SITE-SPECIFIC SPECTRA CONSIDERATIONS FOR HIGH-RISE BUILDINGS

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ABSTRACT

Optimization of design criteria for structures against earthquake is one of the main concerns of seismic codes all over the world. Hence, in most of the world's seismic codes, there are some requirements and suggestions in order to utilize site-specific design spectra for high-rise buildings that site effects are needed to be investigated in specific points.

By study of site effects in specific points, ground level seismic parameters such as peak ground acceleration and the normalized design spectra are estimated during the earthquakes in the scope of the project. In order to estimate the value of peak ground acceleration for each point of sediment, firstly, appropriate accelerograms are selected for seismic bedrock based on results of site Seismicity studies. Secondly, geotechnical earthquake model of basement layers of the site is provided in accordance with results of geological, geotechnical and geophysical engineering studies. Then seismic bedrock accelerograms are applied to geotechnical earthquake profile of the site. Finally, the results are analyzed and the peak acceleration at the desired level is estimated. Generally, the normalized design spectra are extracted based on statistical analysis of acceleration response spectra which is resulted from sediment dynamic analysis.

In this research, considerations associated with aforementioned process in extracting the site-specific spectra for high-rise buildings are investigated and according to a case study necessary recommendations are presented.

1. INTRODUCTION

Optimization of design criteria for structures against earthquake is one of the main concerns of seismic codes all over the world. Hence, in most of the world's seismic codes, there are some requirements in order to utilize site-specific design spectra for high-rise buildings that site effects are needed to be investigated in specific points. The aim of the site effects study at a specific point is to estimate the ground level seismic parameters seismic parameters during the desired earthquakes. Generally, Two important characteristics of ground level seismic parameters include the following:

1. Peak ground acceleration
2. Normalized design spectra

In order to estimate the value of peak ground acceleration for each point of sediment, firstly, appropriate accelerograms are selected for seismic bedrock based on results of site Seismicity studies. Secondly, geotechnical earthquake model of basement layers of the site is provided in accordance with results of geological, geotechnical and geophysical engineering studies. Then seismic bedrock accelerograms are applied to geotechnical earthquake profile of the site. Finally, the results are analyzed and the maximum acceleration are estimated.

Generally, the normalized design spectra are extracted based on statistical analysis of acceleration response spectra which is resulted from sediment dynamic analysis. Due to the sensitivity of the high-rise buldings to the long term periods from one side and the geometry of the basement layers, microtremor studies are usually accomplished to estimate the frequency characteristics of the sediment magnification function and the results of these studies are used to completing and auditing the normalized design spectra.

In this research, considerations associated with aforementioned process in extracting the site-specific spectra for high-rise buildings are investigated and according to a case study necessary recommendations are presented.

2. CONSIDERATIONS

2.1 PEAK GROUND ACCELERATION

Estimation of peak ground acceleration, requires determining of the site geotechnical earthquake profile, selecting the appropriate input motion for seismic bedrock and dynamic analysis of mentioned profiles according to selected input motion.

2.1.1 SITE GEOTECHNICAL EARTHQUAKE MODEL

Site effects have an important role on the design of structures resisting to earthquake forces. Local soil classification and earthquake characteristics affect amplification of ground motions and maximum surface acceleration. In investigating of site effects, only part of the basement layers are considered that Strengthening (or weakening) the seismic motions. Sediment layers with such a characteristics are above a high stiffness layer named seismic bedrock that seismic waves in this layer does not strengthened. The following, explanations of identification the basement layers and seismic bedrock are presented.

One the most important factors plays main role in the study of geotechnical earthquake microzonation is geologic and soil conditions at the site. The most important parameters, including texture, density, and the depth of basement layers that give an impact on the dynamic response, are concerned of identification the basement layers. Most important resources using for determining the geotechnical texture and the situation of site basement layers are the following:

- Information of general and engineering geology of the zone
- Local studies to assessment the stratigraphy and lithology situation of site sediment layers
- Geotechnical studies reports conducted at the site
- Geophysical studies such as borehole seismicity
- microtremor studies

It is noteworthy that the microtremor studies for direct measurements of shear wave velocity propagation with depth are very important.

It should be mentioned about the seismic bedrock that the seismic bedrock is not necessary the geology bedrock and sediment layers with high elasticity stiffness can also play its role. In practice, the seismic bedrock is defined by shear-wave velocity. According to the TC4 microzonation guide for typical buildings, soil layers with shear wave velocities of more than 600 (m/s) are considered as seismic bedrock (The Japanese Geotechnical Society, 1999). TC4 also recommended for high-rise buildings, soil layers with shear wave velocities even up to 3000 (m/s) are considered as seismic bedrock. In precious code such as Uniform Building Code 1997 (UBC 97), International Building Code (IBC), and National Earthquake Hazards Reduction Program (NEHRP), soil layers with a shear wave velocity more than 760 m/s are defined as seismic bedrock (UBC 97). In the microzonation project of Balkan region, Ishihara et al (1982) have used the shear velocity of the soil layers between 600 (m/s) to 1000 (m/s) as seismic bedrock. The first, second, and third version of Iranian seismic code consider the soil layers as rock type materials. As mentioned above, a medium is considered as seismic bedrock, whose the shear velocity must be over 750 (m/s) (standard No. 2800-05).

The most important parameters, including the depth of bedrock position, and thickness, density, and how to distribute soil layers in the depth give an impact on the evaluation of the influence of site effect to seismic waves characteristics. Hence, the consideration of the appropriate examination to soil deposit conditions and rock units in each area can affect to evaluate the more real effectiveness of the main characteristics of seismic waves.

2.1.2 INPUT MOTION

In areas where there is a complete database of recorded earthquakes, it can be used in real accelerograms. The ideal situation would arise only when that a complete network of accelerograph are installed at the study area and a considerable number of large and small earthquakes are recorded in a reasonable time domain.

In areas that the real accelerograms are not recorded, should be required to simulate the accelerograms. The other word, the seismotectonic environments of the selected accelerograms should be as much as possible similar to those of the study area.

2.1.3 DYNAMIC ANALYSIS OF SEDIMENT

In order to dynamics analysis of sediment and according to the input motion, selecting the appropriate behavioral model can enhance the accuracy of the results. If the intensity of the seismic motion is weak and seismic behavior of the sediment remain in an elastic domain, a linear elastic model can be used. Shear strains is between $10^{-4}\%$-$10^{-2}\%$ and the sediment behavior is non-linear and equivalent linear models can be used for dynamic analysis of sediment. In the larger shear strain that occurs during severe earthquakes, an appropriate elastoplastic model is generally recommended to use and thus step by step integration method in time domain is used for dynamic analysis of sediment.

Due to the long history of the use of equivalent linear dynamic analysis of sediment and widespread use of this method in many investigations of the world, this method is considered.

2.2 NORMALIZED DESIGN SPECTRA

Normalized design spectra of the Site is usually preparing based on the following data:

1. Statistical analysis of acceleration response spectra resulting dynamic analysis of sediment.
2. Frequency characteristic of site magnification curves using microtremor studies.
3. Statistical analysis of acceleration response spectra such as accelerograms recorded at the sites with seismotectonic and geotechnical characteristics as much as possible similar to those of the study area.

It is noteworthy, however, estimation of peak ground acceleration and Normalized design spectra using lowering Relationships in conventional studies of the risk assessment is possible, but has the least accuracy considering the site effects. Hence strongly recommended, estimation of peak ground acceleration according to peak bedrock acceleration with dynamic analysis of sediment in order to exact evaluate the magnification capacity and also nonlinear behavior of sediment and normalized design spectra are extracted according to the above. In this research, according to a case study recommendations in extracting the site-specific spectra for high-rise buildings in Mashhad city are presented.

3. CASE STUDY

Due to the Iranian Seismic design code (Standard, 2800), ground motion effects in the form of "acceleration reflection spectra" or "acceleration time history" to be determined and for determining of "acceleration reflection spectra", "standard design spectra" or "site-specific design spectra" can be used and the use of any of these approaches is optional for all buildings. It is necessary the use of site-specific design spectra, only in which buildings that one of the following conditions is available:

1. Buildings "with high and very high importance" which are constructed on the ground type IV.
2. Buildings higher than 50 meters which are constructed on the ground type IV.
3. Buildings higher than 50 meters which are constructed with more than 60 m thickness of soil layer on the ground type II-B and III-B.

According to the above, use of site-specific design spectra for high-rise buildings based on deep sediment layers is necessary and seismic bedrock characteristics especially in relation to it's shear wave velocity and depth is not exactly explained and it's effects on the site-specific design spectra for high-rise buildings is not investigated and comments on this subject were presented in the previous section and then, according to a case study recommendations in extracting the site-specific spectra for high-rise buildings in Mashhad city are presented. About the site geotechnical earthquake model the following took into account.

Based on the engineering geology information according to figure 1, it seems that Mashhad city basement is periodic formed of the sedimentary and Metamorphic rocks.

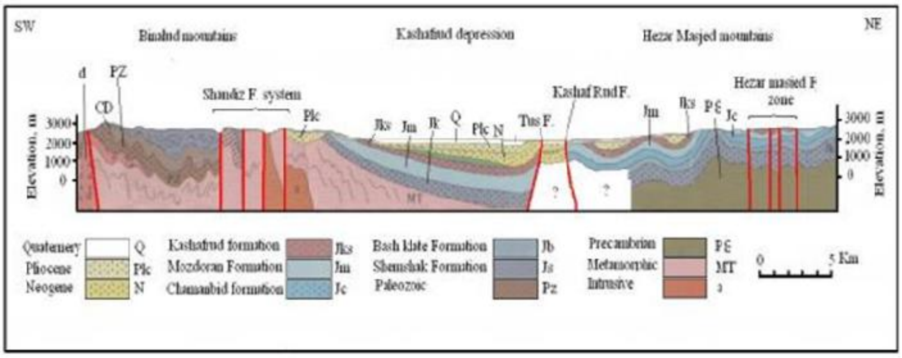

Figure 1. Simplified cross-section of rugged topography and geology of the study area

The layer wise soil characteristics and the depth to the base of the layer from the surface are shown in Tables 1. The variations of N values with depth are available from the geotechnical data are shown in Tables 1.

Table 1. Geotechnical profile at Site

Layer No.	**Description**	**Thickness (m)**	**Depth to the bottom of each layer(m)**	**SPT (N values)**	**Total unit weight (KN/m3)**
1	Fine dominant texture and approximately homogeneous from clay and silt of low plasticity	5	5	25	1.6
2	Sandy silt and sand clay with the lenses of CL and ML	15	20	40	1.7
3	Layer of the SM, SC and GM	10	30	50	1.8
4	Layer of the SC and SM with layers of CL and ML	10	40	> 50	1.8
5	the same characteristics as upper layer with high humidity and saturation	-	> 40	> 50	1.8

Generally, based on standard penetration test (SPT), soils strength of the site is evaluated moderate to good.

As mentioned, borehole seismicity studies for direct measurements of shear wave velocity propagation with depth are very important. Based on borehole seismicity studies the shear wave velocity propagation with depth can be seen in figure 2.

According to above as mentioned about seismic bedrock, in this project the value of shear wave velocity of seismic bedrock is considered about 760, 900, 1200, 1500, 2000 and also 2500 and 3000 (m/s). Since the building is high-rise and according to the site microtremor studies, sediment natural period is estimated at about 4.1 seconds, to the seismic bedrock with shear wave velocity of 760, 1200, 1500 and 2500 were given more weight.

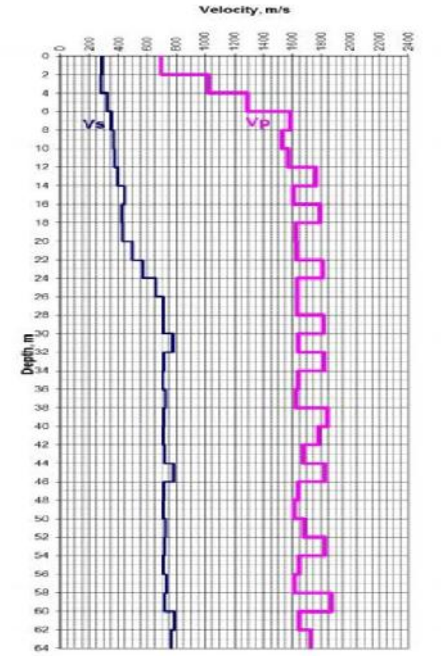

Figure 2. The results of borehole test

Finally, according to the geological, geotechnical, geophysical engineering and microtremor information and to perform sensitivity studies, a total of 13 different geotechnical earthquake profiles were extracted and analyzed for the calculation of dynamical analysis of sediment. Mentioned profiles were how regulated to simulate the most likely choices for geotechnical earthquake of the site.

Total thickness of sediment, thickness and shear wave velocity of basement layers in extracted profiles are how chosen that moreover concordance with the increase of shear wave velocity of borehole seismicity test, also cover the natural period domain of the microtremor measurements. Finally the results of the dynamic analysis were used to extract the site spectra and peak acceleration. It is noteworthy that due to variations of shear wave velocity the representative profiles of site can be classified in categories with a thickness of 84, 104, 154, 184, 254 and 304 meters.

About the input motions, according to the epicentral distances variety of active faults of the site and the height of the constructed buildings at the site, two seismicity categories related to near and medium-field ground motions (30 accelerogram) and far-field ground motions (15 accelerogram) were accounted among the accelerograms from valid databases. Since the thickness of the geotechnical earthquake profiles representative varies from 84 to 304 m, the importance of considering the far-field ground motions of the site is enhanced.

In order to dynamic analysis of sediment, program SHAKE (Schnabel et al., 1972) is used in the present study. Since SHAKE is a total stress analysis program depth of water table has not been considered in the analysis. One dimensional ground response analyses based on equivalent linear approach are commonly implemented by SHAKE program. The software defines each of the soil layers based on independent of frequency parameters such as shear modulus, damping ratio, density and thickness.

4. RESULTS

Since the thickness of sediment representative varies from 84 to 304 m, computation of dynamic analysis of sediment was performed for near and medium-field and far-field seismicity categories. For this purpose, prepared geotechnical earthquake analyzed by applying 30 accelerograms for near and medium-field and 15 accelerograms for far-field. It should be mentioned that according to results of seismicity studies and hazard assessment and also according to shear wave velocity of the seismic bedrock, near and medium-field accelerograms according to 475-year return period are scaled to peak acceleration (28% to 35% gravity acceleration) and were applied to seismic bedrock. Accordingly, the far-field accelerograms is scaled to peak acceleration (10% gravity acceleration) and were applied to seismic bedrock.

Dynamic analysis of sediment in Mashhad city site show the following results:

1. Peak acceleration related to near and medium-field has dominant effect in comparison with peak acceleration related to far-field.
2. Value of peak ground acceleration of the site according to 475-year return period is 0.46g (gravity acceleration)
3. Value of peak acceleration of the site according to 475-year return period in depth of 24m is 0.3g (gravity acceleration).

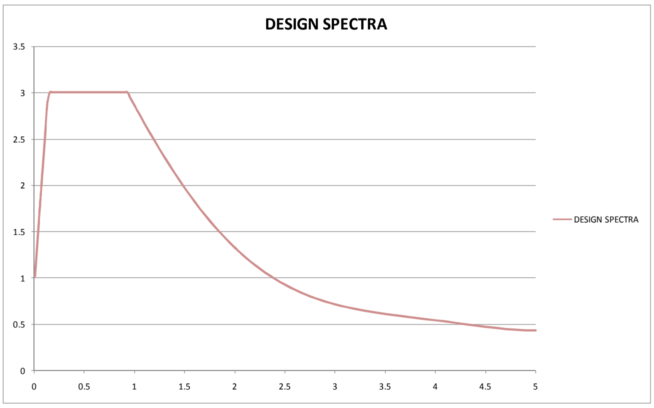

Figure 3. Proposed site design spectra

Proposed non-scaled site-specific design spectra for corresponding peak acceleration (0.3g) with average curve plus standard deviation of non-scaled response spectra acceleration related to accelerograms that resulted from dynamic analysis of sediment of near and medium-field earthquakes using different softwares (SHAKE and DEEPSOIL) and average curve plus standard deviation of non-scaled response spectra related to accelerograms that resulted from far-field earthquakes (Far Ave+Standard) are compared with Iranian Seismic design code (Standard, 2800) and UBC97 (with consideration of near-field effects) and the related curves are shown in figure 4.

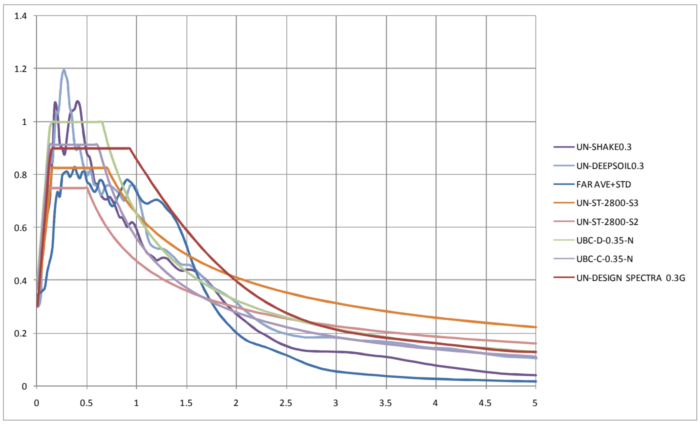

Figure 4. Proposed non-scaled site-specific design spectra for corresponding peak acceleration (0.3g) with presented curves in comparison with Iranian Seismic design code (Standard, 2800) and UBC97 (with consideration of near-field effects)

As can be seen, proposed design spectra is how extracted that be greater than extracted spectra from calculations and be closer to calculated spectra of near and medium-field earthquakes. Proposed non-scaled site-specific design spectra with average curve plus standard deviation of response spectra acceleration related to accelerograms that resulted from dynamic analysis of sediment of far-field earthquakes are compared. As can be seen, proposed design spectra is considered stronger in period domain that response spectra acceleration of far-field earthquake in comparison with near and medium-field earthquake is stronger.

General procedure for design response spectra acceleration in different codes is as following:

- Soil classification of site
- Determination of seismic zone
- Determination of site coefficients and design response spectra acceleration

Also proposed non-scaled site-specific design spectra is compared with Iranian Seismic design code (Standard, 2800) and UBC97 in figure 4:

- UBC97 code of America; site classification according to table 1-16 of the current code is (C, D) and peak seismic bedrock acceleration is Z= 0.35g (gravity acceleration).
- Third edition of Iranian Seismic design code (Standard, 2800); soil classification is (2, 3).

As can be seen, proposed design spectra and standard design spectra of UBC97 code in long and short term period are close together. Proposed design spectra in short term period, actually in 1-1.5s period interval is more stronger than design spectra of UBC97 code that seems reasonable according to significant thickness of sediment and it's natural periodic domain (1.4s). Proposed design spectra in the short and medium term period is stronger than Iranian Seismic design code (Standard, 2800). Not only spectra of Iranian Seismic design code (Standard, 2800) in the term of longer than 2.7s period domain is stronger than proposed spectra, but also is stronger than most of the standard design spectra provided by countries of the world that does not seem reasonable.

5. CONCLUSIONS

In this research, considerations associated in extracting the site-specific spectra for high-rise buildings including determination of geotechnical earthquake model of the site, choose the appropriate input motions for seismic bedrock and dynamic analysis of geotechnical earthquake model for input motions are investigated and according to a case study necessary recommendations in this regard are presented. Also according to a case study and estimated proposed design spectra, is shown that proposed design spectra in the short and medium term period is stronger than Iranian Seismic design code (Standard, 2800). Not only spectra of Iranian Seismic design code (Standard, 2800) in the term of longer than 2.7s period domain is stronger than proposed spectra, but also is stronger than most of the standard design spectra provided by countries of the world that does not seem reasonable.

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