Analysis Of Earthquake Records of Istanbul Earthquake Rapid Response System Stations Related to the Determination of Site Fundamental Frequency

A. C. Zulfikar, H. Alcik & E. Cakti
Bogazici University,Kandilli Observatory and Earthquake Research Institute, Istanbul, Turkey

SUMMARY:
In this study the data from the Istanbul Earthquake Rapid Response System (IERRS) are studied for 11 recent earthquakes recorded in the central part of Istanbul. The object is to identify the predominant frequencies of the station sites through the acceleration data and to investigate the site response consistency of the IERRS. The system consists of 100 strong motion recorders. Since its deployment in 2001 the IERRS recorded 11 events with magnitudes ranging from 3.1 to 5.2. We make use of these recordings to investigate whether classical site response tools such as H/V and spectral ratios yield consistent results throughout the central part of Istanbul. In calculating H/V and spectral ratios the stations with the number of recordings three and above are chosen. Analysis of ground motion records show that the IERRS stations are located at sites with 4 different fundamental frequency ranges. These frequency groups are; $f_0<1.0$ Hz, 1.0 Hz$<f_0<$2.0 Hz, 2.0 Hz$<f_0<$3.0 Hz and 3.0 Hz$<f_0<$5.0 Hz. In general, fundamental site frequencies at NEHRP C site classes are observed as less than 1.0Hz, in contrast to NEHRP D site class stations, where the fundamental frequencies are in the range of 3.0 Hz$<f_0<$5.0 Hz.

Keywords: Istanbul Earthquake Rapid Response System, Local Site Effects, H/V, spectral ratios

1. INTRODUCTION

Observations in recent earthquakes reveal that surface geology is one of the important parameters affecting seismic ground motion and damage.

Identification of local soil conditions and their effects on earthquake ground motion are important to assess possible effects of a future Marmara Sea earthquake in Istanbul ultimately. Various seismic risk mitigation projects are carried out and/or supervised by the Universities, Istanbul Governorate and Istanbul Metropolitan Municipality (IMM). Assessment of site conditions constituted an important part of these efforts (www.ibb.gov.tr, 2007).

In this study, the acceleration records recorded by the Istanbul Earthquake Rapid Response System (IERRS) are used to determine the fundamental site frequencies of strong motion stations situated in the central part of the city. The results are compared with existent soil classification maps of the study area. The reliability between the fundamental site frequency and spectral ratios for the earthquakes with magnitudes between 3.1 and 5.2 is also examined.

2. ISTANBUL EARTHQUAKE RAPID RESPONSE SYSTEM

Frequent occurrence of historic destructive earthquakes clearly demonstrates the high seismic activity and the potential seismic hazard in the Marmara Region (Parsons, 2004; Erdik *et al*., 2004; Atakan *et al*., 2002; Ambraseys and Jackson, 2000). Especially, two recent destructive earthquakes, the Kocaeli earthquake on 17 August 1999 (M_w 7.4) and the Duzce earthquake on 12 November 1999 (M_w 7.2) that occurred along the western part of the right-lateral north Anatolian fault zone, caused major concern about future earthquake occurrences and their possible consequences in the Istanbul area. The city faces a significant earthquake hazard with probability of exceedence 41±14% in the next 30 years for an event of moment magnitude above 7.0 (Parsons, 2004).

In order to assist the reduction of losses in a possible future disastrous earthquake in Istanbul, a strong motion network encompassing 100 stations (Figure 1), two data centers and several end-user nodes were implemented. Strong motion instruments are generally located at ground level in small and medium-sized buildings (police stations, fire stations, military posts and schools). The system generates automatically shake maps, damage maps and casualty distribution maps after an earthquake and disseminate them to the end users (currently Istanbul Governorate, First Army Headquarters and Istanbul Metropolitan Municipality) within 5 minutes (Erdik *et al.,* 2003; Alcik *et al.,* 2009).

3. FUNDAMENTAL SITE FREQUENCY AND GROUND MOTION ACCELERATION RECORDS

Determination of site fundamental frequency is important to derive local site effects and amplification factors. Classical site response tools such as Horizontal-to-Vertical (H/V) (Nakamura, 1989) and Reference Site (RS) Ratios (Borcherdt, 1970) of acceleration records are utilized in this study. The use H/V ratio of earthquake ground motion records in site characterization is proposed by Nakamura (1989). The amplification function is obtained by either arithmetical or geometrical averaging of the Fourier Amplitude Spectrum (FAS) of the two horizontal components and dividing it by the vertical component. The frequency that corresponds to peak amplification is related to dominant site frequency.

RS Ratio, also called Standard Spectral Ratio technique, uses the spectral ratio of earthquake ground motion records at a soil site and at a nearby hard-rock site to estimate relative amplification and dominant site frequency.

IERRS recorded 11 earthquakes that occurred in the Marmara region from 2003 to 2011 with magnitudes changing between M3.1 and M5.2. The stations which recorded 3 or more earthquake events are included in the analysis. The details of earthquake events are given in Table 1 and in Figure 3. All acceleration records are baseline corrected and band-pass filtered. In the calculation of site fundamental frequency, H/V (Nakamura, 1989) and RS Ratio (Borcherdt, 1970) methods are utilized. H/V ratios are obtained by dividing the FAS of the average horizontal ground motion to the FAS of the vertical ground motion records. RS Ratios are obtained by dividing the FAS of the horizontal ground motion record of the station to the FAS of the reference station. Station R52 is chosen as the reference station in Istanbul. Standard deviation of the H/V ratios and RS ratios are also shown in the Figure 4. The analysis showed that H/V and RS ratios are consistent with each other. The obtained ratios can be grouped in the following frequency ranges: $f_0<1.0$ Hz, $1.0<f_0<2.0$ Hz, $2.0<f_0<3.0$ Hz and $3.0<f_0<5.0$ Hz.

The distribution of the site fundamental frequencies for the IERRS stations is shown in Figure 4. The frequency ranges for the H/V and RS ratios are presented in Table 2. The site classes for different methodologies can be seen in Figure 5.

Figure 1. IERRS stations in Istanbul

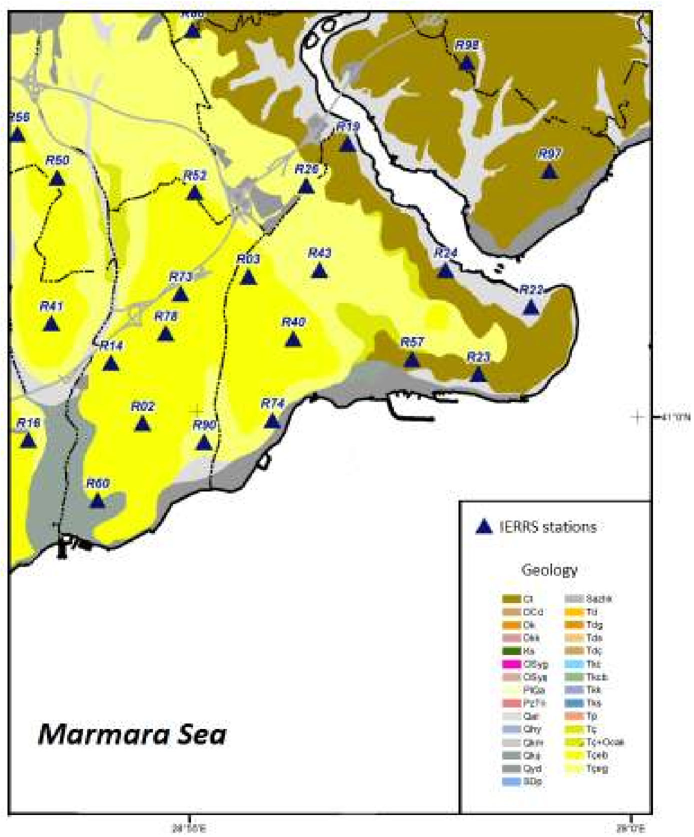

Figure 2. IERRS stations in the central part of Istanbul (The geology units are taken from www.ibb.gov.tr)

Table 1. Information on the earthquakes used in the analysis as reported by KOERI.

Event No.	Date	Time	Lat. (N)	Long. (E)	Depth (km)	Magnitude		Location	Number of triggered stations
						M_D	M_L		
1	2003.09.19	00:51:08	40.850	29.287	8.2	3.1	3.2	GUZELYALI/ ISTANBUL	16
2	2004.05.16	03:30:48	40.696	29.322	11.0	4.2	4.3	YALOVA	73
3	2004.05.16	21:07:48	40.699	29.317	9.2	3.3	3.4	YALOVA	5
4	2004.06.24	13:28:54	40.868	29.268	16.7	3.2	3.2	GUZELYALI / ISTANBUL	14
5	2004.09.29	15:42:07	40.780	29.020	12.4	-.-	4.0	MARMARA SEA	86
6	2006.10.20	21:15:24	40.264	27.984	12.9	5.2	-.-	KUS LAKE	43
7	2006.10.24	17:00:21	40.424	28.995	14.3	5.2	-.-	GEMLIK BAY / MARMARA SEA	47
8	2006.12.19	21:15:37	40.391	28.321	11.1	4.2	-.-	MARMARA SEA	5
9	2008.03.12	20:53:31	40.621	29.011	11.2	-.-	4.8	CINARCIK / YALOVA	61
10	2010.10.03	20:49:02	40.847	28.110	11.2	-.-	4.4	MARMARA SEA	53
11	2011.07.25	20:57:20	40.811	27.729	15.3	-.-	5.2	MARMARA SEA	21

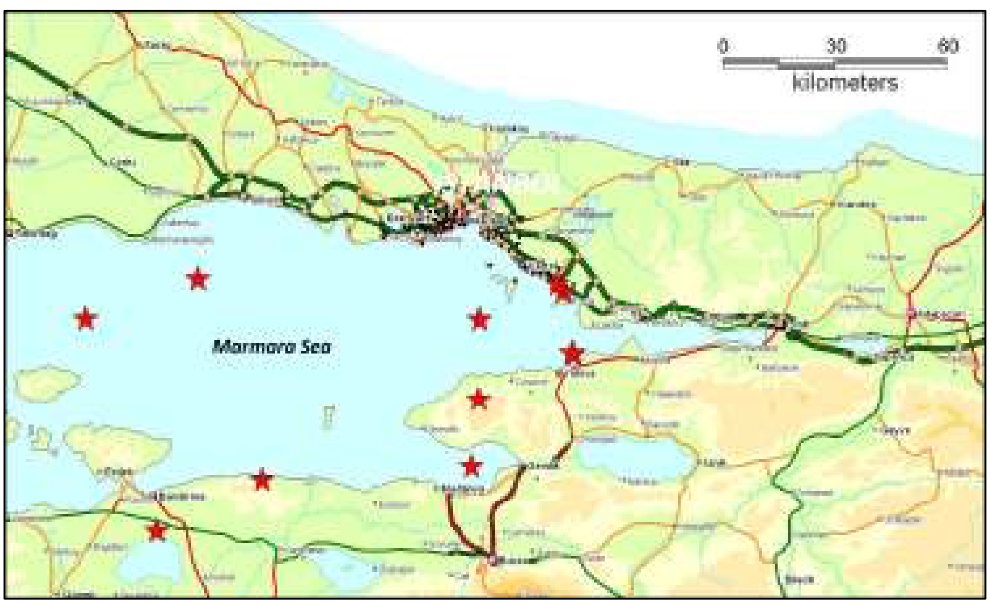

Figure 3. The epicenters of earthquakes given in Table 1

According to the results of the analysis, the fundamental frequency at the station sites in the old city of Istanbul is around 1.0-2.0 Hz. At south-east part of the old city stations R23 and R57 the range of dominant frequencies is estimated as 3.0-5.0 Hz indicating stiff soil conditions.

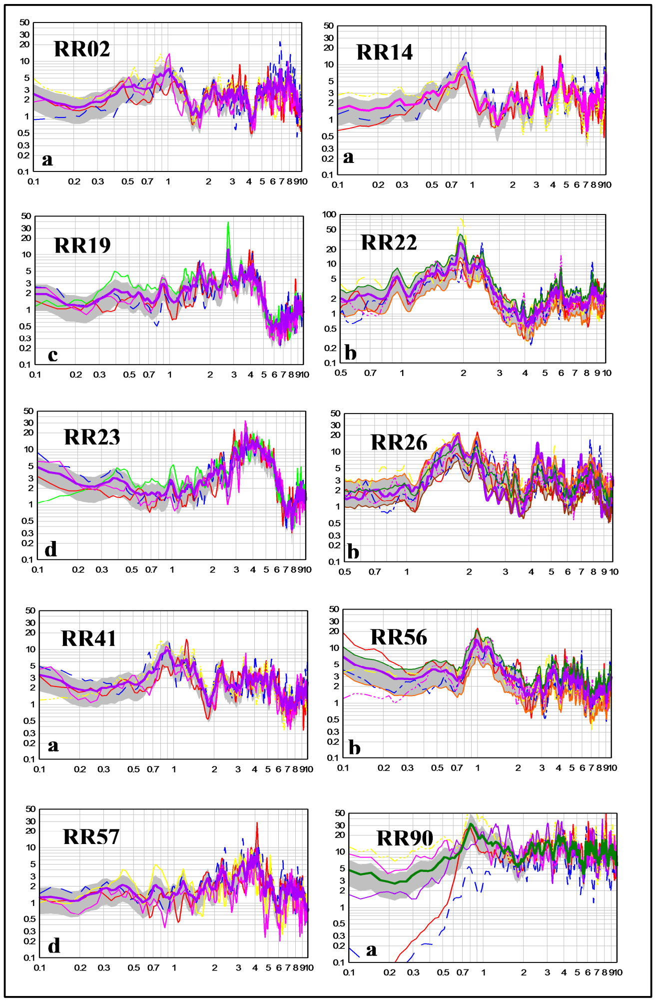

Figure 4. Fundamental frequencies: a, b, c and d indicate f_0<1.0 Hz, 1.0<f_0<2.0 Hz, 2.0<f_0<3.0 Hz, 3.0<f_0<5.0 Hz respectively. RR indicates Rapid Response Station.

4. COMPARISON OF SITE FUNDAMENTAL FREQUENCIES WITH THE SITE CLASSES

The distribution of the fundamental site frequencies for the Istanbul Earthquake Rapid Response System Stations is compared with the local site classes found by three different methodologies.

The most suitable approach for the evaluation of regional geotechnical conditions is the soil classification maps. The NEHRP (1997) soil classification map of Istanbul was completed by KOERI (2002) (Figure 5a) by taking into account the surface geology map which was prepared by IMM.

Development of QTM maps is another site classification approach in the geotechnical literature proposed by (Wald *et al.*, 1999). Turkey's QTM map was completed by digitizing the surface geology map which had originally been prepared by the General Directorate of Mineral Research and Exploration (MTA). In the QTM maps, Q represents the Quaternary (Sedimentary) class with an average shear-wave velocity (Vs) of 333m/s, T represents the Tertiary (soft rock) class with an average Vs of 406m/s and M represents the Mesozoic (stiff rock) class with an average Vs of 589 m/s. The QTM map for the study area is presented with the IERRS stations in Figure 5b.

Wald and Allen (2007) developed a correlation between site topography and site classes. NEHRP related soil classification map for Istanbul on the basis of Wald and Allen (2007) (Figure 5c).

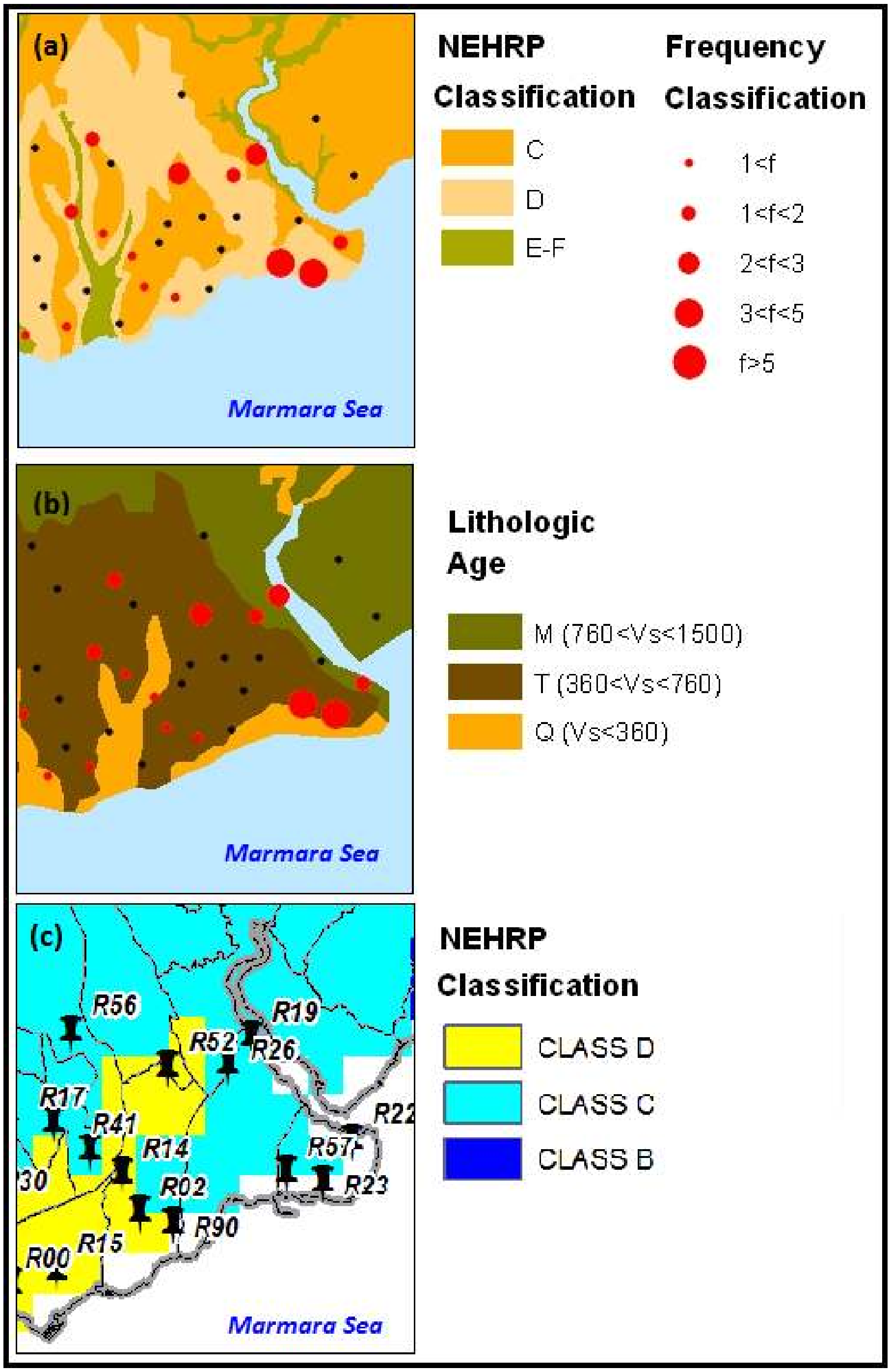

Figure 5. (a) NEHRP site classification map and (b) QTM map for the study area with IERRS stations fundamental frequency distribution, (c) Site classification map for Old City prepared using topography.

The comparison of the IERRS stations' fundamental site frequencies with the soil classes obtained from site classification maps is presented in Table 2. In the Table, according to NEHRP site classification C and D represent very dense soil and soft rock conditions with a Vs range 366m/s-

762m/s and stiff soil profile with a Vs range of 183m/s-366m/s respectively. For the stations with site class defined as C-T-C, the dominant site fundamental frequency is generally less than 1 Hz. However, in D-Q-D soils no dominant frequency range can be identified.

RESULTS

Analysis of earthquake ground motion records show that the IERRS stations are located at sites that can be characterized by four fundamental frequency ranges. They are; f_0<1.0 Hz, 1.0 Hz<f_0<2.0 Hz, 2.0 Hz<f_0<3.0 Hz and 3.0 Hz<f_0<5.0 Hz. In general, fundamental site frequencies of the C-T-C site class are observed as less than 1.0Hz, while for the D-Q-D site class they are in the range of 3.0 Hz<f_0<5.0 Hz. The R19 and R22 stations characterized as C-T-C site class are in the frequency range 1.0 Hz<f_0<2.0 Hz and 2.0 Hz<f_0<3.0 Hz, respectively. The frequency range for R26 and R90 stations D-Q-D type soils are 1.0 Hz<f_0<2.0 Hz and f_0<1.0 Hz, respectively.

Table 2. Results of the predominant frequencies (f_0) obtained at the Old City part of Istanbul

							Predominant Frequency (Hz)		
Station Code	Location	Reference Station for RS ratio	Distance (km)	NEHRP' Soil Class.	QTM'' Soil Class.	NEHRP''' Soil Class.	H/V Ratio	RS Ratio	Frequency Range
R26	Fatih	R52	1.8	D	Q	D	1.0-2.0	1.5-2.0	1<f_0<2
R90	Zeytinburnu	R52	4.0	D	Q	D	0.7-0.9	0.7-0.9	f_0<1
R23	Kumkapi	R52	5.4	D	Q	D	3.0-5.0	4.0-5.0	3<f_0<5
R57	Aksaray	R52	4.4	D	Q	D	3.0-4.0	3.0-4.0	3<f_0<5
R02	Zeytinburnu	R52	3.7	C	T	C	0.8-1.0	0.7-0.9	f_0<1
R19	Balat	R52	2.5	C	T	C	2.0-3.0	3.0-4.0	2<f_0<3
R22	Eminonu	R52	5.7	C	T	C	2.0	1.5-2.0	1<f_0<2
R41	Merter	R52	3.2	C	T	C	0.8-0.9	0.8-0.9	f_0<1
R56	Esenler	R52	3.0	C	T	C	1.0	1.0-1.5	1<f_0<2
R14	Zeytinburnu	R52	3.1	C	T	C	0.7-1.0	0.7-1.0	f_0<1

' NEHRP soil classification : based on IMM geological maps and log data
'' QTM soil classification : based on MTA geological maps
''' NEHRP soil classification : based on topography

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