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# Applying empirical methods in site classification, using response spectral ratio (H/V): A case study on Iranian strong motion network (ISMN)

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**Abstract**

Shear wave velocity, measured recently at 107 strong motion stations, is a new empirical basis in the applicability investigation of empirical classification techniques. These stations are classified considering Iranian Practice Code criteria (Standard 2800). To check the applicability of empirical methods, three different empirical techniques are applied to re-classify the stations using previously determined site classes. The first method is based only on the determination of peak periods at each station. It is found that the fundamental periods in different site categories are within the ranges proposed by Japanese Road Association. The second one is upon the site classification index (SI), suggested by Zhao et al. In this study, a new site index term is proposed for quantitative site classification using the empirical H/V spectral ratio (here after HVRS) method. It is shown that the results from this scheme are comparable with those obtained by applying the method of Zhao et al. and are more reliable than the results from using only peak periods. A large number of strong motion stations are classified in Iran for more control of proposed SI applicability. The mean response spectral ratio curves for all data of ISMN stations are found to be fairly consistent with those obtained by Zhao et al. The results show the practicability and efficiency of the proposed method in site classification. However, more shear wave measurements and further information, like surface geology, borehole data etc., are still needed to clarify the uncertainties of such empirical schemes.


*Keywords:* Response spectra; Site classification; Iran strong motion network

## 1. Introduction

Local site conditions profoundly affect the ground motion record characteristics. Local site response at different site conditions can amplify different period ranges of ground motion. Therefore, it is a reasonable explanation for the observed damage of buildings with structural natural periods near local site fundamental period [1,2]. Several numerical and/or empirical techniques have been proposed to estimate local site responses [3,4]. Such studies showed distinct amplification levels in the sites of different geological and geotechnical characteristics; therefore, it is an ordinary practice to categorize sites into different general classes. Different sites of the same classes are supposed to have local site responses of similar main characteristics. Building codes have widely applied site categorization schemes (such as surface geology, average shear wave velocity over 30 m ($V_{S30}$), etc.) to classify the sites into different categories. In this regard, surface geology and $V_{S30}$ are suggested by NEHRP2000 [5] and Iranian practical building code (Standard 2800) [6] as the categorization schemes. It is worth mentioning that each scheme has its own advantages and disadvantages; $V_{S30}$ is relatively cheaper and more practical in comparison with the geotechnical methods, which is recommended by Borcherdt [7] as means of site classification. However, $V_{S30}$ has no significant effect on the peak ground motion amplitudes, examined by Lee et al. [8]. They suggested using the average shear wave velocity of 100–200 m as site

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parameter. Applying several schemes simultaneously [9,10] is suggested in order to reduce the uncertainties of each classification scheme.

The present study classifies strong motion stations in Iranian Strong Motion Network (ISMN), which has 1094 instruments. Most of the accelerograph units are placed in active seismic or densely populated and industrialized areas. While the stations are located in the areas of different geological conditions, there is no down-hole array for comparing the surface motions with the deep ones [10,11]. Meanwhile, $V_{S30}$ and surface geology are only available site parameters, determined only for few stations.

According to the lack of information for recording sites, alternative empirical techniques were used in the previous studies on site characterization at ISMN stations. Both the H/V Nakamura technique and the receiver function method were used to determine the amplification period band at each station [12]. It should be mentioned that the latter was applied on the available three component accelerograms. They found generally good correlation between the amplification period band and the measured $V_{S30}$ at 26 selected strong motion sites. In another similar study, Sinaeian [11] applied the receiver function technique to determine the fundamental period of vibration in each site. He considered the fundamental period value at each station as the site parameter by which he classified the strong motion sites into four categories.

In this article, 107 strong motion stations are selected in order to investigate site characterizations for ISMN and to calculate average H/V curves for each site class. The $V_{S30}$ parameter is determined for the selected sites by the refraction technique. A set of empirical techniques is used to classify considered strong motion sites and a new empirical site index is introduced as well. The methodology is explained after a brief survey on the data-bank preparation for this study. The reliability of the classification schemes is carried out using the same data set used to define the average H/V, and the results of different schemes are represented and compared later. Finally, another 347 stations (the ones with at least three recordings) with no $V_{S30}$ have been classified using the proposed site index.

## 2. Accelerometric data-bank

Here, two different strong motion data sets are collected. First, 107 stations of ISMN with a total of 885 recorded strong motions were selected. In these stations the $V_{S30}$ parameter has already been reliably estimated. The location, the $V_{S30}$ parameter, site class and estimated fundamental period for each station are listed in Table 1. The above-mentioned data set, explained later, is used to derive mean response spectral ratio (H/V) for each site class.

For the second data set, 347 stations are selected, each with more than three records, by which 3116 strong motions in total are recorded. The second data set is used to examine the applicability of empirical classification methods. The geographical positions of the stations in both data sets are shown in Fig. 1.

The distribution of data sets, regarding magnitude and hypocentral distances, is shown in Fig. 2. This figure clearly shows a positive correlation between earthquake magnitudes and hypocentral distances. Such positive correlation in attenuation studies for Iran may lead to estimating the attenuation rate lower than the real one in the region. However, having no adverse effects on the present research, it may make studying the effect of magnitude and hypocentral distance on H/V spectral ratio curves variation difficult.

Almost all strong motion records in the data sets show clear baseline shifts, and are contaminated by long period and short period noises. The reasons for such shifts are well addressed in the previous studies [13,14]. Several procedures are proposed to adjust the baseline of strong motion records, and filter out the high and low period noises. Here, the procedure proposed by Boore et al. is followed [13,14]. Fitting a quadratic to the velocity time series and filtering are included in the scheme. Filtering is the most effective tool for reducing long and short period noises in the accelerograms in many cases. The choice of filtering technique, filter parameters, and usable range of spectral ordinates after filtering are all critical issues, addressed by several studies [13,15].

In this study, the fourth-order acausal Butterworth filter is used to reduce noises in the accelerograms. The acuasal filter is used because it is more effective than the causal one. Meanwhile, the response spectra, computed by causally filtered accelerations, can be sensitive to filter corner periods even for the oscillator periods much shorter than the filter corner periods [16,17].

The corner frequencies of high-pass and low-pass filters are taken from the results of a recent study on Iranian strong motion catalogue [11]. The scatter plot of high-pass filter corner periods versus magnitude is shown in Fig. 3 for different site classes, taken from the results of this study. The theoretical FAS corner periods from single-corner (JB88) [18] and two-corner (AS00) [19] frequency models are shown in Fig. 3 in the form of thick and dashed lines, respectively.

The signal-to-noise ratio (SNR) and spectral shape of FAS for each component are considered in order to determine the appropriate period band for each record [11]. However, for some records the chosen corner periods are relatively low, seen clearly in Fig. 3. In this study, SNR and FAS curves are re-checked, especially for those records with corner periods of less than 2 s. The determined corner periods, excluding few records, are generally similar to those proposed by Sinaeian [11]. Actually, such noisy records are mostly recorded during small earthquakes with the magnitudes below 5 and lower corner periods being expected on their FAS, as shown by the theoretical models in Fig. 3. These records normally show low amplitudes for long periods. On the other hand, long period noises are