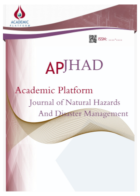

Research Article
Academic Platform Journal of Natural Hazards and Disaster Management
1(1), 25-34, 2020

Site Classification of Kocaeli Region Based on HVSR Method

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Received: / Accepted: 24.12.2019 / 08.06.2020

Abstract

Seismicity and global positioning system (GPS) map of the world displays that Turkey is one of the earthquakes affected region due to active tectonic plates. In current research, one of the highest seismic alert zones of Turkey i.e. Kocaeli district has been selected. The aim of this study is to classify the different sites of Kocaeli region depending on its predominant frequency ranges. More than 300 strong motion data with Moment (M_w) magnitude of 3.0 to 6.5 are available on Disaster and Emergency Management Authority (AFAD) site for Kocaeli. For current region, out of total 32 stations, data recordings from 16 stations have been taken into consideration. Strong ground motion records with Mw≥ 3 have been utilized to check the consistency of graphical results by using classical horizontal to vertical spectral ratio (HVSR) technique. Finally, the results of current method are compared with Eurocode8, NEHRP and the 2008 report of the microzonation work done by Kocaeli Metropolitan Municipality and Scientific and Technological Research Council of Turkey (TUBITAK). The procedure obtained from this study is expected to provide foreknowledge to the researchers who will work on this topic.

Key words: HVSR method, Site classifications, Earthquake, Seismic regions

1. Introduction

Civil engineering is the mother of all engineering that has changed the frame of this world into huge sky catching towers and buildings. The most of economical shares in advanced countries like USA, China, Japan, England and France etc. has been contributed to their infrastructure developments. Like other countries, Turkey has also devoted a huge amount in their construction network. As on one side, country's economy is based on their sustainability of their infrastructure, the other side is to protect them from natural disasters like earthquakes. In the Kocaeli devastating earthquake of 1999, approximately 20000 lives were died, and a hundred-million-dollar property was destroyed [1]. So, this serious issue has attracted a great attention of design and earthquake engineers for safety and rehabilitation.

In earthquake design engineering, primarily horizontal component (i.e. east-west or north-south) of input ground motion has been studied for assessment. However, the vertical component (i.e. up-down) contains remarkable information for structures in areas with high seismicity and not shallow bedrock depth. Both the horizontal and vertical component provide

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This article is an extended and revised version of the contribution to the International Symposium on Natural Hazards and Disaster Management (ISHAD2018).

same information about the source and path which indicates that there is certain mutual correlation between both components [2].

Although earthquake waves move hundreds of kilometers deep, they are influenced by the local site conditions. Many researchers have used HVSR technique to assessment these effects [3-5]. This method includes of using the spectral ratio of horizontal to vertical part of ground motion and approximates the Fourier amplitudes in various frequency range as given in Equation 1.

$$HVSR = \frac{A(f)_{Horizontal}}{A(f)_{Vertical}} \tag{1}$$

Figure-1 shows the common outline of the procedure which was initially employed to the S wave section of the earthquake recordings achieved at three sites in Mexico City [6].

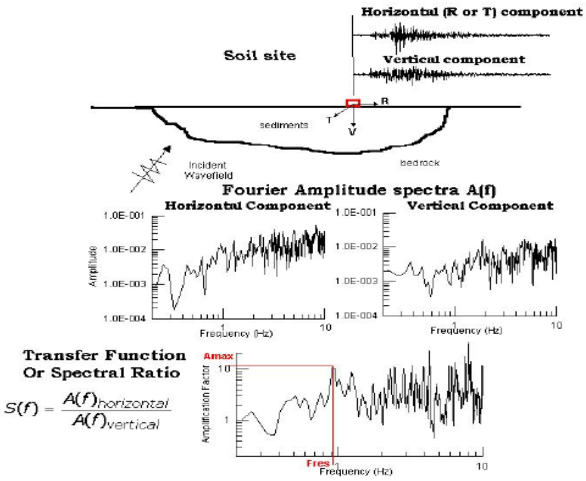

Figure 1. Explanation of the Horizontal to Vertical Spectral Ratio Method [6]

At the same time, the effects of local site conditions on earthquake waves in 1985 Michoacan-Mexico [7], 1989 Loma Prieta [8], 1994 Northridge [9], 1995 Kobe [10], 1999 Kocaeli [11-15], 1999 Chi–Chi [16] and 2000 Western Tottori [17] earthquakes occurring in various parts of the world have been revealed.

Opinions in latest earthquakes indicate that surface geology is one of the essential factors influencing shaking duration [18]. In current study, Kocaeli district has been selected because it is one of the densely populated and industrialized east Marmara regions. 32 stations data are available for Kocaeli state on AFAD website [19]. From total 32 stations, 16 stations are considered due to precise data availability and compatibility with HSVR technique. The purpose is to classify the dominant frequencies of the station regions through the acceleration data and to examine the site response uniformity. The research comprises of more than 300 strong motion records with diverging amplitudes. These data are thus applied to examine whether a traditional site response tool such as HVSR produce stable results all over the region of Kocaeli. Additionally, the dominant frequency values for current results have been compared with NEHRP, Eurocode 8 and with the description of the Microzonation work performed by Kocaeli Metropolitan Municipality and TUBITAK in 2008 [20].

2. Strong Ground Motion Data for Kocaeli Region

Firstly, strong ground motion data records of all 32 stations installed in the region of Kocaeli are carefully analysed and then screening procedure has been adopted. It is observed that data recordings from 16 stations are well presented and is more compatible with the current HVSR technique. Therefore, the strong motion records (approximately more than 300 data) from all 16 stations are saved in the directory for HVSR analysis. Figure-2 shows the locations of selected 16 stations on the seismic fault maps of Kocaeli region.

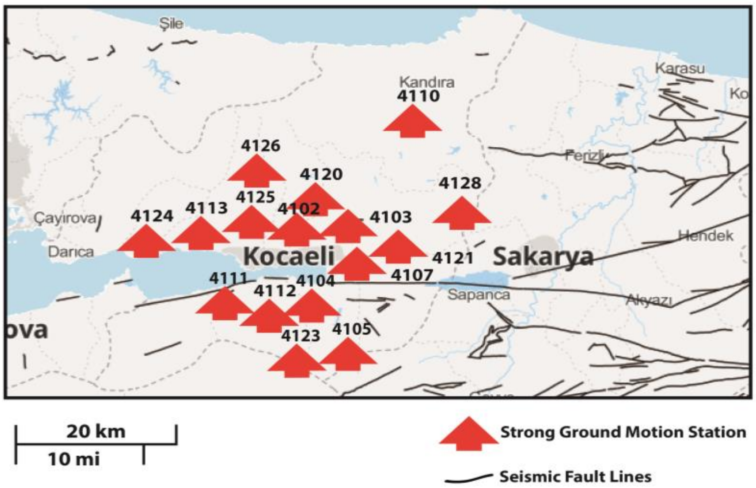

Figure 2. Selected strong ground motion stations of Kocaeli region in current study

Table-1 shows the station codes (SC), their latitude and longitude, installation date and total number of records available in each station used for evaluation of site classifications.

Table 1. Detail of selected stations

No	Station Code	Station Latitude	Station Longitude	Province	Installation Date	Number of Record
1	4102	40.78463	30.02649	Alikahya_Izaydas	2010-09-28	11
2	4103	40.78577	30.02504	Alikahya_Izaydas	2008-03-11	8
3	4104	40.68038	29.96998	Basiskele_Yuvacik	2010-09-28	36
4	4105	40.67441	29.96935	Basiskele_Yuvacik	2008-03-11	44
5	4107	40.76021	29.93244	Karabas	1999-09-12	33
6	4110	41.06910	30.15250	Kandira	2010-05-14	19
7	4111	40.68440	29.58880	Karamursel	2010-05-14	43
8	4112	40.72450	29.84000	Golcuk	2010-05-14	19
9	4113	40.77680	29.73350	Korfez	2010-06-10	24
10	4120	40.76761	30.02737	Alikahya	2012-04-25	15
11	4121	40.72277	29.96985	Kullar	2012-04-25	23
12	4123	40.71515	29.84794	Ihsaniye	2012-04-25	14
13	4124	40.78308	29.60625	Hereke	2012-06-06	8
14	4125	40.76650	29.91721	Kozluk_Meteor	2012-07-06	7
15	4126	40.76252	29.91485	Kozluk_Muze	2013-08-16	15
16	4128	40.72490	30.02435	Kartepe	2014-10-21	10

2.1. Local site classifications

The Metropolitan Municipality of Kocaeli and Marmara Research Center of TUBITAK have produced a seismic microzonation report in 2008 including soil classification map for seismic hazard prediction. Figure-3 shows site classification map for Kocaeli region produced by above two agencies.

In that report, a various, geophysical surveys and geological investigations have been done. These surveys contain macro level site investigations and measurements. Thus, site classification map has been developed based on the average S wave velocity passing through 30 m depth of soil. For investigation of deep underground structure of the Izmit Basin, S wave profiles and gravity data from 327 points have been collected and from these data have been created 3D bedrock depth of the basin. It has been noticed that bedrock is available at the middle of the basin at a depth of 750-800 m [20]. In the study carried out by Ozalabey et al., thickness was given in the same basin in the range of 1200-1400 meters [21].

HVSR method has been adopted to obtain the site resonance frequency and horizontal to vertical amplification parameters. For this, a total of 422 three component micrometer measurements have been made.

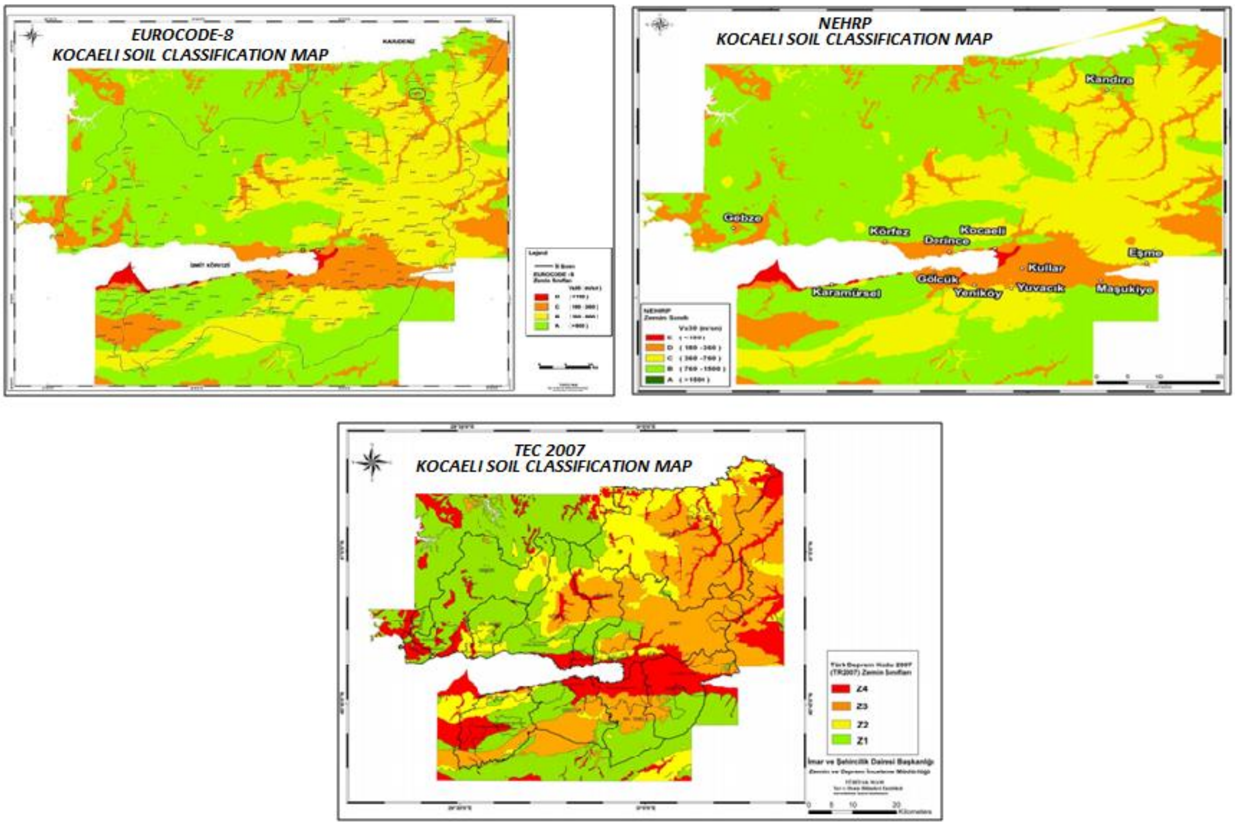

Figure 3. Kocaeli soil classification map according to Eurocode 8, NEHRP and TEC 2007 [22-24]

According to the Eurocode 8 procedure adopted by the Municipality of Kocaeli and TUBITAK Marmara Research Center soil classification has been divided into four categories (A-D site classes). Similarly, According to NEHRP, soil classification has been divided into five categories (A-E site classes). Whereas Turkish Earthquake Design Code 2007 classifies the soil (Z1-Z4 site classes). Figure-3 shows the soil classification map presented for Kocaeli region according to Eurocode 8, NEHRP and TEC 2007. The HVSR technique [25] is commonly used in seismic hazard evaluations since it is comparatively consistent, suitable, and valid for urban areas. To date, the use of the HVSR procedure for site seismic classification is still in progress [26]. For the current research, Figure-3 have been used as reference maps for comparison of the results. Total 16 stations have been considered for the current research to check their soil classifications. All three components (NS, EW, and UD) of records have been considered.

Firstly, raw data is analyzed by using MATLAB code [27] and then most suitable records are selected for further processing. In data acquisition and processing, noisy waves with frequencies smaller than 1 Hz and higher than 70 Hz should be separated from the real data [28]. Therefore, a baseline linear correction and a band pass butter worth filtering, with a range of 1 Hz and 70 Hz is applied. Fourier spectra graphs for data acquisition and processing is shown in Figure 4.

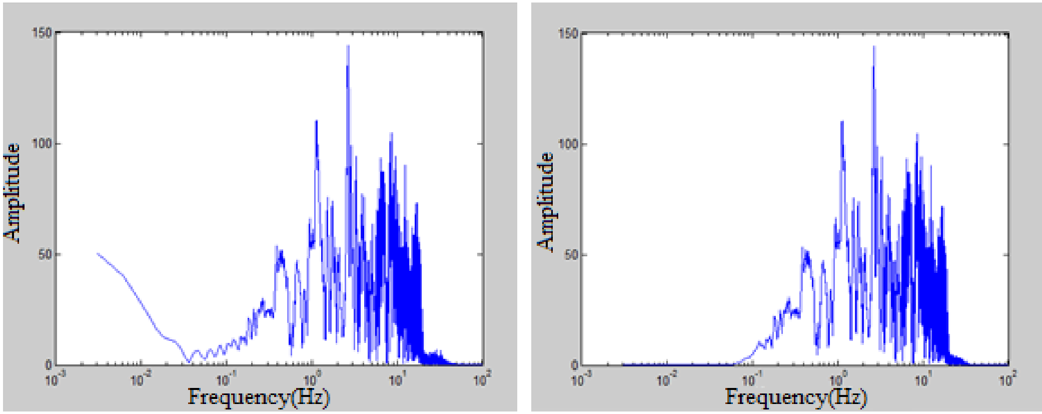

Figure 4. Unfiltered (a) and Filtered (b) Ground Surface Fourier Spectra

3. Results & Discussions

As discussed before, recordings from 16 stations have been considered to classify the site classes (A-D). The output obtained from HVSR ratios are shown in the Figure 5-8. The analysis shows that HVSR are consistent with each other. The obtained ratios are grouped in the following frequency ranges: f0<1.0 Hz, 1.0<f0<2.0 Hz, 2.0<f0<3.0 Hz and 3.0<f0<5.0 Hz [29]. In Figures 5-8, SC denotes station codes of selected stations. Different color of graphical curves in Figures 5-8 represents each strong ground motion data that is utilized in HVSR method.

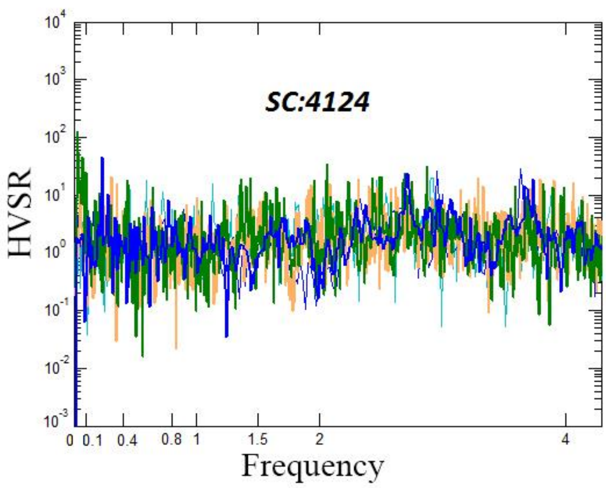

Figure 5. Distribution of the fundamental site frequencies for A site

According to Figure 5. the frequency ranges obtained from station SC4124 (Hereke region), HVSR technique outputs f_0 <1.0 Hz. It is classified as fundamental frequency A class site.

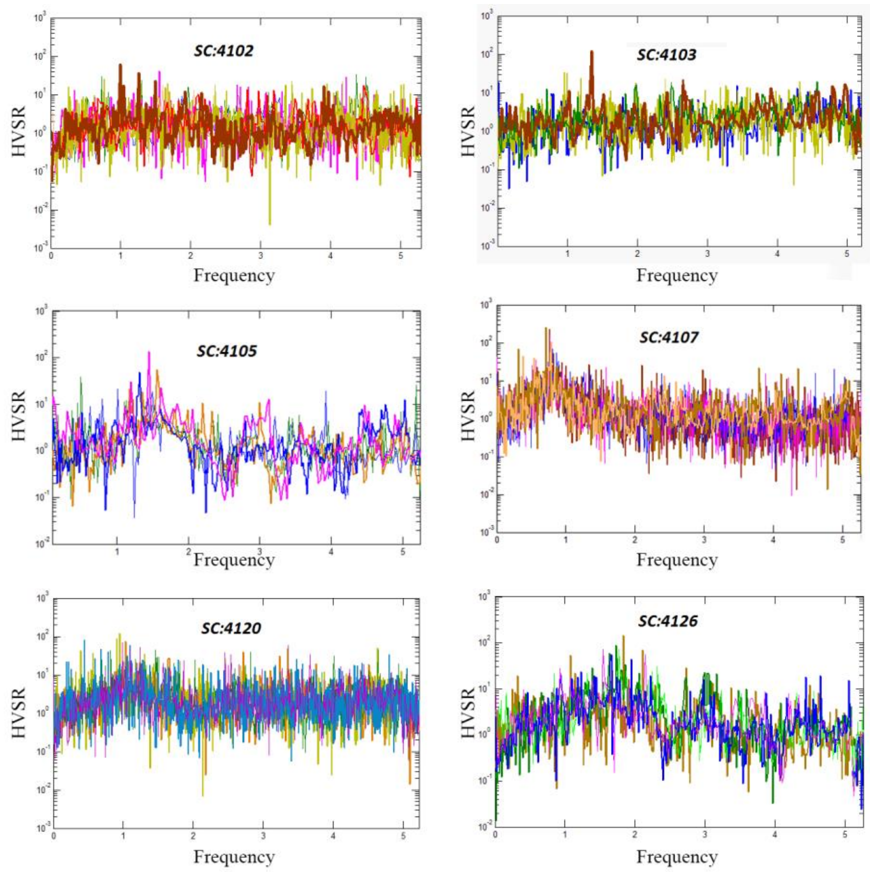

Figure 6. Distribution of the fundamental site frequencies for B site

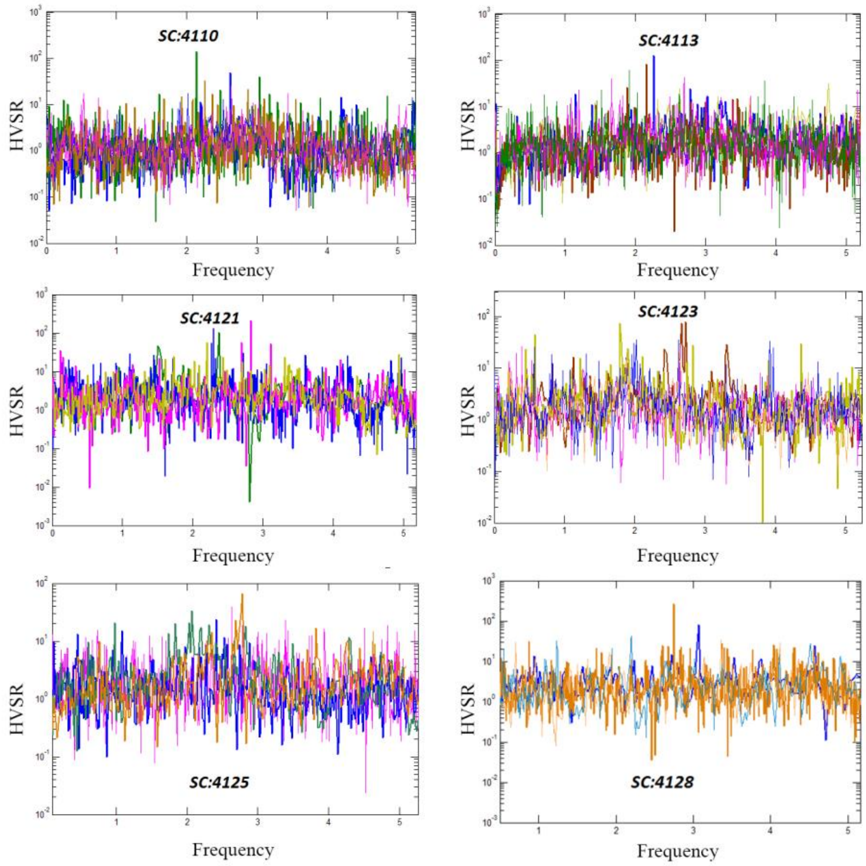

Figure 7. Distribution of the fundamental site frequencies for C site

It is observed in Figure 6 that for SC4102, SC4103, SC4105, SC4107, SC4120 and SC4126, the fundamental frequency ranges $1.0 < f_0 < 2.0$, Hence selected station sites are classified as B site.

It has been seen in Figure 7 that SC4110, SC 4113, SC4121, SC4123, SC4125 and SC4128 are within the range of $2.0 < f_0 < 3.0$, thus a site class C is assigned.

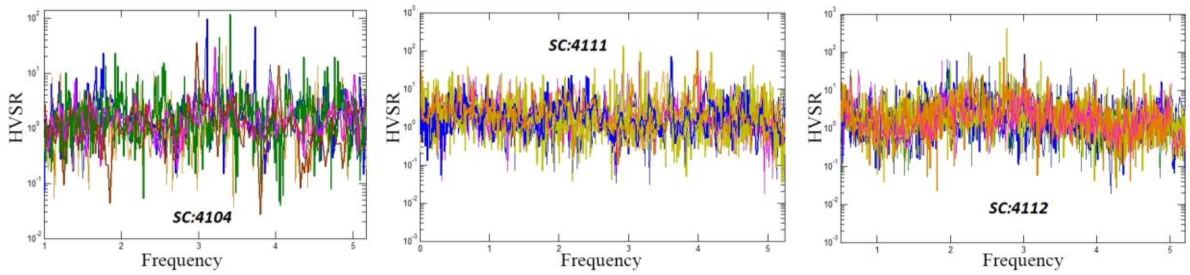

Figure 8. Distribution of the fundamental site frequencies for D site

Figure 8. presents the highest frequency ranges $3.0 < f_0 < 5.0$ Hz, thus according to classification rule, it is classified in site D.

To conclude, the strong ground motion recording station positioned at the site of Hereke possess fundamental frequency ranges less than 1 Hz. Similarly, stations of Alikahya, Basiskele, Karabas are found at fundamental sites frequency ranges of 1.0-2.0 Hz. Stations at Kozluk shows variability that defines the non-uniformity of site classed between B and C. Further, recording sites of Kandira, Korfez, Kullar, Ihsaniye, and Kartepe are found in 2.0-3.0 Hz. Like Kozluk, Basiskele also show non uniformity of soil sites and its stations vary from B and D classes. However, Karamursel and Golcuk stations have ranges of 3.0-5.0 Hz, thus classified in D class.

3.1. Comparison of site fundamental frequencies with the site classes

The distribution of the fundamental site frequencies for the selected Kocaeli stations have been compared with the local site classes in different codes. Site classification maps given in Figure 3 have been used for comparison. Table-2 yields the comparison results and it can be seen that HVSR provides similar results like other techniques used before for site classification. Thus, HVSR method can also be recommended for the site classification because it is simple and quick method to evaluate fundamental frequency of a site.

In the Table-2, the site classification has been done for the current study in terms of A (frequency ranges: $f0<1.0$ Hz), B (frequency ranges: $1.0<f0<2.0$ Hz), C (frequency ranges: $2.0<f0<3.0$ Hz) and D (frequency ranges: $3.0<f0<5.0$ Hz) respectively.

Table 2. Comparison of the results obtained from this study with previous studies

					This Study		
Station Code	**$V_{S(30)}$**	**NEHRP**	**Euro Code 8**	**TUBITAK 2008**	**Dominant Frequency**	**Frequency Range**	**Site Classification**
4102	1000	A	A	Z1	1.0	$1.0<f_0<2.0$	B
4103	1013	A	A	Z1	1.0-2.0	$1.0< f_0<2.0$	B
4104	770	C	B	Z3	3.0-4.0	$3.0< f_0<5.0$	D
4105	-	C	B	Z3	1.0-2.0	$1.0< f_0<2.0$	B
4107	305	D	C	Z3	1.0	$1.0< f_0<2.0$	B
4110	380	D	C	Z3	2.0-3.0	$2.0< f_0<3.0$	C
4111	300	E	D	Z4	3.0-4.0	$3.0< f_0<5.0$	D
4112	352	D	C	Z3	2.0-3.0	$3.0< f_0<5.0$	D
4113	300	D	C	Z1	2.0-3.0	$2.0< f_0<3.0$	C
4120	-	A	A	Z1	1.0	$1.0<f_0<2.0$	B
4121	-	D	C	Z4	2.0-4.0	$2.0< f_0<3.0$	C
4123	-	D	C	Z3	2.0-3.0	$2.0< f_0<3.0$	C
4124	-	A	A	Z1	0.2	$f_0<1.0$	A
4125	826	D	C	Z4	3.0	$2.0< f_0<3.0$	C
4126	-	D	C	Z4	2.0	$1.0< f_0<2.0$	B
4128	-	D	C	Z4	3.0	$2.0< f_0<3.0$	C

Conclusions

In this study, data from the saved directory of 16 stations are utilized to investigate whether a classical site response tool such as HVSR yield consistent results throughout the region of Kocaeli. Therefore, the predominant frequency values for current results are evaluated and compared with NEHRP, Eurocode8, and the report of the Microzonation work conducted by Kocaeli Metropolitan Municipality and TUBITAK in 2008 to assign site classes.

Analysis of earthquake ground motion records show that all the selected stations are located at sites that can be characterized by four fundamental frequency ranges. The obtained ratios can be grouped in the following frequency ranges: f0<1.0 Hz, 1.0<f0<2.0 Hz, 2.0<f0<3.0 Hz and3.0<f0<5.0 Hz. Results shows that HVSR method gives reasonable similar results like other site classification techniques and can be used for the quick site response classification and analysis. Thus, HVSR method can also be recommended for the site classification because it is simple and quick method to evaluate fundamental frequency of a site.

For future works, the results evaluated in this study can be compared with the SSR method. This will allow the future researchers to examine the consistency, precision, and reliability of both techniques.

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