A STUDY BETWEEN THE RELATIONS OF CASPIAN SEA WAVES HEIGHT AND THE LOW FREQUENCY SEISMIC NOISE MEASUREMENT IN TEHRAN

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ABSTRACT

The correlation of ambient noise energy at low frequency with oceanic waves height are studied in Tehran by using weighted average function for measuring oceanic wave's mean. Based on some article that published in mid-twentieth century about the correlation between microtremor and meteorological activities the authors showed that the low frequency microtremors are generated by the pressure variations on the sea floor caused by the ocean waves. These pressure variations are the result of the standing waves and their frequency is twice the frequency of the original traveling ocean waves. For Tehran (capital of Iran) with a direct distance about 80Km from Caspian Sea, based on the low attenuation of microtremor generated in seas we assumed this sea as a source for low frequency energy. Haghshenas (2005) examined the relationship between the evolution of the microtremor’s maximum spectral amplitude on the north-south component, at the low frequency at some stations in Tehran, and variations of wind speed recorded at Caspian Sea’s meteorological stations. In this article we used significant wave height (that defined as four times of the square root of the zeroth-order moment of the wave spectrum based on numerical modeling) as a source parameter because in oceanography Significant wave height is commonly used as a measure of the height of ocean waves. So, we performed the 1-week continuous recording at North of Tehran as an experiment for study about the correlation between microtremors and significant wave height. The results show that the wave heights were not the main factor that generates low frequency amplitudes in Tehran region.

Keywords: Microseism; Significant wave height; HVSR; Caspian Sea

1. INTRODUCTION

Classification of ambient noise sources, its stability over time and its effect on temporal variation (in frequency and amplitude) of H/V curves are important are the important challenges in site effect studies using the H/V method. Gutenberg (1958) was the first one that studied in this issue by establishing a list of the different types of noise sources according to their frequency. He showed that noise has basically two different origins (natural or cultural) based on its frequency content. These two categories of sources led researchers to distinguish between microseisms and microtremors, corresponding respectively to natural and cultural sources, and relatively low and high frequency. The terms microseisms (vibratory motion caused by the sea waves) and microtremors (cultural noise such as traffic, machinery etc.) are sometimes synonymously used for ambient noise but in literature high frequency noise signals with periods below 2sec are called “microtremors” and those above 2sec are called “microseisms” or "long-period microtremors" (Kulhanek, 1990; Yamanaka et al., 1994). Bonnefoy-claudet (2004) revealed the sensitivity of the microseism’s H/V ratio to the variations in the spectral amplitudes of the noise by the continuous recording over a long period of time (several weeks). Guillier et al (2007) confirmed this result performing the experiment on selected sites in

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different regions. Besides, Haghshenas (2005) observed that the arrivals of energetic noises in Tehran are mostly associated with augmentation in wind speed at the stations installed at Caspian Sea coast. In this study, according to the close distance between Tehran and Caspian Sea, we assumed this sea as a main source for low frequency energy. 1 week continuously recorded ambient noise data was used in order to study the temporal behavior of the spectral amplitude and of the H/V spectral ratio in low-frequency and its relation with significant wave height at Caspian Sea.

1.1 Microseism

Microseisms, the persistent oscillations of seismic waves unrelated to earthquakes or local noise sources, have been observed on seismic records since the 19th century. They are characterized by long-period waves with dominant periods between 2 and 40 sec. Wiechert (1904) proposed that these microseisms are caused by ocean waves on coasts. It was found that there were smaller primary ocean microseisms with periods around 14 ± 2 seconds and secondary ones related to the main noise peak around 6 seconds. Primary ocean microseisms are generated only in shallow waters in coastal regions and can be converted directly into seismic energy through vertical pressure variations, or by the smashing surf on the shores. (Bormann 2010) These long-period waves propagate very efficiently through the granitic layer as $R_g$ (Rayleigh-wave) and $L_g$ (Love-wave) phases over continental paths (Lermo and Chavez-Garcia, 1994).

1.2 Significant wave height

Generally, wave height is defined as the vertical distance between the highest and the lowest surface elevation in a wave. In a wave record with N waves, the mean wave height $H$ is:

$$H = \frac{1}{N} \sum_{i=1}^{N} H_i$$

Where $i$ is the sequence number of the wave in the record.

Another expression of energy-related wave heights is called $H_{rms}$ because the wave energy is proportional to the square of the wave heights. Therefore, sometimes a quadratically weighted average value is used to define the root mean square wave height or $H_{rms}$:

$$H_{rms} = \left( \frac{1}{N} \sum_{i=1}^{N} H_i^2 \right)^{1/2}$$

These characteristic wave heights ($H_{rms}$) are not very often used, because they show little resemblance to the visually observed wave height. Instead, another wave height, called the significant wave height $H_s$ is used. The significant wave height (SWH or $H_s$) is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves ($H_{1/3}$).

$$H_{1/3} = \frac{1}{N/3} \sum_{j=1}^{N/3} H_j$$

$j$ is the rank number of the wave, not the sequential number in the record and it is defined based on wave height (i.e., $j = 1$ is the highest wave $j = 2$ is the second-highest wave, etc.). Statistically significant wave height is defined as the mean value of the highest one-third of wave heights identified in the Rayleigh distribution (Figure 1). It can be determined as an expected value, i.e., with the zeroth- and first-order moments of the highest third of the distribution. We denote this estimation of the significant wave height as $H_{m0}$. 

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The analytical expression for the Rayleigh distribution gives the following result:

\[ H_{m0} = E[H]_{H\geq H^*} = \frac{\int_{H^*}^{\infty} H_p(H) dH}{\int_{H^*}^{\infty} p(H) dH} \]  

(4)

\[ H_{m0} = 4.004 \sqrt{m_0} \]  

(5)

Where \( m_0 \) is the zeroth-order moment of the variance density spectrum \( E(f) \).

So numerically we can define significant wave height as four times of the square root of the zeroth-order moment (area) of the wave spectrum. This expression used by INCOH to numerical modelling of waves. Experiments shown the value of this expression is very close to the value of the visually estimated wave height.

![Figure 1. The significant wave height in the Rayleigh probability density function (Holthuijsen 2007)](image)

2. GEOLOGICAL SETTING

Tehran, the capital city of Iran, with a population about 12.5 million is one of the largest cities in the Middle East within the seismically active Alpine–Himalayan orogenic belt. The city experienced Historical earthquakes in 958 A.D., 1665 A.D., and 1830 A.D. on the Mosha and Taleghan strike-slip faults, passing beyond the northern border of the city and earthquakes in 312–280 B.C., 855 A.D. and 1177 A.D., located in the southern parts, (within the Tehran plain) that destroyed the old city of Rey (Ambraseys & Melville 1982). So, the study about alluvial deposits for site effects hazard assessment was inevitable because any similar events in future would cause heavy damage to Tehran.

The first study about Tehran alluvial stratigraphy have been published by Rieben in 1955. He assigned the exposed alluvial deposits to four units from A (the oldest) to D (figure 2). All of the later studies were more or less adapted the classification of Rieben, except Engalcenc (1968) that provided a more detailed map of alluvial deposits, and also drew attention to the strike-slip faults north of Tehran.

Unit A (Hezradareh formation) is the oldest and thickest of the deposits, with up to 1000 m exposed mainly throughout higher hills to the northeast of Tehran. The main identifying characteristics of the Unit A are the regularity of its bedding, cementation by lime carbonates and pale grey hue with pebbles originated from the older rocks in Alborz. The Kahrizak, or Unit B, formation refers to laterally heterogeneous deposits that overlie the Hezardareh Formation deposits. This unit consists of

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sandy or clayey loam with patches of gravel and numerous elongated concretions, while to the north it starts with basal conglomerate and contains large boulders. The Tehran, or C, formation is an alluvial conglomerate that is characterized by its regular stratification and red laterite crusts. The upper surface of unit C is relatively even and lies under the youngest deposits of the Tehran playa (Unit D) (JICA 2000).

Figure 2. Geological map of Tehran (a-d station shown in black and IIEES station shown in red)

3. DATA ACQUISITION

We recorded ambient vibration in north of Tehran (IIEES station) during 1 week from 14 November to 21 November 2017 using the three components 20s Lennartz seismometer with 100 sps sample rate. In this station and most part of the city a broad peak around 0.08 Hz and sometimes another tiny peak at 0.4 can be observed (figure 3). This site is selected because of presence of clear peak in the low frequency domain.

All data have been processed with the open-source Geopsy software. 200sec stable windows were used to ensure a reliable computation at interested low frequencies peaks. Windows were selected using a STA/LTA anti trigger with lower and upper bounds fixed at 0.3 and 2.0. Then each individual curve smoothed using Konno and Ohmachi (1998) method with a value of \( b = 40 \). Finally, H/V spectrum obtained for individual 1hour segments over 1-week recorded data. The results of the spectrum show in section 4.
Figure 3. 1-week recorded data from 14/11/2017 to 21/11/2017 at IIEES in IIEES station. Left - up: H/V curves for every 6 hours during the day (from 6 am to 6 pm) Left - down: H/V curves for every 6 hours during the night (from 6 pm to 6 am)
Right (a-d): Similar behavior in different stations in north, south, west and east of Tehran

The frequency range introduced by Bonnefoy-Claudet (2004) as distinction between microseisms and microtremors are 0.01 to 1Hz so spectral amplitudes are just presented between these range.
Besides, the average of significant wave height extracted from INCOH database for 9 stations in Caspian Sea coast (Figure 4 and Table 1).
The wave heights reported at these 9 stations were compared to spectral amplitudes of ambient noise separately as well as the weighted average wave height for all of these stations. The weighting coefficients based on distance was added to the results. For example, the Astara station has the smallest coefficient than other stations due to its further distance to Tehran. The coefficient is represented by:

\[ \text{Coeff} = 1 - \frac{X_i}{\sum X_i} \]  

Where \(X_i\) is the station number \(i\);
4. DISCUSSION AND CONCLUSION

Calculation of correlation coefficient between Caspian Sea’s average wave heights and low frequency spectral amplitude of ambient noise in Tehran shows in this case there is not a good agreement between the spectral amplitudes and wave heights (Figure 5). The correlation coefficient is -0.171 that implies these two parameters have no meaningful relation and the wave heights is not the main factor that generate the low-frequency spectral amplitudes.

Also, we can be sure that the wave’s dataset was reliable because there is just a little difference behavior between the stations Chalus and Astara, the nearest and furthest stations to Tehran respectively and using the average of these stations does not justify the discrepancies (Figure 6).

The result shows that the state of the sea is not the main factor that generates high spectral amplitudes in Tehran region and prove that we should perform more detail experiments with another method such as f-k or azimuthal analysis to enhance the accuracy of observations.

Although Bensalem et al (2017) showed that the microseism spectral amplitudes in Mediterranean Sea in the low frequency domain vary inconsistently with time with strong influence of the sea conditions

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Direct distance (Km)</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>AmirAbad</td>
<td>53.210</td>
<td>37.040</td>
<td>218</td>
<td>.89</td>
</tr>
<tr>
<td>Babolsar</td>
<td>52.625</td>
<td>36.820</td>
<td>162</td>
<td>.92</td>
</tr>
<tr>
<td>Noor</td>
<td>52.000</td>
<td>36.725</td>
<td>118</td>
<td>.94</td>
</tr>
<tr>
<td>Chalus</td>
<td>51.420</td>
<td>36.780</td>
<td>115</td>
<td>1.0</td>
</tr>
<tr>
<td>Ramsar</td>
<td>50.750</td>
<td>37.030</td>
<td>154</td>
<td>.93</td>
</tr>
<tr>
<td>Kiashahr</td>
<td>50.130</td>
<td>37.490</td>
<td>226</td>
<td>.88</td>
</tr>
<tr>
<td>Anzali</td>
<td>49.480</td>
<td>37.670</td>
<td>275</td>
<td>.86</td>
</tr>
<tr>
<td>Hashtpar</td>
<td>49.400</td>
<td>38.060</td>
<td>310</td>
<td>.84</td>
</tr>
<tr>
<td>Astara</td>
<td>49.190</td>
<td>38.430</td>
<td>355</td>
<td>.82</td>
</tr>
</tbody>
</table>
but it seems we could not generalize this results to the other parts of the world and we need to perform other experiment to find the low frequency sources.

The importance of these result comes from the observation of very strong variations of the fundamental soil period in the low frequency range that means we had not easy task to do specially in thick alluvium deposit studies such as Tehran. So, we need to study more details in future to find the origin of seismic noise in Tehran region.

Figure 5. Spectral amplitude and weighted average of Hs measurements (correlation coefficient is -0.171)
Figure 6. Slight difference behavior between the Chalus and Astara stations respectively the nearest and furthest stations to Tehran

5. REFERENCES


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