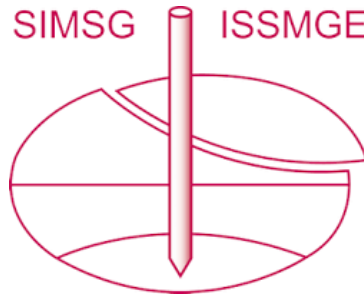


INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Site Specific Response Analysis of a Soil Deposit With Different Techniques – A Case Study



Dr. Şahin Çağlar Tuna, Prof. Dr. Selim Altun
Ege University, Izmir, Turkey
Department of Civil Engineering – Ege University, Izmir, Turkey

ABSTRACT

Local site effects play an important role in earthquake resistant design and must be accounted for on a case-by-case basis. Site specific response analysis are becoming to be widely used in engineering design practice and in taking its place in country design codes.

The site specific response analysis needs time histories as an input at the engineering rock or seismic rock level. The selected time histories and the geologic and geotechnical characteristics of a site have a strong influence on the nature of the ground shaking experienced by a structure. There are not enough recorded time histories in many part of the world, therefore a number of techniques and computer programs have been developed either to completely synthesize an accelerogram or modify a recorded accelerogram.

In this study, a uniform hazard spectrum is constructed as a target spectrum and ground motions are simulated for the city. The simulated time histories and the geotechnical site soil properties are then used to generate the soft soil response of the given site. The site response and related parameters are then compared with results coming from the recorded time histories in the same site conditions. Also, the results are compared with the different type of analysis (One, Two- Dimensional, equivalent linear-nonlinear) used in the study.

1 INTRODUCTION

Nowadays, with the improved computer technology and technical information, the nonlinear analysis and time-history dynamic analysis increase substantially (NIST GCR 11-917-1, 2011). To perform damage risk analysis, sufficient number of time-history ground motion which suits the seismotectonic environment of Izmir should be selected. Therefore, the first step in analyses starts with the selection of time-history ground motions.

There are 3 ways for selecting time history ground motions (Kramer, 1996); synthetic time histories, previously recorded time histories from the region and using recorded time histories from other regions after doing some manipulations.

In Aegean region and specifically in Izmir, however, largely due to lack of earthquake records of intensity of engineering interest, such ground motions have not been available. Although there are recorded time histories in seismically active regions, not all of these records are suitable (the length and quality of the records) to use in further seismic analysis per earthquake standards in Turkey (DLH, 2008). For that reason, recorded strong time histories from other regions of the world shall be appropriately scaled for use in projects region.

The methodology starts with a probabilistic seismic hazard analysis using Monte Carlo simulation methods, generation of uniform response spectrum and then selecting and scaling time histories based on the generated uniform hazard response spectrum.

For the simulation of ground motions, a simple and powerful method for simulating ground motions is used. The aim is to combine parametric or functional

descriptions of the ground motion's amplitude spectrum with a random phase spectrum modified such that the motion is distributed over a duration related to the earthquake magnitude and to the distance from the source. This method is widely used to predict ground motions for regions of the world in which recordings of motion from potentially damaging earthquakes are not available. (Boore, 2003)

The ground motion simulation method is largely based on Boore's point-source simulation method SMSIM (Boore, 2000). The tectonic and seismological data are mainly taken from Turkey Kandilli Rasathanesi Open-File Reports.

Finally, to facilitate site response analysis, suites of 7 ground motions are selected from the large pool of simulated ground motions such that the medians of the response spectra of the suites match those of UHRS in a least square sense at two probability levels, 10 % and 2% in 50 years.

2 SEISMIC HAZARD ANALYSES

Earthquake seismic risk analyses can be performed by using deterministic and probabilistic methods. In the deterministic case, the earthquake mechanism is independent of the probability, and it just tells us about the maximum earthquake that can happen in a given region. It is calculated by some empirical methodologies (Kramer, 1996).

For example, for a Project site in the city of Izmir, the earthquake of $M_w=6.5$ magnitude has a chance to happen (Radius Project). In the east-west plane, a probable earthquake will have the effect to break a 30+-5

km part and 10 km depth of a given normal fault plane (Emre et al., 2005).

The characteristics of the design ground motion at a particular site are influenced by the location of the site relative to potential seismic sources, the seismicity of these sources, the nature of rupture at the source, travel path effects between the source and the site and the local site effects (Figure 1) (Boore,2000).

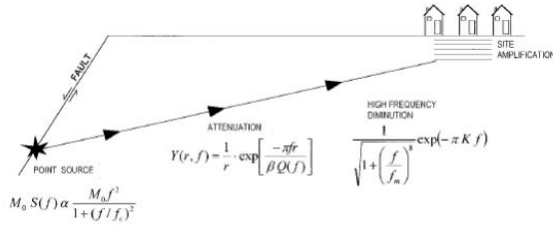


Figure 1. Source to Site Modeling of Seismic Motion

Probabilistic seismic hazard analysis (PSHA) carries out an integration over the total expected seismicity during a given exposure period to provide an estimate of strong-motion parameters with a specified confidence level.

At its most basic level, PSHA is composed of five steps.

1. Identify all earthquake sources capable of producing damaging ground motions.
2. Characterize the distribution of earthquake magnitudes (the rates at which earthquakes of various magnitudes are expected to occur).
3. Characterize the distribution of source-to-site distances associated with potential earthquakes.
4. Predict the resulting distribution of ground motion intensity as a function of earthquake magnitude, distance, etc.

5. Combine uncertainties in earthquake size, location and ground motion intensity, using a calculation known as the total probability theorem.

This general layout is subdivided into different steps, adhering to the Cornell (1968) methodology above, while implementing the Monte-Carlo simulations at the same time (Sen T.K., 2009).

For the proposed simulation in the context of seismicity of the city of Izmir, a 100 km diameter circle is selected to determine the seismic records which affects the city directly. Every event is categorized for its magnitude and epicenter (Katsonas v.d., 2010) and the analyses are conducted using the SMSIM software (Boore 2000, 2003). The resemblance of ground motion time histories to transient stochastic process was noted years ago (Housner, 1947). The main philosophy behind this method is to follow the physical process which begins with the break of fault and then propogation of the earthquake wavefront (Brune, 1970).

This method is more confidential than other empirical formulas if there are no enough information at hand in the region of interest (Kramer,1996). These stochastic simulation methods are used in nearly all parts of the World and literature about the topic is vast (Han and Choi, 2008; Zafarani et.al., 2009; Mammo, 2005; Pulido

et.al.,2004; Carvalho et.al.,2008, Berardi et.al., 2000; Wu and Wen,1999).

2.1 Earthquake Source Identification

Izmir is located in a very active seismic region in Western Anatolia (Figure 2). Earthquakes in the Aegean Graben System and the Aegean Trench dominate the seismicity of the region.

The seismicity of a region can be determined by investigating the close and far away faults and the earthquake records. For that aim, all the faults can be investigated one by one or an area method which takes into account all the faults. For our case, in where a complex fault structure can be seen, areal methodology is followed (Ansal and Tonuk, 2007).

Furthermore, due to the shallow dip angles of the most of the fault zones, earthquake epicenters associated with a given fault zone varied in the latitude-longitude coordinate system for different focal depths. Therefore, accounting all the facts discussed so far, a simple single areal source model was adopted to estimate the regional earthquake hazard for the city of Izmir.

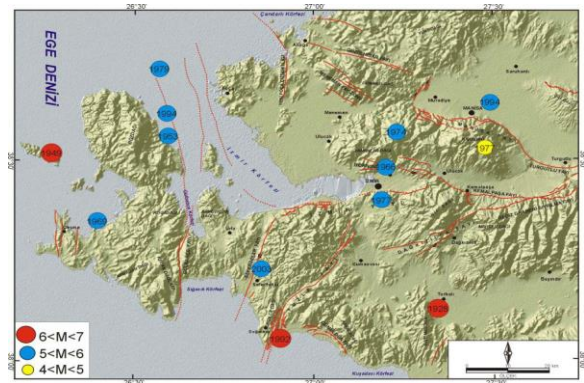


Figure 2. Main Highlights of the Earthquakes and related fault zones in Izmir Region.

2.2 Identifying The Earthquake Magnitude

The second stage in probabilistic seismic hazard analysis is the estimation of the probable earthquake magnitude based on seismological and geological data for the region. The effective zone is taken to be a circular area with a radius of 100 km centered at the given city center. Earthquake records for the historical era (approximately between 1654 and 1899) with intensity $I_0 > V$, for Izmir region were compiled based on available earthquake catalogues (Ergin et.al., 1967; Sipahioglu, 1984; Ambraseys and Finkel, 1985). Since the records for this period are in terms of intensities, the relation developed for Turkey by Ansal, 1997 is used;

$$M = 0.594 I_0 + 1.36 \quad [2]$$

Seismic hazard curve is determined by the Gutenberg-Richter recurrence relations and defined by the following formulation:

$$\lambda_m = 10^{a-bm} = \exp(\alpha - \beta m); \alpha = 2.303a; \beta = 2.303b \quad [3]$$

In the above equation, the earthquake magnitude and formation recurrence is defined with an exponential equation, which takes into a wide range of earthquake magnitudes. A lower limit of magnitude, M_0 , is defined below (Kramer, 1996), so that earthquakes smaller than m_{min} will be ignored in later calculations due to their lack of engineering importance.

$$\lambda_m = \text{vexp}[-\beta(m - m_0)] \quad m > m_0 \quad [4]$$

$$v = \exp(\alpha - \beta m_0) \quad [5]$$

This method of evaluation is not without some drawbacks. To mention some, the historical data compiled for a longer time interval may not be very accurate with respect to the given epicenter locations, dates, and intensities. Using the instrumental records, however, will not represent the tectonic regime going on for millions of years.

Using the earthquake data, the resulting probability distribution of magnitude for the Gutenberg-Richter law with lower bound is expressed in terms of cumulative distribution function (CDF):

$$F_M(m) = P\{M < m | M > m_0\} = \frac{\lambda_{m_0} - \lambda_m}{\lambda_{m_0}} = 1 - e^{-\beta(m - m_0)} \quad [6]$$

Probability density function (PDF) is defined in Eqn. [7] below

$$f_M(m) = \frac{d}{dm} F_M(m) = \beta e^{-\beta(m - m_0)} \quad [7]$$

Cumulative distribution function of earthquake magnitudes is given in Figure 3 based on the Gutenberg-Richter formulation.

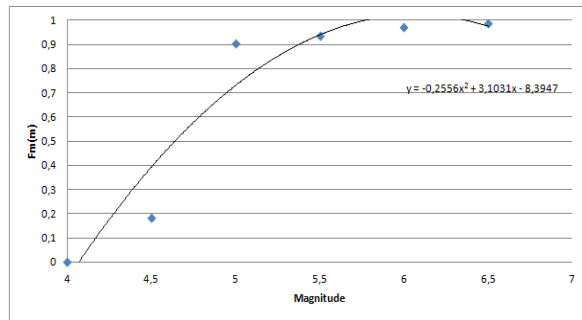


Figure 3. Gutenberg-Richter evaluation of moment magnitude v.s. $f_m(m)$.

2.3 Identifying Earthquake Distance

The aerial source model predicted for the area produces earthquakes anywhere within 100 km of the site.

The possible earthquake epicenters of future events are generated using cumulative distribution probability $F\lambda(i)$ is evaluated in Eqn [8] and given in Figure 4.

$$F\lambda(i) = \sum_{k=1}^{k_i} P_{ki} \quad [8]$$

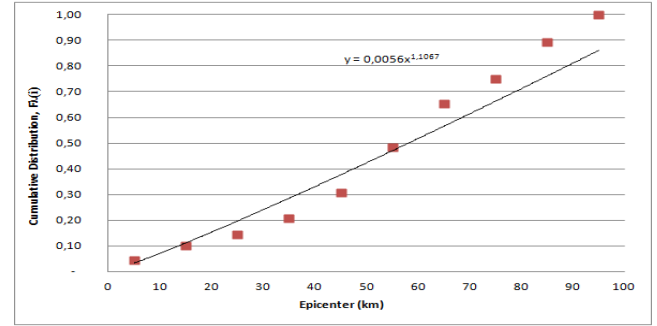


Figure 4. Cumulative distribution function of possible future earthquake epicenters

2.4 Ground Motion Simulation

After quantifying the distribution of potential earthquake magnitudes and locations, the next step is to analyse ground motions—a ground motion prediction model.

Since earthquake magnitude (M) and distance (R) of the rupture zone from the site of interest are the most common parameters related to a seismic event, it is evident that the simplest selection procedure involves identifying these characteristic (M, R) pairs (E.I.Katsonas et.al., 2010).

For the evaluation of earthquake hazard, the possible future earthquake moment magnitudes and epicenters are defined using the available earthquake magnitude and epicenter records mentioned in the previous section.

Based on the past earthquake data and occurrence rates, 1050 earthquakes will be generated for the next 1000 years in the aerial limit of Izmir center. Therefore, a set of uniformly distributed 1050 random numbers is generated from 0 to 1, which represent both the $F_M(m)$ and $F\lambda(k)$ for the future 1000 years. For the analysis, the moment-distance pairs are chosen using the cumulative distribution curves given above by selecting randomly numbers between [0-1] (Tapan K.Sen, 2009). The random selection is handled with a computer program in Matlab.

A ground motion simulation method based on stochastic approach (Boore, 2003) is used. In this method the ground motion is modeled as band limited finite-duration Gaussian white noise in which the radiated energy is assumed to be distributed over a specified duration.

One of the important features of this method is that it puts together the various factors affecting ground motions—source, path, and site factors—into a physically determined algorithm so that it can be used to predict ground motion. Modeling parameters of the point source model for the city of Izmir is adopted from the previous studies (Boore, 2003; Horasan et.al., 2002; Boore and Boatwright, 1984; Akinci et.al., 1985; Cong and Mitchell, 1999).

In current seismic performance evaluation procedures two different seismic hazard levels are generally used, which are defined by probabilities of exceedance of 10% and 2% in 50 years. For these two levels, annual occurrence rates can be calculated using Poisson process shown in Eq [9]:

$$P(S_a > a_j, t = 50 \text{ years}) = 1 - e^{-\lambda(S_a > a_j) \times 50} \quad [9]$$

The annual occurrence rate, $\lambda (S_a > a_j)$ is calculated as 0.0021 and 0.004, corresponding to for 10% and 2% probabilities of exceedance in 50 years ($P(S_a > a_j, t = 50 \text{ years})$). Thus, spectrum acceleration value is calculated for the annual exceedance probabilities of 0.0021 and 0.0004 for each 91 periods.

The simulated spectrum is then calibrated with the so-called code-based generated spectrum (Wu and Wen, 1989). DLH code based spectrum is usually used as a target spectrum in dynamic analysis being carried out in this region. The results are given in Figure 5 with the generated spectrums by D1, D2 and D3 earthquake levels, which are conforming to the related outcomes.

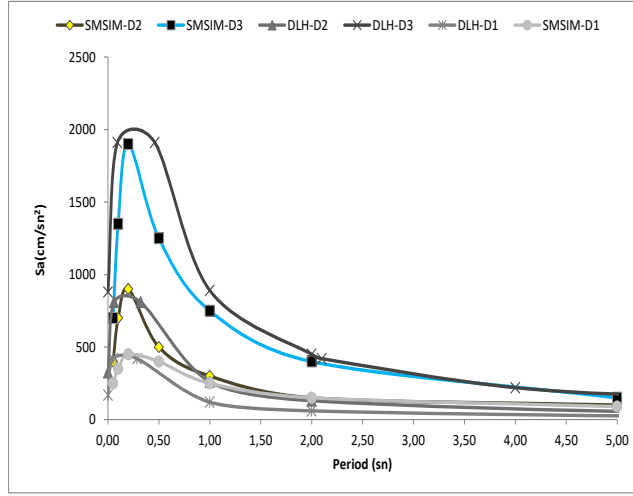


Figure 5. Uniform Hazard Response Spectrum-Engineering Rock Level (UHRs-İZMİR)

The results at different hazard levels are generally close to each other. This indicates a close relationship by the two methods, which serves a basic standpoint for us for further studies and development of site-specific ground motions.

2.5 Selecting and Scaling Time Histories

Earthquake records were selected from the PEER (2010) ground motion database in accordance with the characteristics of active faults in the region so that they represent target DLH D1, D2 and D3 acceleration spectra. Soil profiles with varying thickness and features were used in the analyses. These are; the engineering rock level ($V_s \geq 760 \text{ m/sn}$).

The quantitative measure used to evaluate how well a time series conforms to the target spectrum is the mean squared error (MSE) of the difference between the spectral accelerations of the record and the target spectrum, computed using the logarithms of spectral period and spectral acceleration.

The mean squared error – MSE - between the target spectrum and the response spectrum of a recorded time series is computed in terms of the difference in the natural logarithm of spectral acceleration. The period range from 0.01 second to 10 seconds is subdivided into a large

number of points equally-spaced in $\ln(\text{period}, T_i)$ (100 points/log cycle, therefore 301 points from 0.01 second to 10 seconds, end points included) and the target and record response spectra are interpolated to provide spectral accelerations at each period,

$$MSE = \frac{\sum_i W(T_i) \{ \ln[SA^{hedef}(T_i)] - \ln[f x SA^{kayit}(T_i)] \}^2}{\sum_i W(T_i)} \quad [10]$$

The parameter f is the linear scale factor applied to the time history. $W(T_i)$ is the linear weight factor that will be applied to different periods, which is generally taken is $w(t_i) = 1$.

Each earthquake record is scaled with a single scale factor (f). It is determined from the selected records to minimize the difference between spectral accelerations and target values for a specified period range. In these circumstances, f can be defined as below:

$$\ln f = \frac{\sum_i W(T_i) \ln \left(\frac{SA^{hedef}(T_i)}{SA^{kayit}(T_i)} \right)}{\sum_i W(T_i)} \quad [11]$$

The records selected from PEER database were listed based on the magnitude, fault mechanism, distance and time considerations. The selected and scaled earthquake records are given in table 1 below.

Table 1. Selected Earthquake Records

Earthquake	Moment Magnitude (Mw)	Fault Mechanism	Station	Horizontal-1	Horizontal-2	MSE	f (Scaling Factor)
Tabas, İran	7,35	Ters Atımlı	Tabas	T-LN	T-TR	0.05	0.185
Irpinia, İtalya 1980	6.90	Normal	Auleta	Irp-000	Irp-270	0.06	3.08
Loma Prieta	6.93	Reverse-Oblique	San Francisco-Sierra	SF-115	SF-205	0.08	2.48
Northridge	6.69	Ters Atımlı	Antelope Buttes	Nr-00	Nr-90	0.04	4.52
Kocaeli, Türkiye	7,51	Doğrultu Atımlı	Tekirdağ	K-90	K-180	0.14	5.23
Northridge-01	6.69	Ters Atımlı	Lake Hughes	LH-00	LH-90	0.09	3.22
Duzce	7,14	Doğrultu Atımlı	Lamont531	D-E	D-N	0.10	1.53

3 SITE RESPONSE ANALYSES

Site response analysis methods can be classified by the domain in which calculations are performed (frequency domain or time domain), the sophistication of the constitutive model employed (linear, equivalent linear, and/or nonlinear), whether effects of pore water pressure generation are neglected or not (total stress and effective stress analyses, respectively), and the dimensionality of the space in which analysis is performed (1-D, quasi 2-D, 2-D, and 3-D). Other considerations in classifying site response analysis methods include modeling of cyclic reduction and degradation in a total-stress mode.

The ground response analyses were performed using the equivalent-linear viscous-elastic code EERA and the finite element (FEA) code PLAXIS 2D.

The code EERA is software, which is in spreadsheet format and has the ability to include unlimited dynamic soil models in soil response calculations by one-dimensional linear equivalent method. A damped linear elastic model and equivalent linear analyses are used to

demonstrate the non-linear behavior of the soil layers. The stress–strain properties of the soils are instructed by use of the relationships expressing the change of shear modulus and damping with the shear strain level. Modulus reduction curve G/G_0 and variation of damping ratio D with shear strain level were defined according to typical results reported in the literature (J.P.Bardet et.al., 2010) as a function of IP (Fig. 6).

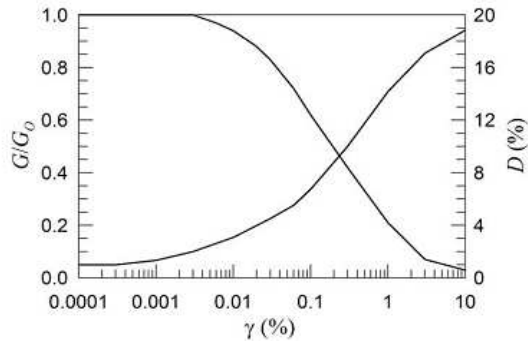


Figure 6. Modulus Reduction Curve G/G_0 and variation of damping ratio D with shear strain adopted in EERA

Plaxis software is used for the finite element analysis. The program can be solved with the finite element analysis and can be used in a variety of different cases. 15 noded triangular elements are used in the program. The finite element model used in the analysis can be seen in Figure 7. The system width is 400 m; height is 80 m. The calculated earthquake width/depth ratio is $d/h=5$, which is an acceptable way.

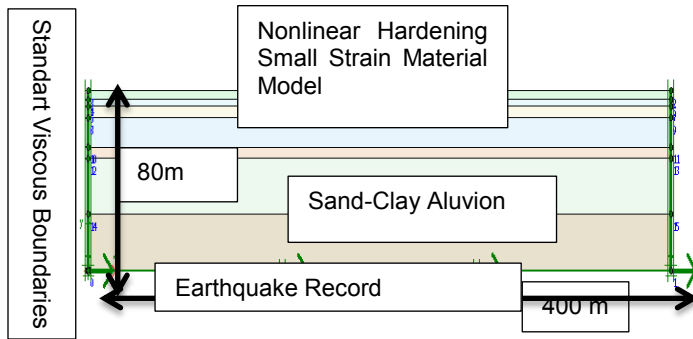


Figure 7. Finite Element Model used in the analysis

The soil profile consists of 300-350 meter depth alluvial soil profiles. The 80 meter depth of soil profile is taken into account in the analysis. The earthquake waves are transferred to 80 meter level by the equivalent linear soil program called the EERA program. Newton-Raphson methodology is followed for the solution of static finite element methods. Improved Newmark methodology is solved in the dynamic analysis. The nonlinear analysis is performed with the equal spaced time solutions.

$$M\ddot{u} + C\dot{u} + Ku = -M\ddot{u}_g \quad [12]$$

In the above equation $[M]$, $[C]$ and $[K]$ are mass, damping and rigidity matrices respectively. $\{u\}$, $\{\dot{u}\}$ and $\{\ddot{u}\}$ are the displacement, velocity and acceleration matrices for the

mass M body. The stiffness matrix is used in the material soil model and defines the soil nonlinear behaviour.

The amount of viscous damping is typically selected such that the sum of hysteric and viscous damping is equal to the total damping measured for the given soil type. The boundary conditions adopted for the static stages are standart ones: nodes at the bottom are fixed in horizontal and vertical directions, while those along the lateral sides were only fixed in the horizontal direction. In the dynamic analysis, the bottom of the mesh was assumed to be rigid and the lateral sides were characterized by the viscous boundaries proposed by Lysmer and Kuhlmeyer.

3.1 Case Study and Analysis Results

Acceleration time histories were recorded at strong ground motion stations located in different parts of Izmir during the 8 January 2013 $M_L=6.2$ Bozcaada earthquake (Kandilli Observatory). The stations and the peak ground accelerations are given in Table 2.

Table 2. Recorded Earthquake Records – 2013 Bozcaada Earthquake

İzmirNET Recording Station	PGA (m/s ²)	
	NS	EW
Bayındırlık	0,043	0,041
Bayraklı	0,016	0,014
Urla	0,023	0,024
Balcova	0,022	0,025
Pınarbaşı	0,013	0,013
Yesilyurt	0,016	0,017
Kaynaklar	0,012	0,009
Mavisehir	0,043	0,05

To calibrate the finite element model (FEA), the earthquake record from the Yesilyurt station will be further used as an engineering rock record with the Bayındır station with a 300-350 meter deep alluvion (Figure 8).

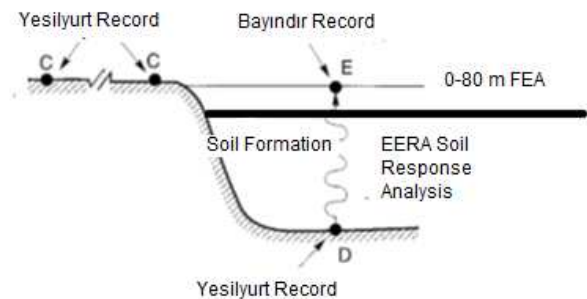


Figure 8. Model and Methodology Used in the analysis

The comparison of the selected time history from the surface and the rock outcrop is given in figure 9. In this figure a comparison with the nonlinear methodology and the one-dimensional site response methodology with the real record is given.

As the selected time histories are from the lateral recording stations, not the vertical arrays, a full conformity cannot be expected. The results are also based on the success of the choice of control motions (Stewart v.d., 2008). The distance of the control motions also have some effect on the final agreement of the results.

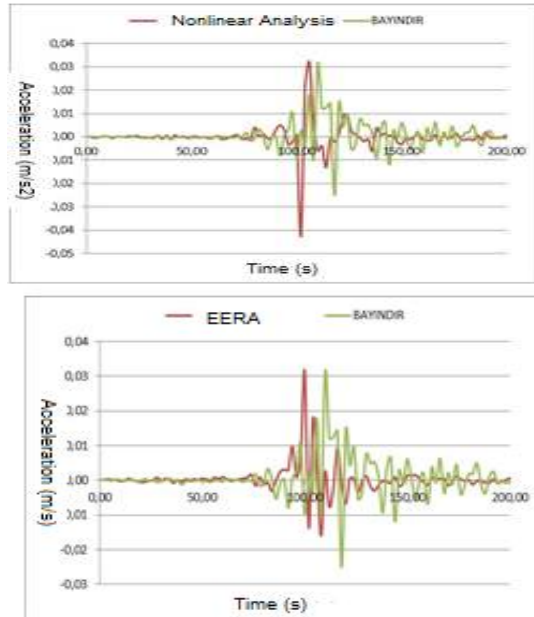
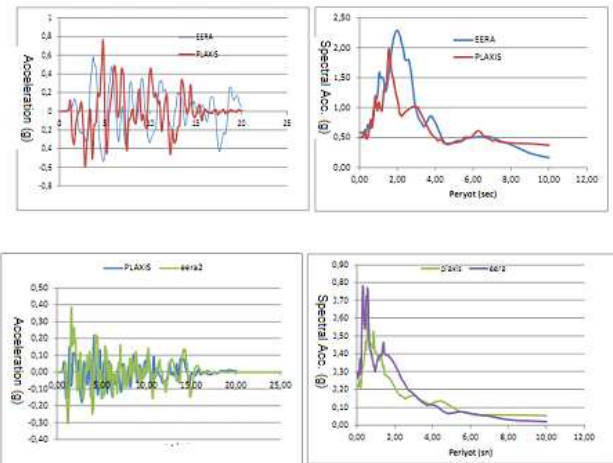


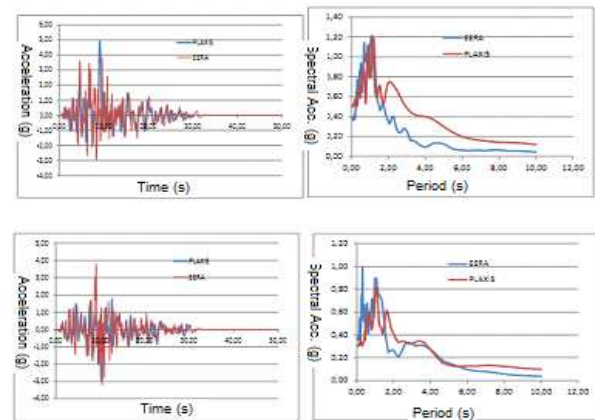
Figure 9. Comparison of Bayindir record Model and Methodology Used in the analysis

Idriss (1993), in his study with two different source motions having different distances, shows the different spectral values. In far away motions, the recorded high frequency components vanish away easily than the low frequency effects.

After calibrating the finite element model and the one-dimensional modal with the real record, in the context of the analysis, one-dimensional and two-dimensional analysis were also compared with the selected and scaled time histories gathered from the uniform hazard response spectrum. The response spectrum and the time histories gathered from one and two-dimensional analyses are given in the figure 10 below.



Northridge Records



Lome-Priata Earthquake

Figure 10. Comparison of 1D-2D results

Finn et.al. (1978) compared site response analysis using 3 different program (2 of them is nonlinear and 1 of them is linear Figure 11). The results by two nonlinear analyses are almost the same but Shake gives larger shear stress.

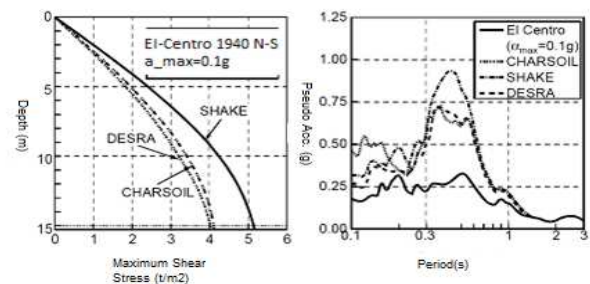


Figure 11. Comparison and related studies by Finn et.al. (1978)

Generally, equivalent linear analysis has a tendency to give larger peak acceleration and shear stress under large earthquakes, and lower amplification in high frequency range. The reason of the latter phenomena is resulting from the damping ratio evaluated from the effective strain which is too large for small amplitude (high cycle) vibration. This effect becomes predominant under small to medium earthquake, resulting in smaller acceleration.

The maximum shear stress values are seen to be unrealistically higher than the compared finite element results (Figure 12).

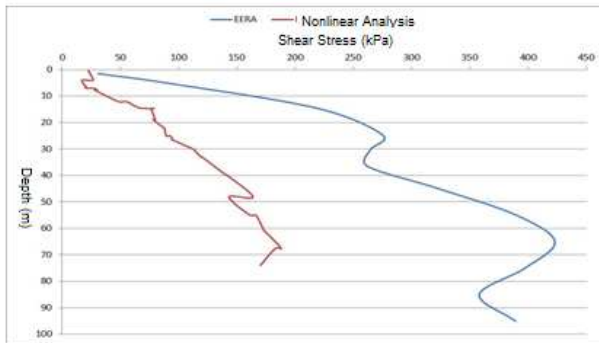


Figure 12. Shear stress comparison in equivalent linear analysis and nonlinear analysis

As can be seen in figure 13, the stress-strain curve of an equivalent linear analysis is the line OAC, in which case, the maximum stress at point C is unrealistically higher than that of the point B. This point clearly gives the reason why the equivalent linear analysis gives larger shear stress than the nonlinear analysis. The larger acceleration values of the program SHAKE begin to appear as the nonlinear behavior becomes predominant.

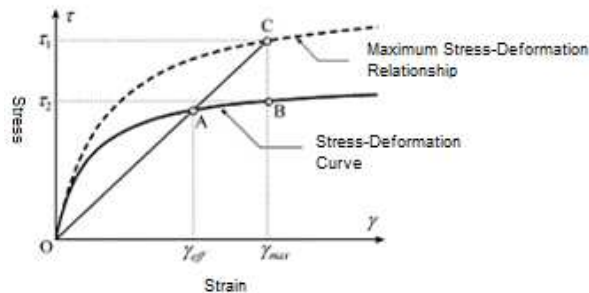


Figure 13. Shear stress comparison in equivalent linear analysis and nonlinear analysis (Yoshida et.al., 2002)

4 CONCLUSION

Site-specific ground response analysis is becoming to be widely used in projects under soft-soil conditions. The embedded procedures and methodologies are detailed in this paper. A random vibration theory is used for generating uniform response spectrum for the project site. The response spectrum is then compared with the code-based target spectrum. Time history ground motions are then selected and scaled based on the generated hazard spectrum.

Site-specific ground response analysis is performed with the selected and scaled time histories. The calculations are performed using both one-dimensional and two-dimensional analysis, therefore comparing the equivalent linear and nonlinear material models and different solution strategies. It is seen that, one of the important issues in specifying site-specific input design motion is to account for nonlinearity in site response, which is dependent on expected earthquake source and existing site characteristics. The effect of nonlinearity is to reduce the

amount of amplification. This phenomenon is due to the increase in hysteretic damping and degradation and softening in soils with strain level and accumulation.

It is believed that as strain increases, an increasingly hysteretic character of the stress-strain relationship in soils causes this phenomenon. At low strains, that is for the weak ground motion accompanying small earthquakes, the relationship is essentially linear and the amplification due to sediments is well understood in terms of linear elasticity, but for strong ground motions such as large earthquakes there has been always a debate on the associated amplification.

5 REFERENCES

- Akinci A., Ibanez J.M., Pezzo E.D., Morales J. (1995). Geometrical spreading and attenuation of Lg waves: a comparison between western Anatolia (Turkey) and southern Spain, *Tectonophysics*, 250:1–3, 47–60
- Ambraseys N.N. and Finkel C.F., (1995). Seismicity of Turkey and Adjacent Areas, Historical Review, 1500–1800, Eren Publications, Istanbul.
- Ansal, A.M. (1997). Design Earthquake Characteristics for Istanbul, Proceedings of Prof. Dr. Rifat Yazar Symposium, *Turkish Earthquake Foundation*, 1:233–244 (in Turkish)
- Ansal A. ve Tonuk G., 2007, Source And Site Factors In Microzonation, K.D. Pitilakis (ed.), *Earthquake Geotechnical Engineering*, 73–92.
- Berardi R., Áñez, M.J., Jime Z.G., Áñez M. G.-F., 2000, Calibration of stochastic finite-fault ground motion simulations for the 1997 Umbria-Marche, Central Italy, earthquake sequence, *Soil Dynamics and Earthquake Engineering*, 20 : 315–324p
- Boore D.M., Boatwright J. (1984). Average body-wave radiation coefficients, *Bulletin of the Seismological Society of America*, 74:5, 1615–1621.
- Boore D. M., 2003, Simulation of Ground Motion Using the Stochastic Method, *Pure Appl. Geophys.* 160 : 635–676 p
- Boore D. M., 2000, SMSIM – Fortran Programs for Simulating Ground Motions from Earthquakes: Version 2.0—A Revision of OFR 96-80-A, *U.S. Geol. Surv. Open-File Rept. OF 00-509*, 55 pp. (available at <http://geopubs.wr.usgs.gov/open-file/of00-509/>).
- Bogazici University, Kandilli Observatory and Earthquake Research Institute, *Earthquake Catalogue*
- Brune, J.N., 1970, Tectonic Stress and the spectra of seismic shear waves from earthquakes, *Journal of Geophysical Research*, Vol 75:4997–5009 p
- Carvalho A., Zonnob G., Franceschina G., Serra, J. Bile A. Costa Campos, 2008, Earthquake shaking scenarios for the metropolitan area of Lisbon, *Soil Dynamics and Earthquake Engineering*, 28 : 347–364p.
- Cong L. and Mitchell J.B., (1999). Lg Coda Q and Its Relation to the geology and tectonics of the Middle East, *Pure App. Geophys.*, 153, 563–585.
- Cornell, C.A. 1968, Engineering seismic risk analysis, *Bull. Seismological Soc. of America*, 58: 1583–1606p.
- DLH, *Earthquake Technical Regulations for the Construction of Coastal and Harbor Constructions and Railways*, 2008

- Ergin K. Guclu D. Uz Z., (1967). Earthquake Catalogue of Turkey (11-1964), *ITU Mine Engineering Faculty Publications* (In Turkish).
- Emre Ö., Özalp S., Doğan A., Özaksoy V., Yıldırım C., Göktaş F., 2005, Active faults in the vicinity of İzmir and their earthquake potential, Report No:10754, *Turkish General Directorate of Mineral Research and Exploration, MTA*, Ankara.
- Finn, W.D.L., Michael K.W.L. and Martin G.R., 1978, Comparison of Dynamic Analysis of Saturated Sand, *Proceedings of the ASCE Geotechnical Engineering Division, Specialty Conference on Earthquake Engineering and Soil Dynamics*, Pasadena, CA, June 19-21, 472-491 p
- Horasan G., Gulen L., Pinar A., Kalafat D., Ozel N., Kuleli H.S., Isikara A.M. (2002). Lithospheric Structure of the Marmara and Aegean Regions, Western Turkey, *Bulletin of the Seismological Society of America*, 92, 1, pp. 322–329
- Housner G.W., 1947, Characteristics of Strong motion earthquakes, *Bulletin of Seismological Society of America*, Vol 37, No 1:19-31p
- Han Sang-Whan, Choi Yeon-Soo, 2008, Seismic hazard in low and moderate seismic region-Korean peninsula, *Structural Safety*, 30: 543–558 pp.
- Idriss, I.M., 1993, Assessment of site response analysis procedures, *Report to National Institute of Standards and Technology*, Gaithersburg, Maryland, Dept. of Civil & Environmental Eng., Univ. of California, Davis
- J. P. Bardet, K. Ichii, and C. H. Lineera, 2010, EERA, A *Computer Program for Equivalent-linear Earthquake site Response Analyses of Layered Soil Deposits*
- Katsanos E.I., Sextos A.G., Manolis G.D., 2010, Selection of earthquake ground motion records: A state-of-the-art review from a structural engineering perspective, *Soil Dynamics and Earthquake Engineering*, 30:157–169p
- Kramer, S.L. (1996). *Geotechnical Earthquake Engineering*, Prentice Hall, Inc., Upper Saddle River, New Jersey, USA
- Mammo T., 2005, Site-specific ground motion simulation and seismic response analysis at the proposed bridge sites within the city of Addis Ababa, Ethiopia, *Engineering Geology*, 79: 127–150 p
- NIST - NEHRP Consultants Joint Venture 2012. *Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analyses*, Washington D.C., USA
- PEER, Guidelines for Performance-Based Seismic Design of Tall Buildings, *Developed by the Pacific Earthquake Engineering Research Center (PEER) as part of the Tall Buildings Initiative*, Report No. 2010/05, November 2010, Pacific Earthquake Engineering Research Center College of Engineering University of California, Berkeley.
- Plaxis 2D Scientific Manual, version 9.01. Delft University of Technology&PLAXIS B.V.
- Plaxis 2D Dynamics Manual, version 9.01. Delft University of Technology&PLAXIS B.V.
- Pulido N., Ojeda A., Atakan K., Kubo T., 2004, Strong ground motion estimation in the Sea of Marmara region (Turkey) based on a scenario earthquake, *Tectonophysics*, 391: 357– 374 p
- Sen, T.K., 2009, *Fundamentals of Seismic Loading On Structures*. John Wiley & Sons, Ltd, USA
- Sipahioglu S. (1984). Investigation of North Anatolian Fault Structure and Earthquake Intensity, *Earthquake Investigation Report*, 45, 1-139 (In Turkish).
- Wu C.L. and Wen Y.K., 1999, Uniform Hazard Ground Motions and Response Spectra for Mid-America Cities, *report on a Research Project Sponsored by NSF-MAE Center*,
- Yoshida, N., S. Kobayashia, I. Suetomia and K. Miura, 2002, Equivalent Linear Method Considering Frequency Dependent Characteristics of Stiffness and Damping, *Soil Dynamics and Earthquake Engineering*, Vol. 22, No. 3, pp. 205-222.
- Zafarani H., Noorzad A.A, Bargi A.K., 2009, Stochastic modeling of Iranian earthquakes and estimation of ground motion for future earthquakes in Greater Tehran, *Soil Dynamics and Earthquake Engineering*, 29: 722–741p