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Site-Specific Approach for Seismic Design Spectra in Iran, Based On Recent Major Strong Ground Motions

Danesh Nourzadeh, Majid Ebad-Sichani, Shiro Takada

***Abstract*—**Widespread use of response spectra in seismic design and evaluation of different types of structures makes them one of the most important seismic inputs. This importance urges the local design codes to adapt precise data based on updated information about the recent major earthquakes happened and also localized geotechnical data. In this regard, this paper derives the response spectra with a geotechnical approach for various scenarios coming from the recent major earthquakes happened in Iran for different types of hard soils, and compares the results to the corresponding spectra from the current seismic code. This comparison implies the need for adapting new design spectra for seismic design, because of major differences in the frequency domains and amplifications.

***Keywords*—**Earthquake engineering, response spectra, seismic design, site response.

I. Introduction

IRAN plateau has been located in an area with high seismicity, in which catastrophic earthquakes with large casualties have happened during past decades. Although most damaged areas in the past shakings were rural areas with fragile masonry, the most harmful events for the big cities are awaiting, as most important cities in Iran are located in the vicinity of active faults. In this regard, the need for accurate and reliable seismic input for design of structures arises.

Iranian code of practice for seismic resistant design of buildings was first published as a chapter in the standard no. 519 in 1960s. Later, the first revision of this code was published in 1987 as an independent code. It was also named standard no. 2800, of which up to now, two other revisions have been published. According to this code, there are two methods to determine the effective seismic forces on buildings: equivalent static method and dynamic methods. Dynamic methods include time history analysis and spectral analysis [1].

As a more accurate analysis method, spectral analysis can be used for all building structures with any conditions. In comparison, using time history analysis method needs more time and effort than spectral analysis method does, and also the results are very sensitive to the conditions which need precise set of data for each element. Based on these facts, engineers tend to use spectral analysis method because of its simplicity, yet efficiency.

In spectral analysis method, it is necessary to use spectra to determine the maximum response of each mode of the structure, so the spectra have a direct effect on the seismic behavior of the structure. On the other hand, the spectra should be generated considering recent significant earthquakes occurred in the area, seismic properties of the site, geotechnical properties in different layers of soil, geological characteristics of the region, and the selected performance level of the structure. According to the current seismic design code in Iran, two types of spectra are allowed to be used: standard design spectra (which are given in the code) and the specific design spectra for the site (which has to be generated by the engineer).

As discussed above, response spectra have an important role in spectral analysis method. They should be generated considering a wide range of parameters and accurately enough to be reliable, so that designed structures would be safe yet economical. In this research, considering local geotechnical data, elastic response spectra are generated based on five recent major earthquakes scenarios occurred in Iran. The generated spectra are compared with the ones given in the current seismic design code and results are presented at the end. The exclusive motivation of this paper is to derive the spectra based on a site specific geotechnical approach [2] to challenge the soil classifications in the present seismic code.

II. Local Geotechnical Data

A. Current Seismic Code Requirements

The current seismic code's spectra have a general shape as shown in Fig. 1. These spectra were generated based on the assumption of a 5% damping for the structure. According to the code there are four different regions with different levels of seismicity and therefore different peak ground accelerations (PGAs) which are 0.2g, 0.25g, 0.3g and 0.35g, and the spectra is normalized to the maximum value; however, this normalization should not be done similarly for all the frequency ranges [3], [4].

In Fig. 1, T is the period of vibration. Other parameters shown on Fig. 1 are determined in the code based on the level of seismicity and soil type. There are four different soil types based on the structure of the soil and the average shear wave velocity in soil profile ($\overline{V}_S$). $\overline{V}_s$ is calculated in the depth of 30 meters from ground surface. The formula offered for calculating $\overline{V}_s$ in the code is shown below. The code also

D. Nourzadeh is Research Associate and alumnus graduate student in School of Civil Engineering, University of Tehran, Iran (phone: +989133185587; e-mail: nourzadeh@ut.ac.ir).

M. Ebad-Sichani is alumnus graduate student in School of Civil Engineering, University of Tehran, Iran (e-mail: m.ebad.s@alumni.ut.ac.ir).

S. Takada is Adjunct Professor in School of Civil Engineering, University of Tehran, Iran (e-mail: takada_smartinfra@kobe.zaq.jp).

allows using other acceptable formulas.

$$\overline{V_s} = \frac{\sum d_i}{\sum (d_i / V_{si})} \tag{1}$$

V_{si} and d_i are shear wave velocity and depth of each layer of soil respectively.

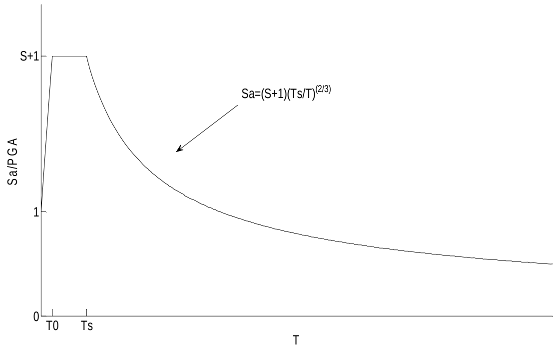
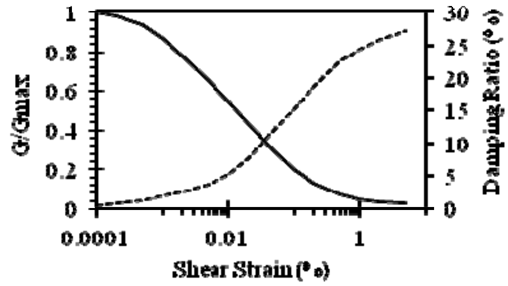
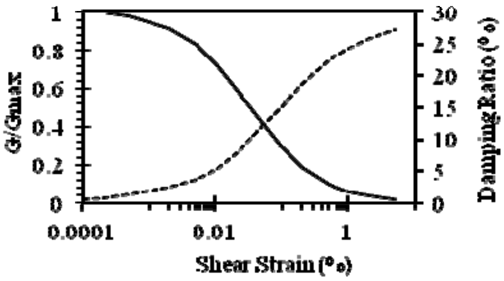


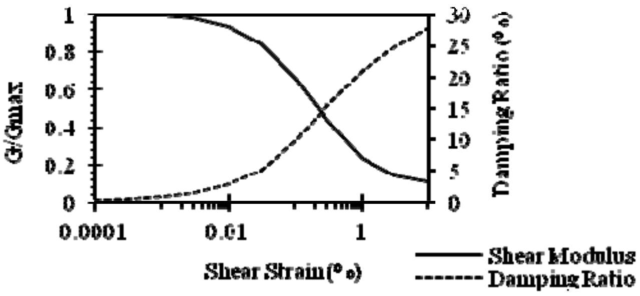
Fig. 1 General shape of current design spectra



Gravel Model [5]



Sand Model [6]



Clay Model [7]

Fig. 2 Dynamic moduli and damping ratios used for different Soils

The spectra generation in this research was done for the lowest and highest seismicity levels (0.2g and 0.35g) in different soil profiles all classified as soil class I (hard soils and rocks). According to the code the parameters shown on Fig. 1 are determined as T_0 = 0.1 sec, T_s= 0.4 sec and S = 1.5.

A. Soil Models

For the type of analysis that is used in this research, dynamic soil moduli and damping ratio based on shear stress level are needed. There are references which have carried out these curves to be used in the dynamic analyses. Soil models used in this research are shown in Fig. 2. The figure shows the models for gravel, sand and clay respectively from left to right.

B. Soil Profiles Specification

As mentioned before, geotechnical data has an important effect on the generated spectra, so it is necessary to use accurate data to generate spectra. According to the code, geotechnical data should come from in-site surveys or be based on reliable references. In this research data of three different types of hard soil are used to generate spectra. The data sets come from in-site surveys in some practical projects and simplifications to reach a better classification. According to the code all of the soil types are classified as Soil Class I based on their structures and shear velocities.

Soil 1 is a 9.45 meter deep layer of gravel on the bedrock. The properties of different layers of this soil are shown in Table I. $\overline{V_s}$ is about 400 m/s for this soil.

TABLE I
SPECIFICATIONS OF SOIL PROFILE 1

Layer no.	Soil material	Thickness of layer (m)	Shear wave velocity (m/s)
1 (surface)	gravel	~3.05	335.3
2	gravel	~3.05	396.2
3	sand	~3.35	472.4
Bedrock			1523.9

Table II shows soil 2's specification. This soil shows a layer of gravel and sand with a depth of 20.3 meters on the bedrock. The calculated $\overline{V}_s$ for soil 2 is about 710 m/s.

TABLE II
SPECIFICATIONS OF SOIL PROFILE 2

Layer no.	Soil material	Thickness of layer (m)	Shear wave velocity (m/s)
1 (surface)	gravel	~3.05	558.8
2	gravel	~3.05	609.6
3	gravel	~3.05	660.4
4	sand	~4.05	762.0
5	sand	3.05	812.8
6	sand	4.05	914.4
Bedrock			1523.9

Soil 3's specification is shown in Table III. This soil is a 30.5 meter deep layer on the bedrock with $\overline{V}_s$ = 605 m/s. It consists of gravel, sand and clay.

TABLE III
SPECIFICATIONS OF SOIL PROFILE 3

Layer no.	Soil material	Thickness of layer (m)	Shear wave velocity (m/s)
1 (surface)	clay	~3.05	355.6
2	clay	~3.05	406.4
3	clay	~3.05	457.2
4	gravel	~3.05	508.0
5	gravel	~3.05	558.8
6	gravel	3.05	609.6
7	gravel	3.05	660.4
8	sand	3.05	812.8
9	sand	3.05	863.6
10	sand	3.05	914.4
Bedrock			1523.9

C. Selected Major Earthquakes

In this paper, response spectra are derived based on recent strong earthquakes happened in Iran, considering the effect of geotechnical parameters for a specific overall soil type in the code. The selected earthquakes which were used in this research are Bam, Changoure-Avaj, Qaen (Ardekoul), Manjil-Rudbar and Golbaf earthquakes.

Bam earthquake was a major earthquake that struck Bam and the surrounding Kerman province of southeastern Iran on December 26, 2003. The most widely accepted estimate for the magnitude of the earthquake is a moment magnitude (Mw) of 6.6 estimated by the USGS. The earthquake was particularly destructive, with the death toll of 26,271 people and injuring an additional 30,000 [8], [9].

Changoure-Avaj earthquake occurred on June 22, 2002. It shook a large area in southwest of Iran, about 250 kilometers of west of the city of Tehran [3]. The institute of geophysics at University of Tehran reported a moment magnitude of 6.3 for this earthquake. It left more than 230 killed and 1,466 injured people [10].

Qaen earthquake, also known as the Ardekoul earthquake, was a major earthquake that struck Northern Iran's Khorasan Province on May 10, 1997. The largest in the area since 1990, it was measured 7.3 on the moment magnitude scale and was centered approximately 270 kilometers south of Mashhad on the village of Ardekoul. It devastated the Birjand-Qaen region, killing 1,567 and injuring over 2,300. The earthquake which left 50,000 homeless and damaged or destroyed over 15,000 homes was described as the deadliest of 1997 by the USGS [11].

Manjil-Rudbar earthquake occurred on June 21, 1990. It caused widespread damage in areas within a 100 kilometer radius of the epicenter near the city of Rasht and about 200 kilometers northwest of Tehran. The cities of Rudbar, Manjil, Lushan and 700 villages were destroyed, and over 300 villages were affected. 100,000 adobe houses sustained major damage or collapsed resulting in 40,000 fatalities, and 60,000 injured. 500,000 people were left homeless [12], [13].

Golbaf fault is an active one which has caused many earthquakes during past years. All of these earthquakes had magnitudes more than 5 [14]. One of these earthquakes was 1989 Golbaf earthquake, which destroyed Golbaf city in Kerman Province on November 20, 1989. The measured magnitude of this earthquake is 5.7 on the scale of surface waves (Ms) [15].

III. DERIVATION OF RESPONSE SPECTRA

In derivation of the seismic response spectra for the defined scenarios and soil types, commercial code ProShake version 1.1 [16] was used. This program provides a frequency solution for the ground response problem, in which the overall response is derived by the summation of the responses in each frequency of inputted periodic waves by generating site-specific amplification functions based on an iterative procedure on the strain level in each soil layer. Detailed outline of the methodology for analysis of wave propagation in a layered soil column is described by Kramer [2].

IV. RESULTS AND DISCUSSION

The models including the combination of five inputted ground motions, three different soil profiles, and two different PGAs were analyzed. The acceleration spectra for these selected cases are derived and shown in Figs. 3-5.

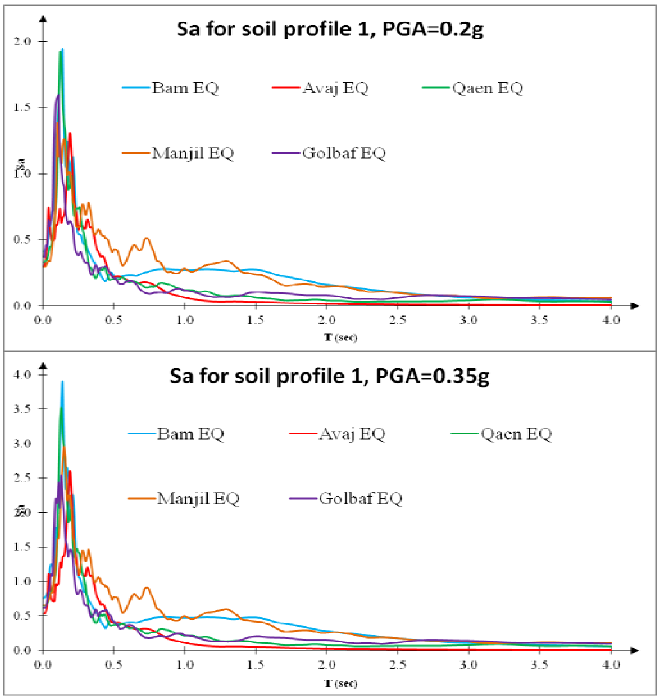


Fig. 3 Derived spectra for soil profile 1 and different ground motion time histories

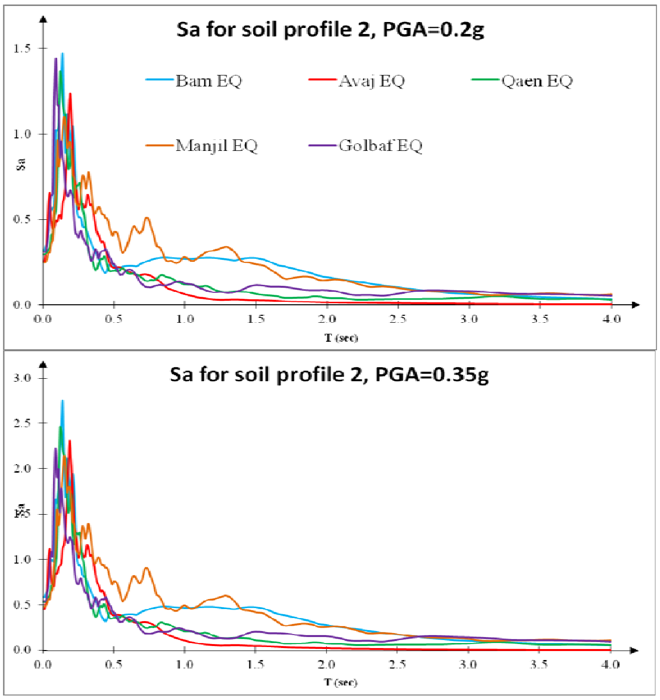


Fig. 4 Derived spectra for soil profile 2 and different ground motion time histories

In the current seismic design code, an importance factor is defined which should be multiplied to the spectra values for structures with higher levels of importance. In this regard, if the generated spectra are to be compared with the current suggested ones in the code, the values of maximum envelope, mean, mean plus and minus one standard deviation spectra are meaningful and probably the mean minus one standard deviation could be compared with the pure design spectra. The mentioned spectra are derived statistically based on the previous ones for each soil profile and PGA, and are shown in Figs. 6-11. In order to have a better comparison of the generated spectra with the current design spectra in different frequencies, semi-logarithmic curves are used in these figures.

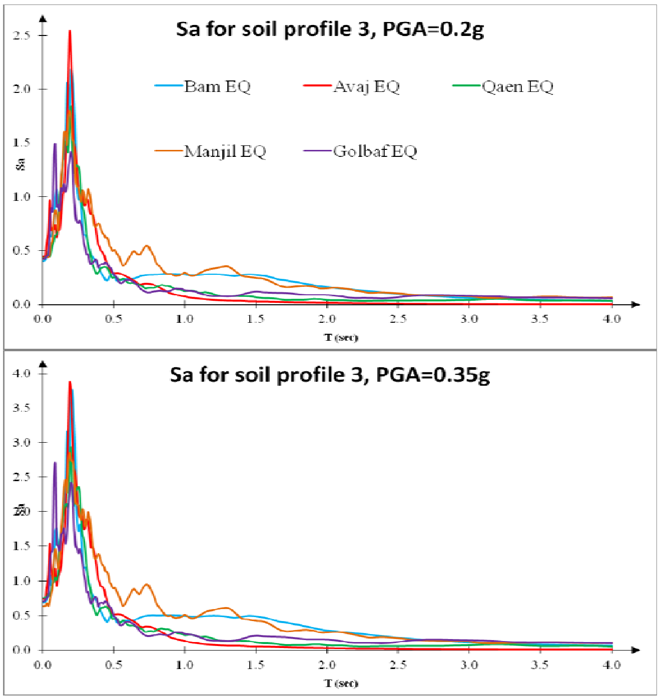


Fig. 5 Derived spectra for soil profile 3 and different ground motion time histories

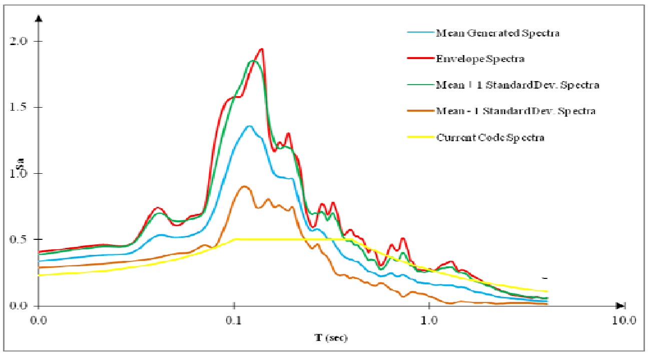


Fig. 6 Comparison of response spectra for soil profile 1 with current design spectra in PGA=0.2g

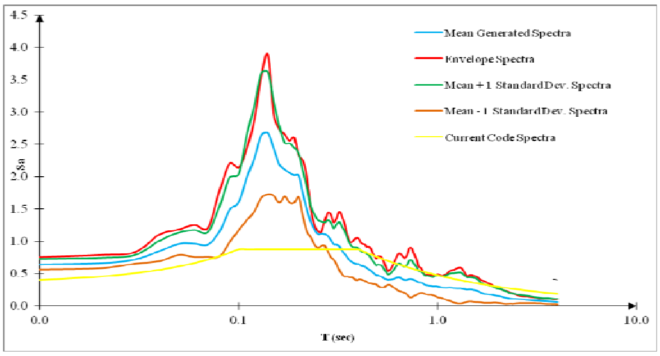


Fig. 7 Comparison of response spectra for soil profile 1 with current design spectra in PGA=0.35g

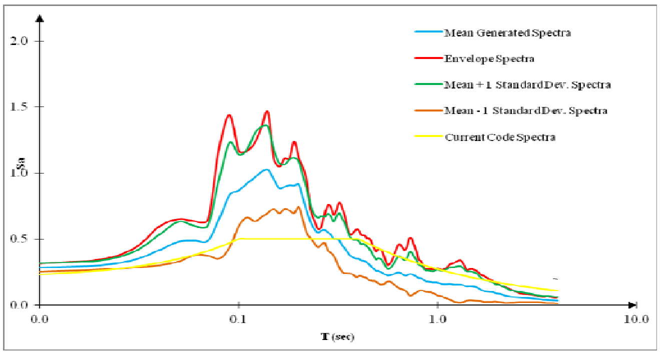


Fig. 8 Comparison of response spectra for soil profile 2 with current design spectra in PGA=0.2g

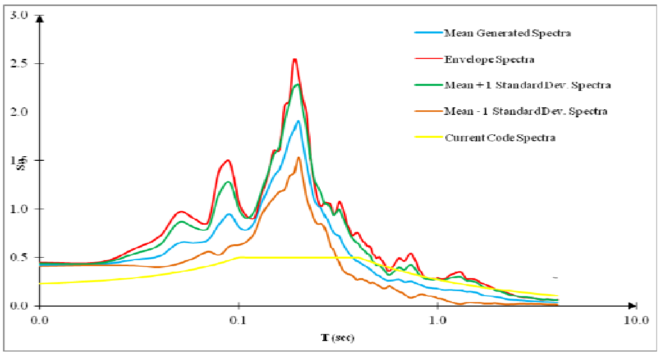


Fig. 9 Comparison of response spectra for soil profile 2 with current design spectra in PGA=0.35g

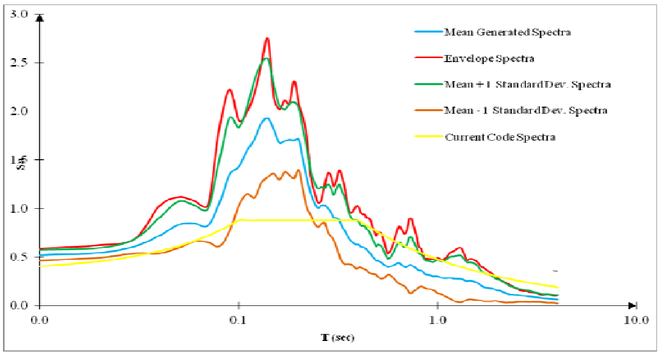


Fig. 10 Comparison of response spectra for soil profile 3 with current design spectra in PGA=0.2g

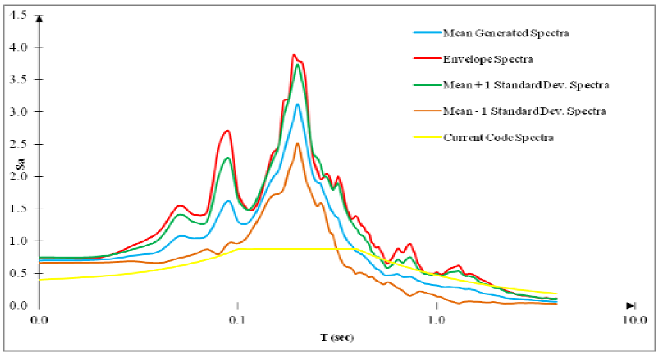


Fig. 11 Comparison of response spectra for soil profile 3 with current design spectra in PGA=0.35g

After comparing different spectra for different soil conditions to the current seismic design code requirements, several points are resulted as below:

1- The normalization of spectra with the PGA level, which is suggested in the current design code, is not so accurate like it was previously expected. In each soil condition, the form of the derived spectra differs for 0.2g and 0.35g PGAs.
2- The peak level of mean minus one standard deviation spectra for each case is higher than the current design spectra by a margin of 10 to 90 percents.
3- The cut-off periods for the plateau in the acceleration spectra in every case are different from the current code suggestion, resulting to narrower plateaus in the derived spectra.
4- Short period values of derived spectra are higher than the corresponding values in the code requirements; on the other hand, the long period values are lower.

In order to compare the results for different soil conditions, the mean spectra for PGAs of 0.2g and 0.35g are compared in Figs. 12 and 13.

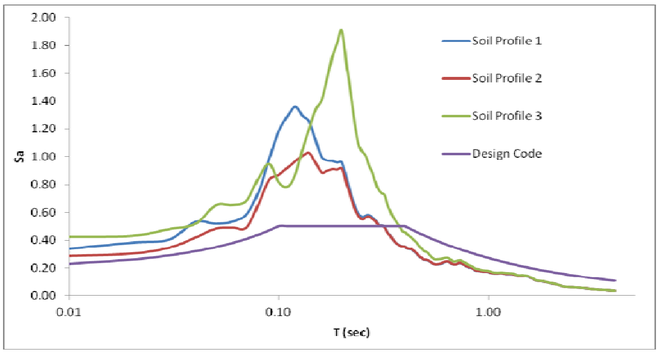


Fig. 12 Mean spectra for different soil profiles and PGA=0.2g

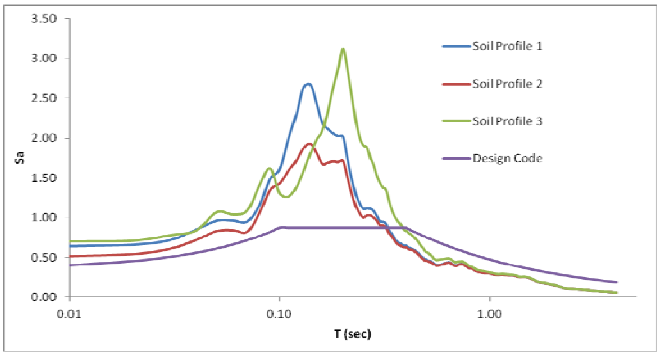


Fig. 13 Mean spectra for different soil profiles and PGA=0.35g

As it is shown in the figures above, soil profiles 1 and 2 are somehow consistent but the soil profile 3 shows major differences in the value and also the cut-off frequencies, which urges the need for a new categorization of soil types. Considering the soil classification in the current seismic code, the total acceleration spectra for Soil Class I, which includes all three soil profiles analyzed here, are compared for different PGAs in figures below.

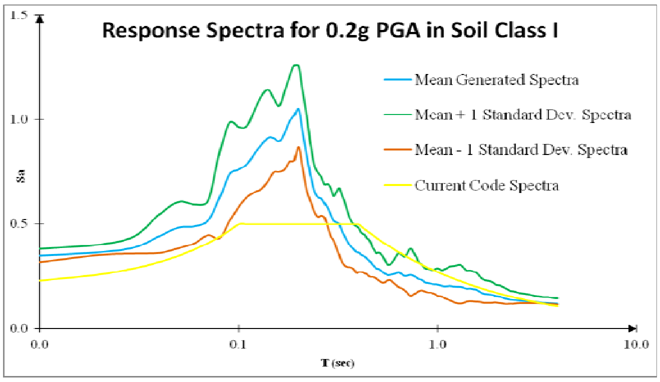


Fig. 14 Response spectra for Soil Class I in PGA=0.2g

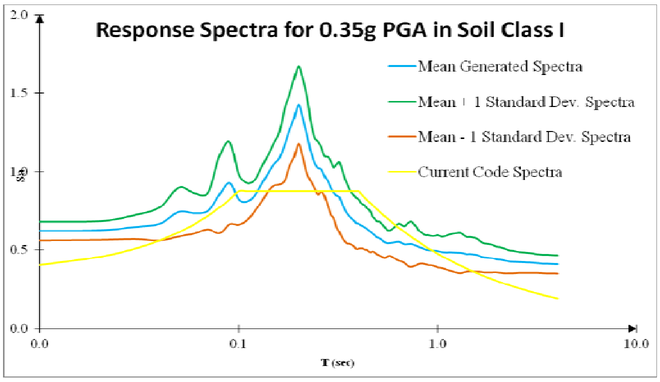


Fig. 15 Response spectra for Soil Class I in PGA=0.35g

V. Conclusion

In this research, using practical geotechnical data and considering some recent major earthquakes, the process of derivation of site-specific response spectra was done for the country of Iran. The results were compared with the country's current code's spectra. The comparison showed that the derived spectra have higher values than the code's spectra in low periods, and lower values in high periods, which implies it is not safe to design low-period structures according to the code. Finally it is strongly recommended that the code's spectra should be revised accurately based on accurate sufficient data, especially considering geotechnical data, in which several major changes to be considered are the implementation of uniform hazard maps and spectral values instead of normalization of spectra to PGA, and also a new soil classification criteria.

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