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# Site Effects and Classification of Iran Accelerographic Stations

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**ABSTRACT**

Site effect could be strongly affected by the earthquake ground motions and highly change the pattern of damages. Even though different methods are proposed for the study of site effect, most of them are time consuming and costly. There are more than 1100 accelerographic stations in Iran Strong Motion Network (ISMN) and it will take a great deal of time and money to study site classification. ISMN have recorded more than 3200 reliable three-component accelerograms in 620 stations from 1994 to 2003, which constitute a rich database for this investigation. We tried to compare the results of Vs-30 obtained from geoseismic measurements and H/V spectral ratio using the recorded accelerograms to modify the previous criteria for a fast and reliable classification. The final results show the convenience of the newly- defined criteria that could be used with more confidence for the stations with more records.

**Keywords:** ISMN, Iran, Site Effects, H/V Spectral Ratio, Strong Motion, Site Response, Fundamental Frequency.

## 1. INTRODUCTION

Important facilities are one of the most popular techniques to estimate site effects in regions of moderate to high seismicity. Among them are using spectral ratios of earthquake records as well as using microtremor introduced by Nakamura (1989).

In this study, we are going to investigate the site condition effect on the resulted ground motion due to the earthquakes, which were felt throughout the country and triggered Iran Strong Motion Network (ISMN) accelerographs. The characteristics of soil response were evaluated in terms of mean shear wave velocity of 30 meter uppermost layer called Vs-30 and frequency-dependent amplification using H/V spectral ratio technique. The well-known horizontal-to-vertical Fourier Spectral Ratio (FSR), which Nakamura (1989) proposed using microtremors and first applied for earthquake ground motion data by Lermo and Chavez-Garcia 1993, is used for estimating the site fundamental frequency called FF.

The FSR includes the effects of source rupture characteristics and inhomogeneous propagation path beside the local site response, as well. However, when using a large enough number of events varying in terms of magnitude, source depth and azimuth for each site, the effects of source parameters and directivity are expected to be averaged out and minimized (Stewart et. al., 2001).

The regression analysis of measured Vs-30 and estimated FF could give up new single criteria for fast site classification. Since the recorded ground motion is affected by whole sediment layer that may be much deeper than 30 meters and not included in Vs-30, measuring both quantities can help to have more accurate site classification.

## 2. MATERIALS AND METHODS

### 2. 1. DATA USED IN THE STUDY

In this study, we employed the strong motion records, which are recorded by Iran Strong Motion Network (ISMN), controlled by Building and Housing Research Center (BHRC) of Iran. There are more than 3700 three- components accelerograms that are recorded in about 650 stations from 1994 to 2004. After some investigations, about 3200 accelerograms recorded in 620 stationswere selected as the database of the present study.

Lermo and Chavez (1993) and Sankar Kumar et al (2000) used S wave window of earthquake records for the method of H/V that was proposed for microtremors by Nakamura (1989). Bonilaet. al., (1997), Rodríguez et. al., (2001) and Sokolov et al., (2004) used S and Coda windows in their studies on

 

 

H/V ratio. We tested the methods of applying S window, S and Coda wave window and the signal (P and S wave) window in few stations with different number of records. The final result for a station is presented in figure 1 as a sample. It can be seen that the estimated FF using these criteria are nearly the same, and there is a negligible difference in the amplitude of H/V ratio. The limitation of applying S and/or Coda wave indication could cause elimination of a large amount of data. Therefore, we used the whole recorded signals including P and S wave windows as used by Theodulidis and Bard (1995) to keep and utilize the available data as much as possible. This assumption enables us to use more than 3000 accelerograms recorded in about 620 stations; among them 395 stations have two or more recorded accelerograms.

The database of this research is the recorded accelerograms in the period of 1994 to 2003, in which more than 3700 accelerograms are recorded, and the results of geoseismic measurements handled in 74 stations around the country (Figure 1).


Fig 1. The location of stations in which geoseismic investigations handled.

## 2. 2. METHODOLOGY

In this study, we applied shallow refraction and H/V spectral ratio methods for site classification. The first method determines the mean shear wave velocity called Vs-30 and the second scheme will present the fundamental frequency (FF) of vibration in each specific site. The H/V spectral ratio is computed for all the stations but we managed to carry out the geoseismic measurements just in 64 stations, which were located in Boushehr (20), Kerman (6), Qazvin (17), Mazandaran (7), Tehran (16) and Zanjan (4) provinces and there were the results of 10 stations studied by Zare et. al.,(1999). The number of the recorded accelerograms, the importance of the registered earthquakes, the peak values of acceleration and abnormal recorded ground motions were the main criteria considered in station selecting for shallow refraction investigations and mean Vs-30 measurements. Figure 2 shows the geoseismic investigation in an accelerographic station.


Fig 2. a) Geoseismic measurements in accelerographic stations b) S wave measurements

## 2. 3. SHEAR WAVE VELOCITY (VS-30)

The measurements were interpreted and the results were presented as separate seismic sections for P and S wave measurements for each profile. Figure 3 is presented as samples for S and P wave interpretations of data measured in Deh Jalal station. In each figure, the uppermost graph represents the Travel-Time curve; the middle section shows the boundary of the distinguished seismic layers by depth and the lateral velocity variation are presented in the lower section. The final statistic results including the maximum, minimum and the average velocities and layer thickness are presented below the figures. We explored the thickness and shear wave velocity for the shallow soil layers along with the mean values in each. The soil groups are classified considering the different references and are presented in table 1.

 

 

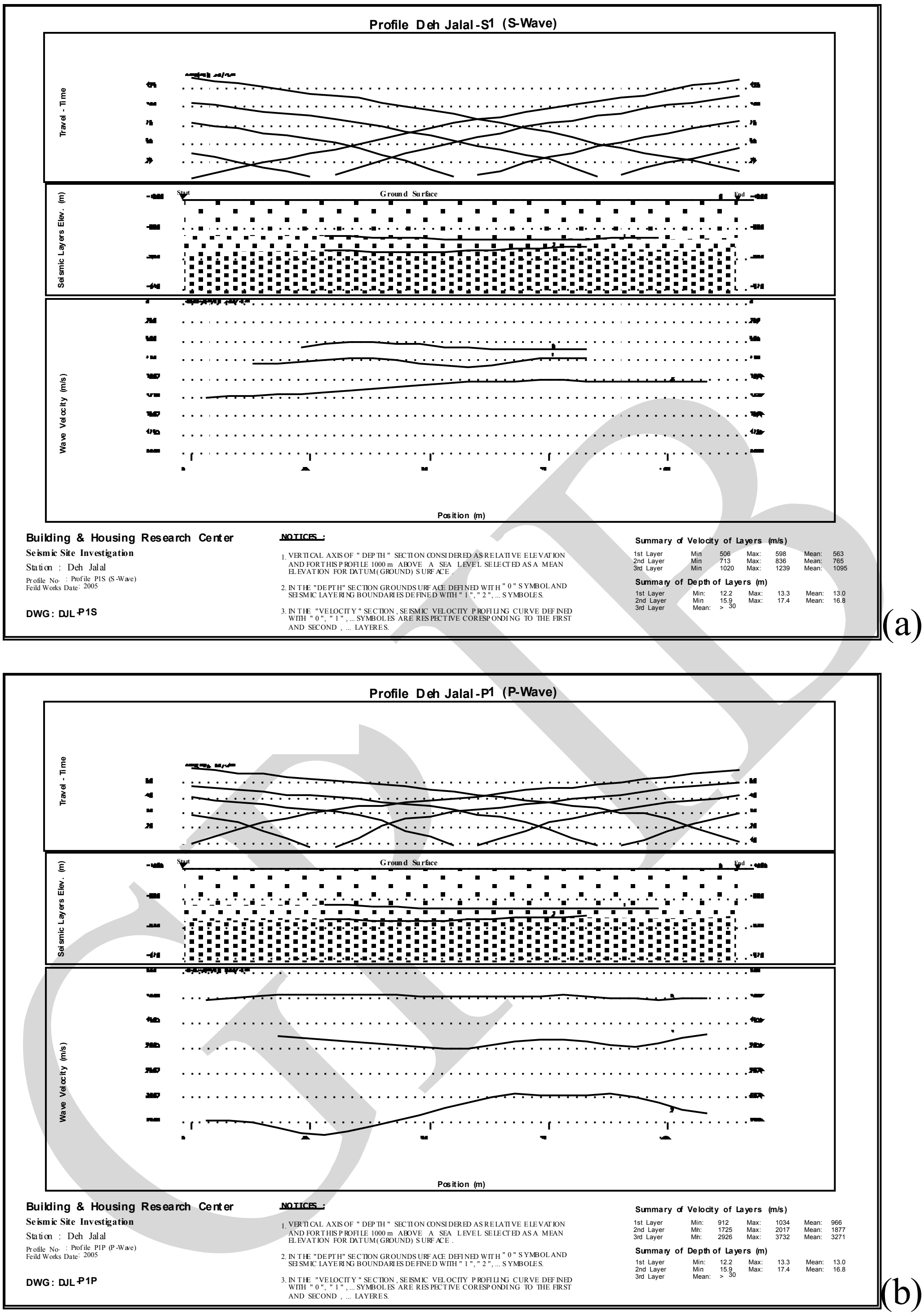


**Figure 4.** The result of a) S wave and b) P wave shallow refraction and data interpretation in Deh Jalal station. Up) Travel time curves, Middle) Seismic section, Down) S wave velocity lateral changes.

In table 1 the quantity Vs-30 is the shear wave velocity that has been averaged considering the thickness impact of uppermost 30 meter layers. For example if and respectively represent the thickness and the shear wave velocity of the layer, then it is possible to obtain Vs-30 from equation 1:

(1) $$Vs-30=\frac{\sum d_i}{\sum\left(d_i/V_{Si}\right)}$$

in which, $d_i$ and $V_{si}$ are the thickness and shear wave velocity of the layer i and the values of numerator consist the summation of all layers up to the depth of 30 meters below the ground surface level.

## 2. 4. H/V METHOD FOR STRONG MOTION RECORDS

H/V ratio that called receiver function (Theodulidis et al., 1996 and Riepl et al., 1998), (Zare 1999, H/V ratio, also called receiver function (Theodulidis et al., 1996 and Riepl et al., 1998), (Zare 1999, Teodulidis and Bard 1995, SankarHumar 2000 and Sardinal 2004) and Quasi-Transfer Spectra (QTS) technique (Nakamura 1989), is a reliable tool to estimate the effect of surface geology or surface soil/sediment layer without needing other geological information. It has received great attention across the world due to its simplicity together with quick information about dynamic characteristics of ground and structures, as well. In order to estimate the spectral seismic response function for a specific single three component station without hard rock site reference station, we calculated and analyzed spectral ratios of horizontal to vertical components (H/V ratio) of the whole signal including P and S wave parts of the strong motion records as proposed by Teodulidis and Bard (1995). For this reason, we show that the use of different windows did not affect the results and nearly the same outcome occurred (Figure 4). The calculation procedure includes:

i) Selection of a processing time window

ii) Calculation of amplitude spectra

iii) Calculation of the average H/V ratio (over both horizontal components and all available recordings of several earthquakes at each station), and their smoothing in a frequency window.

Table 1. The result of site geology investigations in 74 accelerographic stations and site classifications

| No. | Station | No. of Records | Vs-30 (m/sec) | Site Classification | | | | | FF (Hz.) | H/VAmpl. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | NEHRP 2000 | Zare 1999 | ST RD 2800 | BHRC S.Geo. | This Study | | |
| 1 | Abad | 21 | 482 | II | III | II | II | III | 4.5 | 3 |
| 2 | Abbar | 7 | 621 | II | II | II | I | II | 1.0 | 3 |
| 3 | Abdan | 1 | 952 | I | I | I | I | I | 15.0 | 2 |
| 4 | Abgarm | 6 | 199 | III | IV | III | III | IV | 0.5 | 5 |
| 5 | Abhar | 2 | 263 | III | IV | III | III | III | 4.0 | 3 |
| 6 | Aghababa | 3 | 617 | II | II | II | II | II | 5.3 | 4 |
| 7 | Ahram | 10 | 988 | I | I | I | I | I | 15.0 | 2 |
| 8 | Alihoseini | 13 | 439 | II | III | II | II | II | 5.5 | 4 |
| 9 | Alulak | 2 | 1458 | I | I | I | I | I | 15.0 | 2 |
| 10 | Asadiyeh | 5 | 858 | I | I | I | I | I | 15.0 | <3 |
| 11 | Avaj | 8 | 814 | I | I | I | I | I | 3.5 | >3 |
| 12 | Babolsar | 2 | 187 | III | IV | III | III | IV | 1.8 | 7 |
| 13 | Bakandi | 3 | 308 | III | III | III | III | III | 2.1 | >3 |
| 14 | Bandar-e-Dayyer | 13 | 508 | II | II | II | II | III | 3.7 | >4 |
| 15 | Bandar-e-Genaveh | 3 | 508 | II | II | II | II | III | 2.2 | >6 |
| 16 | Bardkhoon | 4 | 401 | II | III | II | II | III | 2.1 | >5 |
| 17 | Boeen Zahra | 1 | 255 | III | IV | III | III | III | 2.4 | 4 |
| 18 | Boomehen | 1 | 696 | II | II | II | | II | 7.0 | >3 |
| 19 | Booshehr 1 | 2 | 511 | II | II | II | II | III | 1.5 | >6 |
| 20 | Bushkan | 5 | 1172 | I | I | I | I | I | 8.0 | 3 |
| 21 | Changoureh (old) | 35 | 1154 | I | I | I | | I | 15.0 | <2 |
| 22 | Chatrood | 2 | 852 | I | I | I | | I | 15.0 | <3 |
| 23 | Chehel Zaree | 21 | 360 | III | III | III | III | III | 4.8 | >3 |
| 24 | Danesfahan | 2 | 478 | II | III | II | | III | 1.4 | >3 |
| 25 | Darsejin | 3 | 636 | II | II | II | | II | 1.1 | >3 |
| 26 | Deh Jalal | 2 | 748 | II | I | II | | I | 15.0 | <3 |
| 27 | Delvar | 7 | 336 | III | III | III | III | III | 3.9 | <4 |
| 28 | Faryab | 14 | 827 | I | I | I | I | I | 15.0 | 2 |
| 29 | Fin-1 | 61 | 480 | II | III | II | IV | III | 3.7 | 3 |
| 30 | Firouzabad | 20 | 478 | II | III | II | I | III | 4.0 | >3 |

 

| No. | Station | No. of Records | Vs-30 (m/sec) | Site Classification | | | | | FF (Hz.) | H/VAmpl. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | NEHRP 2000 | Zare 1999 | ST RD 2800 | BHRC S.Geo. | This Study | | |
| 31 | Golbaf | 33 | 439 | II | III | II | | III | 3.5 | 4 |
| 32 | Hasan Keyf | 1 | 339 | III | III | III | III | III | 2.5 | >5 |
| 33 | Hosseiniyeh Olya | 17 | 563 | II | II | II | II | II | 1.0 | 4 |
| 34 | Joshan | 64 | 776 | I | I | I | I | I | 8.3 | >3 |
| 35 | Jovakan | 52 | 1017 | I | I | I | I | I | 15.0 | <3 |
| 36 | Kahrizak | 1 | 323 | III | III | III | III | III | 1.9 | >6 |
| 37 | Kaki | 7 | 470 | II | III | II | II | III | 2.5 | 3 |

a) Standard 2800 (2003) [26]
b) NEHRP (1994-2000), UBC (1997) and IBC (2000-2003) [22]
c) Zare (1999) [2]

The formulation used for the computation of horizontal to vertical spectral ratio is (Sankar Kumar 2000 and Sardinal 2004):

(2)
$$SR_{hv} = \frac{\sqrt{\frac{1}{2}\left(\frac{S_{H1}^{\;2}}{T_{H1}} + \frac{S_{H2}^{\;2}}{T_{H2}}\right)}}{\frac{S_V(f)}{\sqrt{T_V}}}$$

in which TH1, TH2 are the horizontal components and TV is the vertical component signal durations. Since the same time window is used for each three component record, then TH1 = TH2 = TV and this equation are simplified as:

(3)
$$SR_{hv} = \frac{\sqrt{\frac{1}{2}\left(S_{H1}(f)^2 + S_{H2}(f)^2\right)}}{S_V(f)}$$

Herein, this ratio is considered, where the signal to noise ratio is greater than or equal 3 (Zare 1999 and Sardinal 2004). The signal to noise ratio is computed using equation 4:

(4)
$$R_{sn} = \frac{S(f)/\sqrt{t_s}}{N(f)/\sqrt{t_n}}$$

Where $t_s$ and $t_n$ are signal and noise windows duration. In the computation of this ratio the smoothing method of Konno and Ohmachi (1998) is used.

### 2. 5. SITE CLASSIFICATION

As mentioned before, the method of H/V spectral ratio used for earthquake strong motion records is used for estimating FF in each station. For this purpose, we used the whole signal windows to keep as much of the signal as possible in order to achieve better spectral resolution Teodulidis and Bard (1995). Then, we look for a correlation between the results of geoseismic investigations of 74 stations and their estimated FF. We used three different ranges of Vs-30 criteria that were proposed in NEHRP (2000), Zare (1999) and standard 2800 (2003) for site classification. The classification proposed in standard 2800 [26] is too close to the one introduced in NEHRP (2000).

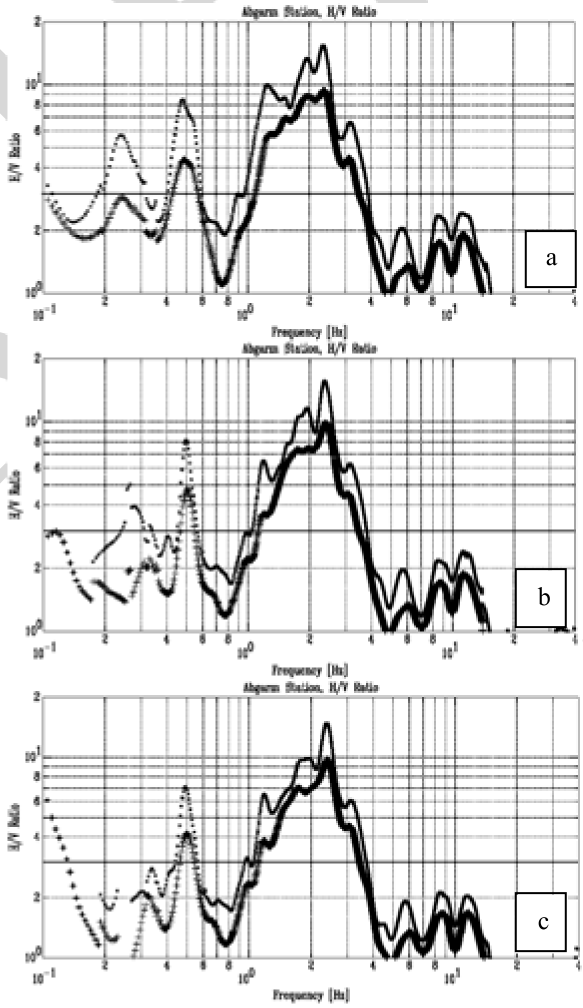


Fig 4. Estimation of H/V mean and mean+$\sigma$ spectral ratio in Abgarm station using a) S window b) S and Coda window and c) signal window of 6 recorded accelerograms.

There was little expectation to find reliable results using any single recorded accelerogram for site effect studies, since the earthquake records are affected by source, path and site effect. But increasing the number of records and averaging the results could minimize the source and path effects and cause improvement in the achieved results (Bonila et al., 1997). Figures 5 to 7 represent the discrepancy of the results when we tried to find a correlation between the estimated site class and FF. As for the stations with more accelerograms the results divergence decreases.

Using different classifications, we obtained results that are somehow different, which was predictable. In figures 5, 6 and 7, four boundaries of <2.0 Hz, 2.0 to 5.0 Hz., 5.0 to 8.0 Hz and more than 8.0 Hz. could be selected to be in accordance with soil class IV, III, II and I, respectively. But these limits are not very clear and have some overlap, which is not equal in both references. Even though in most studies we observed transition zones at the boundaries, there is some expectation for overlaps, but the overlaps we find here, is too wide to be normal. Especially for classes II and III, there is nearly complete coverage instead of some overlap. This may be closely related to data inconsistency. As figures 5 to 7 show, increasing the data will improve the results by decreasing overlaps. But still the results are not reliable.

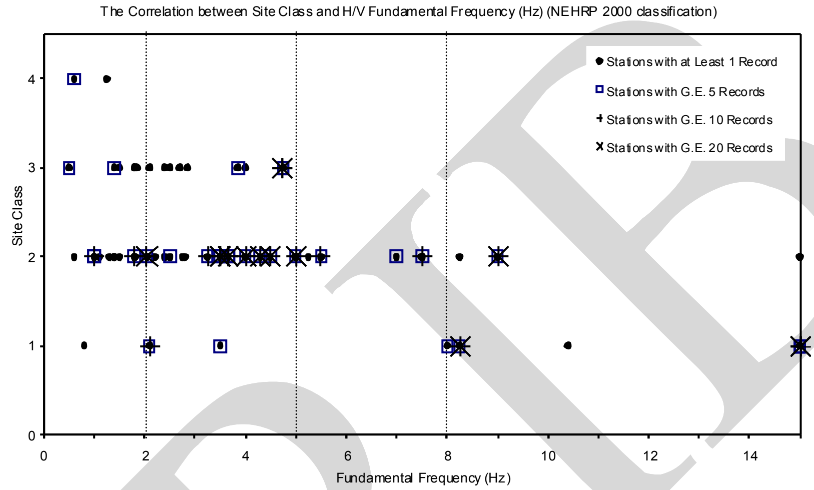


Fig 5. The comparison of site class (NEHRP 2000 criterion) and FF estimated using H/V spectral ratio. The effect of considering the stations with more recorded accelerograms is shown.

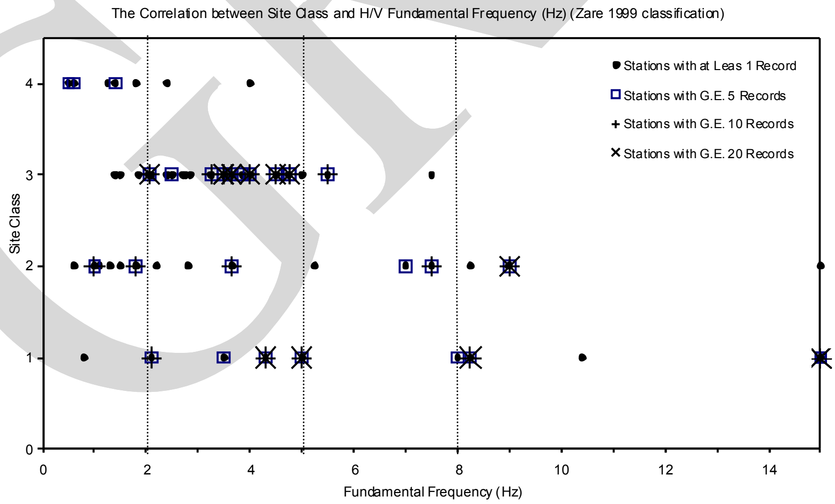


Fig 6. The comparison of site class (Zare 1999 criterion) and FF estimated using H/V spectral ratio. The effect of considering the stations with more recorded accelerograms is shown.

 

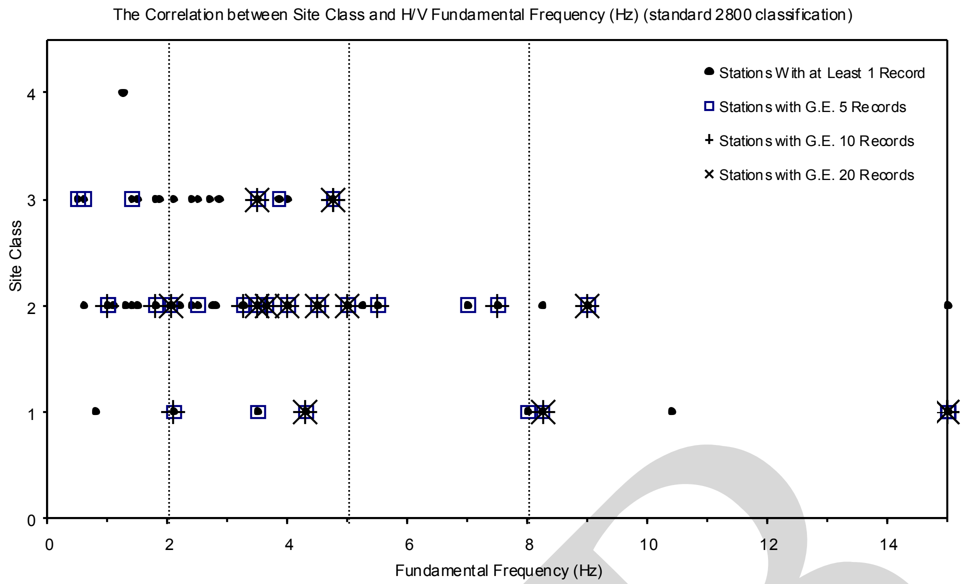


Fig 7. The comparison of site class (standard 2800 criterion) and FF estimated using H/V spectral ratio. The effect of considering the stations with more recorded accelerograms is shown.

The frequency bands overlap for classes I and II that occurred using the NEHRP (2000) criterion is less than the one obtained using Zare criteria, but the result is vice versa for classes II and III.

Inconsistency of the results hindered the progress and the study is followed by looking for the correlation between the measured Vs-30 and estimated FF for finding new site classification criteria.Figure 8 is the plot of FF versus Vs-30, which shows the general increasing of FF with velocity, from soft soil to hard rock. It means that even when the soil amplification is expected, rock is not free of amplification, but it is in higher frequencies (Teodulidis and Bard, 1995). This figure indicates the shear wave velocity and FF at boundaries of about 250, 500and 750 m/sec and 2.0, 5.0, and 8.0 Hz for Vs-30 and FF that could be considered as new boundaries for four different site classes. Of course these limits are not absolute and could be modified by increasing the database used. Increasing the data may help to have a better and more accurate judgment. Theodulidis and Bard (1995) find the boundary of 5.0 Hz to seperate rock from alluvium sites using Taiwan strong motion data with 1 Hz (4.0 to 5.0 Hz) overlap. The selected shear wave velocity ranges of different references are presented in table 2.

The boundaries proposed here have some overlaps but cover most of the available data. Not only will the existence of transition zones at boundaries in the nature smear the sharpness of boundaries, but also the inconsistency of the available data will exaggerate these overlaps. A statistical investigation shows that, if there is possibility to calculate the FF, these new defined criteria cover more than 75% of the stations even with 1 recorded accelerogram.

Table 2. The Vs-30 criterion proposed in different considered references

| Ref / Soil Type | NEHRP 2000 | Zare 1999 | Standard 2800 |
|---|---|---|---|
| IV | <180 | <300 | <175 |
| III | 180 ≤ < 360 | 300 ≤ < 500 | 175 ≤ <375 |
| II | 360 ≤ < 760 | 500 ≤ < 700 | 375 ≤ < 750 |
| I | 760 ≤ | 700 ≤ | 750 ≤ |

We used these criteria for site classification in the lack of complementary information or data. The site classification using new selected criteria is shown in figure 9. A better separation of soil classes with much lower overlaps can be observed.

## 3. RESULTS AND DISCUSSION

It is clear that the ground motion characteristics are affected by site surface geology and soil condition as well as the source and path effects. In this chapter, we tried to study the site effect to categorize site soil condition using two methods of H/V spectral ratio and seismic shallow refraction. The H/V spectral ratio computed using different windows of earthquake records such as S, Coda and S-Coda waves and the whole signal including P and S wave windows. Considering the limitations of recording the wave arrivals and discrimination of different wave windows, we examined the whole recorded signal (P-S wave windows) in comparison with S and S-Coda windows for H/V computation and found that the results are nearly the same.

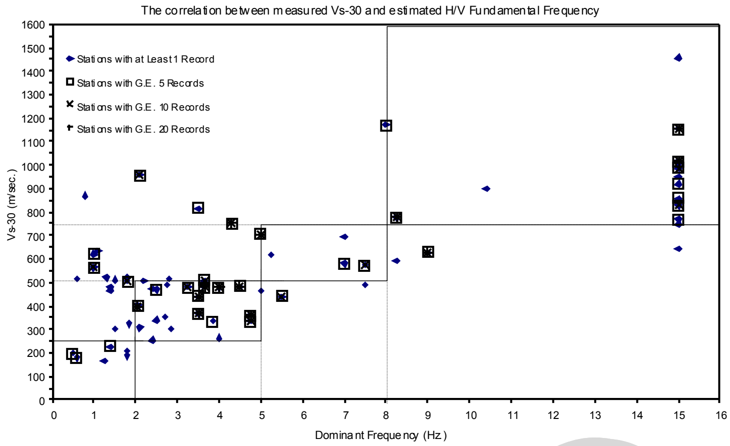


Fig 8. Defining the new limits for Vs-30 and FF boundaries

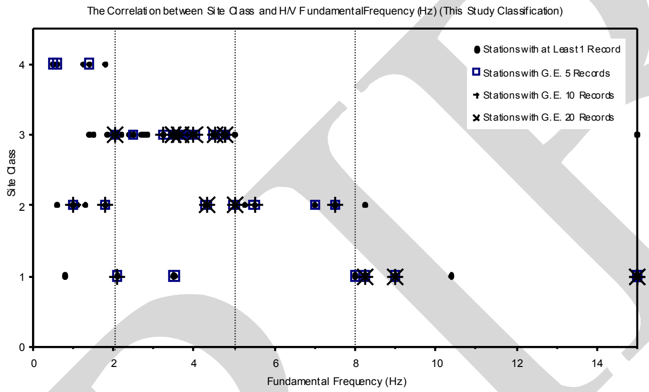


Fig 9. The comparison of site class (this study critera) and FF estimated using H/V spectral ratio. A better separation of classes and lower overlap is seen.

We used the whole signal window in this investigation. We tried to find a FF-based reliable criterion for classifying the soil types of 620 accelerographic stations in which a total number of 3200 strong motion accelerograms were recorded from 1994 to 2003. Moreover, 74 stations with computed Vs-30 were investigated to find a correlation between Vs-30 and the estimated FF. Based on the computed Vs-30, the studied stations are categorized in four groups I, II, III and IV. The classification of NEHRP (2000), Iranian Building Codes (standard 2800) and Zare (1999) are proposed in this study. The mean FF is estimated for all stations using the H/V spectral ratio, but because of the discrepancy in the number of accelerograms, source parameters and path effect, the obtained results do not have the same quality and reliable confirmation.

Figures 5 to 7 signify the correlation between the estimated FF and site class for the stations with different number of records. In the first place, all stations for which the shear wave velocity were measured, even if they have just one record, were considered. As it is clear, a single record cannot be representative of site characteristics, and it reflects a combination of site, source and path effects that cannot be separated. Increasing the number of records will minimize the source and path effects by averaging and the consequential is mainly representative of the site effect. We tried to find a correlation between the site class estimated by Vs-30 and FF resulted in H/V spectral ratio. The obtained results from different classifications proposed in NEHRP (2000) and Zare (1999) and standard 2800 (2003), show differences in few stations and another scale will lead to different result. Although this correlation help us to find the boundaries of < 2.0 Hz, 2.0 to 5.0 Hz, 5.0 to 8.0 Hz and ≥ 8.0Hz., high overlaps of the defined boundaries made us find a direct correlation between the measured Vs-30 and the estimated NF. This idea enabled us to define new criteria for site classification which are presented in table 3.

Table 3. New criteria defined for site classifications

| Site Class | Vs-30 (m/sec) | FF(Hz) |
|---|---|---|
| I | $750 \le$ Vs-30 | $8.0 \le$ NF |
| II | $500 \le$ Vs-30 $< 750$ | $5.0 \le$ FF $< 8.0$ |
| III | $250 \le$ Vs-30 $< 500$ | $2.0 \le$ FF $< 5.0$ |
| IV | Vs-30 $< 250$ | NF $< 2.0$ |

Figure 8 shows that these defined criteria cover more than 75% of the studied stations, even if there was a single good quality record with the possibility of estimating H/V spectral ratio. These boundaries are considered as site classification criteria which were considered in this research and figure 10 shows a better separation of site classes by using the new defined criteria.

## 4. CONCLUSIONS

The ground shaking felt or recorded at the ground surface is affected by the total sediments overlaying the seismic bedrock; therefore Vs-30 cannot be an absolute indicator of site condition. Thus, the estimated FF using any method including H/V spectral ratio, and the site are affected by source and path characteristics and cannot be used as criteria even if averaging increases the reliability. It is particularly difficult to have any judgment at the boundaries. Even though it is possible to use the afore-mentioned criteria for a rough site classification, as is widely used, the limitations of both methods impose the parallel use of different methods along with an engineering judgment for more accurate site classification.

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