Local Site Effects Using Elasto-Plastic Constitutive Model

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Abstract

From engineering view of point earthquakes' importance is for its' effect on constructions like dams, bridges and residential regions. In most cases these constructions are not built on the bed rock surfaces but they are on the deposits over the bed rocks. Quake waves falls a victim to change while passing through deposit layers which is known as "site effect ". Site effects are considerable in two pivots: topography and soil conditions of any region.

Babol city is the site that considered in this research. Babol is a small city in northern of Iran, Babol city is selected for investigation of layered soil deposits' effect on seismic response of the ground. Because of the variation of layering condition in Babols' soil and providing needed layering research (sovereignty of loose layers, sovereignty of dense layers and loose-dense intermittent layering) the soil of this site were taken under investigation as a real model. Because the earth was flat in Babol; topography did not considered importantly and geotechnical properties of Babols' soil layering understanding considered most determiner factor in Babols' site effect. Babol region geotechnical data is collected based on diggings which were done in Babol. These data are consisted as two major branches of data. First one is one hundred bore holes in twenty points in Babol city to depth of sixty meter and second is seventy deep wells to depth of two hundred fifty meter in Babol region. Five zones are found to investigate the site effect of Babol city based on the obtained data from geotechnical parameters. In this research dynamic analysis are done in a time period by using elasto-plastic model, which models soils' behavior more realistic and the results are presented as normalized site response spectra. The obtained response spectra from fully nonlinear method for layered soil was compared with response spectra obtained from fully nonlinear method done for homogenous soil and response spectra of 2800 code and the effect of being layer analyzed in site effect analyzing too. Response spectra obtained from fully nonlinear method were also compared with site response spectra of Iran's' 2800 code.

Keywords: Babol City; fully nonlinear method; equivalent linear method; site effect; dynamic analysis; response spectra; Plaxis; Iran 2800 code.

1. Introduction

The most intense shaking experienced during earthquakes generally occurs near the rupturing fault, and decreases with distance away from the fault. In a single earthquake, however, the shaking at one site can easily be 10 times stronger than at another site, even when their distance from the ruptured fault is the same. Scientists have assumed that local geologic conditions are the cause of this difference in shaking intensity, but they have not been certain of the particular conditions that are most responsible, and the degree to which they affect earthquake shaking. Combining this information with estimates of where and how often earthquakes will occur would allow for better estimates of how intense shaking will be during future earthquakes.

2. Nonlinear site amplification

Studying nonlinear characteristics of site amplification has been a popular research subject in recent years. Geotechnical engineers have long recognized from laboratory experiments that under cyclic loads the stress-strain relationship of soils is nonlinear and hysteretic for strains larger than about 10^{-4} [17]. The 1994 Northridge, California, earthquake has allowed researchers to investigate soil nonlinearity from strong motion records [5, 18]. Various techniques have been used to investigate soil nonlinearity from field data. The earlier ones were based on assumed models of earthquake source and wave propagation [19]. The nonlinearity is assumed when the model results differed significantly from the observations. However, the results were strongly dependent on the model selected. Other studies used generalized inversion schemes to simultaneously calculate site amplifications at multiple sites ([18], Field et al.). The study by Hartzell used spectral ratios between soil and rock sites for strong and weak motions to infer the extent of nonlinear site amplification. It was concluded that the site has nonlinear amplification if the spectral ratios obtained from strong motions differ from those obtained from weak motions. Hartzell's results showed that there was nonlinear site amplification at the frequencies between 0.75 and 10 Hz during the Northridge earthquake at stations with peak accelerations larger than 600 cm/s2 and peak velocities larger than 80 cm/s. Generally, all strong motion studies have shown the presence of nonlinear site amplification at soft soil sites when subjected to large amplitude motions. A straightforward method to detect and identify nonlinear site amplification is to model it by a time-varying linear Filter. It is well known from the systems theory that any nonlinear system can be modeled as a linear system with time-varying coefficients. We represent the nonlinear site amplification by a time-varying (i.e. adaptive) filter, where the rock- and soil-site records are the input and the output, respectively, of the filter; that is:

$$y(t) = H(q, t)x(t) + \gamma(t)$$

Where H(q, t) is the time-varying filter representing site amplification, and g(t) is the noise term. We can express H(q, t) as the ratio of two polynomials, A(q, t) and B(q, t), in the time-shift operator q^{-1}, where q^{-1} is defined as:

$$q^{-1}x(t) = x(t-1),$$

$$H(q,t) = \frac{B(q,t)}{A(q,t)} = \frac{b_0(t) + b_1(t)q^{-1} + \cdots + b_n(t)q^{-n}}{1 + a_1(t)q^{-1} + \cdots + a_m(t)q^{-m}}$$

For given x(t) and y(t), the filter coefficients $a_j(t)$ and $b_j(t)$ can be calculated at each time step by using recursive prediction error techniques [4]. This method can not only track the time variations of filter parameters, but also filter the noise (in the least-squares sense) over the whole frequency band. The amplitude of site amplification is obtained at each time step by putting $q = e^{i(2\pi f)\Delta}$ in H(q, t) and taking its amplitude. The resulting amplification is a two-dimensional surface, where horizontal axes representing the period, and the vertical axis representing the amplification.

3. Site Characteristics and Modeling Circumstances

In this study, a dynamic analysis has performed on Babol city that the thicknesses of soil deposits were over 30 meters. Babol city separated to 5 zones by diffrent soil properties. Four accelerograms have applied to each site in each field and then the response spectra have calculated. Then, these response spectra normalized and the average of four response spectra in each field for each site reported. The constitutive model that is used in this study is Mohr-Coulomb plasticity.

Findings are then compared to the normalized response spectra estimated by equivalent homogenous non-linear method and 2800 code of Iran.

For applying tectonic circumstances of near, middle and far fields, 12 different ground strong motions are chosen that each field has four accelerogram. For missing the effect of soil layers, it is necessary that these motions had been recorded on stiff layers. All of the accelerograms that are used in this study recorded on stiff soil. These accelerograms are recorded during real earthquakes and in this study have applied to the bedrock. In selection of earthquakes, has tried to choose accelerograms that cover wide range of frequencies. Specifications of selected accelerograms in this study are as Tables 1 to 3

Table 1. Specifications of strong motions used for near field analyses

Distance to fault(km)	Magnitude (M)	Country	Station	Number
22	5.19	USA	Anza (Horse Canyon)	A11
10	7.62	Taiwan	Chi-Chi	A12
23	6.19	USA	Morgan Hill	A13
12	6.93	USA	LOMA PRIETA	A14

In Table 1 collection of near field accelerograms used in this study has shown. In this table, the fault distance to place that the earthquakes has recorded is from 0-40 km.

Table 2. Specifications of strong motions used for middle field analyses

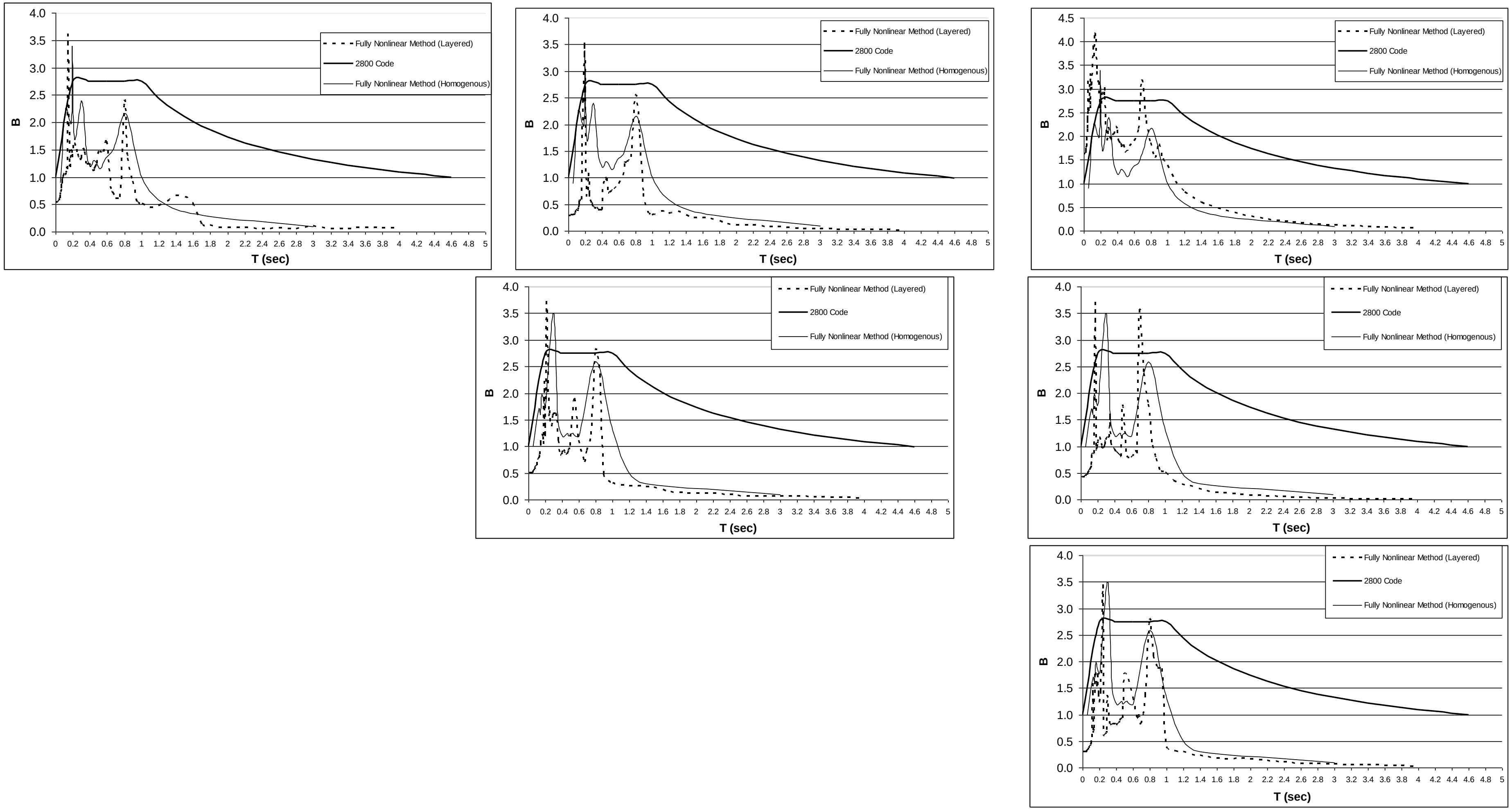
Distance to fault(km)	Magnitude (M)	Country	Station	Number
70	6.20	USSR	GEORGIA	A21
55	6.50	ITALY	FRIULI	A22
61	6.50	USA	BORREGO MOUNTAIN	A23
50	5.19	USA	Anza (Horse Canyon)	A24

In Table 2 and 3, collections of middle field and far field earthquakes have shown, respectively. The fault distance to place that the earthquakes have recorded is from 40-70 and 70-110 km for middle and far field earthquakes, respectively.

Table 3. Specifications of strong motions used for far field analyses

Distance to fault(km)	Magnitude (M)	Country	Station	Number
88.6	6.50	USA	BORREGO MOUNTAIN	A31
68.2	6.50	USA	BORREGO MOUNTAIN	A32
71.5	7.62	Taiwan	Chi-Chi	A33
110	7.62	Taiwan	Chi-Chi	A34

The underground water level has neglected.



Near Side

Middle Side

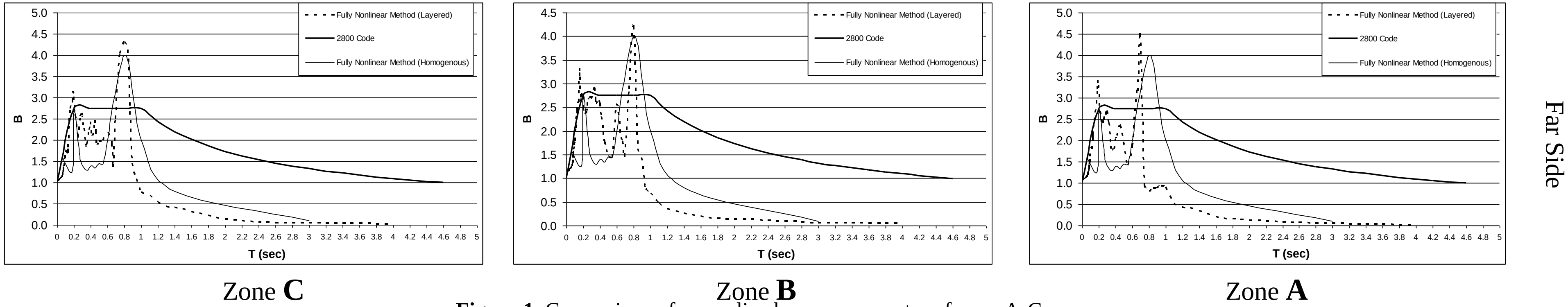
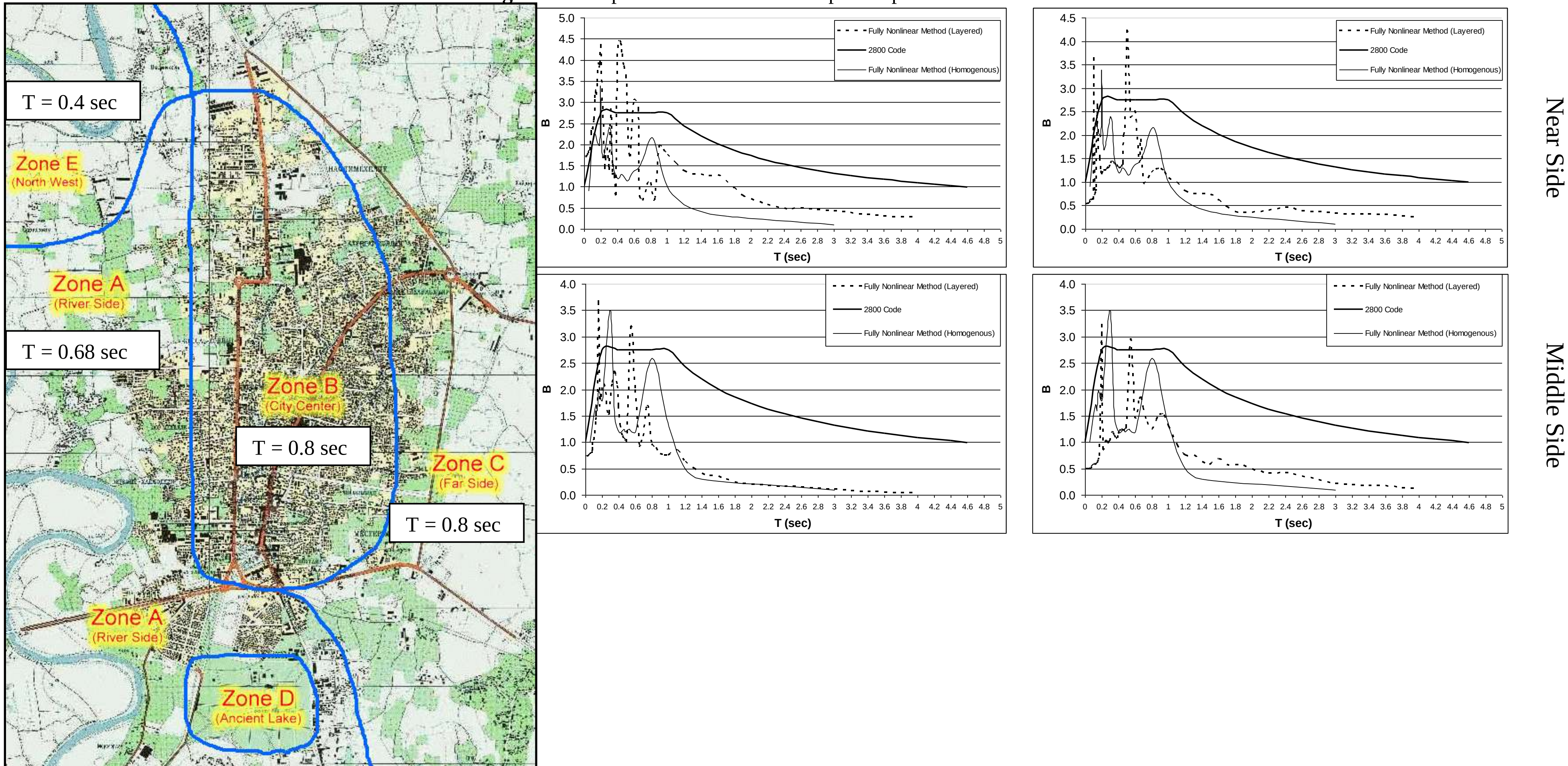
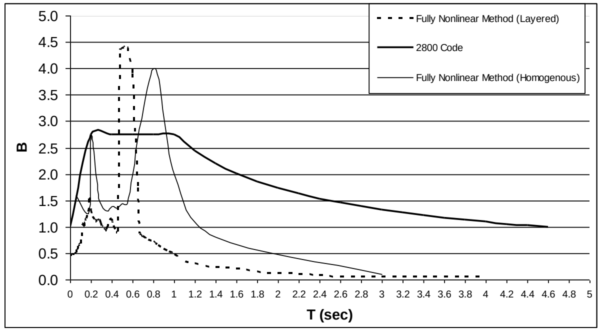


Figure 1. Comparison of normalized response spectra of zone A-C

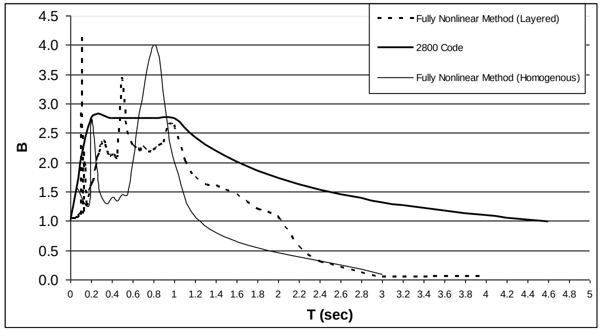


T = 0.51 sec

Figure 3. Babol city microzonation by natural period.



Zone **E**



Zone **D**

Far Side

Figure 2. Comparison of normalized response spectra of zone D-E

4. Discussion

This section is concentrated on the site response of the performed analyses on different types of soils. The normalized response spectra estimated by fully nonlinear method is presented and compared to response spectra of equivalent linear method and 2800 code of Iran.

4.1. Zone A

In Figure (1) normalized response spectra of zone A estimated by fully nonlinear for layered and homogenous soil and 2800 code of Iran have shown.
As be seen, natural period estimated for layered soil by fully nonlinear method is 0.68 sec. The natural periods calculated by fully nonlinear method for zone A is equal in all three fields (Figure 1). On the other hand fully nonlinear for homogenous soil has estimated different natural periods for this zone in 3 fields, therefore with changes in frequency of dynamic loads, scatter values estimated for natural period.
In resonance period, calculated values by 2800 code of Iran in all three fields with respect to fully nonlinear method are underestimated and consequently unsafe. In other periodic domains, equivalent linear method's results are overestimated in comparison with fully nonlinear method in all three fields. Because fully nonlinear method in estimating of spectra uses mass-spring model and equivalent linear method (used in 2800 code of Iran) uses thin layer model, moreover, fully nonlinear method works in time domain and equivalent linear method in frequency domain, observed that, two method's results have some differences.
In all periods, outside resonance period of site, fully nonlinear method's spectra for layered soil of Babol with respect to 2800 code of Iran, is in allowable domain of code.

4.2. Zone B

In Figure (1) normalized response spectra of zone B estimated by fully nonlinear for layered and homogenous soil and 2800 code of Iran have shown.
As be seen, in figure (1) there is two maximum points in both non linear method's spectra. Second maximum point related to the initial natural period of site and the first related to the resonance period of site after changing in shear modulus because of nonlinear behavior of site. When strains left elastic domain, shear modulus decreases and consequently natural period of the site changes. As be seen in figure (1) this behavior of soil has modeled by two methods but there is not exact correlation in their results.
Estimated resonance period by fully nonlinear method for Babol layered soil is 0.8 sec. In near field there is good correlation between two method's spectra in periods higher than 1.2 sec but not exact correlation in lower periods. In near field analyses, 2800 code of Iran are overestimated with respect to fully nonlinear methods but the resonance amplitude calculated by fully nonlinear method is higher. Normalized response spectra of middle and far field of zone B are shown in figure (1). As be seen, fully nonlinear method for layered and homogenous soil has estimated same natural period in near ad middle fields for zone B but there is a different in natural period in far field. In all there fields analyses, equivalent linear spectra used in 2800 code of

Iran is over estimated with respect to the fully nonlinear spectra but in resonance period, values estimated by fully nonlinear method are higher and in this case 2800 code spectra aren’t safe.

4.3. Zone C

In Figure (1) normalized response spectra of zone C estimated by fully nonlinear for layered and homogenous soil and 2800 code of Iran have shown.
As be seen, natural period estimated for layered soil by fully nonlinear method is 0.41 sec. The natural periods calculated by fully nonlinear method for zone E is not equal in all three fields (Figure 1).
At near and middle fields, the power of applied earthquakes are enough high to cause site behaves elasto-plastically. Existing of two maximum point at near and middle field’s spectra indicates this issue. Second maximum point related to initial natural period of site and the first related to the resonance period of site after changing in shear modulus.
Figure (1) shows that fully nonlinear method for layered soil has estimated initial natural period of zone C, 0.8 sec same as fully nonlinear method for homogenous soil. there is suitable correlation between two method’s results.
As be seen, near field spectra in figure (1) at periods higher than 1.60 sec and middle field spectra at periods higher than 1.20 sec, by two nonlinear methods, have good correlation.
In middle field as shown in figure (1), two nonlinear method’s spectra have high correlation and the results are very near. In far field existing of one maximum point indicate that site has behaved elastically.
In all three fields and in whole periodic domains without resonance period, fully nonlinear spectra are in allowable domain of 2800 code of Iran. in resonance period of site, 2800 code of Iran is underestimated and consequently unsafe.

4.4. Zone D

In Figure (2) normalized response spectra of zone D estimated by fully nonlinear for layered and homogenous soil and 2800 code of Iran have shown.
As be seen in figure (2), different maximum points in spectra indicate that the site has showed nonlinear behavior.
By fully nonlinear method, initial natural period of site has estimated 0.51 sec in all three fields but fully nonlinear method for homogenous soil has estimated 0.8 sec for all there fields. It was seen that by changing in period content of dynamic loads, scatter results has reported by fully nonlinear method for homogenous soil.
In figure (2) existing of several maximum points indicate that the site has showed nonlinear behavior. Two method’s spectra have good nearness in near field analysis in elastic domain. In middle field, differences between two method’s spectra are growth. It seem that by increasing the frequency content of dynamic loads, the equivalent linear method’s precise decrease because, in spit of calculation of 0.8 sec for initial period of site in near field, different value has given in middle field. Existing of two maximum point in spectra in middle field indicate that nonlinear behavior has occurred.
In far field, figure (2), shows that the zone D has exhibited one maximum point, this case indicate that site has behaved elastically under far field earthquakes.
In all three fields and in whole periodic domains without resonance period, fully nonlinear spectra are in allowable domain of 2800 code of Iran. In resonance period of site, 2800 code of Iran is underestimated and consequently unsafe.

4.5. Zone E

In Figure (2) normalized response spectra of zone E estimated by fully nonlinear for layered and homogenous soil and 2800 code of Iran have shown.

By fully nonlinear method, initial natural period of site has estimated 0.4 sec in near field, 0.55 sec in middle and far field. Because of the large stiffness of Zone E, its natural period, in comparison with other site types is small. Zone E is the densest site that has investigated in this research. In spite of the fact there are differences in result of fully nonlinear Method's spectra in 3 fields.

In all three fields and in whole periodic domain without resonance period, fully nonlinear spectra, is in allowable domain of 2800 code of Iran.

The resonance period of the site is underestimated by 2800 code of Iran, which is consequently found to be on the unsafe side.

5. Conclusions

1. At all zones investigated in this study, site response was sensitive to distance to fault. In other words, changes in frequency content and acceleration level of the earthquake loads affect on the results of equivalent linear method. By increasing distance from fault differences between fully nonlinear and equivalent linear method's results growth.
2. Nonlinear behavior of site outside elastic strains has modeled by two methods (layered and homogenous) but there are differences between results by increasing strain level. Also, at middle and large strains, by increasing distance from fault, differences between results more increase.
3. Estimated response spectra by two methods in zones A, B, C, D and E at near field in higher periods, have suitable correlation. In lower periods, in spite of nearness of estimated natural periods, differences between results have seen. The closest results were in near field spectra with respect to other fields.
4. Estimated response spectra by two methods in all sites studied in this paper at middle field analyses, have less correlation in whole periods. By investigating of expected specifications, was seen that equivalent linear method's results at middle field analyses had the most differences with respect to fully nonlinear method.
5. Estimated response spectra by two methods in all sites studied in this paper at far field analyses have good correlation in higher periods. In lower periods differences between zone D and E responses was great but at 3 first zones there was good correlation between two method's results. At zone D, in spite of nearness of estimated natural periods, is seen that after nonlinear response of site, differences between results of two methods growth.
6. By comparison the fully nonlinear method and 2800 Iran code spectra is seen that in all three fields and in whole periodic domain without resonance period, fully nonlinear spectra are in allowable domain of 2800 code of Iran. The 2800 code of Iran underestimated the resonance period of the site, and is consequently unsafe.

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