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Site effect estimation using H/V microtremor and shallow seismic prospecting, Elkawamel, Sohag, Egypt

Abdelbaset M. Abudeif, Marwa M. Masoud

[1] Geology Department, Faculty of Science, Sohag University, Egypt

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Abstract: Shallow seismic refraction survey and Microtremor measurements together were conducted and found out to be an effective approach to study the site effect and also to establish a seismic hazard microzonation overview. The amplification and fundamental resonance frequency and of ground motion at different frequencies were estimated using the microtremor data measured at ten sites in the new industrial zone around the urban areas in Sohag Governorate, Egypt. Also, site effects were calculated applying a numerical technique using shear wave velocities observed from measured profiles at the study area utilizing 24-channel shallow seismic refraction seismograph.

The results show variations in the fundamental resonance frequency values from one site to another depending on its distance from the Eocene plateau scarp that located at the southern and southwestern sides of the study area, where it becomes higher close to the plateau foot. In case of the low frequency, the amplification of the ground motion shows variation from site to the other site depending on its vicinity to the plateau, while in case of high frequency the variation depends on the thickness of the sediment layers. The results using the microtremor technique emphasize that given by the shallow seismic refraction method.

Keywords: horizontal and the vertical component (H/V), site effect, amplification, soft soil.

1 Introduction

The ratio between the Fourier amplitude spectra of the horizontal and the vertical component of microtremors (H/V spectral ratio) was first introduced by Nogoshi & Igarashi (1971) [1], and widespread by Nakamura (1989, 1996, 2000) [2], [3], [4]. These authors have pointed out the correlation between the H/V peak frequency and the fundamental resonance frequency of the site, and they proposed to use the H/V technique as an indicator of the underground structure features. Since then, a number of experiments ([5], [6], [7]) have shown that the H/V procedure can be successful applied for identifying the fundamental resonance frequency of sedimentary deposits.

The existence of a close relationship between damage to the buildings and the properties of the subsoil has been known since long time ago. This relationship has been expressed in saying that “Earthquake damage is great when the subsoil is poor”. Seismic waves propagate in all directions from the focus of an earthquake, and their amplitude decrease with distance. Therefore, if the geological structure of the earth were homogeneous, the intensity of the earthquake motion on the ground would be the same along a circle the epicenter. As the radius of the circle increased, the intensity should decrease. The actual distribution of the intensities is not so simple. Some areas are free from damage and other with the same intensity suffer heavy damage. This phenomenon occurred due local amplification of ground is often controlled by the soft surface layer which leads to the seismic energy trapping, due to the impedance contrast between the soft surface soils and the underlying bedrock. Over the past decades, the effect of local soil conditions is known to have caused serious damage during several earthquakes. Therefore, an accurate and reliable estimation of these site effects during a large earthquake becomes one of the important subjects in earthquake engineering.

In the current work, an estimation and investigation of the fundamental resonance frequency and amplification of ground vibration at different frequencies were done using easy and economical techniques. Depending on microtremors data, that have been measured at the new industrial zone around the urban areas in Sohag Governorate, Egypt, the site effects were determined at the fundamental resonance frequency also at different values of frequencies using the spectral ratio method (H/V or Nakamura technique). Also, the site effect and theoretical ground motion were determined using ground models obtained from the shallow seismic refraction technique at the same site to confirm the results obtained from the microtremor technique.

* Corresponding author E-mail: a.abudeif@science.sohag.edu.eg © 2022 Sohag University

Geologic setting

Geomorphologically, the area under investigation has relief features of the second and third orders where no first order features are occurred. These features are represented by the Lower Eocene plateau, scarps, terraces, plains and drainage lines. Geologically, most of the area under investigation is covered with Paleogene sediments and narrow cultivated stretch bordering the Nile River. The Paleogene sediments composed mainly of gravel, sand and silt while the cultivated land is made up of Nile sediments (Pleistocene and Recent deposits). Figure 1 shows the geological units covering the study area.

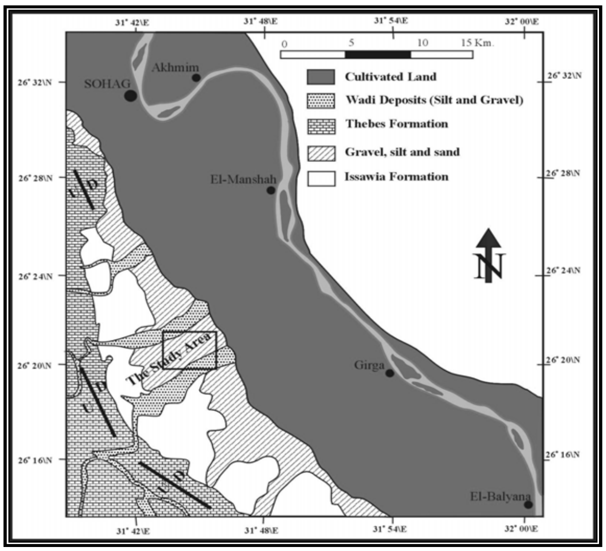

Fig.1: Geologic map for the study area

2 Material and method

The fundamental phenomenon responsible for the amplification of motion over soft sediments is the trapping of seismic waves due to the impedance contrast between sediments and the underlying bedrock. When the structure is horizontally layered (1-D structure), this trapping affects only body waves traveling up and down in the surface layers. When the surface sediments form a 2-D or 3-D structure, in other words when lateral heterogeneities such as thickness variations are present, this trapping also affects the surface waves, which develop on these heterogeneities and thus reverberate back and forth. The interference between these trapped waves leads to resonance patterns. The shape and the frequency of which are related with the geometrical and mechanical characteristics of the structure. ([13]).

There are several methods for site effect estimation. These methods are classified according to various criteria into experimental, numerical and empirical approaches.

Estimting site effect using microtremors technique (experimental method)

The ground is always vibrating at minute amplitudes. The amplitudes of microtremors in ordinary places are less than several microns and their period ranges from tenths of a second to several seconds. Because microtremors are combinations of various types of waves, from many sources such as traffic, industrial machinery and winds, all kinds of waves can be observed depending on the type of the seismograph and on the methods of analysis.

Microtremors may be used basically to estimate the site effect in different ways. In this work, the H/V ratio method (Nakamura technique) used. This method has been introduced by many Japanese scientists among them are: Nogoshi and Igashi (1971) [1]; Shiono et al. (1979) [8]; Nakamura (1989) [2], and Kudo (1995) [9]. They showed that there is a relationship between the ratio of the Fourier spectra of the horizontal components microtremors (recoreded by horizontal seismometer) and the vertical ones (recorded by vertical seismometer) and the elliptictrajectory of Rayleigh waves. Also, they concluded that, the H/V ratio can be used to identify the fundamental frequency of soft soils.

Microtremors survey and the used instruments

Background noise measurements were performed at 10 sites (continuous measurements for at least 10 minutes at each site) covering all the study area as shown in figure (2), with the precautions given by; Duval et al., (1994) [10]; Nakamura (1996) [3]; Mucciarelli et al., (1997) [11] and Mucciarelli (1998) [12].

The field work has been done using the velocity type seismometer and recording instrument model Orion, which is modern field portable and highly flexible digital seismographic event recorder. Orion recording system has 24- bits of resolution and provides a dynamic range of 132 dB, which is achieved using high performance sigma-data analog to digital converters (A/D). The standard Orion seismograph is three-channel recorder, optionally; it can be used with six recording channels. Orion system can be also configured to record data from different type sensors such as Mark product L4C, Kinemetrics SSR ranger, Geotech S13, and Guralp CMG40T. The sensitivity of Orion system is 1.9 V/Bit. For field data acquisition and operating the Orion's system, an IBM PC compatible computer is required.

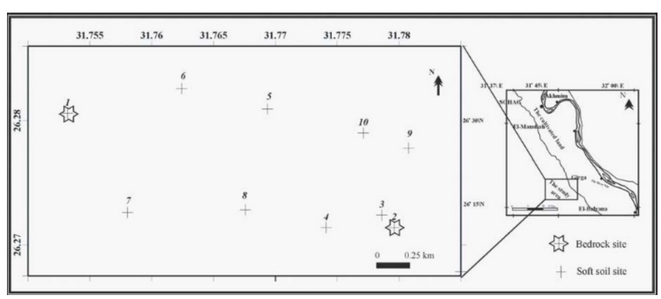

Fig.2: Location map for the microtremors record sites.

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Data corrections and processing

The tri-axial measurements (2 horizontal and 1 vertical components) of microtremors were recorded to each site. These records for each component are classified into windows with 20 seconds length. It is important to check the stability of the result in order to determine the required numbers of noise windows to have a good reliability, for that aim, 10 windows were analyzed for each site. Each window passed through a number of corrections as follows;

Base line correction

In order to determine and subtract the slowly varying components of a seismic trace or to adjust the zero line of the noise window, a process known as baseline correction is carried out. Figure (3a) represents a time window with 20 seconds as length, and the middle part of figure (3b) its baseline correction. This correction is achieved using the running average technique by sliding an average window of a given length over the data series. For each window position, the baseline is calculated as the average value in the data window.

Instrument correction (Calibaration)

The seismic signals, as recorded at a seismic station differ considerably from the true ground motion. The recording system acts as a filter, which changes the signal contents of the seismic waveforms. Before we can interpret the recorded signals in terms of the source and/or the earth properties, we have to do calibration for the recording instruments.

This calibration was done by sending the sinusoidal signal with definite amplitude, frequency and duration to the calibration coil of the seismometer through the digitizer. Then measure the output from the signal coil through the digitizer and the procedure is repeated for different frequencies. The output is divided by the input amplitudes at each frequency and then draw this relation versus the corresponding frequencies to get the response curve of the recording system for each component. The instrument correction is shown in figure (3c) .

Band pass filter

The next step is to filter the data to allow the frequencies in the range 1.0 to 30.0 Hz by using Butterworth filters, which are recursive time domain filters using the bilinear z-transform design ([15]). This step has been done as shown in figure (3e) parts number 5. This figure reveals the band pass filter effect on the corrected data.

Fast Fourier Transform (FFT)

All the previous steps were carried out in the time domain, which can transformed to amplitude-frequency domain as shown in figure(3f), last part. Fast Fourier Transform (FFT) The spectrum is estimated using PITSA program ([14]).

Average spectra or arithmetic mean

At each site, the average spectra for all windows for each component is estimated in order to get the final vertical component window and the final two horizontal components windows at each site.

Geometric mean

The geometric mean is computed to merge the two horizontal components to get the (H) component. This step is carried out in the frequency domain by using the following equation;

$$H= (|X (f).Y(f)|)^{0.5} \quad (1)$$

where: H is the horizontal component computed by geometric mean, X(f) is the modulus of spectra of the N-S component and Y(f) is the modulus of spectra of the E-W component.

Smoothing the spectra

The smoothing is mandatory to avoid spurious peaks linked with sharp troughs on the vertical component spectrum. It has important consequences on the spectral shape and may strongly affect the determination of the peak frequency. In the present study, the data were manipulated in different smoothing modes, first with no smoothing, then with 0.2, 0.3 and 0.5 Hz of wide triangle window. Figure (4) is an example for the smoothed spectral ratio of recorded natural noise at the studied sites (example site 10).

Microtremors data interpretations

The corrected and processed microtremors records can be interpreted in varying techniques. During this work, the output noise data was interpreted using H/V Spectral ratio (Nakamura's technique). Where, Nakamura, (1989) [2], reported that, the H/V ratio is a reliable estimation of the site response to S-wave, providing reliable estimates, not only of the resonance frequency, but also of the corresponding amplification.

Using this technique, the H/V spectral ratio is determined for the 10 sites at the study area , figure (5) shows some examples of the spectral ratios versus frequencies at the different geologic site conditions, at different sites with different thicknesses of soft soil.

Study area are shown at figure (6), while the corresponding amplifications determined by the H/V spectral ratio are shown in figure (5). As shown in the contour map of the fundamental frequencies (figure 6), the study area is characterized by zones of high fundamental frequencies at the southeastern and western parts of the map. In case of the amplification factor at the fundamental frequencies, as shown in figure (7), gradual increase in observed area toward the west, where it reached a maximum value of 9. Some local anomalies are distributed at the eastern side of the study area.

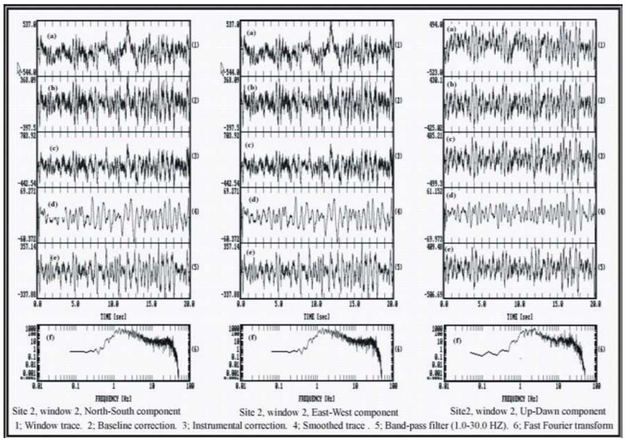

Fig.3: The correction steps and FFT for one window recorded at the bedrock site.

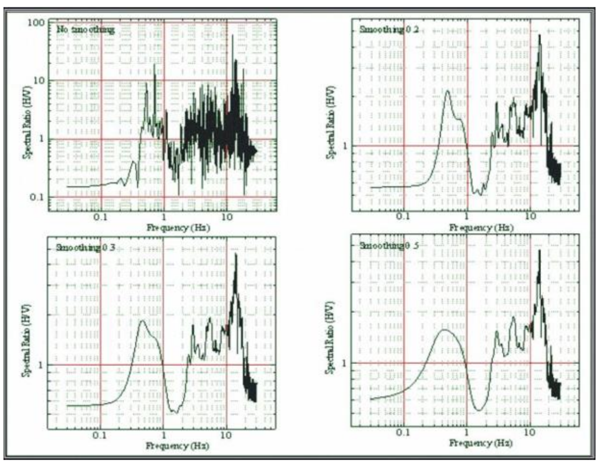

Fig.4: H/V spectral ratios at different smoothing factors at a studied site (site 10).

As a step of studying the effect of the surface geology on the ground motion, we calculated the ground motion amplification factors at the area under investigation at different frequencies, for examples at 3, 5, 7, and 9 Hz, as shown in figures (8, 9, 10 and 11) as follows:

* At frequency 3 Hz, the amplification values increase towards the south to be about 2.2 at the southern part of the study area, as shown in figure (8).

* At frequency 5 Hz, the amplification values increase reaching value of 2.8 at the southern part of the study area and also at the western side as well as at the northeastern part to be about 1.8 as shown in figure (9).

* At frequency 7 Hz, and as shown in figure (10), the highest amplification values determined to be at the western side of the study area to be about 2.5, and also at the northeastern part at the study area to reach 1.8.

* At frequency 9 Hz, the amplification factor of the soil layers increased to be maximum values at the frequency 9 in the western with value of (figure 11).

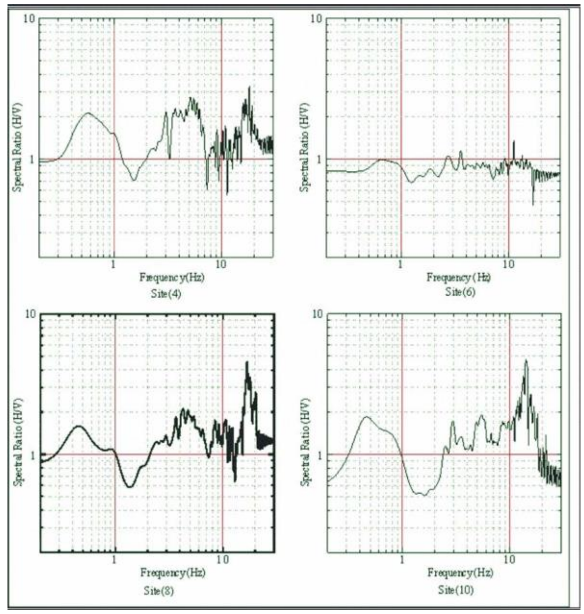

Fig.5: Examples for the spectral ratios measured at the different thicknesses of the soft sedimentary sites.

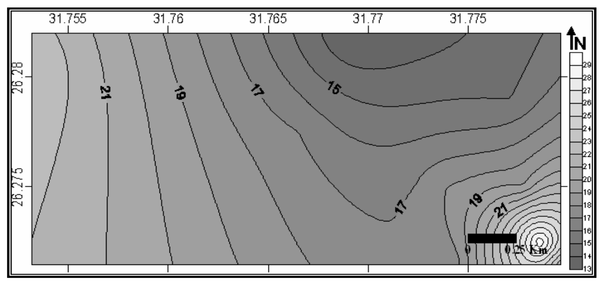

Fig.6: Fundamental frequency distribution contour map at the study area

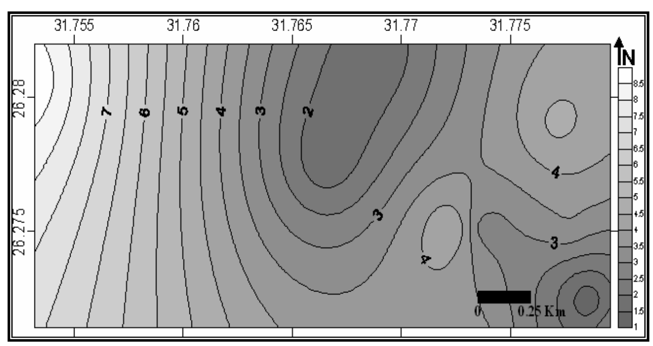

Fig.7: Amplification distribution contour map at the fundamental frequencies

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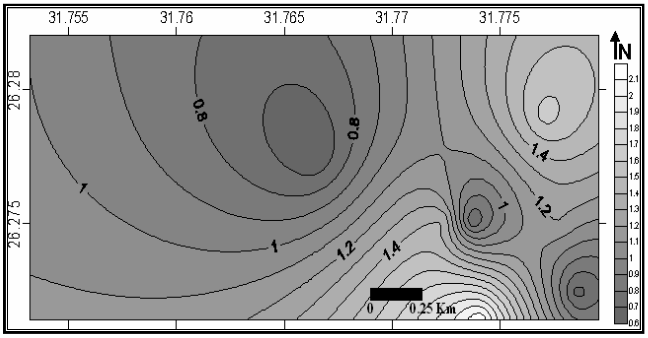

Fig.8: Amplification distribution contour map of the study area at frequency 3 Hz using microtremor method.

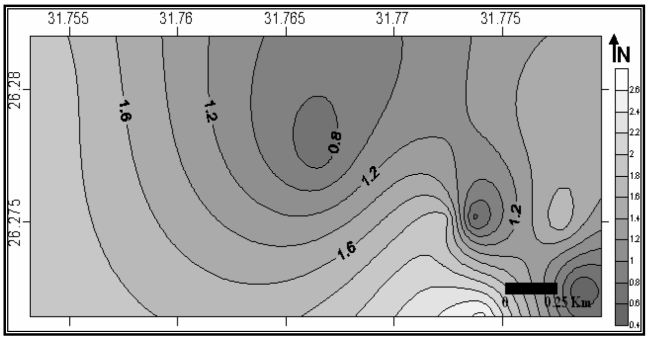

Fig.9: Amplification distribution contour map of the study area at frequency 5 Hz using microtremor method.

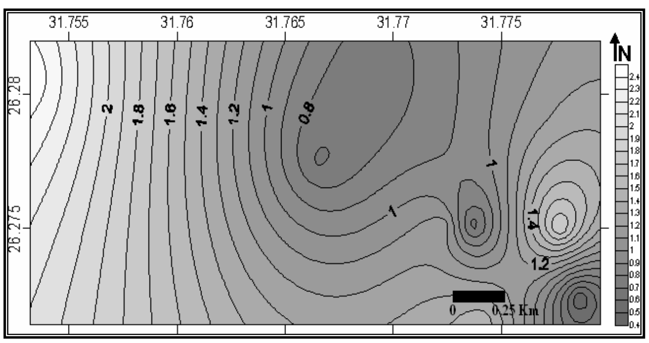

Fig.10: Amplification distribution contour map of the study area at frequency 7 Hz using microtremor method.

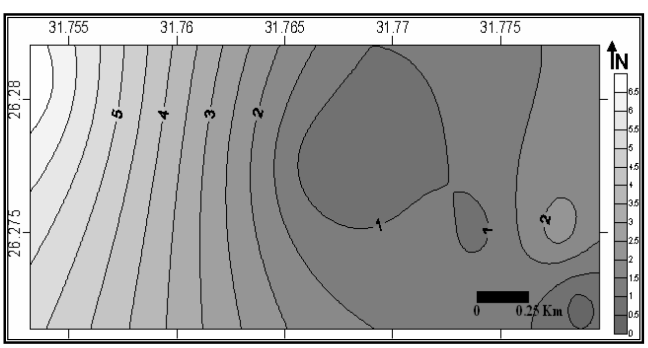

Fig.11: Amplification distribution contour map of the study area at frequency 9 Hz using microtremor method.

Estimting site effect using seismic data (numerical method)

Depending on both the properties and configuration of the near surface materials through which seismic waves propagate, the amplitude of earthquake ground motion can be increased or decreased. The level of ground motion is affected by the impedance and absorption. In the presence of sharp changes in impedance contrasts between the subsurface layers resonance occurs as some of the seismic waves transmitted into the upper rock (or soil) layer. They become trapped in this layer and begin to reverberate. This effect is maximum when the reverberating waves are in phase with each other. Resonance is a frequency-dependent phenomenon, in the simplest case it is the maximum occurrence for waves whose wavelength is four times the thickness of the layer, in which the seismic waves are trapped. In other words, for shear waves the frequency, which is mainly amplified, is equal to $\beta/4H$, where (β); is the shear wave velocity of the layer and (H); is its thickness. Takahashi and Hirano (1941) [16], derived the following relationship for a vertically propagating harmonic wave of unit amplitude;

$$|U(\omega)| = 2\{\cos^2(\omega H/\beta_L) + (\rho_L\beta_L/\rho_R\beta_R)^2 \sin^2(\omega H/\beta_L)\}^{-1/2} \quad (2)$$

Where: U (ω) is the frequency domain surface displacement and the subscripts L and R indicate the properties of the overlying layer (of thickness H) and underlying one, respectively.

Twenty-two shallow seismic refraction profiles were measured at the same sites where the microtremors measurements have been done, subsoil structure for each site was estimated. For each model, P-and S-wave velocities and the thickness of each layer were calculated. Using P- and S (shear)-wave velocities, elastic and physical properties for each layer was calculated specially the density. Applying the Eq. (3) and using some of the calculated physical properties (from seismic survey), such as; shear wave velocities, thicknesses and density of the sedimentary layers, the amplification factors were determined theoretically at different frequencies, such as; 3, 5, 7 and 9 Hz. The field data measurements are carried out using an exploration seismograph model SmartSeis TM S12 EG&G Geometerics, which is a multi- channel, painting, and signal enhancement shallow exploration seismograph. It is a microprocessor based and 12-volt battery operated with 24-channels. The instrument is a portable field unit. Figure (12) shows a location map for the distribution of the recorded seismograms at the study area and figures 13, 14 and 15 are some examples of normal, mid point and reverse shooting seismograms done during the shallow seismic refraction survey. Table (1) shows the parameters, (S-wave, P-wave velocities and the thickness of the surface layer), we got from the shallow.

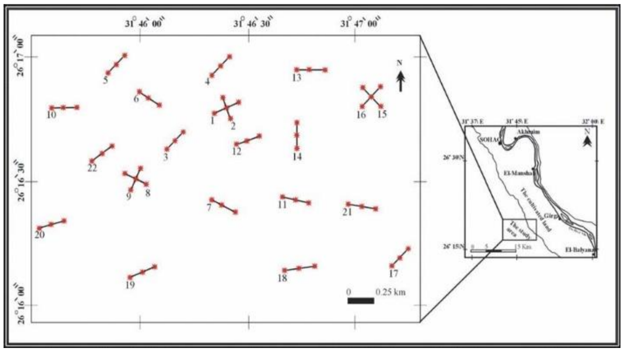

Fig.12: Location map for the distribution of recorded seismic profiles

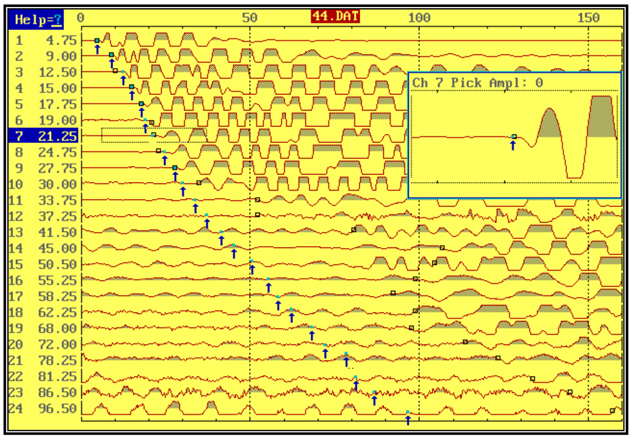

Fig.13: Sample of P-wave recorded seismogram (off spread normal-shot)

Figures (16, 17, 18 &19) illustrate the theoretical amplification factor distribution contour maps for the area under investigation at the different frequencies using the shear wave velocities calculated by the shallow seismic refraction survey.

Figure (16) shows the amplification distribution contour map at 3 Hz frequency for the study area. The amplification factor at this frequency ranges between 0.9 as a minimum value at the northern and southeastern parts and 2.3 as a maximum value at central and western parts of the study area.

- At frequency 5 Hz; the amplification factor ranges between 0.9 and 2.4. The minimum values of the amplification encountered to be at central and southeastern parts, while the maximum values detected at the southwestern and northeastern parts of the study area (Fig. 17).
- At frequency 7 Hz; the amplification distribution contour map, figure (18), shows that, the minimum value is 0.7 and encountered at a NW-SW belt. While the maximum amplification is 2.4 and encountered at Western and Northeastern parts of the study area.

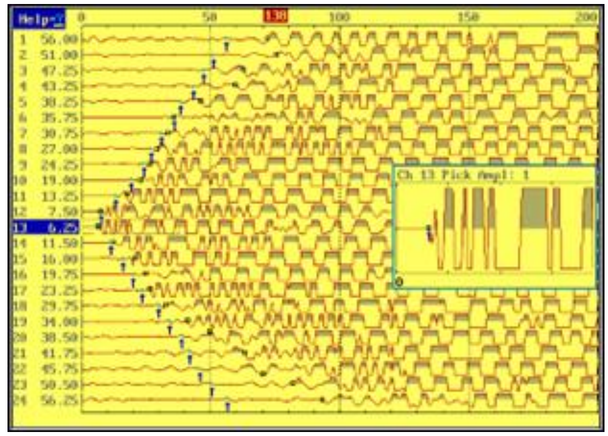

Fig.14: Sample of P-wave recorded seismogram (off spread mid-point-shot)

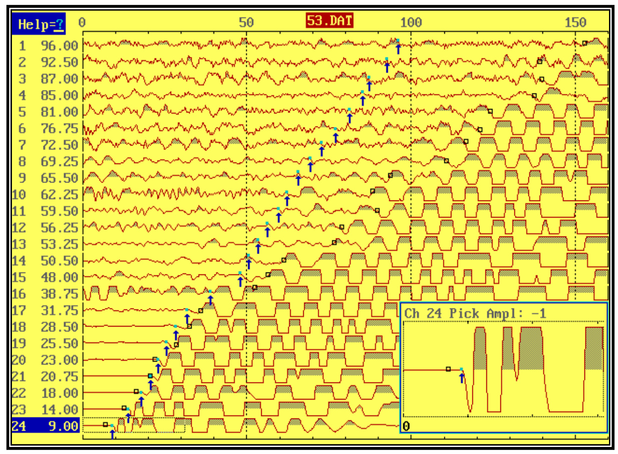

Fig.15: Sample of P-wave recorded seismogram (off spread reverse-shot)

Table 1: Shows the observed body wave velocities and thickness of the studied layers

Profile number	Vp- wave of surface layer	Vp- wave of second layer	Vs- wave of surface layer	Vs- wave of second layer	Thickness of surface layer
1	444	1220	279	825	2.0
2	467	1325	257	865	1.5
3	534	1264	323	811	1.5
4	504	1264	290	823	2.0
5	486	1306	314	856	1.3
6	508	1234	278	844	2.0
7	456	1287	271	828	2.0
8	473	1284	270	862	2.5
9	476	1245	260	870	2.0
10	461	1276	290	862	2.5
11	465	1229	274	852	1.5
12	460	1241	256	860	1.8
13	532	1195	292	831	1.5
14	445	1253	275	807	1.0
15	454	1302	289	863	2.3
16	528	1264	287	885	2.0
17	560	1365	295	831	3.0
18	477	1232	319	839	2.5
19	535	1268	296	828	2.0

- At frequency 9 Hz; the amplification values range between 0.7 and 4.6. The minimum values are encountered to be at the central part while the maximum ones are at the Western side, (fig. 19).

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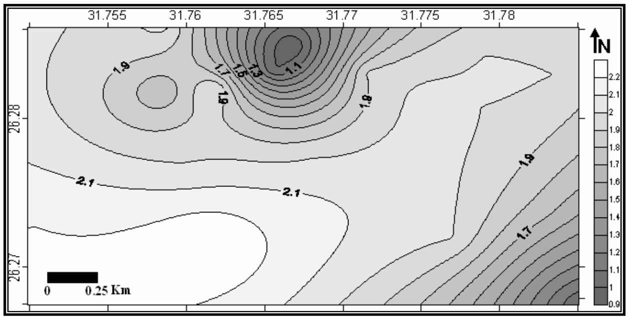

Fig.16: Amplification distribution contour map of the study area at frequency 3 Hz using shallow seismic refraction method

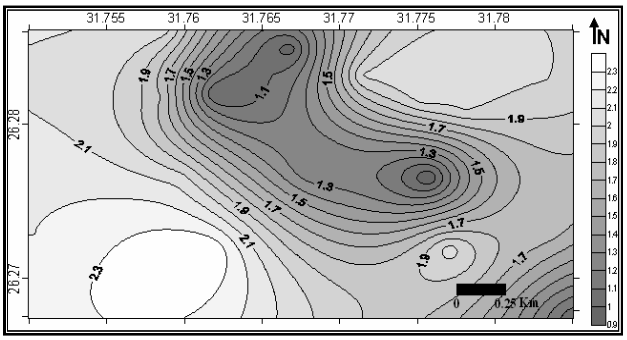

Fig.17: Amplification distribution contour map of the study area at frequency 5 Hz using shallow seismic refraction method

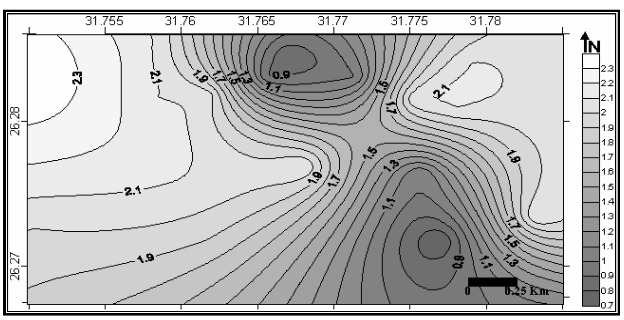

Fig.18: Amplification distribution contour map of the study area at frequency 7 Hz using shallow seismic refraction method.

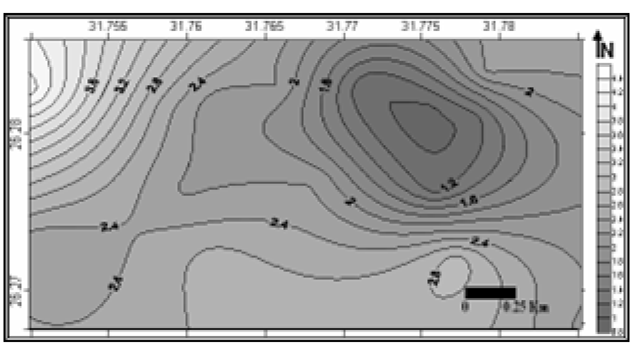

Fig.19: Amplification distribution contour map of the study area at frequency 9 Hz using shallow seismic refraction method

3 Conclusions

The fundamental resonance frequency and amplification of ground vibration at different frequencies were estimated at the study area using microtremor observations. The results showed a change in the resonance frequency according to the vicinity to the plateau scarp that located near to the study area.

The amplification factors of the ground motion were calculated using microtremor (observed) and seismic method using shallow seismic refraction technique (theoretical). The amplification factor changes from site to another depending on the thicknesses of the sedimentary layers and also the distance between the location and the elevated areas.

The amplification factor obtained using microtremor data matches well with that theoretical one obtained using the shallow seismic data.

As a general conclusion, microtremor technique together with shallow seismic refraction method can provide good tool for seismic microzonation and can be used in seismic hazard assessment.

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