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Analysis of Local Site Effects on Seismic Ground Response under Various Earthquakes

A. Asakereh*, M.Tajabadipour

Department of civil engineering, Faculty of engineering, University of Hormozgan, Bandar Abbas, Iran

ABSTRACT: By assessment of induced damages to structures and major infrastructures, seismic geotechnical researchers have concluded that the site conditions significantly influence on the failure distribution in urban and rural areas. Consequently, to determine the characteristics of seismic motions of the ground, it is essential to study the effective geotechnical factors. In this study influence of local site effects and soil conditions on the intensity of ground motion are investigated with two methods (non-linear and equivalent linear methods) based on one dimensional shear wave propagation in soil layer theory. In this regard, some series of site response analyses which consider various input motions, geotechnical parameters of site and non-linear properties were performed. The comparisons demonstrated that non-linear method provides a more accurate characterization of the true non-linear soil behavior compared to the equivalent-linear procedures. The earthquakes with Peak Ground Acceleration (PGA) less than 0.1 g have the most increase in horizontal acceleration at the surface in comparison with the earthquakes with greater peak accelerations.

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1- Introduction

Historical studies from different earthquakes over the past 40 years have shown that local site effects and soil conditions can significantly influence on the intensity of ground movement and earthquake damages. Geotechnical site conditions can intensely affect the different parameters of strong ground-motion (e.g. amplitude, frequency and duration). The site effects should be considered when designating ground motion for seismic designs to prevent earthquake damage or decrease extent of the damage. Therefore, in the ground surveys performed before the construction of a building, it is necessary to examine how the layers, which constitute the ground under and around the proposed building, would behave during an earthquake. The extent of local site effect depends on the kind of soil deposit and material properties in sub-layers, site topography and specifications of the input motion. Thus, site response analyses for being knowledgeable about local site effects on strong ground motion are an influential initial step in the seismic evaluation of many geotechnical structures and soil–structure interaction problems. The dynamic response of soil deposits analyses is used to estimate surface acceleration time histories, surface acceleration response spectra, spectral amplification factors and displacements within the soil profile and liquefaction hazard analyses. One dimensional ground response analyses are often used for estimation of characteristics of ground motion response on the ground surface. Seismic ground response analyses for estimation of soil non-linearity can be divided into linear equivalent and nonlinear approaches.

Lists of widespread computer codes used to perform 1-D seismic site response analyses are reported by several authors [1-3]. Yu et al. (1993) used DESRA2 to examine the differences between linear and non-linear soil response to various levels of base excitations. By using this direct non-linear approach, they demonstrated that in strong excitations soil non-linearity causes de-amplification and also a shift in peak frequencies to lower values for an unsaturated shallow soil deposit of 20 m thickness [4]. Aguirre and Irikura (1997), Fukushima et al. (2000), and Frankel et al. (2002) have reported varying degrees of soil non-linearity, dependent on the site conditions, for the Hyogoken-Nanbu and Nisqually earthquakes [5-7]. Aschheim and Black (1999) studied the seismic response of degrading SDOF systems having prior damage (e.g. damage triggered by prior earthquake ground motions to the design-level earthquake) under a set of 18 earthquake ground motions with different ground motion features. Prior damage was modeled as a reduction in the initial stiffness assuming that residual displacements were negligible [8]. Rodriguez-Marek et al. (2001) indicated that soil depth is an important parameter in site response, and proposed a scheme for geotechnical characterization of sites, which included soil depth and stiffness [9].

Amadio et al. (2003) discussed about the effect of repeated earthquake ground motions on the seismic response of non-linear Single Degree of Freedom (SDOF) systems. The results showed that the response of simple structures under repeated earthquakes depends on the period of vibration, type of sequence and system's available ductility [10]. Pitilakis et al. (2004) identified soil type, stratigraphy and thickness,

Corresponding author, E-mail: asakereh@hormozgan.ac.ir

fundamental site period, and the average shear wave velocity up to bedrock, as the key parameters governing site response [11].

Sun et al. (2005) have shown that the site coefficients specified in the Korean seismic design code (adopted from UBC and NEHRP provisions) underestimate the amplification factor in the short period range while overestimates the amplification factor in the mid-period range; and are not applicable to the Korean Peninsula due to the large difference in the bedrock depth and the soil stiffness [12]. Mohamedzein, et al. (2006) studied the effect of alluvial deposits in Central Khartoum on the propagation of seismic motion parameters to the ground surface. The Equivalent-Linear Earthquake Response Analyses (EERA) Model was used to study the effect of local soil conditions on ground motion parameters [13]. Cavallaro et al. (2008) compared ground response of the Tito Scalo site in Southern Italy using non-linear models GEODIN and linear model EERA [14]. Yang et al. (2011) conducted a systematic investigation to understand the effects of permafrost on the ground motion characteristics using one-dimensional equivalent linear analysis. The results showed that the presence of permafrost can significantly alter the ground motion characteristics and it may not be wise to ignore the effects of permafrost on the seismic design of civil structures [15]. Phanikanth et al. (2011) studied the effect of local soil sites in modifying the ground response by performing one dimensional equivalent-linear ground response analysis for some of the typical Mumbai soil sites [16].

Goda (2012) looked at the non-linear response potential of main shock- after shock sequences from the K-NET and KiK-net databases for Japanese earthquakes. This study examined the validity of artificially generated sequences based on the generalized Omori's law using a probabilistic framework analysis. He also showed that the peak ductility demand ratio between the main shock-after shock sequences and main shock alone depends on the main shock magnitude [17].

Cadet et al. (2012) have proposed a methodology to normalize the site amplification factors with respect to a standard outcropping rock site in line with the present design codes, by applying two correction factors, namely, the depth correction factor and the impedance contrast normalization factor [18].

Zahedi-Khameneh et al. (2013) proposed a real-time prediction model of strong ground motions based on non-parametric wave type, in which an adaptive windowing technology is used to catch the dominant frequency of ground motions, and then a radial-basis function (RBF) network is incorporated to predict next time step acceleration of earthquake record [19].

Zhai et al. (2013) studied the damage spectra for the main shock-after shock sequences with Park-Ang damage index. The proposed damage spectra in their work were computed using the recorded and simulated earthquake ground motions [20]. Ruiz-Garcia et al. (2014) investigated the effect of soft soil seismic sequences on the response of reinforced concrete frame buildings in terms of peak and residual lateral inter-story drift demand. They employed two sets of artificial seismic sequences and showed that the building seismic response depends on the ratio of damage period of vibration to the dominant period of the aftershock [21].

Nagashima et al. (2014) showed the effects of soil non-linearity on the horizontal-to-vertical spectral ratio (HVSR) of the observed ground motions [22]. Han et al. (2015) presented a methodology to examine the seismic performance of non-ductile reinforced concrete buildings with highlighting of the interaction between the aftershocks and various post-quake decisions [23]. Hashash et al. (2015) investigated the response of an equivalent 26 m-thick deposit of Nevada Sand under six horizontal earthquake motions in the centrifuge. The results revealed that 1-D seismic site response analyses used for medium-density dry sand can reliably compute soil response [24]. Stamati et al. (2016) studied the effects of local site conditions on earthquake ground motion for the city of Xanthi, North-Eastern Greece, focusing on the influence of complex site effects and soil non-linearity. Comparisons between 1D and 2D analyses, indeed, revealed differences on the estimated ground motion, implying complex site effects [25]. Mianshui Rong et al. (2016) utilized strong ground motion records from the main shocks and aftershocks of the 2008 Wenchuan (Ms 8.0) and 2013 Lushan (Ms 7.0) earthquakes for studying the horizontal-to-vertical spectral ratio (HVSR).The results demonstrated that the spectral ratios from 1-D simulation for the inverted soil models agree quite well with the observed HVRSs [26].

The purpose of this study is to develop a comprehensive influence of soil behavior model based on geotechnical aspects. The properties and dynamic behavior of the quaternary alluvial soils in the studied area were assessed using geotechnical and geophysical data gathered from 6 boreholes. One-dimensional dynamic site response analyses were performed with an Equivalent-linear Earthquake site Response Analysis (EERA) and Non-linear Earthquake site Response (NERA) software by using the simulated earthquake time histories.

2- Earthquake Ground Motion

The ground motion is one of the important tools for the design of civil engineering structures. Ground motion parameters are commonly described as specification of strong ground such as amplitude, frequency content, and duration of strong ground motions. Ground motion usually can be described with acceleration and this parameter can be measured directly by use of the time history of ground motion. However, the other parameters such as velocity and displacement also can be used. The maximum absolute values of acceleration, velocity and displacement describe the intensity of the ground motion at a different frequency band. The Peak ground acceleration (PGA) is one of the main components of an accelerogram.

2- 1- Input Motion

The recorded ground motions were obtained from the PEER database. The recorded strong motions are used as outcrop strong motions on hard rock or stiff soil (NEHRP site class A/B). In this study, twelve earthquake motions with different parameters are used to cover a wide range of amplitudes (e.g. Arias Intensities, and peak ground accelerations, PGA), frequency contents (e.g. predominant periods, Tp), and durations. However, the main purpose of this paper is studying the peak ground accelerations (PGA) in the surface of the ground. In this regard, three types of recorded ground motions were used to the maximum acceleration in a range of 0.001 to 0.1g (type I), 0.1 to 0.3g (type II) and 0.3 to 0.8g (type III). Determination of peak ground acceleration at a certain zone depends on the earthquake magnitude and epicenteral distance. Earthquake magnitude (M) certainly affects the spectral amplification and the acceleration amplification for earthquakes with 6<M<7 is more than the amplification for earthquakes having magnitude within 5<M<6 [27]. In this study, earthquake motions are selected with the magnitude within 6 to 8. The properties of the selected base motions are summarized in Table 1. The acceleration time histories of the recorded motions of different earthquakes at the outcrop are shown in Figures 1-3.

Table1. Input ground motion properties

Event	year	MW	Station name	Recording identifier	PGA (g)	Vs	Group no.
Denail	2002	7.9	“Valdez - Valdez City Hall”	DENALI_VALCH090	0.0087	709	1
Hector Mine	1999	7.13	“LA - Griffith Park”	HECTOR_GPO090	0.0163	1015	1
El Mayor	2010	7.2	“Toro Canyon”	SIERRA.MEX_TOR360	0.0026	1100	1
Morgan Hill	1984	6.19	“Gilroy Array #1”	RSN455_MORGAN_G01230	0.0942	1428	1
Whittier Narrows	1987	6	“LA - Wonderland Ave”	RSN643_WHITTIER.A	0.0414	1222	1
Tottori	2000	6.61	“HYG004”	RSN3893	0.0198	834	1
Chi Chi	1999	7.62	“TAP077”	CHICHI_TAP077-N	0.1378	1022	2
Kobe	1995	6.9	“Kobe University”	KOBE_KBU000	0.2758	1043	2
Northridge	1994	6.69	“LA - Chalon Rd”	RSN989_NORTHR_CHL070	0.215	740	2
Parkfield	2004	6	“PARKFIELD - TURKEY”	RSN4083	0.2453	906	2
Loma Prieta	1989	6.93	“Los Gatos - Lexington Dam”	RSN3548_LOMAP_LEX000	0.442	1070	3
Tabas	1978	7.35	“Tabas”	TABAS_TAB-T1	0.854	766	3

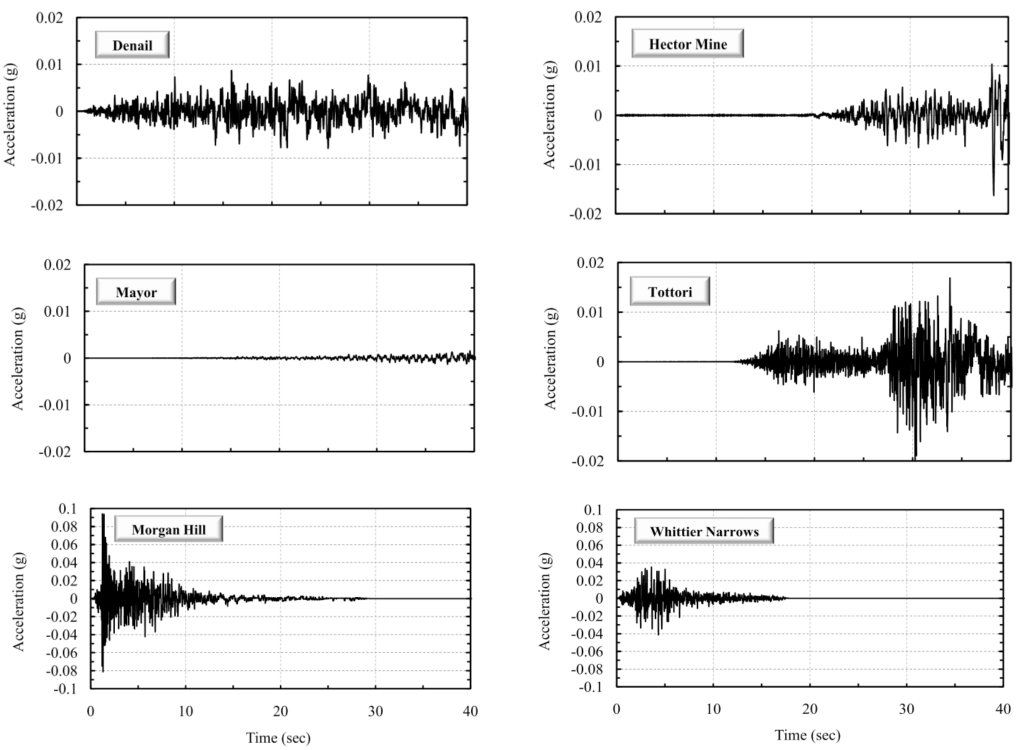


Figure 1. Ground motion acceleration time-history of type I

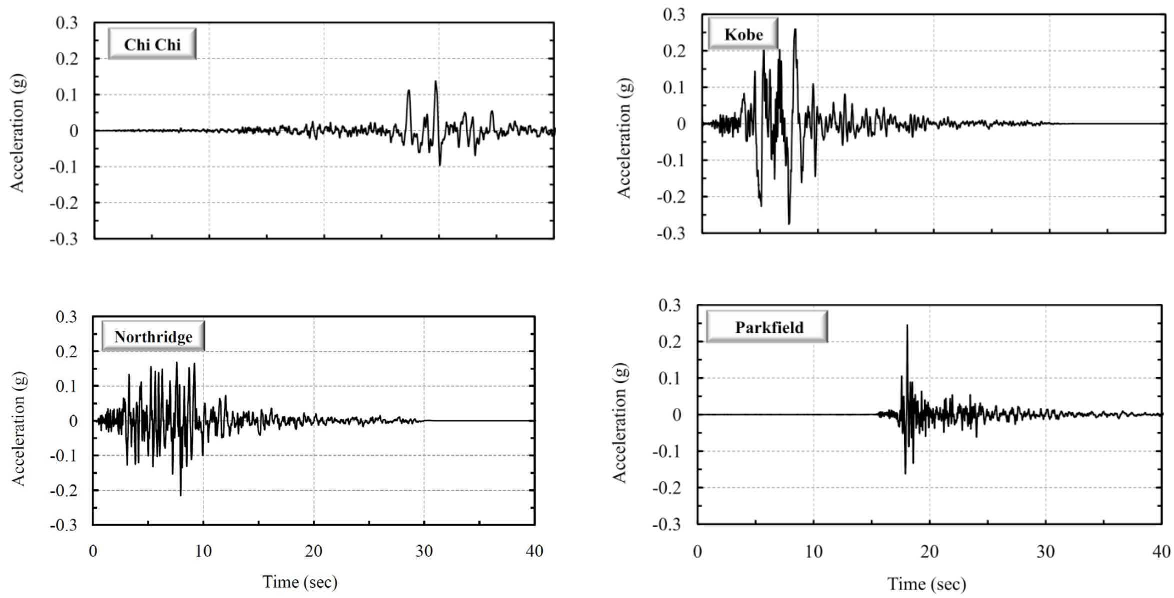


Figure 2. Ground motion acceleration time-history of type II

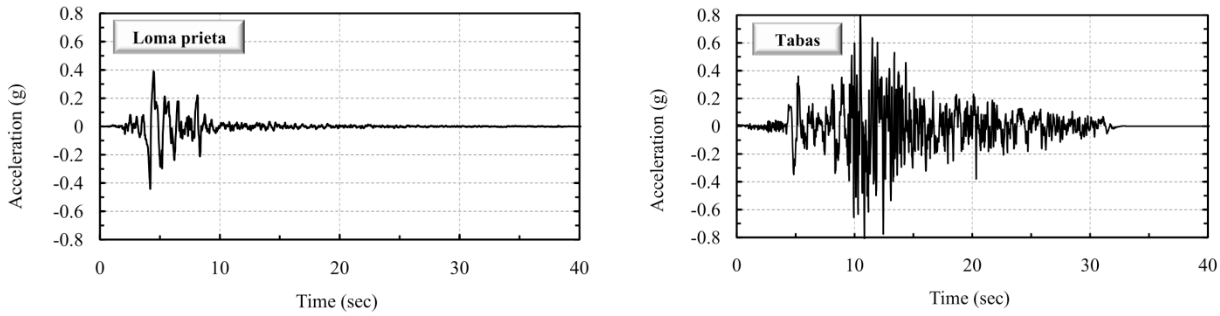


Figure 3. Ground motion acceleration time-history of type III

2- 2- Classification of near field and far field earthquake

In the numerical analysis of this study the following earthquake registers have been considered:

- Denail, recorded in a far-field area.
- Hector Mine, recorded in a far-field area.
- El Mayor, recorded in a far-field area.
- Morgan Hill, recorded in a near-field area.
- Whittier Narrows, recorded in a far-field area.
- Tottori, recorded in a far-field area.
- Chi Chi, recorded in a far-field area.
- Kobe, recorded in a near-field area.
- Northridge, recorded in a near-field area.
- Parkfield, recorded in a near-field area.
- Loma Prieta recorded in a near-field area.
- Tabas, recorded in a near-field area.

In case of near-field motion, that is when the monitoring station is located in the area of fracture propagation of the fault, the registers are significantly different from the usual ones recorded in areas away from faults (far-field). In near-field areas the component of the motion normal to the fault is impulsive, with a high pulse period of acceleration [28-30]. The differences between near-field and far-field areas can be summarized in the following points:

- The direction of propagation of the fault has a major influence in a near-field area, the stratification of the soil having minor effects. On the contrary, in case of far-field zone, the stratification of the soil and site conditions are of primary importance for the horizontal components of the seismic waves.
- In near-field areas the ground motion time-history acceleration plot shows a pulse in the field of low frequencies and a pronounced pulse in the velocity and displacement time-histories. In this case, the motion is of short duration; on the contrary, in far-field areas, the acceleration, velocity and displacement recordings have the characteristic of a cyclical movement, with a long-lasting action [30, 31].
- In near-field areas there are very high velocities; in such areas the velocity appears to be the most significant parameter in the design, replacing the acceleration, which represents the most significant parameter in the design in far-field areas.
- In contrast to what happens in far-field zones, in near-field areas vertical components may be higher than the horizontal ones [32, 33].

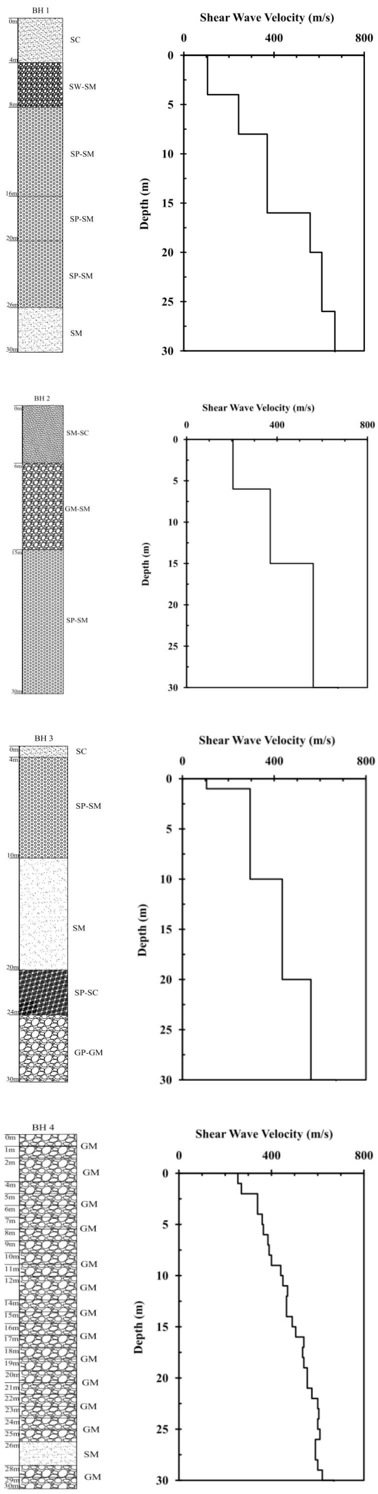


Figure 4. Bore Hole from different site (Type I sandy)

3- Geotechnical Characterization of the Site

Geotechnical bore-holes were selected in six different sites with various geotechnical specifications to determine the subsurface layering characteristics. The depth of the bore-hole was limited to at most 30 m as the Iranian code requirement (Standard 2800). The bore-holes are drilled in Hormozgan and Kerman province and in Haji Abad, Qeshm and Bam city. The sediments in Bam are yellow to brown sand and silt, coarse grain, brown gravel deposits of flooded plains, coarse grain gravel of alluvial fans and coarse grain deposits of the rivers. Figure 4 shows geotechnical parameters of soil in the Bam city (BH 1-3). Hormozgan Province is one of the 31 provinces of Iran. It is in the south of the country, in Iran's Region 2, facing Oman and UAE. Qeshm and Hajiabad are important cities of Hormozgan province. Qeshm Island is located a few kilometers off the southern coast of Iran (Persian Gulf).The most important geological structures of this island, have east-west or northeast-southwest strike. Various deposits with Upper Precambrian to Quaternary age have profiles at the island surface. Figure 5 shows geotechnical parameters of soil in the Qeshm city (Figure 5, BH 5, 6). The Haji Abad county is located about 100 km north of Bandar Abbas (the central city of Hormozgan Province). The county is divided into three districts: the Central District, Fareghan District, and Ahmadi District. The sediments in Haji Abad are coarse grain brown gravel (Figure 4, BH 4).

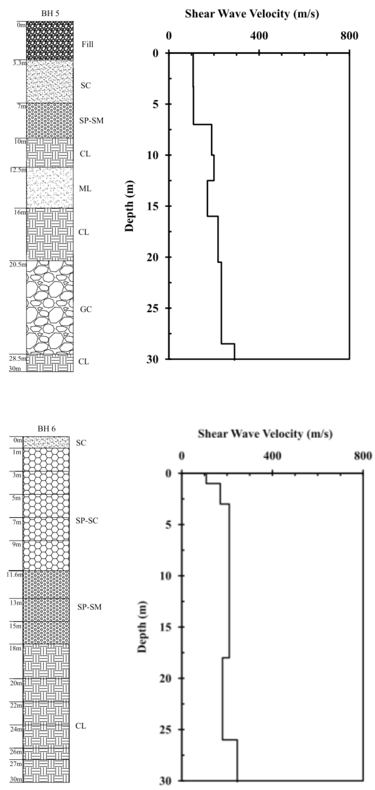


Fig.5.Bore Hole from different site (Type II sand & clay)

3- 1- Dynamic Soil Properties

Site response analysis requires information on dynamic soil properties which control the response of a site to seismic excitation. These properties are shear wave velocity (VS), soil density, shear modulus at low strain (G0), G/G0–γ (G is the shear modulus and γ is the shear strain) and D– γ (D is damping) curves. The dynamic soil properties were estimated from in-situ measurements (e.g. Standard Penetration Test, down-hole seismic survey) together with complimentary laboratory tests. In this study, shear wave velocity is measured based on in-situ geophysical test with spectral analysis of surface waves (SASW) method. The soil profiles were modelled for site response analyses (profiles shown in Figures 4 and 5). Mean weighted value for Vs are computed for each site (borehole) according to the following formula:

$$Vs=(\sum_{i=0}^{n} h_i)/(\sum_{i=0}^{n} h_i /V_{Si}) \qquad (1)$$

In equation Equation 1, hi and V_{Si} denote the thickness (in meters) and the shear-wave velocity (in m/s) of the i-th layer.

The shear modulus, G, was determined from the measured shear wave velocities, Vs, i.e.

$$G=V_s^{2}\,\gamma_s /g \qquad (2)$$

Where γ_s is soil unit weight.

The G/G0 –γ and D–γ curves are usually obtained through laboratory cyclic loading tests. However, such experimental data were not available for the soils studied in Hormozgan provide and Bam city. Accordingly, degradation curves (G/G0 – γ and D– γ) have been allocated based on soil types and their index properties and the empirical relations (e.g. Idriss (1990), Vucetic and Dobry (1991), Seed et al. (1996), and Darendeli (2001)). These relations allow the determination of G/G0–γ and D–γ curves in terms of the plasticity index, PI, and the mean effective normal stress, σ´0, of a soil element. In this study, the degradation curves for six sites were accomplished by using the SHAKE program (SHAKE91 1992). The main sets of curves are shown in Figures 6- to 9.

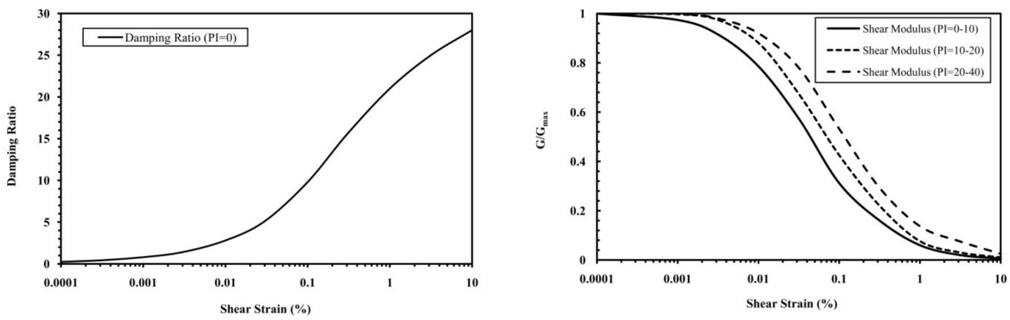


Figure 6. Modulus reduction and damping curves for CL materials

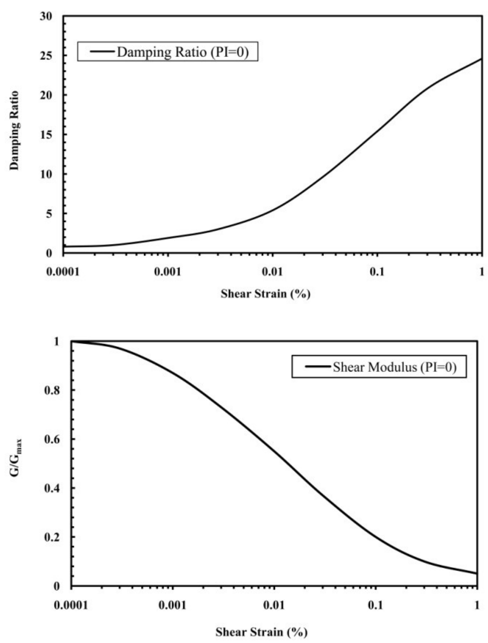


Figure 7. Modulus reduction and damping curves for GP&GM materials

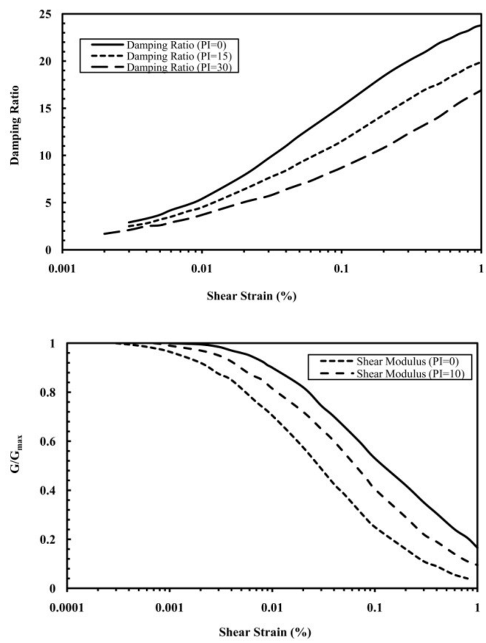


Figure .8. Modulus reduction and damping curves for SC-GC materials

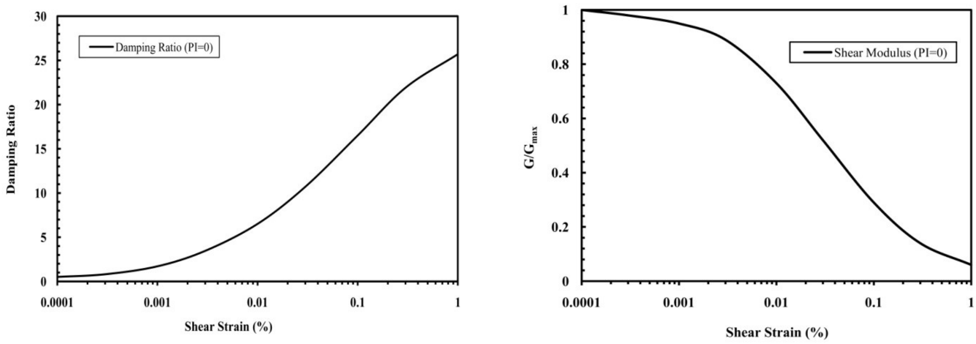


Figure 9. Modulus reduction and damping curves for SP&SW materials

3- 2- Validation of numerical model

The Treasure Island site is one of the rare sites, which has a nearby rock outcrop which facilitates direct comparison of motion at rock outcrop and soil surface and determination of the site amplification factors, empirically. In this study, the Loma Prieta earthquake recorded at the Treasure Island has been used as the control motion at the rock outcrop for the numerical ground response analysis. The 5% damped response spectrum obtained using site response analysis of the Treasure Island site for the rock crop motion recorded during the Loma Prieta earthquake is shown in Figure 10 along with the experimentally observed response spectrum for the same earthquake. The obtained response spectrum is in good agreement with the spectrum of the recorded motion in Treasure Island.

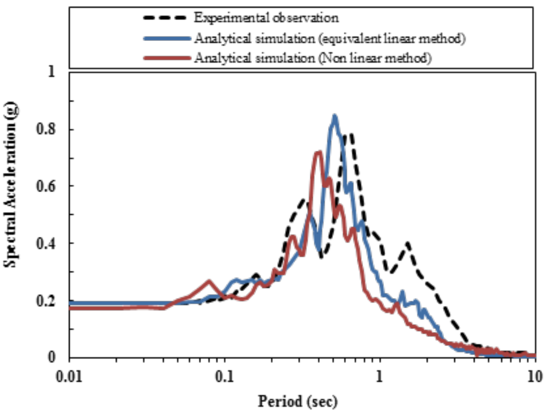


Figure 10. Comparison of observed and numerically obtained 5% damped acceleration response spectra at Treasure Island, for Loma Prieta earthquake

3- 3- Equivalent Linear Method

Since the non-linearity of soil behavior is well known , the linear approach must be modified to provide reasonable estimates of ground response for practical problems of interest. The equivalent linear shear modulus , G, is generally taken as a secant shear modulus and the equivalent linear damping ratio, ξ ,as the damping ratio that produces the same energy loss in a single cycle as the actual hysteresis loop. Since the linear approach requires that G be constant for soil layer, the problem becomes one of determining the values that are consistent with the level of strain induced in each layer. Since the computed strain level depends on the values of the equivalent linear properties, an iterative procedure is required to ensure that the properties used in the analysis are compatible with the computed strain levels in all layers. The iterative procedure operates as follows:

1. Initial estimates of G and ξ are made for each layer. The initially estimated values u suallyusually correspond to the same strain level; the low strain values are often used for the initial estimate.
2. The estimated G and $\xi$and ξ values are used to compute the ground response, including time histories of shear strain for each layer.
3. The effective shear strain in each layer is determined from the maximum shear strain in the computed shear strain time history. For layer j

$$\gamma_{effj}^{(i)}=R_{\gamma}\,\gamma_{max\ j}^{(i)} \tag{3}$$

Where the superscript refers to the iteration number and R_{γ} is the ratio of the effective shear strain to maximum shear strain. R_{γ} depends on earthquake magnitude (ldriss and Sun, 1992) and can be estimated from

$$R_{\gamma}=(M-1)/10 \tag{4}$$

4. From this effective shear strain, new equivalent linear values, $G^{(i+1)}$ and $\xi^{(i+1)}$ are chosen for the next iteration.
5. Steps 2 to 4 are repeated until differences between the computed shear modulus and damping ratio values in two successive iterations fall below some predetermined value in all layers. Although convergence is not absolutely guaranteed, differences of less than 5 to 10% are usually achieved in three to five iterations (Schnabel et al., 1972).

3- 4- Non-linear Method

Soil behavior is non-linear when shear strains exceed about 10-5 (Hardin and Drenvich, 1972). The non-linear behavior of soils is the most important factor in ground motion propagation and should be accounted for when soil shearing strains are expected to exceed the linear threshold strain. In site response analysis, soil properties including shear modulus and cyclic soil behavior are required. Shear modulus is estimated using field tests such as seismic down-hole or cross- hole tests. Cyclic soil behavior is characterized using laboratory tests such as resonant column, cyclic triaxial or simple shear tests. Instead of defining the actual hystersishysteresis loop, the cyclic soil behavior is often represented as shear modulus degradation and damping ratio curves. The shear modulus degradation curve relates secant shear modulus to cyclic shear strain, whereby shear modulus is normalized by the maximum or initial shear modulus.

By consideration a uniform soil layer lying on an elastic layer of rock that extends to infinite depth and the subscripts s and r refer to soil and rock, the horizontal displacement due to vertically propagation harmonic S wave in each material can be written as:

$$u_s\,(Z_s,t)=A_s e^{i(\omega t+Ks^*\,Zs)}+B_s e^{i(\omega t-Ks^*\,Zs)}$$
$$u_r\,(Z_r,t)=A_r\,e^{i(\omega t+Kr^*\,Zr)}+B_s\,e^{i(\omega t-Kr^*\,Zr)} \qquad (5)$$

u: displacement, ω: circular frequency of the harmonic wave, k^*: complex wave number

No shear stress can exist at the ground surface (z_s=0), so

$$\tau_{(0,t)}=G\gamma_{(0\,,t)}=G\ \partial u(0,t)/\partial Z \qquad (6)$$

Where G is the shear modulus of the soil. G can be driven from the below equation:

$$\tau=G\gamma+\eta\ \partial\gamma/\partial t \qquad (7)$$

Where η is media of viscosity. By substituting the above equations we can get the numerical formulation for response analysis which can solve in frequency or time domain.

The motion at any layer can be easily computed from the motion at any other layer (e.g. input motion imposed at the bottom of the soil column) using the transfer function that relates displacement amplitude at layer i to that the layer j:

$$F_{ij}\,(\omega)=|u_i\,|/|u_j|=(a_i\,(\omega)+b_i\,(\omega))/(a_j\,(\omega)+b_j\,(\omega)\,) \qquad (8)$$

4- Results and Discussion

A set of equivalent linear (EQL) and non-linear (NL) site response analyses, using the six sites with different geotechnical specifications was carried out in order to evaluate the influence of the site respond on the parameters of ground motion. The difference between NL and EQL analyses is compared to information (PGA, spectral acceleration) at the surface.

4- 1- Peak Acceleration at Ground

The peak acceleration at the ground surface for each location is obtained from ground response analysis with two methods of NL and EQL. The values of acceleration at bed rock are presented in the tableTable .1 which is between 0.0- and 0.8g.

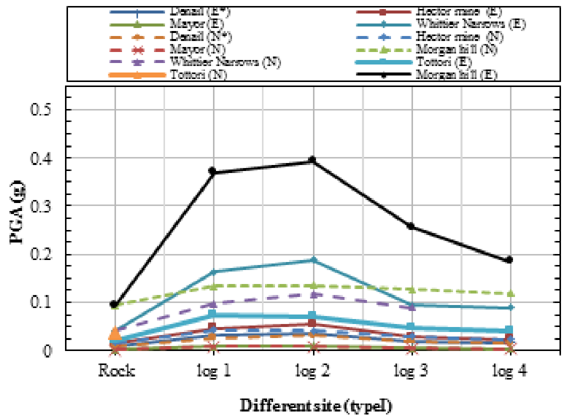
In order to analyze the site effect for different geotechnical and seismic conditions, the ground response has been analyzed using two different sites and three different earthquake types employing equivalent linear and non-linear methods. In this regard, selection of earthquakes to study is based on maximum horizontal acceleration as follows:

- Type I: the earthquakes with PGA less than 0.1g
- Type П: the earthquakes with PGA between 0.1-0.4g
- Type Ш: the earthquakes with PGA more than 0.4g

Figure 11 shows the maximum horizontal acceleration for earthquakes with acceleration less than 0.1g and granular site. For all earthquakes with acceleration less than 0.1g)Denail, Hector Mine, Mayor, Morgan Hill, Whittier Narrows, Tottori (and for both equivalent linear and non-linear methods, their maximum acceleration has increased after crossing the granular logs)BH1, BH2, BH3, BH4(. This is in good agreement with the results of Seed 1989.

It must be noted that the amount of increment is different for various earthquakes which is inevitable since the utilized earthquakes have different frequency content, amplitude and duration and this study only aims to investigate the effects of several soil types with different stratification (layering).

The selected earthquakes with PGA less than 0.01g have the maximum increase in horizontal acceleration at the ground surface. This trend is 2.5 times on average for various sites and the increment is more than earthquakes with higher acceleration. The nonlinear method presented the maximum acceleration values less than the linear method and the values of acceleration increment for all cases have decreased in nonlinear method. This can be attributed to the larger amplification of the motion components characterized by frequencies close to the predominant frequencies of the adopted seismic motions. Among these cases, the acceleration decrease is significant for the Morgan Hill earthquake with the highest horizontal acceleration in the bedrock (Figure .11).



* Denote: E=Equivalent linear method & N=Non linear method

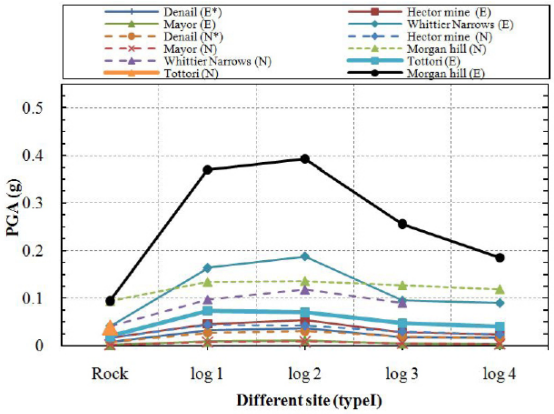
Figure 11. Ppeak ground acceleration for earthquake type I

The difference between the results of equivalent linear and non-linear methods for various sites and earthquakes is different, but on average it is about 13% of earthquake and sites of type I.

Among the sites of type I, the maximum amount of acceleration increase is related to site II, which is made of silty sand of high thickness and a silty gravel layer in-between. The site I is thoroughly sandy while the site III is made of a gravel layer in addition to sandy materials. For all earthquakes, the first type of sites has caused the acceleration increment more than the third site type. Among the studied sites, the site IV which is made of layered gravel material has the lower maximum acceleration relative to the other sites. The reason seems to be the gravel material's characteristics and their high Attenuationattenuation. Regarding the obtained results, one can infer that the layered sites increase the maximum horizontal acceleration at the ground surface less than the other types (Figure .11).

The two sites I and II have approximately the same geotechnical parameters but the layering is different. For type I earthquakes, the thickness of the layers has had a slight increase in PGA, and with increasing earthquake acceleration the surface acceleration in a site with a greater thickness has increased. For earthquakes of type II and III, sites with less thickness than the second site have less acceleration, which means that the different layers cause more damping.

In the next section, the earthquakes with an acceleration range of 0.1g to 0.4g, (Parkfield, Chi Chi, Kobe, Northridge) is investigated. For both of equivalent linear and non-linear methods, the values of maximum horizontal acceleration at the surface have become more than the same value at the bedrock. Using the equivalent linear method, site I has the most influence on increasing the horizontal acceleration. This finding is in conformity with site II, using nonlinear method (Figure .12). According to the results, it seems that by increasing the maximum horizontal acceleration in the bedrock, the acceleration at the surface increases more and this result is more significant for bore hole I and II. The non-linear method has lower values (16% difference in average) in comparison with the equivalent linear method. It should be noted that these methods have resulted in different values of different ratios for site I and II.



* Denote: E=Equivalent linear method & N=Non linear method

Figure 12. Ppeak ground acceleration for earthquake type II

Additionally, for Tabas and Loma prieta earthquakes, after applying geotechnical logs, the maximum horizontal acceleration in equivalent linear method for all sites have increased which is more obvious for site I. By equivalent linear method, the maximum and minimum increase in acceleration occurs for site I and II respectively. On the other hand, the non-linear method has resulted in different values for different earthquakes. As an example, considering the Loma earthquake with maximum horizontal acceleration of 0.442g in bedrock, different amount of increase in acceleration are obtained from different sites. However, for the Tabas earthquake, using the non-linear method one can see the decrement by the amount of maximum horizontal acceleration at the surface for sites I, II, III and an increment for site IV (Figure .13).

For earthquakes of type II and III, sites with less thickness than the second site have less acceleration, which means that the different layers cause more damping. In fourth site, due to the fact that the entire site is composed of gravel, and due to its layering and damping, more significant reductions were achieved in reducing the acceleration compared to the first and second sites. It is noteworthy that site III according to it has similar conditions to sites I and II, but it has been slightly less accelerated, and this may be due to a sandy layer near the bedrock.

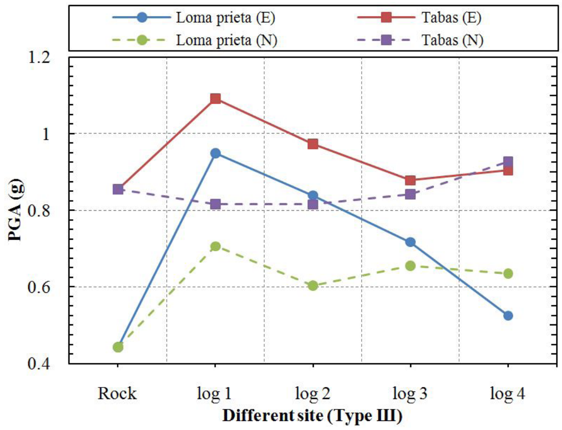


Figure 13. Ppeak ground acceleration for earthquake type III

The effects of site V and VI for all earthquakes have been illustrated in Figure 14. In the equivalent linear method for both sites and for all earthquakes (except Tabas earthquake), the maximum horizontal acceleration at the surface has increased which is noticeable for site V.

The Morgan Hill earthquake for all sites has greater values of PGA relative to the earthquakes of the same group. For both linear and non-linear methods, Tabas earthquake has a less acceleration than the bedrock for site conditions V, VI.

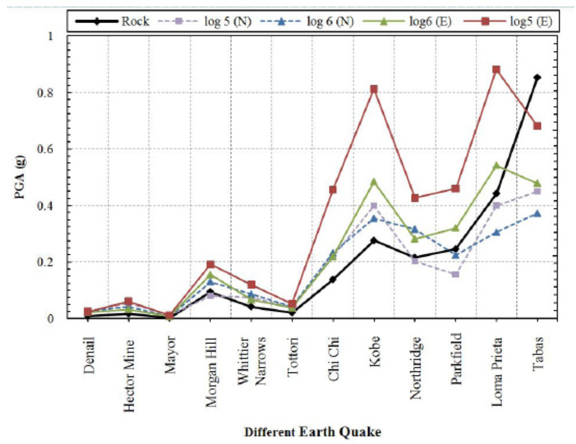


Figure 14. Peak ground acceleration for site V and VI

4- 2- Spectral Acceleration Computed for 30 m Depth Models

In this part of the article a comparison between three types of earthquake response spectra at surface level for 5% damping was carried out with two methods of equivalent linear (EQL) and non-linear (NL). This comparison is between maximum acceleration (previous section) and spectral acceleration.

4- 2- 1- Spectral Acceleration Response for Earthquake Type I

This study attempts to analyze the ground response under different earthquakes for sites with different geotechnical characteristics and to determine the site effect on the properties of parameters of strong ground motions. In this regard, the site effect on maximum horizontal acceleration at the surface was evaluated in the previous section. In this section the site effect for different earthquakes on the acceleration response spectrum is investigated.

Figure 15 shows the site effect for earthquakes with acceleration less than 0.1g for0.1g for all studied sites based on the equivalent linear and non-linear methods. Among the six studied earthquakes, the Morgan Hill earthquake has the greatest response spectrum, which is different for various boreholes.

The mentioned result of Morgan Hill earthquake was evaluated among the six earthquake with the PGAs less than 01g. The effects of the near and far field also affect evaluating the site response.

The least value of response spectrum corresponds to the Mayor earthquake which comprised of too small values (less than 0.05g). For all earthquakes, site I has the highest value of response spectrum. It should be noted that sites I and II include a wide range of frequencies (or periods) which increase the probability of resonance phenomenon (Figure .15). In the response analysis using the non-linear method, lower values of response spectrum is obtained for different earthquakes and sites relative to the equivalent linear method. This result may be due to different strains created and for low shear strain levels (produced by weaker excitations) the two approaches provide quite similar results. However, as the level of excitation increases, EQL approach tends to estimate, for the entire range of periods, a larger amplification relatively to that estimated by the non-linear approach. for For example for mayorMayor, denailDenail, hector Hector mine, tottori Tottori the results of the two methods are very close together, it should be noted aforementionaforementioned earthquakes with given considerable magnitude but very low PGA (far field effect) and for morganMorgan hill earth quake because of higher PGA difference between results has increased. Differences approaching revealed that soil formations with high attenuation seem to play an important role on site response.

For earthquakes such as the Mayor and for site III, these methods approximately resulted in the similar values. Using both equivalent linear and non-linear methods for all earthquakes of type I, sandy site IV have presented a similar response spectrum and included a great frequency band. Response spectrum of Morgan Hill earthquake which has the highest horizontal acceleration includes single peaks in lower periods (under 0.1s) and the results using the equivalent linear method and non-linear method are very different, so that using the non-linear method, spectral diagram has transferred to greater periods and this result holds true for Narrows Whittier earthquake. It seems that for type I earthquakes, by increasing the horizontal acceleration, the difference between two linear and nonlinear methods has been increased and response spectrum has shifted toward the greater periods (Figure .15).

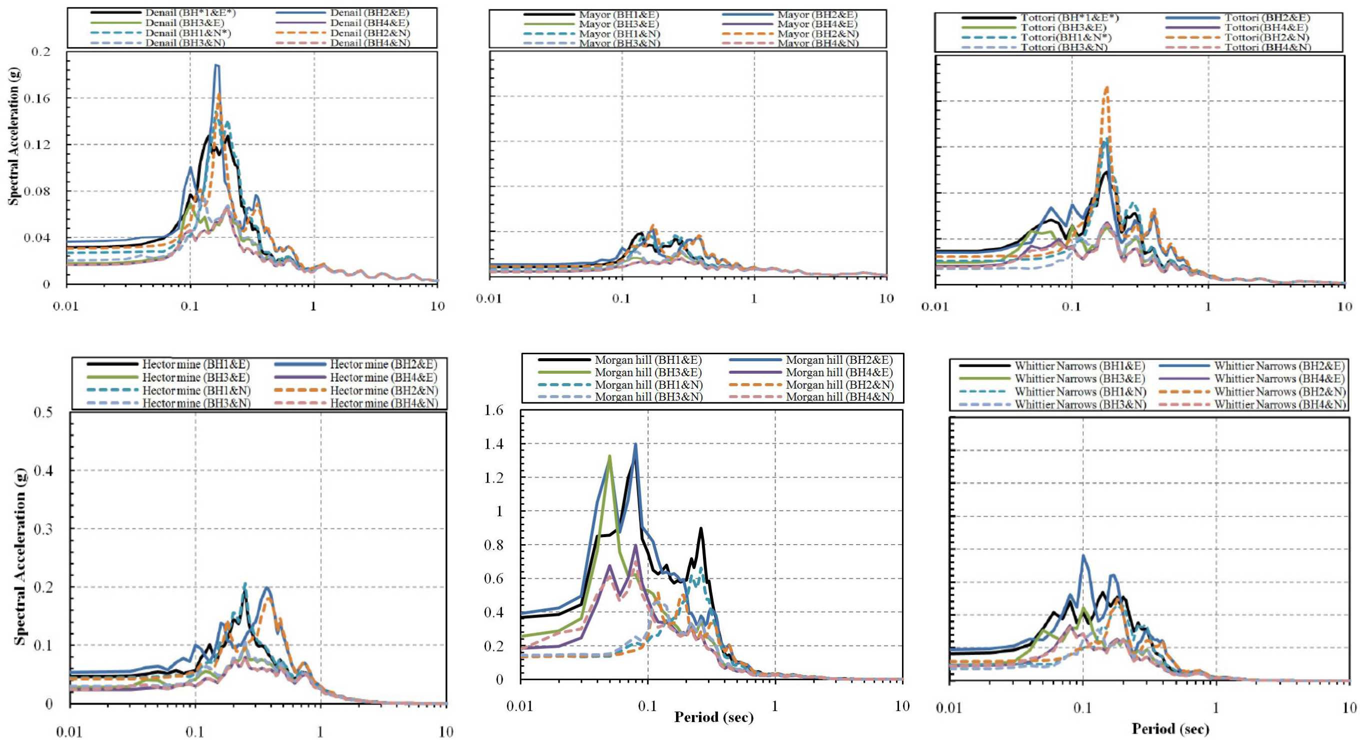


Figure 15. Spectral acceleration for earthquake and site type I

Figure 16 shows the values of response spectrum for site of type II (Combination of granular and fine materials). As can be seen, type II sites cause rougher spectrum, which is different for various earthquakes. itIt can be observed that sitethat site V has had more effect relative to site VI. The non-linear method resulted in lower values than the linear method and in this method the frequency band for different earthquakes has increased. The remarkable point is that this behavior causes the frequency band to increase and leads to resonance.

4- 2- 2- Spectral Acceleration Response for Earthquake Type II

In this section, the site effect is investigated for earthquakes type II (i.e. maximum horizontal acceleration range of 0.1g to 0.4g). In this type of earthquakes, the first site type includes the most response spectrums and sandy site IV has the least response spectrum. The values of response spectrum obtained using the non-linear method is less than those in the equivalent linear method. These values are approximately the same for boreholes 3 and 4 for all earthquakes.

In all earthquakes of type II, for site I and II, the equivalent linear method has predicted large spectral values which have a direct relationship with earthquake magnitude but the non-linear method has presented accurate and less value. Indeed, in the other sites, especially in sandy site IV, the values obtained by both methods are similar (Figure .17).

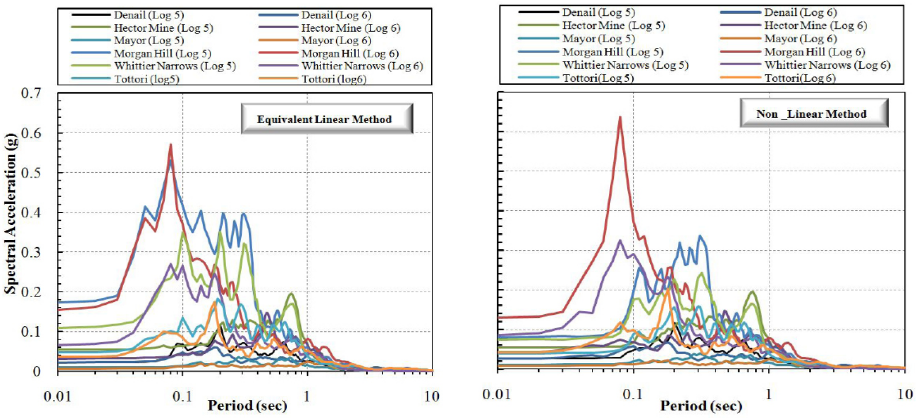


Figure 16. Spectral acceleration for earthquake type I and site type II

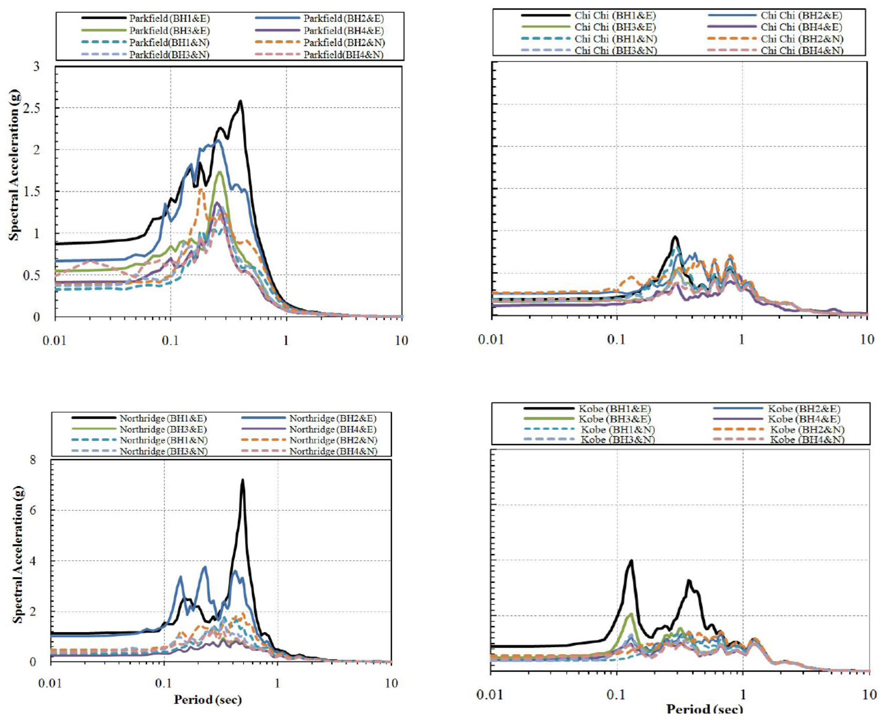


Figure 17. Spectral acceleration for earthquake type II and site type I

The response spectrum in site V and VI approaches to higher periods and includes more ripples and it has different values for different earthquakes. The maximum spectral values have decreased in the nonlinear method, but include more frequency bands and linear and non-linear values significantly changed. It seems that the non-linear method provides a more accurate response spectrum, relative to equivalent linear method (Figure .18).

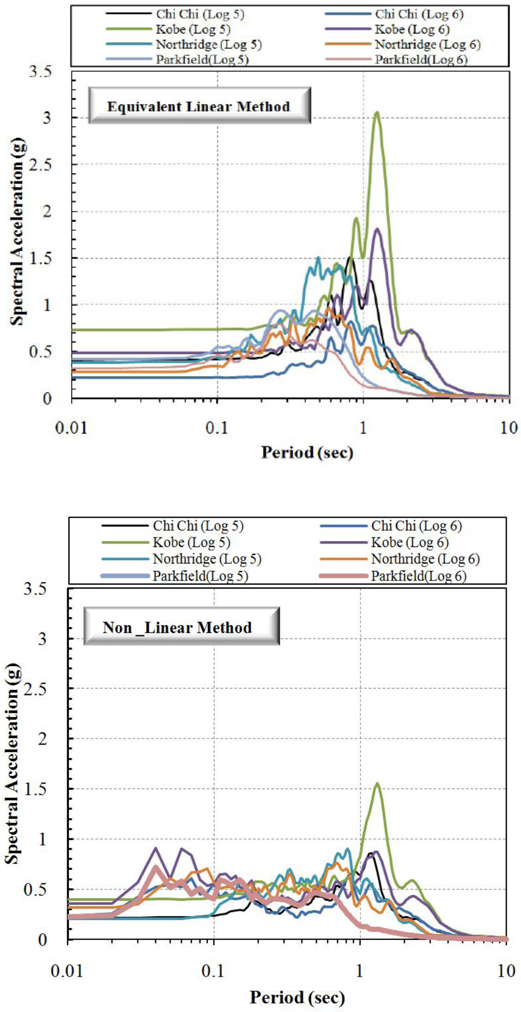


Figure 18. Spectral acceleration for earthquake type II and site type II

4- 2- 3- Spectral Acceleration Response for Earthquake Type III

Loma preita and Tabas earthquakes are two important earthquakes in the history which have caused large failures with acceleration of 0.44g and 0.87g. This study attempts to use them and analyze their effects on different sites.

For the two mentioned earthquakes and for site I and II, while the equivalent linear method has resulted in very large and unexpected values for the acceleration response spectra, the non-linear method has estimated more accurate values.

Site I and II in these earthquakes have also the highest value of spectrum and sandy site IV has the least acceleration response spectrum (Figure .19).

According to the obtained diagrams, it is specified that the non-linear method includes wider frequency bands for this type of site (type II). Indeed, for these earthquakes the maximum amounts of response spectrum in the non-linear method is greater than that in the equivalent linear method. This finding is in reverse for earthquakes with acceleration less than 0.4g.

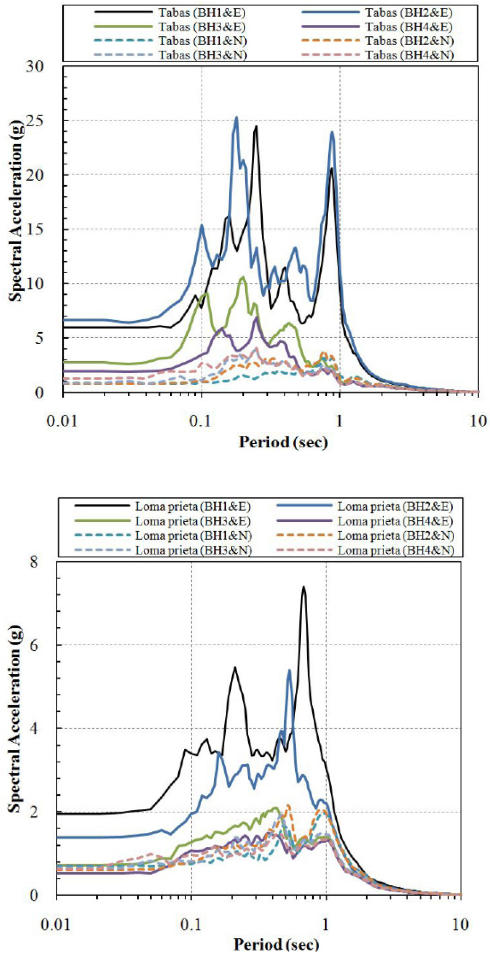


Figure 19. Spectral acceleration for earthquake type III and site type I

5- Conclusions

The aim of this study was to perform one-dimensional equivalent linear and non-linear site response analysis. Specifically, the influence of site response to the recorded motions in special sites in southern of the Iran with various geotechnical parameters was studied. The main conclusions are as follows:

1. One-dimensional non-linear ground response analyses provide more accurate characterization of true non-linear soil behavior than equivalent-linear procedures, but determination of dynamic properties of the site is difficult and costly. Both approaches exhibit more differences in the first two sites and less different from other sites and with an increase in the PGA of an earthquake the difference is increased.
2. The selected earthquakes with PGA less than 0.01g have the most increase in horizontal acceleration at the

surface which is 2.5 times on average for different sites and in comparison to the other earthquakes have greater acceleration, and also in what have more increase. Among the sites of type I, the most increase in acceleration corresponds to the site II. Site IV having layered gravel materials, has the least PGA.

3. In both equivalent linear and non-linear methods for all types of earthquakes and sites, maximum horizontal acceleration value at the surface has been obtained more than that in the bedrock which is significant for first and second site type and has decreased with the increase of the intensity and PGA. For all types of earthquakes and sites, the non-linear method has predicted wider frequency bands which increase the probability of creating resonance.
4. The maximum spectral acceleration in equivalent linear method was on average 13.16% higher than the non-linear method for soil types I and II respectively. Hence, based on findings of this research, the equivalent linear method showed higher amplification and higher response spectra compared to the full non-linear analysis. This difference might be acceptable in the analysis of most projects, but it is better to use full non-linear approach in critical projects.
5. In type I earthquakes, by increasing the horizontal acceleration the difference between two linear and non-linear methods has been increased and response spectrum has shifted toward the greater periods and type II sites have had rougher spectrum. The non-linear method resulted in lower values than the linear method and in non-linear method the frequency band for different earthquakes has increased.
6.

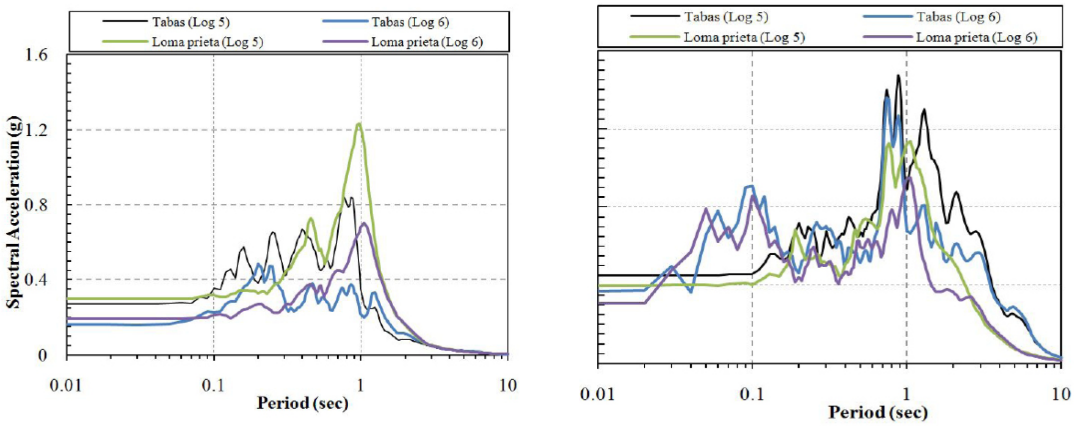


Figure 20. Spectral acceleration for earthquake type III and site type II

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