Design of Earthquake Resistant Building Using Site Specific Response Spectra

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Abstract-*The energy released due to earthquake as seismic wave is propagated from the epicentre to the earth surface. This seismic wave causes the ground shaking which in turn causes severe damages to the structure overlying on the surface. During the propagation of this wave it has to travel through rock and soil types having different properties and of variable depth. According to the Indian standard for Earthquake resistant design (IS: 1893), the seismic force depends on the zone factor (Z) and the average response acceleration coefficient (Sa/g) of the soil types at thirty meter depth with suitable modification depending upon the depth of foundation. As per IS 1893, only three types of soils (soft, medium and hard) is considered without any consideration for the site specific soil parameters. In the present study an attempt has been made to generate response spectra using site specific soil parameters for some sites in seismic zone V, i.e. Arunachal Pradesh and Meghalaya and the generated response spectra is used to analyze some structures using commercial software STAAD Pro.*

I. INTRODUCTION

Seismic design of buildings depends on peak ground acceleration values and shape of Response Spectra curves as depicted by relevant Building codes [1]. Underestimation of peak ground acceleration or wrong evaluation of response spectra may lead to grave consequences during the earthquakes. These two values depend upon earthquake magnitude and distance, as well on the regional propagation path properties and local geological conditions. At the present, there is no doubt that instead of standard design parameters, it is necessary to construct site-specific ones reflecting the influence from different magnitude events at different distances that may occur with certain probability during the lifetime of the construction, as well as the variety of local site conditions [2]. The influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years and has been shown by many earthquakes. On September 19, 1985 Michoacan, earthquake of magnitude 8.1 occurs with only moderate damage in the vicinity of its epicentre but the loss of lives and properties was catastrophic even though the buildings were design according to their codal provisions at Mexico city which was around 350 km away from the epicentre. As shown in the Fig. 1 below the response of ground shaking is different for different types of soil. The magnitude in unconsolidated sediment is higher than in bedrock for same frequency. Thus the intensity of an earthquake is dependent on the types of soil irrespective of magnitude. The influence of soil deposits on seismic ground motion is enormous in terms of site amplification and thus structural damage and ground failures.

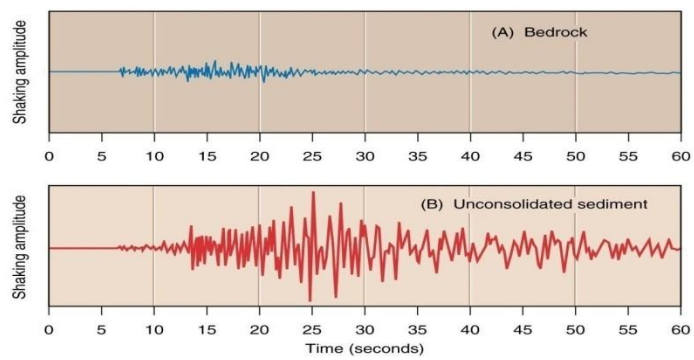


Fig. 1- Response of ground shaking for, a) Bedrock and b) Unconsolidated sediment.

II. LITERATUREREVIEW

Borcherdt (1994) presented a comprehensive technique for calculating free-field, site- dependent, a response spectrum that utilizes, as one of its parameters, the average shear-wave velocity of the uppermost 30 m of soils at sites underlain by soils. This method which was derived from observations in California hence provides alternative procedures for estimating both input ground-motion spectral levels and amplification factors, depending upon available information. He suggested that the technique provides a general framework for design, as well as site-dependent building-code provisions and predictive maps of strong ground motion for purposes of earthquake hazards mitigation [8].

Chandler and Lam (2004) had worked on the large magnitude earthquakes which were generated at source–site distances exceeding 100 km are typified by low frequency seismic waves. This ground shaking can be disproportionately destructive due to its high displacement, and possibly high velocity, shaking characteristics. Distant earthquakes represent a potentially significant safety hazard in certain low and moderate seismic regions where seismic activity is governed by major distant sources as opposed to nearby background sources. He found that majority of ground motion attenuation relationships currently available for applications in active seismic regions may not be suitable for handling long- distance attenuation, since the significance of distant earthquakes is mainly confined to certain low to moderate seismicity regions. Thus, the effects of distant earthquakes are often not accurately represented by conventional empirical models which were typically developed from curve-fitting earthquake strong-motion data from active seismic regions. He developed various well-known existing attenuation relationships in his paper, to highlight their limitations in long-distance applications. In contrast, basic seismological parameters such as the Quality factor (Q-factor) could provide a far more accurate representation for the distant attenuation behaviour of a region. His paper develops a set of relationships which provide a convenient link between the seismological Q-factor (amongst other factors) and response spectrum attenuation. The use of Q as an input parameter to the proposed model enables valuable local seismological information to be incorporated directly into response spectrum predictions [18].

Mammo (2005) presented the study of synthetic ground motion time histories have been generated at rock sites simulating earthquakes of moment magnitudes 6.8, 6.0 and 5.2 and epicentral distances of 25, 50, 80, 120 and 200 km. He applied these rock time histories as input motions at the base of the soil columns determined using surface seismic, a one- dimensional, equivalent-linear analysis was used to propagate the input motions through the soil columns to determine the ground motions at the ground surface. The computed acceleration time histories, response spectra and amplification spectra were most useful for design engineers [16].

III. PRESENTSTUDY

The present study leads to the study of relationship between local soil conditions and damaging ground motion. The study includes the generation of site-specific response spectra for Zone V for two north-east states i.e. Arunachal Pradesh and Meghalaya. These states rest on Himalayan faults and the damage can be catastrophic if earthquake occurs and due provisions are not taken while constructing any structure in these areas. In Himalayan belt metamorphic type, gravelly soils and sandy soils of geology prevails and according to the Borcherdt [8], the shear wave velocities for this type of rock is very high for the former and also in loose to semi consolidated soil the ground motion amplifies. So as per the IS codal provision [6] the response spectra given is based upon three types of soil rock or hard soil, medium soil and soft soil, which is taken as the average values for all the respective zones, which is relatively inadequate as the strong ground motion is dependent to the geometry and material properties of the subsurface materials, on site topography and on the characteristics of the input motion like shear wave velocities, shear modulus, etc.

IS1893:2002 CODAL PROVISIONS

Dynamic Analysis:

Dynamic analysis is performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to the various lateral load resisting elements, for the following buildings:

Regular buildings - Those greater than 40 m in height in Zones IV and V, and those greater than 90 m in height in Zones II and III.

Irregular buildings - All framed buildings higher than 12 m in Zones IV and V, and those greater than 40 m in height in Zones II and III.

ResponseSpectra:

The response spectra considered according to the Indian Standard for design is as shown in Figure 2 where consideration for different type of soil is based on appropriate natural periods and damping of the structure and these curves represent free ground motion.
The spectral acceleration coefficient i.e. (Sa/g) taken as per IS: 1893 (Part 1): 2002 is as follows, which is consider for designing the structure.

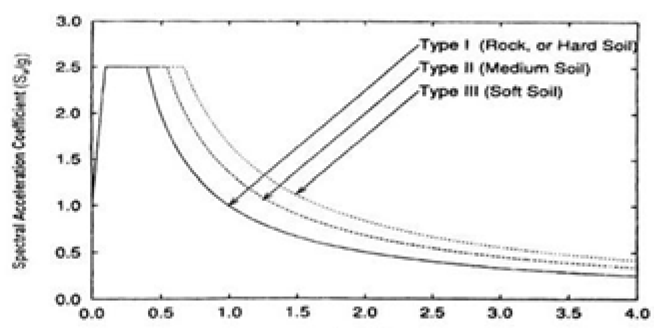


Fig. 2- Response Spectra for rock and soil sites for 5% damping

Types ofSoil:

According to the 1893 code guidelines the following type of soil were considered:

For rocky or hard soil- It is well graded 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.

For medium soil- All soils with N between 10 and 30, and poorly graded sands or gravelly sands with little or no fines (SP), with N > 15.

For soft soil- All soils other than SP with N<10.
These provisions were not sufficient for designing structure as the response spectra generated according to IS code is based upon three types of soil rock or hard soil, medium soil and soft soil, which is taken as the average values for all the respective zones. But the local soil condition is different for the various places and the peak ground acceleration and the response spectra generated will be different for different cases, for the strong ground motion is dependent to the geometry and material properties of the subsurface materials, on site topography and on the characteristics of the input motion like shear wave velocities, shear modulus, etc.

IV. METHODOLOGY

Borcherdt [8] had given procedure for estimating the site-dependent response spectra which are based on empirical correlations between soil properties and mean shear-wave velocity. It is intended to be universally applicable. Using his soil classification scheme, free- field, site-specific response spectra (with 5% damping), SA can be derived for sites using the formula:
Free-field, site-specific response spectra with 5% damping, SA, are defined as:
S_A = Minimum for each periodTof I_aF_a

I_vF_v/T^x
Where,

Ia and Iv are input ground-motion spectral levels for the short-period (acceleration) and mid-period (velocity) bands for an implied reference ground condition.

Fa and Fv are average short and mid-period amplification factors with respect to the reference ground condition used for determination of Ia and Iv.

T represents period in seconds, andx is the spectral decay exponent for the mid-period band.

Shear Modulus ofSoil:

Classification of site was considered by the physical property criteria i.e. by the description of the subsurface soil property. These physical property information like thickness and type of soil present was gathered by doing borehole experiment on the site for up to the depth of 30 m and based on the Borcherdt classification criteria the mean shear- wave velocity were taken for different type of soil. Shear modulus was calculated for each soil type by the formulation given

$$G = E / 2(1 + \mu)$$

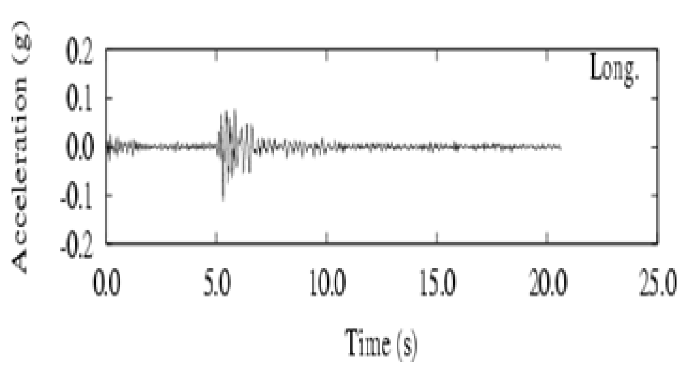
The shear-wave velocity and the shear modulus of each soil particle were generated.

DataCollection:

Data were collected from different sites from two states of India i.e. Arunachal Pradesh and Meghalaya. In these site boreholes experiment was done and the thickness of the different soil particles and its physical property was collected and tabulated. These experiments were mostly done by private consultants for government agencies to know the subsoil strata. In these data only the physical property i.e. the sub soil strata were given with the thickness but no shear-wave velocity experiment was done. So to obtain this shear-wave velocity comparison had been made with Borcherdt soil classification and corresponding shear-wave velocity was obtained. Soil data available are mostly of bridge site. The borehole experiment is not common in these areas for structures due to the increase in overall cost of construction. Data are also missing for some places for which the assumed values were considered for those kind of conditions.

Input BedrockMotion:

Also the appropriate time history data were selected for this region which had occurred at Shillong region (Epicentre- 25.430 N, 92.080 E) on September 10, 1986 of magnitude 5.2, as shown below. This data was taken as the input bedrock motion for the generation of response spectra in these areas [16].



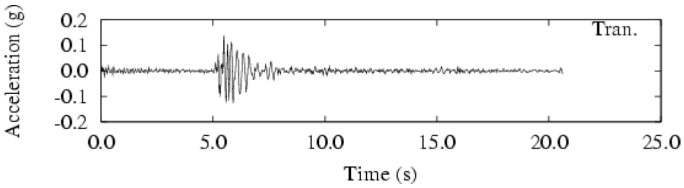


Fig. 3 - Input Bedrockmotion

Response Spectra from Oasys SirenSoftware:

Oasys Siren is a computer software use to analyse the response of a one-dimensional soil column to an earthquake motion at its base. The software allows the user to understand how the seismic wave behaves in magnitude and frequency in various types of soil for different plasticity index. The software uses the physical and material properties such as bedrock level, density, shear wave velocity, strain degradation curve for different soil types and the bedrock motion as the input for the generation of various types of text and graphical output like Input time history, Stress-Strain curve for any element in the soil profile, Relative displacement at various elevations at any time, Base response spectrum and surface response spectrum, Spectral ratio (surface/bedrock) and Displacement, velocity and acceleration time response for any node.

The input data i.e. shear-wave velocity, shear modulus and the time vs. acceleration that were obtained through various method are use in Oasys Siren software so that the response spectra required for the designing for a structure are obtained.

Response spectrum analysis of structure using STAAD Pro Software:

STAAD.Pro is one of the structural engineering software products for 3D model generation, analysis and multi-material design. It has an intuitive, user-friendly GUI (graphical user interface), visualization tools, powerful analysis and design facilities and seamless integration to several other modeling and design software products. This software is used for static or dynamic analysis of bridges, containment structures, embedded structures (tunnels and culverts), pipe racks, steel, concrete, aluminum or timber buildings, transmission towers, stadiums or any other simple or complex structure.

Two structures were considered for analysis the structure, there 3-D space frame models for a 10 storey and a 3 storey buildings were generated in STAAD Pro. The response spectrum analysis was carried out by the IS 1893 response spectrum method as well as for the different types of soil which were found at the sites. Finally the axial load, displacement and the bending moment of column and beams for different floors were compared between the IS 1893 response spectrum method and all the other types of soil.

The general diagram for the two structures is shown below. The heights of each floor were considered as 3 m. The dynamic analysis for these structures were done by STAAD Pro software and the response spectra generated by Oasys Siren for all the different types of soil are provided to STAAS Pro for response spectrum analysis and various results are obtained such as Maximum Displacement, Axial load and Bending Moment.

10 Storey Structure:

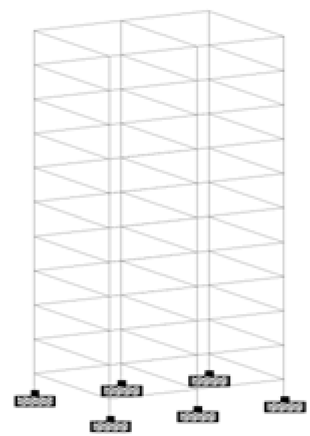


Fig. 4- General diagram of 10 storey building.

3 Storeyed structure:

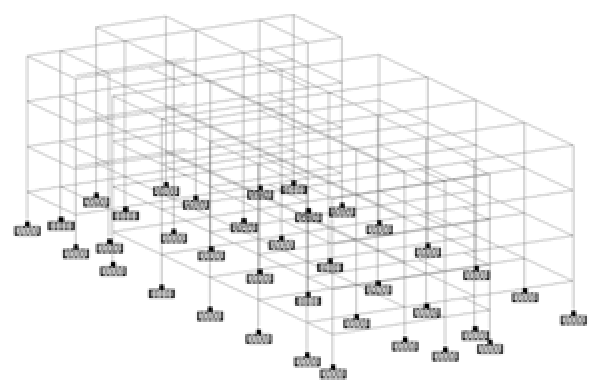


Fig. 5- General diagram of 3 storey building.

V. RESULTS AND DISCUSSIONS

Selection of site:

The data of soil profile which was found out by doing borehole experiment were collected from different sites from government agencies which are dealing with construction in these areas. The sites are listed belowProposed bridge site over the river Sisiri which is situated at a distance of 15 km from Bijari town in Arunachal Pradesh

Proposed bridge site over Jou Korong which is situated at a distance of 6.35 km from Ruksin in Arunachal Pradesh

Proposed bridge site over Myntang River which is situated at Sahsniang- Kuruliya road in Meghalaya

Soiltype:

The different types of soil that are prevalent in these areas which were found out after doing the borehole experiment in these sites are listed below-

1 Poorly gradedgravels
2 Sandstone
3 Sandyclay
4 Silt
5 Well gradedsand

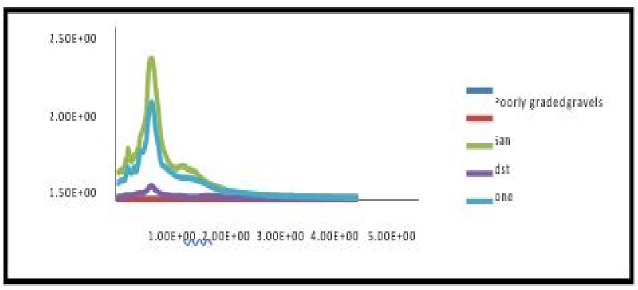


Fig. 6-Response spectrum in longitudinal direction at 0 Plasticity Index

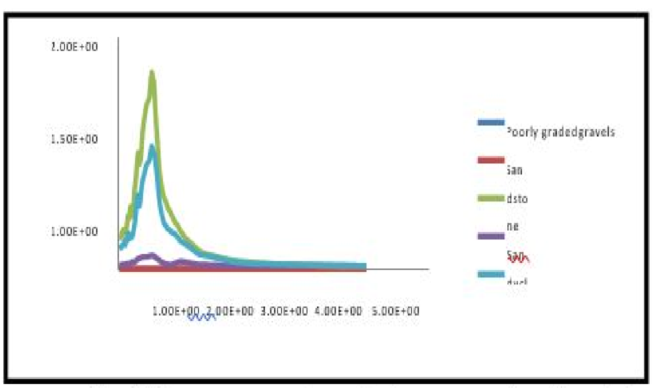


Fig. 7-Response spectrum in transverse direction at 0 Plasticity Index

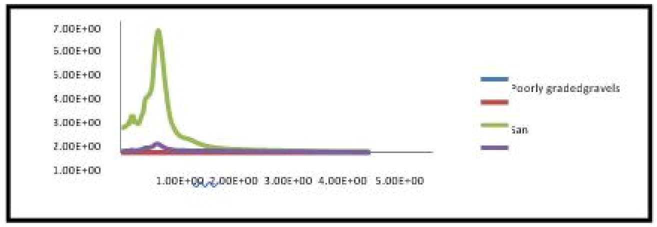


Fig. 8-Response spectrum in longitudinal direction at 30 Plasticity Index

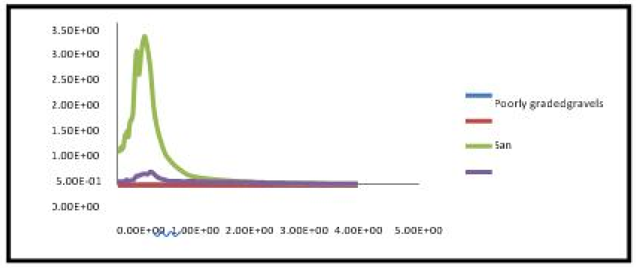


Fig. 9-Response spectrum in transverse direction at 30 Plasticity Index

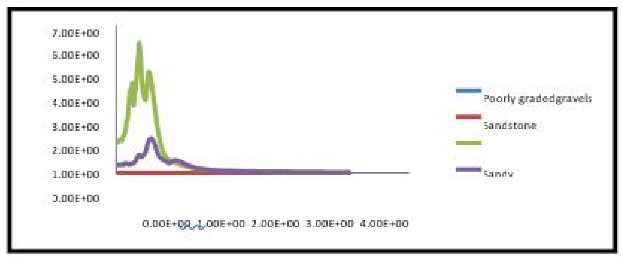


Fig. 10-Response spectrum in longitudinal direction at 200 Plasticity Index

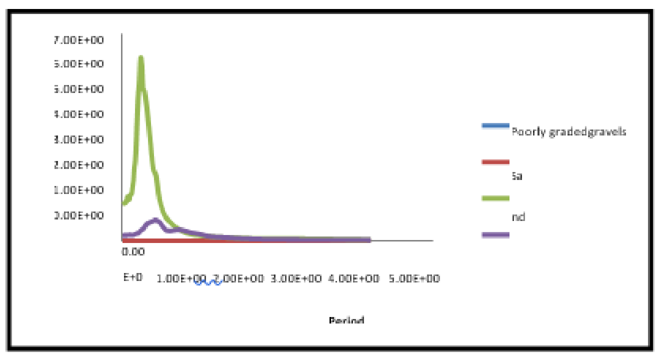


Fig. 11-Response spectrum in transverse direction at 200 Plasticity Index

From the figs. 6,7,8,9,10 and 11 it had been found that the response spectral graph for the Sandy Clay is highest in comparison to other type of soil and for the Gravels and Sandstone it is almost negligible. As the Plasticity Index value of the soil gets higher the spectral response for each soil gets high. So the plasticity index value in proportional to the response spectra for a particular type of soil. And for higher Plasticity Index value i.e. 30 and 200 PI, the spectral response at 0.5 sec. has higher values in compare to the codal response spectrum (see fig. 2). So the design horizontal seismic coefficient for a structure will have higher value thus subsequently increasing the design seismic base shear value along any principal direction.

VI. CONCLUSIONS

In the present study an attempt has been made to generate response spectra using site specific soil parameters for some sites in seismic zone V, i.e. Arunachal Pradesh and Meghalaya and the generated response spectra is used to analyze some structures using commercial software STAAD Pro. The effect of soil properties, its types and the depth of soil in the response spectrum is discussed using Educational Version of the Oasys Siren software. The response spectrum is obtained from Siren 8.2 in which the physical properties and time history data of an earthquake i.e. North-East earthquake of September 10, 1986 which had the magnitude of 5.2 is considered

The response spectral graph for the Sandy clay is highest in comparison to the other types of soil i.e. poorly graded gravels, sandstone, silt and well graded sadn.

As the Plasticity Index of the soil increases the absolute acceleration of the soil gets enhanced with respect to the period.

Plasticity Index value is directly proportional to the response spectra of a particular type of soil.

The maximum displacement, Shear forces, Bending moment and the Reinforcement area as per IS 1893 soft soil has higher value in comparison to all the other types of soil in both the direction of seismic wave propagation at 0 Plasticity Index value for columns.

The poorly graded gravels, sandstone, sandy clay and silt has the same displacement values, shear forces, bending moment and reinforcement area at 0 Plasticity Index value in both the direction of propagation for columns. The well graded sand has the least for both the direction in columns.

The trend continues for both the building for all the 3 plasticity index values that were considered and for beams as well.

Hence, there is a need of analyzing building using site specific response spectra instead of the spectra as per IS 1893.

SCOPE FOR FUTURE WORK

In this a preliminary attempt has been made to study the effect of using site specific response spectra instead of using as per IS 1893. However, the study is very limited to a particular earthquake history and for few soil types. Hence, there is a need to go for such study forOther types of soil conditions and different building geometry.Using dynamic analysis using the site specific earthquake spectraDevelopment of response spectra considering other relevant soil properties.

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