggested by researchers working in this area in order to know the present status which will motivate us to explore the suitable techniques with their limitations and selecting the best approach for our present understanding and application with high reliability.

**Background of Ground Response Analysis**

Ground response analysis is a broad subject area. Different researchers have been using different ways for analyzing ground response. In most of the cases detailed geological and geotechnical studies are conducted at the site. The most common methods employed so far are as follows:

**Geotechnical methods**

a. **Standard Penetration Test**- Nilsun Hasancebi and Resat Ulusay (2006), Kumar Pallav, STG Raghukanth and KD Singh (2010), S T G Raghukanth, J Dixit, S K Dash (2011), Jyotirmoy Haloi and Arjun Sil (2015). The standard penetration test (SPT) is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. The test uses a thick-walled sample tube, with an outside diameter of 50.8 mm and an inside diameter of 35 mm, and a length of around 650 mm. This is driven into the ground at the bottom of a borehole by blows from a slide hammer with a mass of 63.5 kg (140 lb) falling through a distance of 760 mm (30 in). The sample tube is driven 150 mm into the ground and then the number of blows needed for the tube to penetrate each 150 mm (6 in) up to a depth of 450 mm (18 in) is recorded. The sum of the number of blows required for the second and third 6 in. of penetration is termed the "standard penetration resistance" or the "N-value". In cases where 50 blows are insufficient to advance it through a 150 mm (6 in) interval the penetration after 50 blows is recorded. The blow count provides an indication of the density of the ground, and it is used in many empirical geotechnical engineering formulae. The main purpose of the test is to provide an indication of the relative density of granular deposits, such as sands and gravels from which it is virtually impossible to obtain undisturbed samples. The great merit of the test, and the main reason for its widespread use is that it is simple and inexpensive.

b. **Cone penetration test**- McGann st al (2015) in his paper have used multiple linear regression to develop a Christchurch-specific empirical correlation for use in predicting soil shear wave velocities, Vs, from cone penetration test (CPT) data. The cone penetration or cone penetrometer test (CPT) is a method used to determine the geotechnical engineering properties of soils and delineating soil stratigraphy. It was initially developed in the 1950s at the Dutch Laboratory for Soil Mechanics in Delft to investigate soft soils. Based on this history it has also been called the "Dutch cone test". Today, the CPT is one of the most used and accepted in soil methods for soil investigation worldwide.

The test method consists of pushing an instrumented cone, with the tip facing down, into the ground at a controlled rate (controlled between 1.5 -2.5 cm/s accepted). The resolution of the CPT in delineating stratigraphic layers is related to the size of the cone tip, with typical cone tips having a cross-sectional area of either 10 or 15 cm², corresponding to diameters of 3.6 and 4.4 cm

**Geophysical methods**

a. **Seismic velocity measurements**- Nilsun Hasancebi and Resat Ulusay (2006) have used this method very effectively. Measurement of the seismic wave propagation velocity in the given geological area is of the fundamental importance for determination of the source location. Due to this, it is necessary to evaluate the propagation of the seismic wave front between the different points in the ground. During the seismic wave propagation, the front of the waves occupies
distinct positions in the successive time instants. Seismic wave generated under the action of the short pulse, is a complex wave that consists of the following components:

- Longitudinal - compressive $P$-wave;
- Transverse $S$-wave;
- Rayleigh - Surface $R$-wave.

Longitudinal $P$-waves and transverse $S$-waves are known as the body waves. Body waves are propagating through the medium by means of the hemispherical wave front. The type of the component being considered depends on the source of vibrations. Rayleigh wave, which is propagated radially and has the cylinder-like wave front, appears simultaneously with the body waves.

During the propagation through an elastic medium, components of the complex seismic wave have different velocities. Since the $P$-waves are faster than the other types of seismic waves, they can at first be detected by the sensors. $P$-waves are followed by the $S$-waves and Rayleigh-waves, respectively.

b. Resistivity surveys- Hasancebi and Resat Ulusay (2006) have carried out this method in their mentioned study. It is a measure of variations in the electrical resistivity of the ground, by applying small electric currents across arrays of ground electrodes. The survey data is processed to produce graphic depth sections of the thickness and resistivity of subsurface electrical layers. The resistivity sections are correlated with ground interfaces such as soil and fill layers or soil-bedrock interfaces, to provide engineers with detailed information on subsurface ground conditions.

c. Microtremor studies- Nilsun Hasancebi and Resat Ulusay (2006) in the their work have also used this method very effectively. Microtremor is a low amplitude (in the order of micrometres) ambient vibration of the ground caused by man-made or atmospheric disturbances. The term Ambient Vibrations is now preferred to talk about this phenomenon. Observation of microtremors can give useful information on dynamic properties of the site such as predominant period and amplitude. Microtremor observations are easy to perform, inexpensive and can be applied to places with low seismicity as well, hence, microtremor measurements can be used conveniently for seismic microzonation. More detailed information on the shear wave velocity profile of the site can be obtained from microtremor array observation.

d. H/V method - Giulio et al (2008) have executed this method efficiently. It is the use of borehole data to interpret ambient noise H/V spectral ratios in terms of near-surface geology comparing H/V curves to theoretical transfer functions of 1D model along five well-constrained profiles. Yukta Nakamura in 1989, modified microtremor analysis by proposing a new technique, generally referred to as the H/V method. In this technique, it was shown that the source effect can be minimized by normalizing the horizontal spectral amplitude with the vertical spectral amplitude. Assuming that the shear wave dominates the microtremor, Nakamura indicated that the horizontal-to-vertical ($H/V$) spectral ratio of microtremors at a site roughly equals the $S$-wave transfer function between the ground surface and bedrock at a site. This means that the $H/V$ peak period and peak value itself correspond to the natural site period and amplification factor respectively. This method does not require any boreholes and is, hence, more convenient and inexpensive compared to the traditional borehole method. This method is now widely used for microtremor observation although it lacks a clear theoretical background. Lermo and Chavez-Garcia showed the applicability of Nakamura’s method of microtremor in site effect prediction. However, it was found true only for the fundamental resonance peak of the transfer function. The results supported the idea that Nakamura’s technique effectively compensated for the site effects.

The computation of the $H/V$ ratio follows different steps (see Figure 1):

- record a 3-component ambient noise signal
• select of the most stationary time windows (e.g., using an anti-triggering algorithm) in order to avoid transient noise
• compute and smoothing of the Fourier amplitude spectra for each time windows
• Average the two horizontal component (using a quadratic mean)
• compute the H/V ratio for each window
• compute the average H/V ratio

Ad hoc questionnaire - Fabrizio Terenzio Gizzi (2007) have employed this technique. The method observed in the study is the preparation of an ad hoc questionnaire consisting of ten questions that reflect the dissimilar geological-geotechnical conditions typical of the sites all over the world. However, it is possible to make changes in the questionnaire. In this way, the proposed approach will be useful in disparate geological backgrounds. Once the questionnaire is written up, the usefulness of the available information will be evaluated via the ‘Engineering Geological Usefulness Parameter’ (EGUP).

Assessment tools used in site response studies

a. SHAKE - S T G Raghukanth, J Dixit, S K Dash (2011) have done their works with the help of this software. SHAKE (Schnabel et al., 1972) was one of the first computer programs developed for this purpose of soil site response simulation. More than 25 years after its release, SHAKE is still commonly used and referenced computer programs in geotechnical earthquake engineering. SHAKE computes the response in a horizontally layered soil-rock system subjected to transient and vertical travelling shear waves. SHAKE is based on the wave propagation solutions of Kanai (1951), Roesset and Whitman (1969), and Tsai and Housner (1970). SHAKE assumes that the cyclic soil behavior can be simulated using an equivalent linear model, which is extensively described in the geotechnical earthquake engineering literature (e.g., Idriss and Seed, 1968; Seed and Idriss, 1970; and Kramer, 1996). SHAKE was modified many times (e.g., frequency-dependent equivalent strain; Sugito, 1995). SHAKE91 is one of the most recent versions of SHAKE (Idriss and Sun, 1992).

b. EERA - Kilic et al (2006) has used this software in his work. In 1998, the computer program EERA was developed in FORTRAN 90 starting from the same basic concepts as SHAKE. EERA stands for Equivalent-linear Earthquake Response Analysis. EERA is a modern implementation of the well-known concepts of equivalent linear earthquake site response analysis. EERA’s implementation takes full advantages of the dynamic array dimensioning and matrix operations in FORTRAN 90. EERA’s input and output are fully integrated with the spreadsheet program Excel.

The equivalent linear model representing the soil stress-strain response is based on a Kelvin-Voigt model. The relation between shear stress $\tau$ and the shear strain $\gamma$ and its rate $\dot{\gamma}$ can be written as:

$$\tau = G\gamma + \eta \dot{\gamma}$$  \hspace{1cm}  (1.1)

Where, $G$ indicates the shear modulus and $\eta$ the viscosity. The shear strain and its rate in a one-dimensional shear beam column, can be defined from the horizontal displacement $u(z,t)$ at depth $z$ and time $t$ as follows:

$$\gamma = \frac{\partial u(z,t)}{\partial z} \hspace{1cm} \text{and} \hspace{1cm} \dot{\gamma} = \frac{\partial^2 u(z,t)}{\partial z \partial t}$$  \hspace{1cm}  (1.2)

The assumptions for the one-dimensional equivalent linear site response analysis are schematized in Figure 8.2. A vertical shear wave is propagating in a one-dimensional layered soil system of $N$ horizontal layers where the $N$th layer is bedrock as shown in figure 8.2. One-dimensional equation of motion for vertically propagating shear waves is given by:
\[ \rho \frac{\partial^2 u}{\partial t^2} = \frac{\partial \tau}{\partial z} \]

1.3

Where, \( \rho \) is the mass density or unit mass in any layer. Considering that the soil in each layer will behave as a Kelvin-Voigt solid, eq. 1.3 becomes:

\[ \rho \frac{\partial^2 u}{\partial t^2} = G \frac{\partial^2 u}{\partial z^2} + \eta \frac{\partial^3 u}{\partial z^2 \partial t} \]

1.4

The solution to this wave equation can be written in the form

\[ u(z,t) = Ae^{i(\omega t + k^* z)} + Be^{i(\omega t - k^* z)} \]

1.5

Where, \( A \) and \( B \) characterize the amplitudes of waves propagating in the \(-z\) and \(+z\) directions, respectively. The shear stress is then expressed by the product of the complex shear modulus, \( G^* \), and the shear strain, so

\[ \tau(z,t) = G^* \frac{\partial u}{\partial z} = (G + i\omega \eta) \frac{\partial u}{\partial z} = G(1 + 2i\xi) \frac{\partial u}{\partial z} \]

1.6

If we introduce a local coordinate system, \( Z \), for every layer, the displacement at the top and bottom of layer \( m \) will be

\[ u_m(Z_m = 0, t) = (A_m + B_m)e^{i\omega t} \]

1.7

\[ u_m(Z_m = h_m, t) = (A_m e^{ik^* h} m + B_m e^{-ik^* h} m )e^{i\omega t} \]

1.8

The displacements at layer boundaries must be compatible (i.e. the displacement at the top of a particular layer and the displacement at the bottom of the overlying layer must be equal). By applying the requirement of compatibility to the boundary between layer \( m \) and layer \( m+1 \), that is,

\[ u_m(Z_m = h_m, t) = u_{m+1}(Z_{m+1} = 0, t) \]

1.9

gives

\[ A_{m+1} + B_{m+1} = A_m e^{ik^* h_m} m + B_m e^{-ik^* h_m} m \]

1.10

The shear stress developed at the top and bottom of layer \( m \) are

\[ \tau_m(Z_m = 0, t) = ik^* G_m (A_m - B_m)e^{i\omega t} \]

1.11

\[ \tau_m(Z_m = h_m, t) = ik^* G_m (A_m e^{ik^* h} m - B_m e^{-ik^* h} m )e^{i\omega t} \]

1.12

Since stresses must be continuous at layer boundaries,

\[ \tau_m(Z_m = h_m, t) = \tau_{m+1}(Z_{m+1} = 0, t) \]

1.13

So

\[ A_{m+1} - B_{m+1} = \frac{k^* G_m}{1 + G_m^{1+1}} - \frac{ik^* G_m}{1 + G_m^{1+1}} \]

1.14

From the equations 8.10 and 8.14, we get

\[ A_{m+1} = \frac{1}{2} A_m (1 + \alpha_m^*) e^{ik^* h_m} m + \frac{1}{2} B_m (1 - \alpha_m^*) e^{-ik^* h_m} m \]

1.15

\[ B_{m+1} = \frac{1}{2} A_m (1 - \alpha_m^*) e^{ik^* h_m} m + \frac{1}{2} B_m (1 + \alpha_m^*) e^{-ik^* h_m} m \]

1.16

Where, \( \alpha_m^* \) is the complex impedance ratio at the boundary between layers \( m \) and \( m+1 \):
\[ a_m^* = \frac{k_m^* G_m^*}{k_{m+1} G_{m+1}^*} = \frac{\rho_m (v_s')^m}{\rho_{m+1} (v_s')^{m+1}} \]

1.17

At the ground surface level, the shear stress is equal to zero, which implies [from equation 1.11] that \( A_1 = B_1 \). By applying the recursion formulas of equations 1.15 and 1.16 repeatedly for all layers from 1 to \( m \) then the functions relating the amplitudes in layer \( m \) to those in layer 1 can be expressed by:

\[ A_m = a_m (\omega) A_1 \]

1.18

\[ B_m = b_m (\omega) B_1 \]

1.19

The transfer function which relates the displacement amplitude at layer \( i \) to that at layer \( j \) can be expressed by:

\[ F_{ij}(\omega) = \frac{u_i}{u_j} = \frac{a_i(\omega) + b_i(\omega)}{a_j(\omega) + b_j(\omega)} \]

1.20

For harmonic motion \( |\ddot{u}| = \omega |\dot{u}| = \omega^2 |u| \), so equation 1.20 also describes the amplification of accelerations and velocities from layer \( i \) to layer \( j \). From equation 1.20 it can be concluded that the motion in any layer can be evaluated from the motion in any other layer. Hence, the motion at any point can be measured if the motion at any other point in the soil profile is known.

c. FLAC 3D -The ground response analyses have also been conducted considering the nonlinear behavior of the soil deposits using both equivalent linear and nonlinear approaches. The fully nonlinear method embodied in FLAC 3D was used to evaluate the nonlinear soil properties on earthquake wave propagation through the soil layer, and compare with the response from the equivalent linear approach.

**Literature survey**

Hasancebi and Ulusay (2006) have carried out a study to evaluate site amplification and site period with the help of different techniques for an earthquake-prone Yenisehir area, which is located in the Marmara Region of Turkey. In this study, present and future settlement areas of Yenisehir, were evaluated with respect to site amplification and site period. Borings including a total of 37 boreholes accompanied by SPT in connection with in-situ penetration tests, seismic velocity measurements, resistivity surveys and microtremor studies were performed, and available data from previous findings were put together to determine the variation of the soil profile as well as the characteristics of the soil layers within the study site. Among the three methods, the numerical technique and microtremor method yielded higher amplification factors when compared to those obtained from the empirical method. The microzonation map based on soil site amplification suggested amplification factors between 1.6 and 5 in the present settlement, while the areas at the north and south of the settlement generally amplify the motion 5 to 9 times. The site periods obtained from microtremor studies varied from 0.51 to 0.8 s throughout the area. Apart from these, the comparison between fundamental site periods and fundamental building periods, which were measured in a few buildings and estimated from an empirical expression, indicate that importance should be paid to resonance, especially for the northern part where high-rise buildings are still in construction.
Kilic et al (2006) has performed a study on microzonation based on soil amplification of Zeytinburnu region which was a part of Zeytinburnu Pilot Project within the architecture of the Earthquake Master Plan for Istanbul. Minute geotechnical and geological investigations were executed at the location along with the preparation of geological map of the area, and classification of the site was done by estimating the dynamic behavior on the basis of data attained from the 107 borings carried out in the area. Investigation on the effects of local soil condition was done by ground response analyses with EERA software (Bardet et al., 2000) by using the data of field and laboratory tests. From the 1-D ground response analysis the value of average spectral accelerations were ascertained between the periods of 0.1–1.0s. The maps for microzonation are set with respect to earthquake intensity according to the new microzonation manual.

Berilgen (2007) has evaluated the local site effects on damages by earthquake of Fatih Mosque and its Kulliye (complex) which are one of the notable ancient monuments in Istanbul. Built between 1463 and 1470, this structure has faced nine strong earthquakes and has suffered various degrees of structural damage, including the latest August 17, 1999 Kocaeli Earthquake (Mw=7.4). As part of the investigation, local site soil conditions had been determined and site behavior during earthquakes had been studied in detail. To determine the soil conditions at the site, 20 soil borings have been drilled, pressiomenter…… tests in some boreholes have been conducted and an integrated geophysical survey had been carried out. In this paper, the results of 1-D site response analysis, including convolution and deconvolution analyses utilizing the strong ground motions recorded during the August 17, 1999 Kocaeli Earthquake are presented. The results demonstrated considerable degree of site amplification, amicable with the recorded motions and the damage suffered. The anticipated site behavior during a possible earthquake was also studied using a site specific simulated bedrock motion, and earthquake parameters to be used in dynamic structural analysis were assessed. The project has been initiated with the sponsorship of Istanbul Water and Sewage Management Directorate (ISKI) to study the possible causes of earthquake damage and then evolve retrofitting and strengthening methods to protect this heritage monument from further damages in the future earthquakes.

Rayhani et al (2007) have organized a study on site response based on the local geological conditions in the Bam Earthquake with the help of non linear analysis. The 2003 Bam Earthquake caused massive damage to structures in the Bam area due to the amplification of the earthquake motion caused by local geological effects. The strong motions were recorded in 18 stations of the Iranian strong motion network (BHRC). The earthquake recordings recorded at the Bam accelerograph station produced the maximum peak ground acceleration record along the vertical component (about 1 g). Detailed geotechnical and geophysical test (down-hole test) data in two different sites have been collected and site response analyses have been performed applying both equivalent linear and nonlinear techniques. The nonlinear part was done using the program FLAC (Fast Lagrangian Analysis of Continua). The results obtained from both the analysis were equated and was observed that amplification of the ground motion occurred at sites with thick alluvium as a result of which notable damage resulted in residential buildings. Both the analysis ended up in similar response spectra of the motions indicating peak values in the period ranging between 0.3 to 1.5 s. The response spectra from the study are found to be much higher than the NEHRP building code design recommendations at higher frequencies.

Gizzi (2007) deals with a unique method to quantitatively evaluate the usefulness of data available to pinpoint the geological and geotechnical impacts such as landslides, earthquakes, and floods that threaten archeological and monumental sites. An ad hoc questionnaire is
proposed consisting of ten questions that reflect the non-identical geological-geotechnical conditions typical of the sites all over the world. However, it is possible to make alterations in the questionnaire. In this way, the suggested approach will be useful in different geological backgrounds. Once the questionnaire is written up, the usefulness of the available information will be assessed via the ‘Engineering Geological Usefulness Parameter’ (EGUP). To examine cultural heritage sites, the EGUP parameter will allow the decision makers to choose where to first address their economic resources. For this reason, the building of a EGUP-based national database is suggested where an EGUP value score that ranges from 0-3 will be attributed to each cultural site, with this value being constantly updated with new studies, surveys, and investigations. A GIS platform is proposed to make both the management and the updating of the archive easy. Database like this will be a ‘constraint’ for the decision makers responsible for safeguarding the heritage monuments.

Giulio et al (2008) have executed a study on seismic response of Benevento city (Southern Italy) with the aid of a collective analysis of geological and seismological data. In this research, the authors have extended the study from a previous analysis done by [Improta, L., G. Di Giulio, and A. Rovelli (2005)] of the earthquake response of 12 sites to the entire urban area. The authors have accumulated ambient noise data at 100 sites in the city, consolidating measurements within the major shallow geological variations. Ambient noise H/V spectral ratios has been extrapolated in terms of near-subsurface geology and borehole data has been harnessed by comparing H/V curves to theoretical transfer functions of 1-D model along five well-restricted profiles. Three predominant typologies of seismic response in the city have been distinguished based on geotechnical, geological and seismic data. It was further observed that the seismic response was found to be concordant in the town area with the damage pattern produced by a ruinous earthquake with MCS intensity of IX–X that happened in the city in 1688. The ground motions recorded during the study by Improta et al. have been used and response spectra has been figured at different locations after agreeable fitting between synthetic and observed seismograms and the effects of the local site have been presumed at greater level of shaking ,including soil nonlinearity. The authors have also discovered that wide contrast can occur from design spectra as specified by seismic codes for a large area of Benevento, particularly for periods < 0.5 s.

Grasso and Maugeri (2008) have performed a microzonation study of the Catania city of Italy regarding the highest expected scenario of Val di Noto earthquake of January 11, 1693. Ground response analysis in terms of time history and response spectra , have been performed with 1-D equivalent and a 2-D linear model, with use of a design scenario earthquake as an input ground motion parameter at level of bedrock. For the city of Catania there is a great availability of borehole data, geophysical surveys and laboratory tests. Around 1200 boreholes and water-wells available in the data-bank of the Catania city were chosen for study and site effect have been assessed for those particular areas. A seismic microzonation map of the city has been developed according to the response spectra acquired through ground response analyses by using both the methods. It is seen that the map in terms of PGA (g) for Catania approves with the absolute PGA values obtained by other study works. The procedure proposed in the study required a good number of seismic site response estimations which were carried out with GIS raster database one for every pixel. The map will be set as a guideline for the seismic improvement of the different structures to mitigate the seismic hazard.

Pallav et al (2010) compares the seismic susceptibility of the city of Imphal with 10 numbers of synthetically generated samples of the historic earthquake of 1869 occurred in the Cachar region. The source of the earthquake recorded in the Kopili fault is presented based on the finite-fault seismological model in connection with non-
linear site response analysis. Shear wave velocity profiles have been obtained from the SPT N value using the empirical correlation proposed by Imai and Tonouchi (1982). The non-linear site response was carried out using the computer program SHAKE 91. The study was restricted to standard penetration test (SPT) N data of 122 boreholes from different locations as shear wave velocity profiles and cone penetration test data were not available. The mean and standard deviation of surface level spectral ground acceleration at PGA and natural period of 0.3 and 1 s was reported as contour maps for all the synthetic sample earthquake events. With the help of these contours, engineers and planners recognize the vulnerable areas for plausible seismic disaster mitigation of Imphal city.

Raghukanth et al (2011) have performed stochastic finite-fault simulation along with site response analysis to understand the spatial distribution of ground motion in north-eastern city of Guwahati due to three damaging earthquakes (1869 Cachar, 1897 great Assam and an anticipated future event in Assam gap). The rock level earthquake motion for the scenario earthquakes is generated based on the stochastic finite-fault methodology and a set of twenty simulated artificial rock level time histories for each event, are used to compute the surface level ground motion. Ground response analysis was done using the SPT data available from boreholes at 100 different locations in Guwahati city and it was observed that mean amplification because to local soil deposit is as high as 2.2 in most of the regions of the city. Contour maps on the vulnerable areas were generated based on the above study.

McGann et al (2015) in this paper by pursuing the study of McGann et al., seismic piezocone (SCPTu) data which is compiled from various locations in Christchurch, New Zealand area are used with multiple linear regression to develop a Christchurch-specific empirical correlation for use in forecasting soil shear wave velocities, Vs, from cone penetration test (CPT) data. An appropriate regression functional form is selected through an evaluation of the residuals for regression models developed with the Christchurch SCPTu database adopted by previous empirical correlations between Vs and CPT data. An investigation of how the residuals for the chosen regression form vary with the predictor variables identifies the need for non-constant depth variance in the regression model. The performance of the model is assessed through comparisons of predicted and observed Vs profiles and through forward predictions with synthetic CPT data. The new CPT–Vs correlation provides an approach to estimate Vs from CPT data that is specific to the non-gravel soils in their current state. The correlation also enables the utilization of the large, high-density database of CPT logs (415,000 as of 1/1/2014) in the for the development of both site-specific and region-wide models of surficial Vs for use in site response analysis and site characterization.

Haloi and Sil (2015) states that local site condition has an important role to play in amplifying the ground motion parameters during an earthquake. For the estimation of site-specific earthquake hazards and to design earthquake resistant structures, characterization of a site according to its class is very significant. This paper deals with a proposed bridge site located over river Barak on ‘Silchar Bypass Road’ and has made an effort to classify as it lies in a highly seismically active region (zone-V) of India. In the study, due to absence of the shear wave velocity profile, the Vs30 for the top 30 m soil have been calculated using SPT-N value (collected from government agencies, PWD, Assam) for 6 bore hole locations by propounding one new empirical equation connecting Vs and SPT-N for all soil type. The results have displayed that all the bore hole locations are having their Vs30 and SPT-N within 180 to 360 m/s and 15N to 50N respectively, which wind up that the bridge site comes under site class D according to the provisions laid by NEHRP (National Earthquake Hazard Reduction Programme).
Anbazhagan et al (2015) has made a trial in this delving to prepare the seismic intensity map of southern part of India by considering the probable earthquakes in the region. Anbazhagan et al. (Nat Hazards 60:1325–1345, 2012) have distinguished eight presumptive future earthquake zones in southern India founded on rupture-based seismic hazard analysis. Anbazhagan et al. (Eng Geol 171:81–95, 2014) has evaluated the highest number of future earthquake magnitude at these eight zones using regional rupture character. In this research, the author has divided the entire area into several grids of size 1’x1’ and the intensity at all the grid points is calculated using the regional intensity model for the maximum earthquake magnitude at each of the eight zones. The maximum anticipated intensity due to any of these possible sources is within the range of 6 to 7 EMS. Eight seismic intensity maps are prepared by mapping the intensity due to earthquakes at these zones. The final intensity map of southern India is extracted by considering the maximum intensity at each grid point due to the estimated earthquakes. Slight to heavy damage can be expected due to the probable earthquake magnitudes by looking at the seismic intensity map. Chances of heavy damage in areas close to the probable earthquake zones are plausible.

Discussion and Conclusion

From the above discussions it is being observed that majority of the studies are adopting the method of obtaining shear wave velocity profiles obtained from the SPT N value using the empirical correlations proposed by several researchers and non-linear site response carried out using the computer program SHAKE 91/2000 and EERA as this method emerge to be more accurate and less monotonous. Further, it is also observed that methods other than these are costly as well complicated. Also other methods such as H/V method comes to action where data obtained from SPT/CPT are not obtainable. Also it is useful in places where boring is restricted or area is inaccessible. This review would help to understand the techniques available in this area and their applicability considering the feasibility.

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