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## Single microtremor method for estimating site fundamental frequency at a site in the historical city of Byblos - Lebanon

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# Single microtremor method for estimating site fundamental frequency at a site in the historical city of Byblos - Lebanon

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**Abstract.** A single ambient noise measurement has been found to be useful in investigating the near-surface geology in particularly for estimating site fundamental frequency. This single microtremor method is very attractive and has been successfully applied in many projects as the method is non-destructive, low cost, feasible for urban environments, fast, and deep penetration. Furthermore, this single microtremor method has been successfully applied in many projects. This paper presents the application of the single microtremor method to estimate the site fundamental frequency at a site in the historical city of Byblos, Lebanon. Pre-processing of industrial origin detection was carried out. Several durations of the measurements were investigated to obtain the most stable results. The site fundamental frequency was validated using one-dimensional site response analysis. The results are presented in this paper.

## 1. Introduction

Since the simplicity, convenient and affordable method, single microtremor application has been widely used in earthquake engineering-related research. Single point microtremor method is generally used for the following purposes in geotechnical earthquake engineering such as preliminary seismic site classification, local site effects, estimation of bedrock depth, and sub-surface profiling ([1]; [2]; [3]; [4]). The successful application of the single microtremor method (H/V – horizontal/vertical spectral ratio) can be found in Ref. [3]; [5]; [6]; [7]; [8]; [9]; and [10]. This paper presents the application of a single microtremor method for estimating site fundamental frequency at a site in the historical city of Byblos – Lebanon.

Empirically, there is a strong correlation between the damage caused by earthquakes and the near-surface geology setting of the affected area, which is called the site effect ([11]; [12]; [13]; [14]). Generally, seismic wave velocity is higher at rocks than at soils, therefore, to carry the equivalent amount of energy the seismic wave velocity decreases and the amplitude of the seismic wave expands at soils. This causes a couple of effects: firstly, the ground displacement at soil sites is larger than at rock sites, and secondly, the duration of the ground trembling is longer at soil sites than at rock sites. In the case of the seismic-wave frequency matches the fundamental frequency of the ground layer, resonance will occur ([15]; [16]). These site effects have played a principal role in defining the

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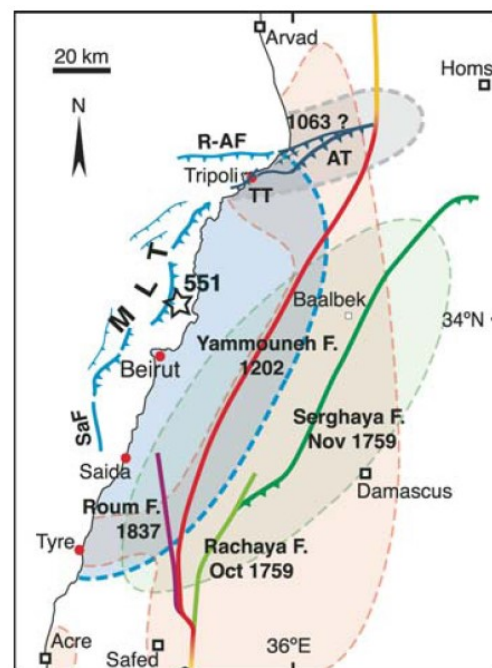
damage to structures, i.e. Mexico ([15]; [17]), Kobe [16], and Izmit [18]. Thus, recognizing the ground response to the seismic waves is important to understand how the seismic waves will affect the structures founded on it.

## 2. The historical city of Byblos and its seismic sources

The city of Byblos is located on the Lebanese coast approximately 40 km north of the Lebanon capital of Beirut. The city area is about 5 km<sup>2</sup>. The city of Byblos' population is approximately 40,000 people. The 8000-years-old site of Byblos city is considered to be one of the oldest continuously inhabited cities in the world. This old site of Byblos city is a UNESCO World Heritage Site (see [19]). The seismic sources for the city of Byblos have been investigated by [20], as shown in Figures 1 and 2.



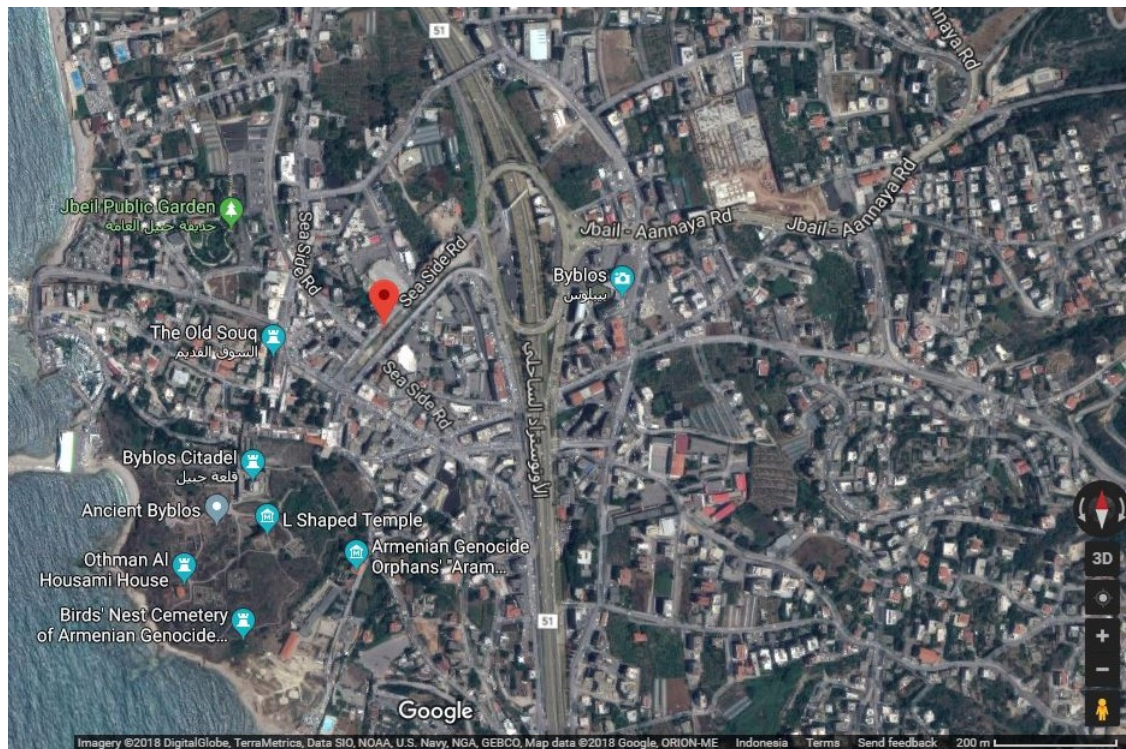
**Figure 1.** Active faults around the Byblos  
Abbreviations: Ar—Arqa; Ba—Batroun; By—Byblos;  
Ch—Chekka; Sa—Sarafand. AT—Aakkar thrust;  
TT—Tripoli thrust; R-AF— Rankine-Aabdeh fault;  
RF—Roum fault; RaF—Rachaya fault; SaF—Saida  
fault [20].



**Figure 2.** Most likely sources of AD. 551  
seismic event (open star—inferred  
epicenter). Blue color corresponds to AD.  
551 seismic event with MMI of VIII  
(from Sieberg, 1932 in [20]).

As shown in Figures 1 and 2, there are at least two main seismic sources for the city of Byblos which are Mt. Lebanon Thrust (MLT) and Yammounieh Fault. In AD 551 one of a seismic event has struck along the MLT [20]. This event has been estimated for more than VIII Mercalli Magnitude scale at the city of Byblos [20].

Figure 3 shows the city of Byblos-Lebanon. The red mark in Figure 3 is the point of the measured location of this study which is along the Sea Side Road of the city of Byblos. The distance of the point is about 600 m from the coast of Lebanon.



**Figure 3.** An ambient noise measurement site at Byblos-Lebanon (red mark)

### 3. Methods

This section describes the equipment, data acquisition, and data analysis used in this study, which is briefly explained, as follow:

#### 3.1. Equipment

The equipment used for the microtremor measurement is Lennartz LE-3D/5sec (0.2 – 50 Hz), as shown in Figure 4. This seismometer with a lower cut off frequency of 0.2 Hz is perfectly suited for a seismic monitor, H/V measurements and seismic microzonation. Essential features and characteristics of this seismometer are a robust instrument, very low power consumption, quick and easy installation (plug and measure), and uniform sensitivity and transfer function. Detailed main features of the seismometer are summarized in Table 1. The used digitizer in this study is CityShark II (Figure 5).



**Figure 4.** Lennartz LE-3D/5 sec.



**Figure 5.** CityShark II N° 76.



**Table 1.** The most important characteristics of the used seismometer.

Parameter	Description	Remarks
Eigen-period	5 seconds	Lennartz LE-3D/5 sec
Upper-frequency limit	50 Hz	
Transduction factor	800 V/(m/s) (differential)	
Output signal	3 analog voltages, max. $\pm 7V$	
Power supply	+10 ... +16V DC, typically 7 mA @12 V	
Dimensions	195 mm diameter, 165 mm height (excluding handle)	
Weight	6.5 kg	
Temperature range	-15 ... +60 °C	
RMS noise @ 1 Hz	< 1 nm/s	
Dynamic range	> 140 dB	

### 3.2. Data acquisition

The original set of microtremor measurements were carried out at 18:40 pm on 22 September 2016. The weather was generally calm with no strong winds or rain. Measurement location was close as possible to the downtown of the city of Byblos. Care was taken to avoid manholes, foundations or other underground structures. Data was recorded for 15 minutes. The field data sheet was used during the data acquisition in this study.

### 3.3. Data analysis using H/V spectral ratio method

H/V spectral ratio method is an experimental technique to assess the dynamic characteristics of the ground surface due to any dynamic loads, i.e. seismic loading. This H/V method is based on the analysis of the spectral ratio between the Fourier amplitude spectrum of the horizontal (H) and vertical (V) components of the recorded ambient vibration. Detailed data analysis using H/V spectral ratio method can be found in [21].

## 4. Results

This result section presents the field data conditions, the HVSR curve, and calculated site fundamental frequency. A further short discussion is elaborated in this section, also.

### 4.1. Field data

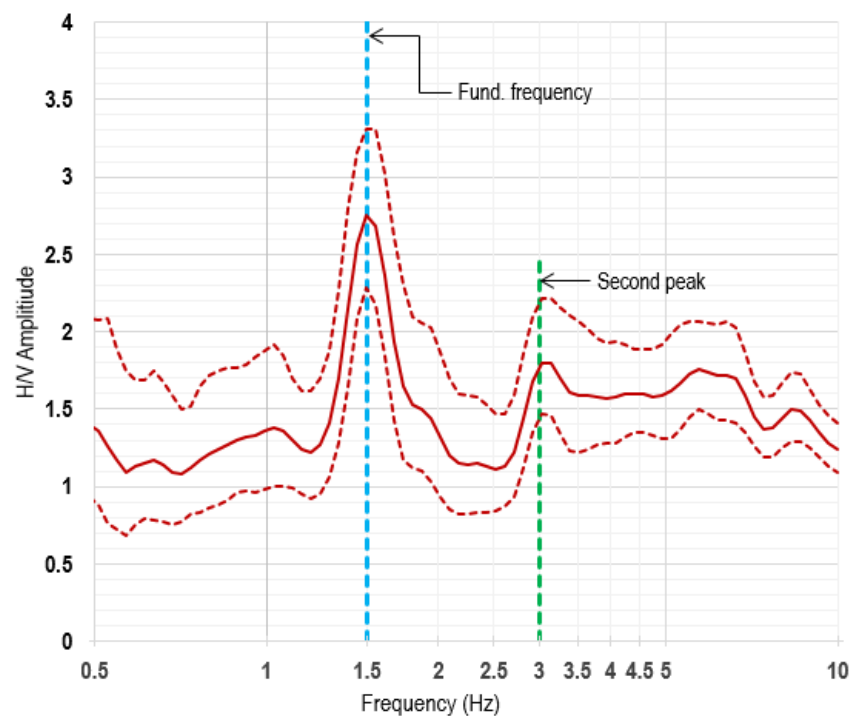
The field measurement was carried out at 18:40 pm on 22 September 2016. The measurement location is Byblos City center (Latitude of 3778866N and Longitude of 744291E) as shown in Figure 3, above. The factual facts recorded in the field data sheet during the ambient noise measurement are summarized in Table 2. About 15 minutes noise data were collected at the dense urbanization area of the city of Byblos.

### 4.2. H/V spectral ratio curve and site fundamental frequency

This section presents the results of the H/V spectral ratio technique and examines the site fundamental frequency. The H/V curve of this study is shown in Figure 6. The site fundamental frequency obtained from the H/V analysis suggests a frequency of 1.5 Hz. Another interesting observation associated with the H/V curve is the presence of the secondary peak of 3.0 Hz.

**Table 2.** A summary of the field data sheet.

Parameter	Description	Remarks
Latitude	3778866N (34 deg 7 min 19.65 sec)	UTM Code 36S
Longitude	744291E (35 deg 38 min 55.608 sec)	
Station type	CityShark II	
Sensor type	Lennartz 5 sec	
Gain	256	
Sample frequency	200 Hz	
Weather conditions	Wind (None); Rain (None); Approx. temperature (28 degrees)	
Ground type	Earth (gravel); Dry soil	
Artificial ground/sensor coupling	None	
Urbanization	Dense	
Continuous noise sources	None	

**Figure 6.** H/V spectral ratio curve.

#### 4.3. Discussion

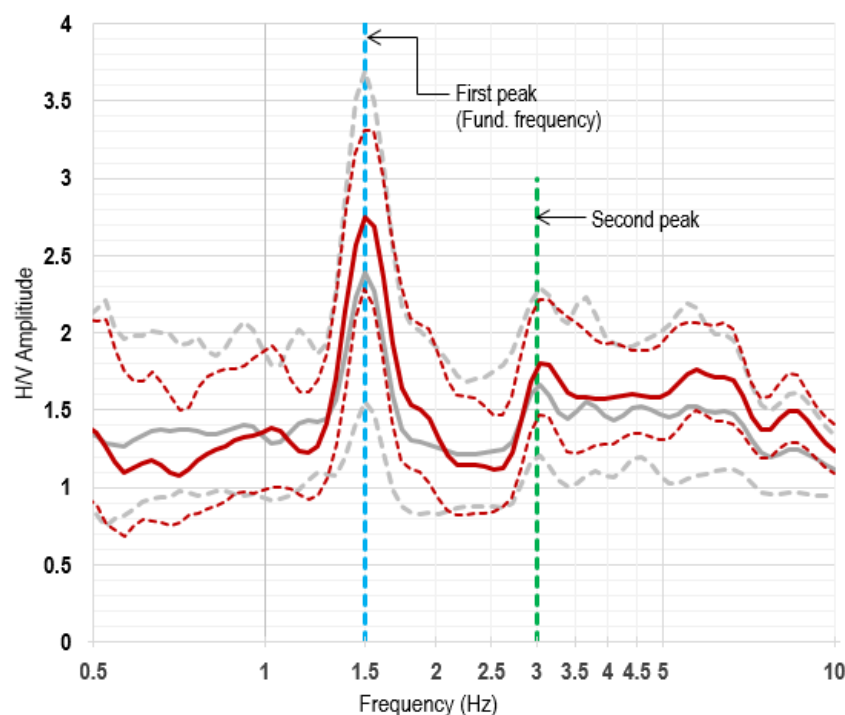
In practice, the relationship between the H/V peak(s) and the resonance frequency of the shear wave has been summarised by [22] from [23] and [24], as follows: 1) The H/V ratio of a body wave-field always exposes a peak around the fundamental shear wave frequency, for high impedance contrast sites; 2) The H/V ratio shows peaks at the shear wave harmonics, in the case of horizontally stratified media; 3) The amplitude of the first H/V peak is likely to be fairly well correlated with the shear wave

amplification, in the case of horizontally stratified media with high impedance contrast. These findings are very useful for interpreting the experimental H/V analysis in this study. The result of the H/V curve of this study suggests 1) the measured site is composed by relatively horizontally stratified layer, 2) the measured site has a moderate to low impedance contrasts ( $< 4-5$ ), and 3) the amplification of the shear wave of the measured site is about 2.5. However, gathering the additional representative sub-surface information to assist further interpretation of this H/V curve is suggested.

The fundamental period of the site ( $\approx 0.65$ s) is obtained by taking the reciprocal of the fundamental frequency of 1.55 Hz. This result suggests a significant seismic amplification for 16 to 20 meters height buildings in the city of Byblos using the general rule for building natural periods as suggested by [25] and [26].

The H/V curve of this study shows two peaks of 1.55 Hz and 3.15 Hz. These two-peaks of H/V curve suggest the presence of two different impedance contrasts at two different depths at the measured site. The first peak can be correlated to a deep structure and the second one is for a shallow structure ([21]; [27]; and [28]).

Additional measurement using a different sensor of Geospace GS11-3D was carried out to validate the repeatability of this result. Figure 7 presents the comparison of the H/V curves obtained from both Lennartz LE-3D/ 5 sec (red lines) and Geospace GS11-3D (grey lines). The comparison suggests a similar curve pattern.



**Figure 7.** Comparison of H/V spectral ratio curves.

## 5. Conclusion

From the literature on various research has demonstrated the applicability of single point microtremor measurement and analysis for site effect study. This single microtremor analysis has several advantages, as follow: 1) effortless in-situ application (no extra source needed, simple equipment setting) and quick interpretation of measurements; 2) cost-effective (short duration measurements, large regions may be surveyed in small amount of time) and very fast application; and 3) provides good estimates of predominant soil period and spectral shapes. This single microtremor measurement

and analysis have been carried out for the city of Byblos which is vulnerable to seismic hazard. The result suggests a site fundamental frequency of 1.55 Hz at the measured site. Therefore, it can be concluded that single point microtremor measurements provide an easily applicable, cost-effective and fast approach to obtain information on local site conditions if sufficient consideration is given to the limitations.

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