1-D STOCHASTIC SITE RESPONSE ANALYSIS OF SOIL DEPOSITS WITH RANDOM PARAMETERS

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SUMMARY

The geologic and geotechnical characteristics of a site have a strong influence on the nature of the ground shaking experienced by a structure. In current engineering practice, site response analysis are performed with a deterministic approach. Hovewer, deterministic analysis of seismic amplification don't necessarily represent the response of a site where uncertainties of parameters used in the subsoil model are high. These uncertainties arise from both earthquake characterization and from the evaluation of geotechnical soil properties. This work will illustrate the results of 1D linear-equivalent stochastic site response analysis of the unconsolidated deposits in the Izmir basin which may have significantly change the propogation of ground motions to the surface. The stochastic analysis at the site have been carried out using Monte-Carlo simulations with the Latin Hyperbolic Sampling technique. In this framework, repetitive numerical surface motion simulation is obtained by applying multiple bedrock earthquake records at the base of a soil column with randomly generated geotechnical parameters varying within properly defined probability distributions. According to the results, the random soil properties and the input earthquake motion causes the variance of the resulting earthquake response spectras.

Key Words: *Site Response Analyses; Seismic Amplification; Monte-Carlo Simulation Probability Distributions*

1. INTRODUCTION

It is a known fact that the surface amplification of ground motions are affected by the geotechnical properties of soil formations below the ground surface. As a general way, a simplified profile of the soil layers are prepared and adopted with the engineering judgement and generally using the mean profile parameters. However, a single analysis does not allow the assessment of the uncertainty of sesimic motion and the soil properties.

The methodology requires the definition of the probabilistic distribution of the input parameters and of their possible cross-correlation coefficients. Usually such distributions are difficult to define for geotechnical parameters whose spatial and aleatory uncertainty can rarely be determined from standart or ever refined ground investigation capaigns. From these statistical parameters, Monte Carlo simulations, associated with the Latin Hypercube sampling technique is used for the random determination of input parameter values for the site-response analysis. The methodology involves repeatedly deterministic evolutions of the model which can be achieved with the computing power.

2. 1-D STOCHASTIC GROUND RESPONSE ANALYSIS

During past earthquakes, the ground motions on soft soil sites were found to be generally larger than those of nearby rock outcrops, depending on local soil conditions (1). These amplifications of soil site responses were simulated using several computer programs that assume simplified soil deposit conditions such as horizontal soil layers of infinite extent. One of the first computer programs developed for this purpose was SHAKE (Schnabel etal., 1972, 1992) which is widely used in analysis. SHAKE computes the response in a horizontally layered soil-rock system subjected to transient and vertical travelling shear waves. The software performs the analysis in terms of total stresses and calculates stresses and deformations at various levels as well as time histories of acceleration, velocity and displacement at the different depths. One of the assumptions in these analysis is the simulation of cyclic soil behavioutr in terms of an equivalent linear model which is extensively used in engineering analysis.

2.1. Analysis Procedures

The algoritm in this study starts from definition of the seismic input, characterization of the soil stratigraphy and statistical parameters of soil properties, generation of Monte-Carlo samples of these parameters and runing the SHAKE91 program to evaluate the results. The procedures and related studies are given in the following sections.

2.2. Definiton of the Seismic Input

Izmir is located in a very active seismic region in Western Anatolia (see Figure 2.1). Earthquakes in the Aegean Graben System and the Aegean Trench dominate the seismicity of the region. To characterize the earthquake ground motion in the vicinity of the city of Izmir, there are several studies and works done before (4,5).

Among the different strategies for defining accelerograms (artificial, synthetic, real) for site response analyses, the use of real accelerograms is preferred, because they have a more realistic frequency content and number of cycles. Unfortunately, in some parts of the world, recorded strong ground motions are not avaible. Even if avaible, these records do not conform to the code requirements (6,7,8). Thus, in these type of regions scaling or simulating methods are widely used. In this study, ground motions are selected from avaible records which scaled to the desired target spectrum. These motions has been spectrum-matched to certain design response spectra. A strong motion database of natural records was constructed mainly from Pasific Earthquake Engineering Research Center (PEER) (9).

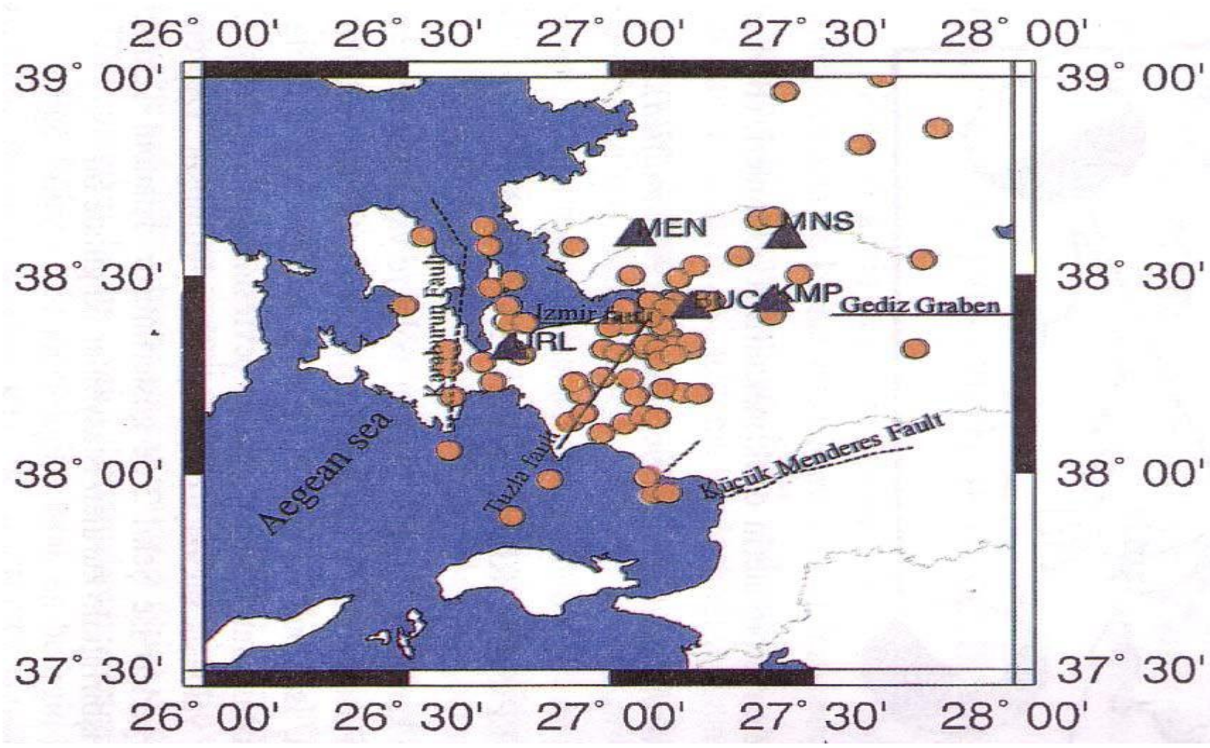


Figure 2.1 Main highlights of the earthquakes and related fault zones in Izmir region. (Akinci et.al.,2000)

The design spectrum is selected conforming to the Ministry of Transportation- Technical Regulations for Earthquake Resistant Design of Shore, Harbour, Railway and Airport Constructions (2008) standarts based on the probabilistc assesment of Turkey design motions at a site of “B” class. B refers to an engineering rock site ,in which Vs (Shear wave velocity) corresponds to 750 – 1500 m/sn. The spectral values are selected based on the values given in the standarts (Ss, S_1). The resulting design spectrum is given in Figure 2.2. The spectral parameters are given in Table 2.1 below.

Table 2.1. Spectral Parametres per "Ministry of Trasportation" (2008) Standarts; (Vs30=760 m/sec)

Design Motion	Return Period	Spectral Acceleration(g) S_s for T=0.2 s	Spectral Acceleration(g) S_1 for T=1 s
D2- Earthquake	475 years in 50 years %10	0.82	0.26

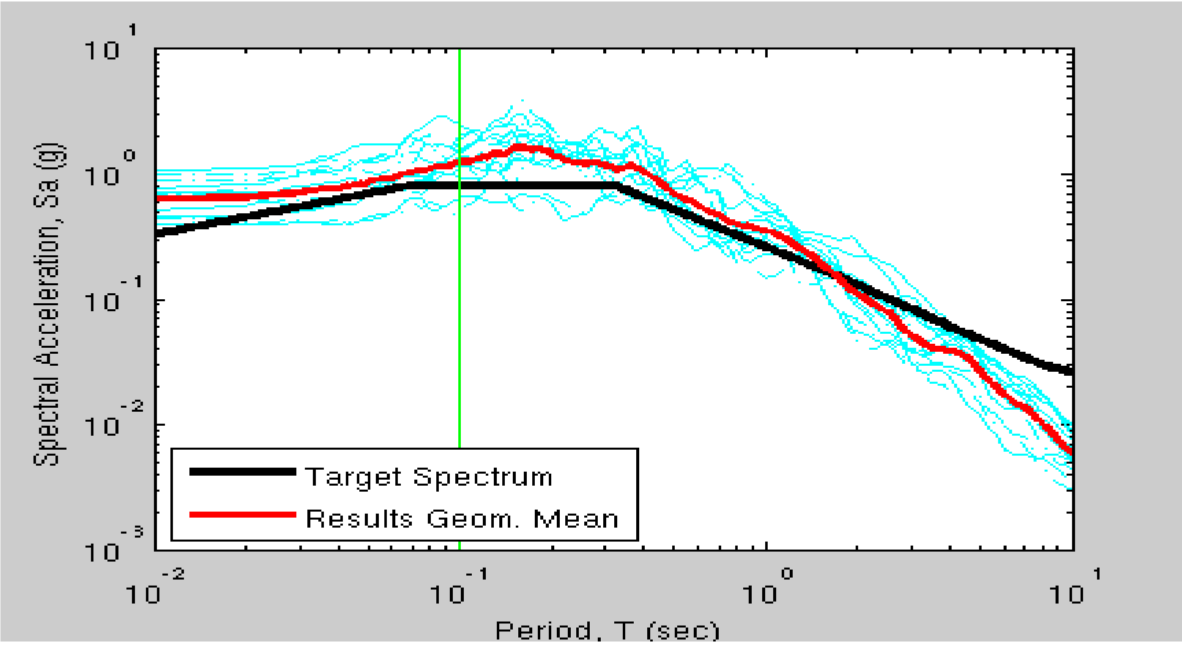


Figure 2.2 Target spectrum and avarage spectrum of the scaled time histories taken from PEER.

In order to determine the magnitude and distance pair governing the seismic hazard at the site of interest, a deterministic seismic hazard assessment has been carried out. From the previous studies, the possible deterministic earthquake magnitude scenario of Izmir earthquke is in the range of 6,0 -7,2 and the possible distance is between 0 – 30 km. Therefore, the search and scale procedure is based on these referenced values.

The criterion is to consider only accelerograms recorded on outcropping rock, to avoid the influence of possible seismic amplification effects. The selection of real accelerograms has been carried out by applying a tolarance on the seismological parameters, magnitude and epicentral distance, which are considered appropriate for the site of interest

The results of the scaling and the selected ground motions and their seismological charateristics are given in Table 2.2. Avarage response spectrums and the target spectrum can also be seen from Figure 2.2 above. The selected input time histories used in the analyses are given in Figure 2.3.

Table 2.2. Seismological Caharacteristics of Records Selected.

No	Name of the Record Set	Data	Scaling Factor	Mw
1	Morgan Hill	1984	9,50	6,19
2	Lome Priata	1989	2,05	6,93
3	Cape Mendocino	1992	0,63	7,01
4	Northridge	1994	1,87	6,69

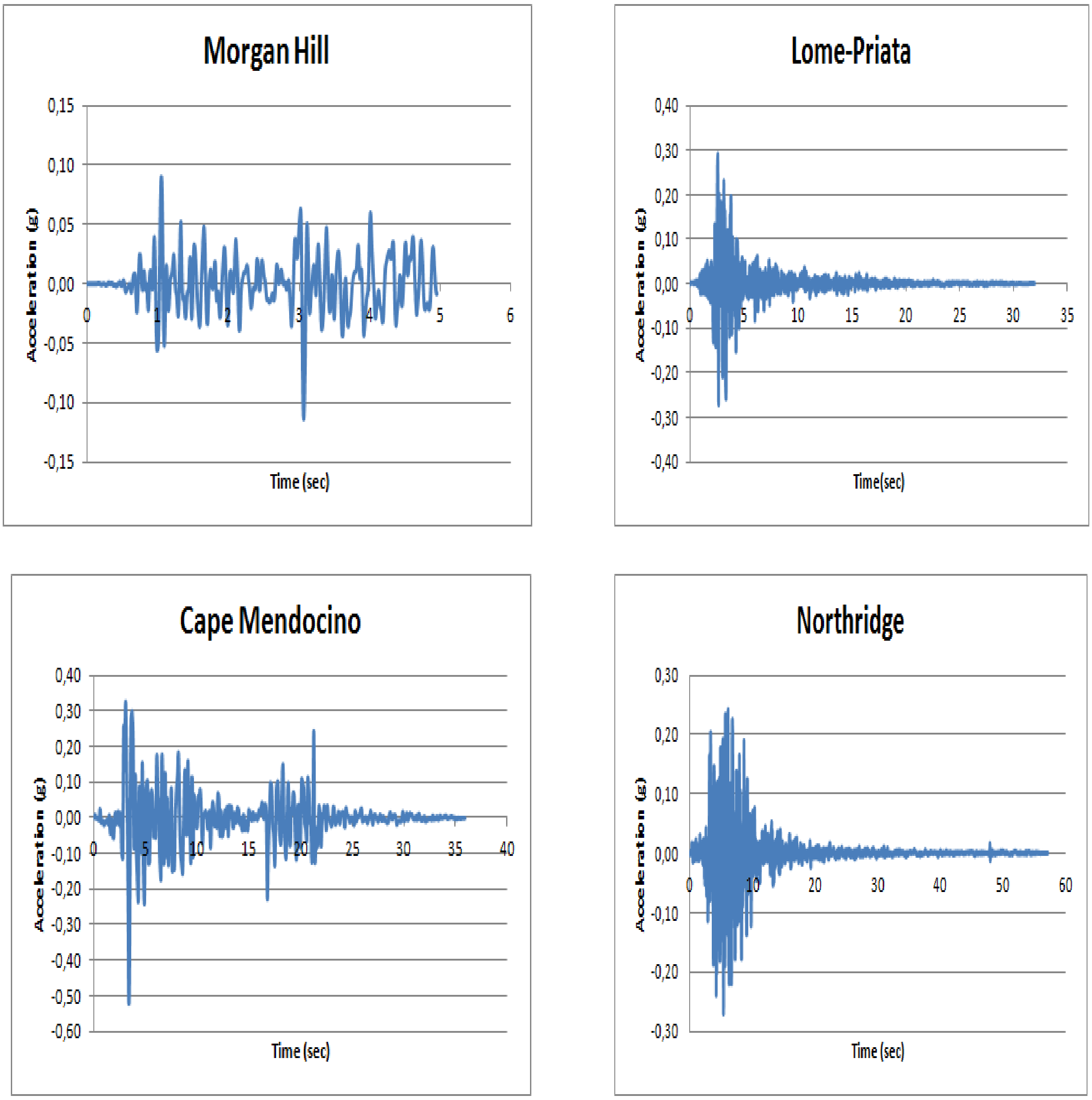


Figure 2.3 Selected input motions to be used in 1D site response analyses.

2.3. Geotechnical and Lithostratigraphic Characterization

The study focused on at the new railway site in Izmir. The proposed site is the Alaybey Station, which is one of the stations in the Izmir Railway system (Figure 2.4).

Definition of a subsoil model requires analysing the soil investigation report, avaible geological, geophysical and geotechnical data. For 1D soil profile, the definition of soil layers (i.e. their thickness and unit weight), the Vs profile and the damping – and shear modulus-degradation curves are needed. The uncertainty in the model parameters has been quantified by an indication of appropriate intervals of variation of the geotechnical parameters, derived from the minimum and maximum values obtained from geotechnical and geophysical tests tests for each parameter. A gaussian probability distribution has been assumed for the thickness, shear wave velocity and unit weight.

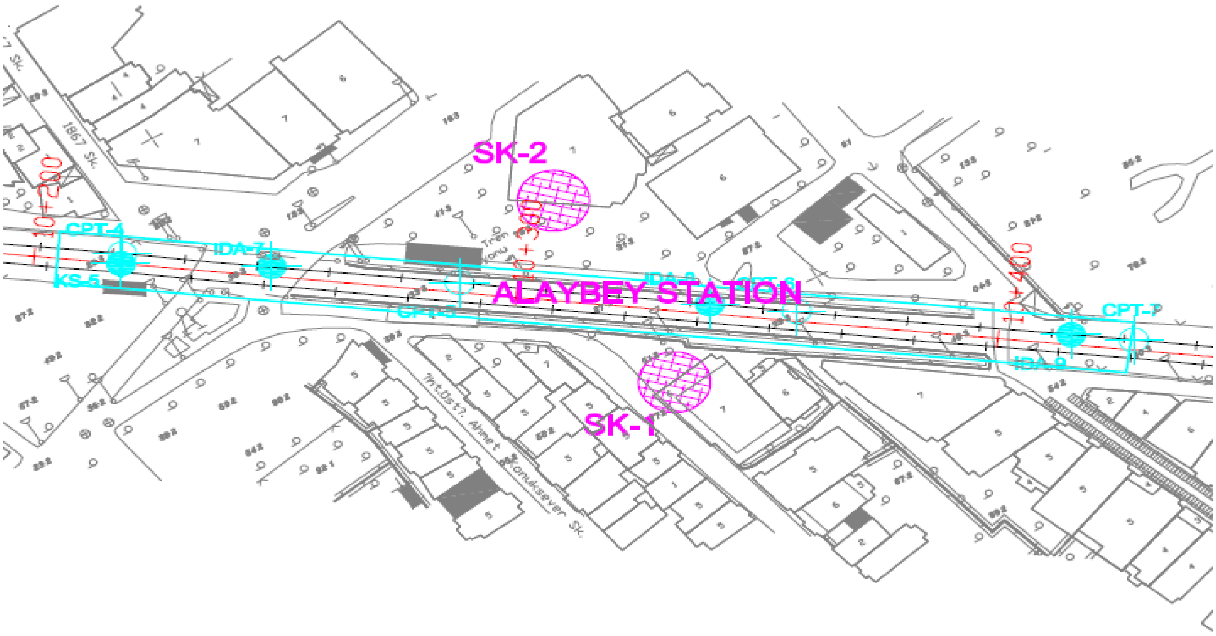


Figure 2.4. Plan View of the Station Site

In order to characterize the site, the soil investigation campaign is followed including:

- 4 boreholes
- 4 CPT
- 4 Geophysical Cross-Hole Tests, providing information on Vp and Vs wave velocities
- Geotechnical laboratory tests on undisturbed soil specimens

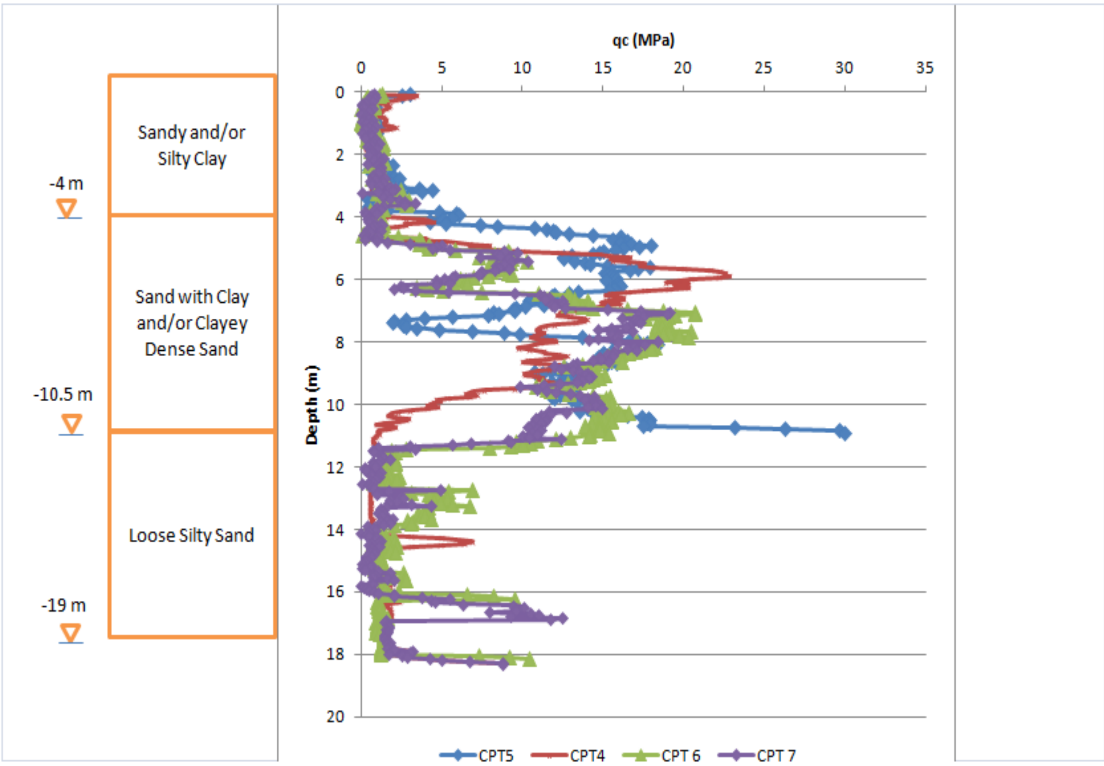


Figure 2.5. Idealized Soil Profile In the Proposed Site

Figure 2.5 shows the idealized soil profile of the site together with the outcome of CPT test results. The profile consists mainly of alluvial deposits with differing layer heights and soil types. The results of geophysical tests and nearby borings suggests that the engineering bedrock (Vs>=750 m/sn) lies approximately at 200 m below the surface. Main constituent of the site is the silty sandy deposits which are prone to liquefaction when subjected to dynamic loads. Shear wave velocity is the main input in equivalent linear site response analysis and gathered with the seismic tests and controlled through the in-situ test results. The shear wave velocity profile of the site and the 1D mean profile can be seen in Figure 2.6.

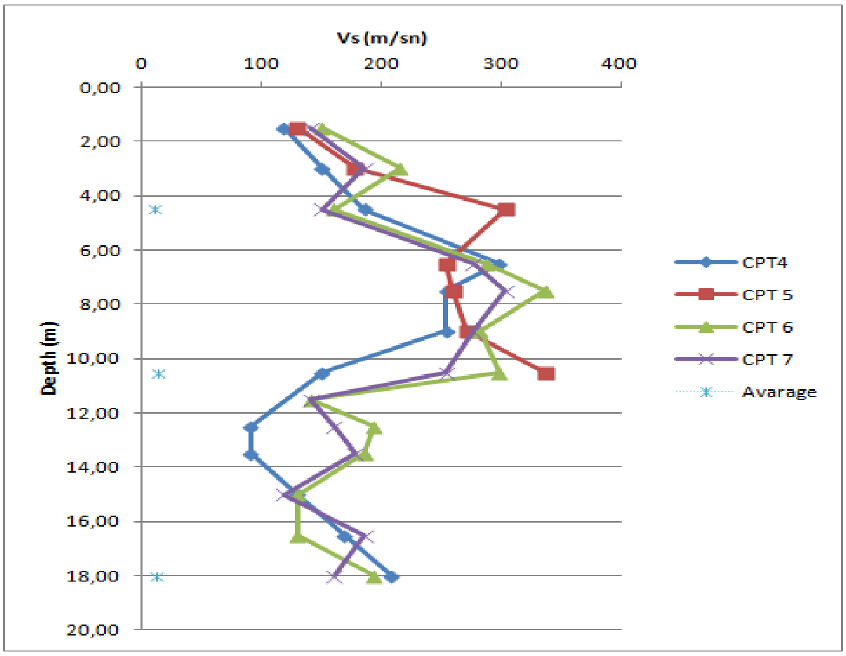


Figure 2.6 Shear-wave velocity profile at the site

Definition of the probabilistic distribution for the geotechnical parameters (e.g. layer thickness, Vs, unit weight of each layer) is given in Table 2.1. considering the statistics of these parameters.

Table 2.3 Mean values and coefficient of variation (CoV) used for geotechnical parameters adopted in Monte Carlo simulations in Alaybey Metro Station

Layer	Soil Type	Thickness (m)	CoV (%)	Vs (m/sn)	CoV (%)
1	Silty Clay	4.25	23.00	160.00	7.00
2	Sand with Clay	5.25	28.00	282.00	5.00
3	Silty Sand	35.00	29.00	153.00	8.00
4	Bedrock			750.00	20.00

The dynamic response of soils is nonlinear even at low to moderate deformation levels. Especially in deep alluvial deposits, soil response will be far from being linear. Specific material degredation curves for the site of interest has been adopted from the avaible models found in the literature. The constitutive model used in SHAKE91 is linear-equivalentvisco-elastic, which means that the shear modulus and damping ratio is updated in every deformation level. There is a rich literature and enough experience about the appropriate soil degradation curves in geotechnical engineering. Since no dynamic laboratory test results were avaible for deriving sepical degradation curves, it is decided to use the widely used curves avaible in literature (11).

2.4. Stochastic Modelling

Once the characteristics of the statistical distributions of each parameter have been defined, a sampling technique called "Latin Hypercube Sampling" (LHS), associated with the Monte Carlo simulation, has been used (12). LHS is a stratified-random procedure, which provides an efficient way of sampling variables from their probability distributions. The cumulative distribution for each variable is divided into N equiprobable intervals. A value is selected randomly from each interval. The N values obtained for each variable are paired randomly with the other variables. Unlike simple random sampling, this method ensures a full coverage of the range of each variable by maximally stratifying each marginal distribution.

The proposed Latin Hypercube Sampling technique is implemented in Matlab. In this study, the correlation among properties does not taken into account as the thickness and shear-wave velocity parameters do not seem to be corralated. There are 6 variables (thickness and shear wave velocity of 3 different layers) used in this study.

3. ANALYSIS AND RESULTS

Ground amplification and the results of the analyses have been described in terms of surface acceleration time histories and surface elastic acceleration response spectra. The variability of the stratigraphic profile used in stochastic analyses illustrates different shear wave velocity profiles, corresponding to random values of Vs and thickness values extracted from the statistical distributions.

For each analysis, one of three accelerograms selected is randomly selected and applied to the outcropping bedrock. The variability of model parameters within the sample obviously determines a variability in the simulation results. Figure 3.1 shows the comparison of mean response spectras calculated from the analysis at the surface and design response spectrum used for evaluating appropriate time histories for analysis. The design spectrum for Class E, which corresponds to the site soil profile, is also given in this figure. The response spectra variability results from the large number of samples used in the analysis. Class B spectrum is the design target spectrum used in the analyses. The resulting spectral acceleration values are higher than the design rock values. Different acceleration time histories substantially affects the resulting motions.

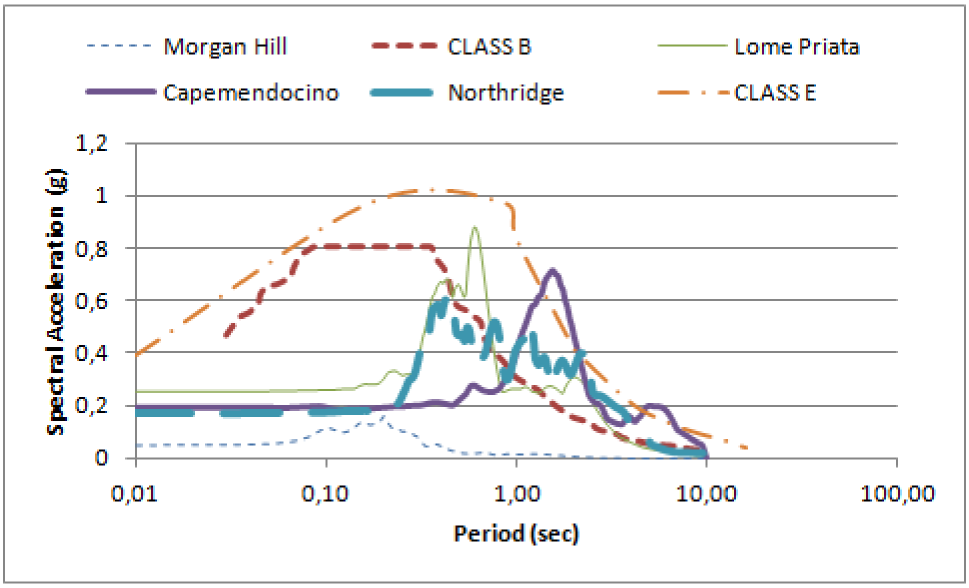
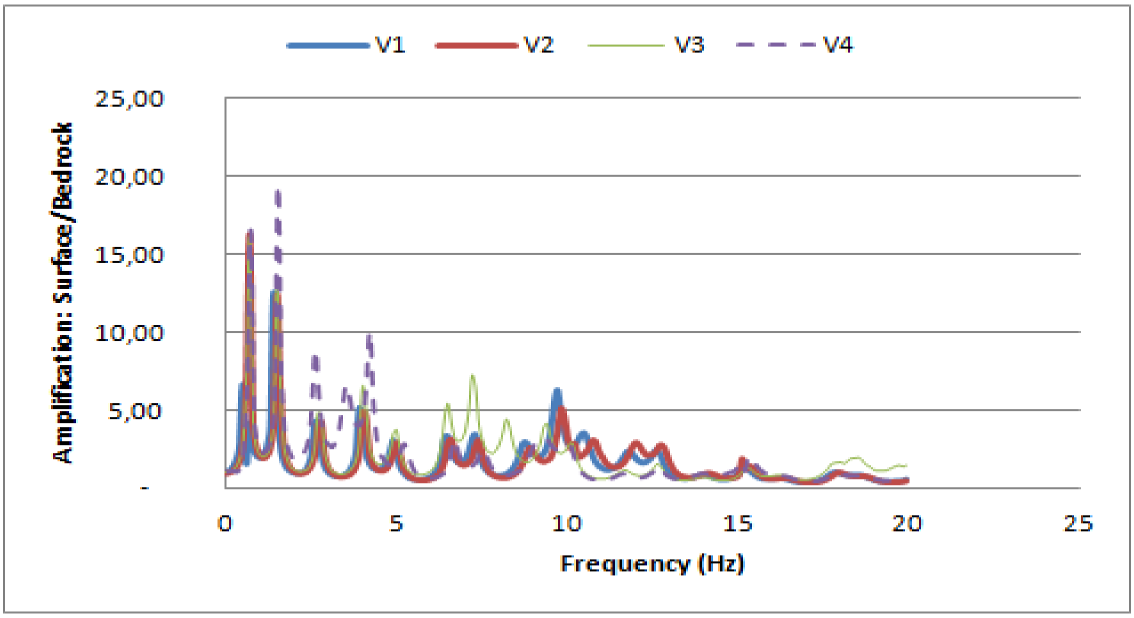


Figure 3.1. Comparison of the acceleration design response spectra and the mean values of the response spectra of different input motions with random shear wave velocities

From Figure 3.2, it can be concluded that the considered soil profile amplifies the response in the long period range, while deamplification occurs at the smallest period range. At the period around T=1-1.5 sec, amplification has reached locally to high levels. It is apparent from Figure 3.2 that the ground amplification of the soil deposit is strongly dependent on the specific accelerogram considered. This figure also implies the importance of selecting ground motion time histories in the analyses. The difference in amplification ratios may stem from the different scaling ratios (See Table 2.2)



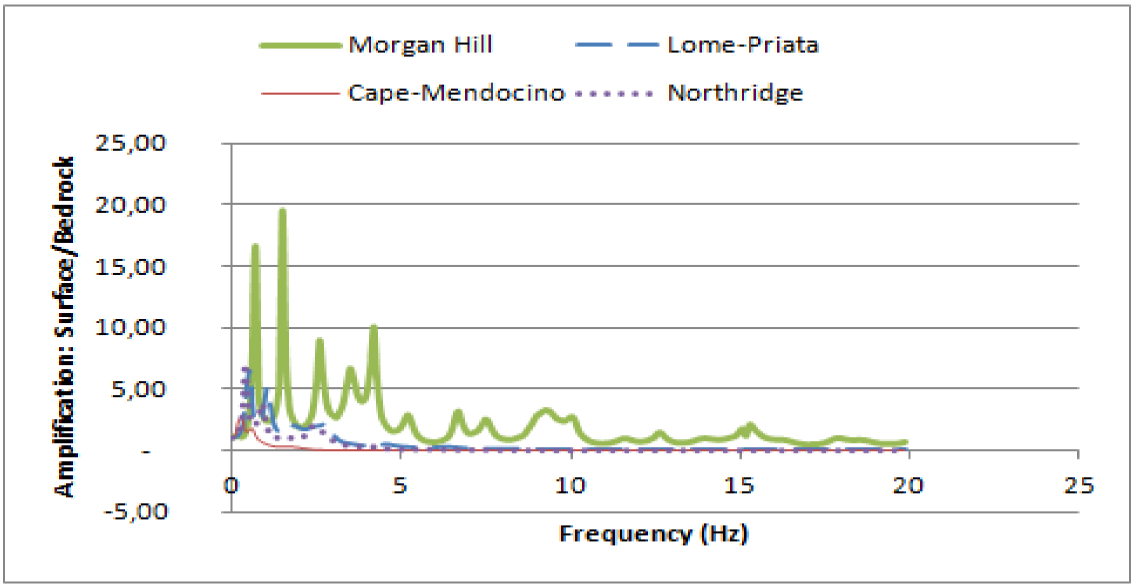


Figure 3.2. Amplification fuctions a- evaluated from different shear wave velocities and the same input motions / layer heights b- same material parametres and layer heights but with different input motions.

4. CONCLUSION

Site response analyses is often characterized by large variability due to uncertain seismic inputs and for a given time history due to gsubstantial soil mechanical uncertainty in subsoil modeling and geotechnical parameters. 1D site response analyses also adds extra uncertainties and adoptions to the problem as the effective soil parameters and true non-linear behaviour of deep soil deposits do not explicitly taken into account. Thus, to better evaluate the effects of uncertainties on the resulting ground motion, and to see the variabilities in ground motions in a site of deep alluvial deposit, a methodology was set up to perform 1D, equivalent linear stochastic site response analyses, taking into account uncertainty of seismic input and model parameters. The procedure allows for selection of the spectrum compatible records, and the results displays the variation of 1-D site response analysis with respect to stochastic inputs. The results obtained confirm that the variability of the seismic input is the most crucial source of uncertainty controlling the dispersion in the response (13,14). It is apparent from Figure 3.2 that the ground amplification of the soil deposit is strongly dependent on the specific accelerogram considered. Therefore, for a site under consideration, selecting time histories and/or simulating time histories are the most important part of the study.

The resulting amplifications show variations from the code requirements. Thus, especially in deep alluvial deposits, site response analysis shall be performed frequently in routine soil investigation studies. Technical spesifications should be prepared for the design engineers which shows them how to select representative accelerograms for their analysis.

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