Geophysical analysis of soil for geotechnical engineering purposes using MASW and microtremor approaches in Jericho region, West Bank, Palestine

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Abstract. Multichannel analysis of surface waves (MASW) and microtremor measurements provide a convenient site evaluation of subsurface rocks and soils for geotechnical site investigation. The main target of this work is to assess the geotechnical characteristics of subsurface soil for foundation purposes of a cement factory in Jericho region. MASW was used to delineate the shear wave velocity (V_s) in the proposed site. Six profiles for MASW was performed to measure the V_s for site class evaluation. S-waves were generated using MASW technique with seismograph of 24-channel model SUMMIT X Stream Pro with 2 to 3 m offset distance and three shooting. Fieldwork was undertaken implementing RT Clark vertical geophone of low frequency (4.5 Hz) and SWAN software was used for processing seismic data. Microtremor measurements were carried out at two locations in the study area and Nakamura's method was applied for determining dominant natural frequency (F_o). Low shear wave velocities (V_s) geoseismic zones were detected ranging between 300-650 m/s, to a moderately high velocities varying between 700-1200 m/s. The values of average S-waves velocity for near-surface geologic units (the top 30 m depth V_{s30}) show that the majority of foundation sites have a soil profile of class C, making them suitable for engineering design. The results of the microtremor measurements showed a dominant natural frequency (F_o) 7 to 11 Hz. The natural frequencies of the proposed construction (F_b) should not be close to the values of the dominant frequency of the site (F_o) in attempt to avoid the resonance phenomena.

Keywords: MASW, Microtremors, Soil effects, Nakamura's method, Geotechnical, Palestine.

1. Introduction

Jericho region lied in the eastern part of West Bank; on exposed sequence of deposits mainly consists of Quaternary-Tertiary sediments (Figs. 1 and 2). Historical earthquakes for the past few hundreds of years and instrumental earthquake monitoring of half a century [1, 2] demonstrate that the damaging earthquakes were located along the Dead Sea Transform fault. Therefore, all available techniques should be used to mitigate the risk of expected medium-high level of seismic hazard in Palestinian regions [3-5]. Seismologists and civil engineers are increasingly accepting of the geophysical approaches for assessing underground engineering sites since they provide a thorough view of the geological structures and lithology [6-8]. Microtremor measurements and 2D MASW are geophysical approaches to assess building fundamental characteristics and to explain issues related to underlying rocks and soils [9, 10]. MASW is thought to be the optimum defining approach of S-wave velocities (V_s), where fieldwork takes less time, and data processing is more quickly completed [11], other method to evaluate site effects was proposed in 1989 by Nakamura [12]. Soil amplification effect and V_s values are well known to provide useful background for the performance of ground motion, and natural frequencies related to subsoil properties [13-15]. Anywhere, knowledge about soil stiffness is the key characteristic for predicting soil ground shaking reaction and is more useful to calculate site amplification [16]. Determining the dynamic engineering properties of underground rocks and soils through interpretation of V_s and site amplification, knowing the likely causes of structural construction damage, and calculating V_{s30} (averaging V_s for the uppermost of 30 m) to determine site class. Thus, estimating the underground geology characteristics and their accurate effects on ground deformation are vital [9, 10].

The main purpose of this work is to identify underlying rock formations and soil profiles through determining S-wave velocities and estimating near-surface local site effects. This will be accomplished by combining multichannel analysis of surface waves (MASW) and microtremor observations. The goal is to conduct geotechnical engineering analysis and to reduce seismic risk for a projected cement factory in the Jericho district of the West Bank, Palestine.

2. Materials and methods

Site geology

The main outcropping around the proposed study area (Fig. 1) is a sequence of limestone of 3 meters, chert sequences of 0.4 to 0.5 meters, and chalk to marly chalk of 2 meters in one side of the Wadies. On the other side, a successive stratigraphy of chert and chalky limestone of folded and fractured layers. The chert is of grey color and fractured type due to the formation of the Jordan Rift Valley [17].

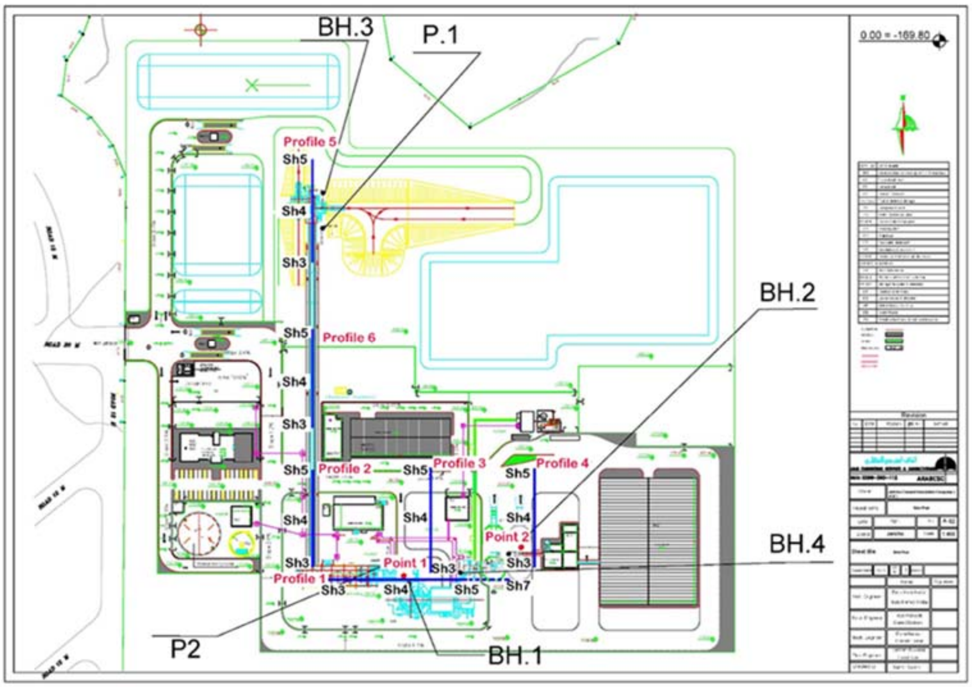

Fig. 1 Location map of the study area, also shown are the distribution of the MASW profiles, also shown on the geological map in Fig. 2

As illustrated in Fig. 2, the typical strata of the lithology in the Jericho region are composed of:

• Dead Sea Group (Q(PE)-Lisan), which mainly consists of carbonates; thinly laminated marl with gypsum bands, and poorly sorted gravel and pebbles, in addition to volcanic rocks back to the upper Quaternary.

• Abu Dis Group (MZ(K-SN)-Nablus), which mainly consists of carbonates; chalk, and it includes other sediments such as chert, in addition to volcanic rocks back to the upper Cretaceous.

• Yatta Group (MZ(K-CN)-BHY), which mainly consists of carbonates; limestone, dolostone, clay, and chalk, in addition to volcanic rocks back to the upper Cretaceous.

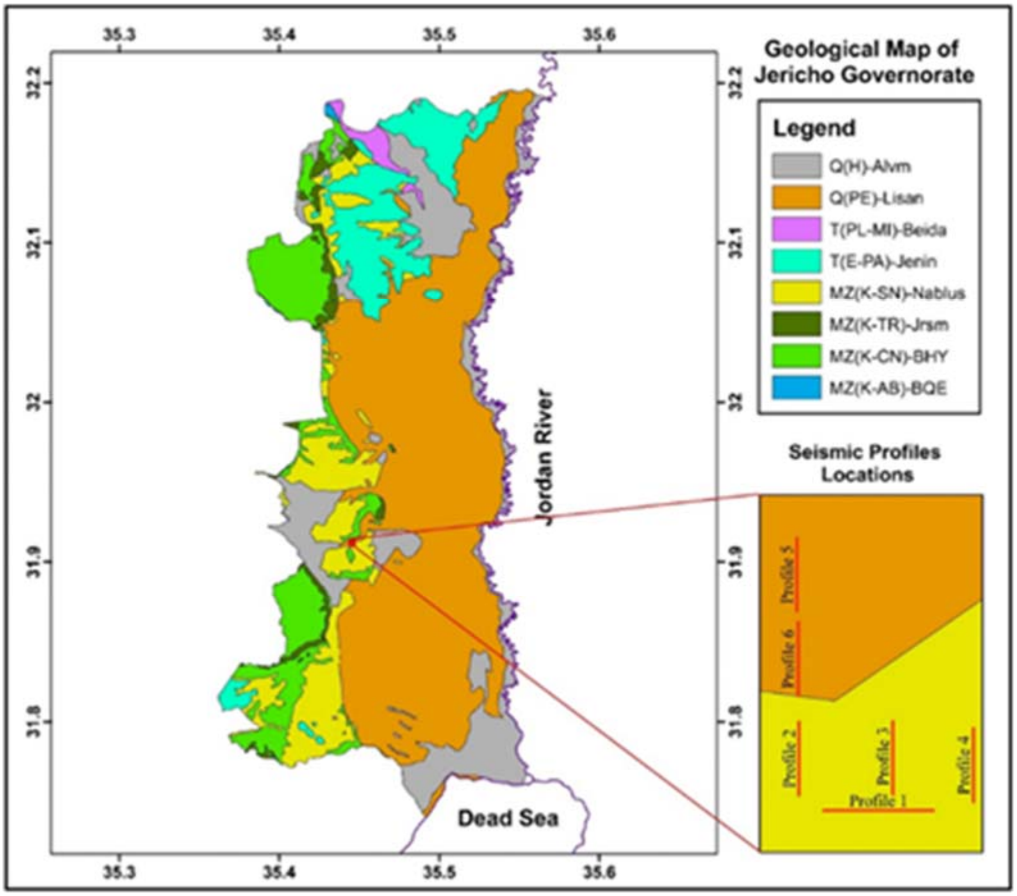

Fig. 2 Geological map of Jericho region

MASW survey

The study applied MASW technique to generate S-waves [11]. A linear spread configuration was employed; the geophones were arranged in a straight line on the ground and connected by a spread cable (Fig. 3). There are many ways to generate the seismic energy needed for active source surface wave surveys, but an 8 kg sledgehammer striking the ground was recommended because it is a cheap, easily accessible item and typically generates enough energy for the majority of near surface investigations with high resolution [9, 10]. A trigger switch was employed as an interface between the signal and the noise to strengthen the signal to noise ratio. The surface wave survey was conducted at six profiles (Figs. 1 and 2) using a 24-channel seismograph model called SUMMIT X Stream Pro; this would result in a spread length of 69 m for profile 1 and 46 m for the other profiles using a 3 m and 2 m offset distance, respectively. For both conventional and reverse shots, the source distance between the first and final geophones is 5 m. Low frequency (4.5 Hz) RT Clark vertical geophones with base plates were used for field measurements.

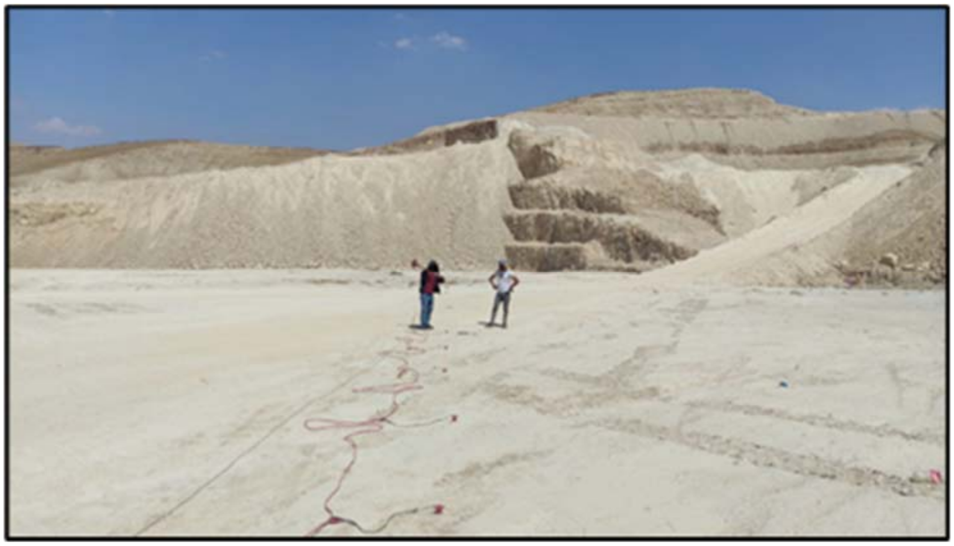

Fig. 1 A photo of carrying out the fieldwork shows the configuration of the geophones

Nakamura's technique

The estimation of site response is crucial in geotechnical studies for earthquake engineering purposes, such assessment may come from microtremor measurements [18]. The application of microtremor measurements, in estimating site response is a reasonable one because the method is inexpensive and fast [12]. The site response estimated is obtained since it only requires records from a single three-component station deployed at the site of interest and does not need a reference seismogram measured at the substratum bedrock. As introduced by Nakamura [12], the technique was intended to assess S-wave amplification from microtremor measurements. There are four components of spectral amplitudes involved in this one- layer problem, namely, the horizontal components of motion at the surface and bottom of the sedimentary layer, referred as $H_s(f)$ and $H_b(f)$, respectively; and the vertical components of motion at surface and bottom, correspondingly denoted as $V_s(f)$ and $V_b(f)$. The prime objective of Nakamura's technique is to isolate the amplification effect suffered by horizontal components of substratum motion. To do this, he first constructs the theoretical borehole ratios that are widely regarded as the most reliable transfer function estimates for horizontal and vertical components, as given below, respectively:

$$S_h = \frac{H_s}{H_b} \text{ and } \quad (1)$$

$$S_v = \frac{V_s}{V_b} \quad (2)$$

With these two ratios, Nakamura constructs an additional transfer function that gives formally the factor by which the horizontal ratio exceeds the vertical one:

$$S_t = \frac{S_h}{S_v} = \frac{H_s/H_b}{V_s/V_b} \quad \text{or} \quad (3)$$

$$S_t = \frac{H_x/H_s}{H_b/V_b} \quad (4)$$

3. Results and discussion

MASW technique analysis

A 2D S-wave velocity model was created using SWAN software; the active source is utilized to input the data file, which is then modified to improve the waveform appearance. Parameters were set for the calculation of phase velocity, the construction of a dispersion curve within the required frequency range, the creation of a preliminary V_s model and the running of an inversion technique to find the final V_s model that fits the experimental data's dispersion curves. Because different frequencies entail different soil thicknesses and thus move at varying speeds, the surface wave dispersion is often correlated with properties of the underlying soil. 2D velocity models of the S-waves variations (V_s) beneath the study area are shown in Fig. 4.

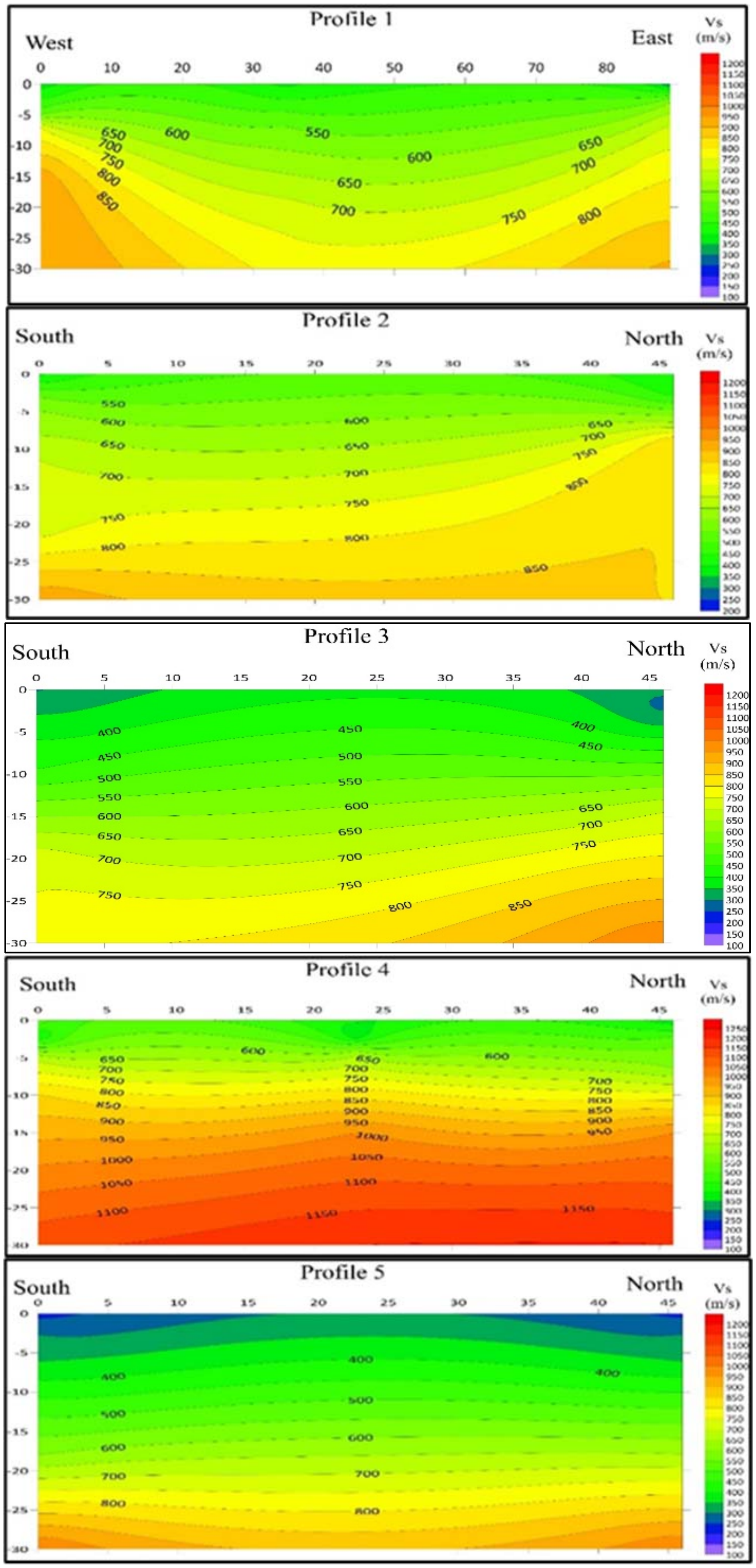
Profile 1
West
East
Vs (m/s)
Profile 2
South
North
Vs (m/s)
Profile 3
South
North
Vs (m/s)
Profile 4
South
North
Vs (m/s)
Profile 5
South
North
Vs (m/s)

Fig. 2 2D velocity model of the S-waves variations (V_s) beneath the study area

The average V_{s30}

The near-surface geology, which governs ground motion disturbances, is the root cause of all engineering issues with structures. Studying the near-surface soils characteristics is crucial for engineering and environmental applications because of their effect on seismic wave propagation and elastic properties. The average V_{S30} is attributed to travel times from surface of the earth to topmost 30 m depth [9, 10, 19, and 20]. According to recommendations made in SWAN software, penetration depths that may be attained range from 10 to 30 m, depending on the materials and conditions of the site, the types of energy sources that may be required, any stacking that may be required, and/or the geophone interval. It is anticipated that locations with the same class order would have comparable seismic impact characteristics.

Microtremor observations and analysis

Site conditions play a major role in establishing the damage potential of incoming seismic waves from major earthquake. There are several small amplitude vibrations, which appear on surrounding ground surface. Vibrations that have small periods, less than 1 sec, are called microtremors [21]. The origin of microtremors is probably due to traffic vehicles, heavy machinery facilities, household appliances and so that are not related to earthquakes; however, small waves propagate from artificial sources surrounding daily life.

The data acquisition system is composed of a three-component high-sensitive seismometer, which has a natural period of 1 second, and a digital recorder (laptop personal computer). The system was used to record the horizontal and the vertical components of microtremors. The site effects were investigated by measuring ambient noise at two places (Fig. 1) using a short period seismic station and doing a spectrum analysis using the Geopsy software. A time window of fifteen minutes was made for each observation and the signals were Fourier transformed and smoothed using a 0.3 Hz window. At the selected points, spectral ratio findings were acquired using microtremor measurements and data processing (Figs. 5 and 6).

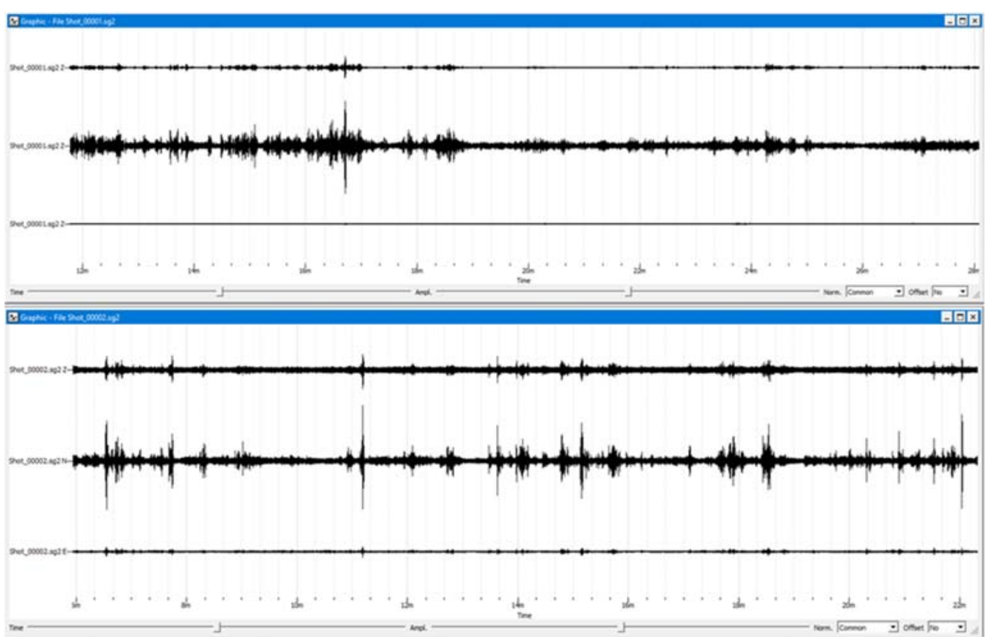

Fig. 5 Spectral ratio was determined using the recording data for points 1 and 2, which are shown above and below.

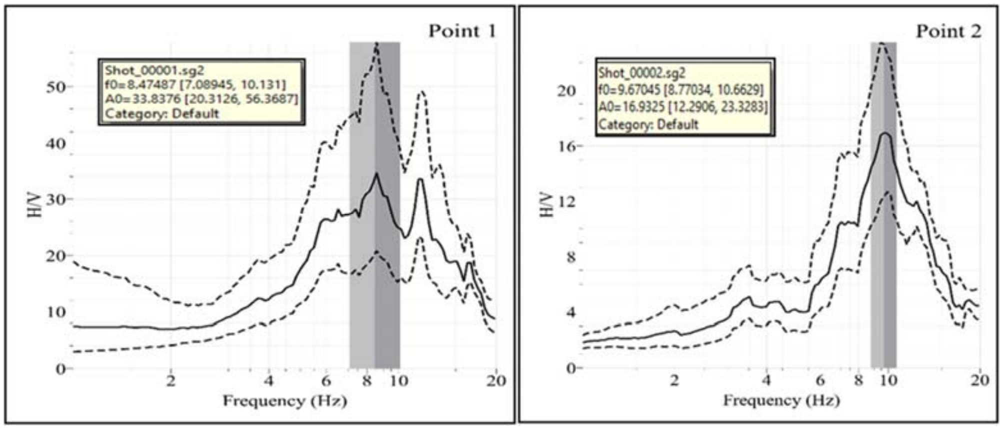

Fig. 6 Spectral ratio for points 1 and 2 for the selected points shown in Fig. 1

Data interpretation

The low shear wave velocities (V_s) of the western section of profile 1 (Fig. 4) are 375 m/s, while the eastern section indicates a low velocity of about 297 m/s. The velocity increases with the depth. In the middle of profile 1, the first layer was estimated to be about 6 meters, decreasing to about 2.86 meters in the eastern profile section. At the same time, profile 3 has a low shear wave velocity in the first layer with about 5 meters depth along profile 3 and that depth increase in the northern direction. The first layer of profile 2 has low shear wave velocity from the surface to one meter depth (Fig. 4). While the velocity rapidly increases by more than 900 m/s after 2 meters depth, which increases with the depth. The low shear wave velocity for the first layer of profile 4 is 365 m/s in the northern part in depths 0 to 2.7 meters. The shear wave velocity for the southern section of profile 4 decreases in the second layer for a depth of about 2 to 5 meters. While, the velocity back increases after 5 meters, which can be estimated at 640 m/s in 5 meters depth. Shear wave velocity for profile 5 was estimated of 347 m/s up to 18 meters in depth. While the velocity slightly increases to about 600 m/s for depths of 18 to 30 meters. Profile 6 appears to have a low shear velocity of 360 m/s or less for depths 0 to 4 meters. In the southern part of profile 6, the velocity increases with a depth significantly compared to the northern part of the profile. According to the Unified Building Code (UBC 1997), the hard rock is classified to have a shear wave velocity higher than 1500 m/sec, while the normal rock should fall in the range between 760 and 1500 m/sec, whereas the soft rock formation characterized by a low shear wave velocities varying between 360 and 760 m/sec. As a result, geologic intermediate hard to soft rock forms the soil profile underneath the study area. The characteristic site period (or site dominant frequency T_s), which depends on the thickness (H) and shear wave velocity (V_s) of the soil, provides a very useful indication of the period of vibration at which the most significant amplification can be expected. The analysis of ambient vibration measurements developed a spectral ratio site response for each site. An example of average Fourier spectra for selected windows and the relation between the dominant frequency at the site and the amplification factor (spectral ratio) was presented in Figs 5 and 6. The dominant natural frequency (F_o) value varies between 7 to 11 Hz as shown in Figs 5 and 6. To avoid the resonance phenomena, the values of fundamental natural frequencies of the proposed buildings and structures (F_b) in the studied area should not be close to the values of the dominant frequency of the site (F_o).

4. Conclusions

Multichannel analysis of surface waves (MASW) is a powerful geophysical tool for identification of different subsurface layer's characteristics and velocity-depth models while microtremor measurements technique is a rapid, cost effective and predictable tool alternative for engineering goals. Based on the velocity model of the S-wave variations (V_s) beneath the study area, low shear wave velocities (V_s) geoseismic zones ranging from 300-650 m/s to moderately high velocities ranging from 700-1200 m/s were detected. The values of average shear wave velocity (V_s) for the upper 30 m depth are labelled as V_{s30}, indicating that the soil profile type C is present across the study area. Yet, the region of profile 5 is extremely near to being type D, with Vs of roughly 347 m/s at a depth of 18 meters. The shear velocity results correlate to moderately hard/ soft rock and very stiff/ very dense soil; thus, it is assessed as a qualified layer for engineering and building purposes. The analysis of ambient vibration measurements developed a spectral ratio site response, where the dominant natural frequency (F_o) value varies between 7 to 11 Hz. To avoid the resonance phenomena, the designer should take special care, and the values of fundamental natural frequencies of the proposed buildings and structures (F_b) in the studied area should not be close to the values of the dominant frequency of the site (F_o).

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