AMBIENT NOISE MEASUREMENTS FOR SEISMIC RESPONSE AND EXPLORATION OF SEDIMENTARY LAYERS: CASE OF KIRYAT SHEMONA

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ABSTRACT

Damage distribution during moderate earthquakes is frequently controlled by site effect. Subsoil impedance contrast can significantly amplify the shaking level, as well as increase the duration of strong ground motion. During a measurement campaign in 2002, instrumental ambient noise recording were conducted at 300 sites in and around the Kiryat Shemona (Zaslavsky et al., 2002). Two methods were applied to estimate site effects: (1) horizontal-to-vertical spectral ratio (H/V) of the ambient motions at the investigated site; (2) horizontal-to horizontal spectra ratios of motions recorded simultaneously at the investigated site and at a reference site. In this stage, two maps that reflected fundamental characteristics of site effects were prepared: distribution of the fundamental frequency and its associated H/V level. The survey suggests site amplifications in the order of 2.0-8.0 over the frequency range 0.7-14.0 Hz. These results imply significant variations in the shear-wave velocities across the area and considerable variations of sediments thickness. Unfortunately, in 2002 there was no available geotechnical and geophysical information.

In the following years the Geophysical Institute of Israel have carried out few seismic refraction lines in the investigated area that allowed calibrating experimental H/V spectral ratios obtained along these lines using analytical 1D model. Later on, the Vs and thickness of sediments were calculated by fitting analytical function to empirical H/V ratios for every measurement point. In addition, we determined the area of expansion of different reflectors and constructed two contour maps: shear-wave velocity of sediments and its thickness in the study area. In addition, in this Report we present part of the Kiryat Shemona fault (left lateral offset along the Dead Sea Rift) not mapped previously by geological survey that was detected by ambient vibration measurements.

We divided the study area into eight zones. The grouping is done manually taking into consideration the fundamental frequency, H/V amplitude and the shape of the response function. The Uniform hazard site-specific acceleration spectra for all zones were computed for a probability of exceedence 10% during an exposure time of 50 years and a damping ratio of 5%. The shape of the spectra obtained for all zones differ significantly from those prescribed by Israel Building Code (IS-413). IS-413 essentially underestimates the accelerations in the period range from 2 sec. to 0.1 sec. These evaluations are very important for realistic assessment of the vulnerabilities of all types of existing and newly designed structures and for urban and land use planning.
1. INTRODUCTION

Kiryat Shemona is a relatively small town (about 22,000 inhabitants), situated in the northern part of Israel alongside the Hula Valley between two major segments of the Dead Sea fault system. Two most recent destructive earthquakes in this region occurred in 1759 and in 1837. These earthquakes had a maximum intensity X on the MM scale and caused severe damage and loss of life in the northern Levant, presently Israel, Syria, Jordan and Lebanon (Amiran et al., 1994).

In the process of assessing the seismic hazard to the Kiryat Shemona area, we have investigated the possibility of site amplification effects that might enhance the earthquake risk to the town. Various empirical techniques have been used to detect locations where site effects are likely to occur. Kagami et al (1982) proposed that spectral ratio of horizontal components of ambient vibration obtained in soil to those in the bedrock can be used for ground motion amplification assessment. Nakamura (1989) hypothesized that spectral ratios of horizontal versus vertical component (H/V ratios) of the ambient vibration represents the site response to seismic waves. Recently, Seekins et al (1996), Chavez-Garcia and Cuenca (1998), Zaslavsky et al (2003) and others have demonstrated that the two techniques provide similar results.

In this study we performed ambient noise measurements at 300 locations on a dense spatial grid from which we obtained a spatial distribution of the frequencies at which amplification is likely to occur and the magnitude of the expected level of amplification at those frequencies. These data were used to divide the study area into zones in which the fundamental frequencies and the spectral ratio levels are similar. For each zone we developed a subsurface model from which we determined the site response functions and evaluated the uniform hazard site-specific acceleration spectra. The subsurface models were derived by combining the results from the ambient noise measurements with available geological and geophysical information. This approach has proven to yield a systematic representation of basic structural parameters of the subsurface to be imbedded in earthquake hazard and risk assessments.
2. GEOLOGICAL SETTING

The town of Kiryat Shemona occupies a territory of 25 km². It is located at the Kiryat Shemona graben in close proximity to the Hula Valley - a structural part of the Dead Sea fault system. The Kiryat Shemona fault (Figure 1), crossing the town in the west, is the master fault (i.e., transform) which separates the African plate from the Arabian plate (Sneh and Weinberger, 2003). The Margaliyyot fault branches off the Kiryat Shemona fault at the southern entrance to Kiryat Shemona and then traces towards the northwest. In the north-west of the study area the local Muftalah fault is characterized by throw direction unknown. The faults of Tel-Hay and Shehumit trending in the north-south direction are also part of the Dead Sea fault system and form the east boundary of the Kiryat Shemona graben.

The geology of the investigated area (Figure 1) is characterized by outcrops of basalt flow of Pleistocene age. The tufa (travertine) overlies the basalt flows in the area between Nahal Iyyon and the Hazbani River and exceeded 25m in thickness near HaGosherim. West of Tel-Hay fault, the marl of Paleocene age covers a horst. Hard conglomerate of Miocene age, dolomite and limestone of Cretaceous age crop out in the north-western part of the town. The sandstone of the Kurnub Gr. (Lower Cretaceous age) is presented in the south-west. There are a complex of slope movement material in the south-west of the Kiryat Shemona area, composed of loam, debris and talus breccias of 15-70 m thick, which cover the basalt, carbonate and sandstone.

The alluvium sediments occupy most part of the study area. They accumulated in the Kiryat Shemona graben that merges in the south with the Hula Valley. Thickness of the alluvium sediments changes from some meters in the northern part till 170meters in the southern part of the study area. These deposits overlay the Plio-Pleistocene basalt flows.

Geological data show that in the most part of study area the basalt of Plio-Pleistocene age is the hard base rock (reflector), which produced the site response. Also the carbonate and conglomerate in the north-west of study area may produce the site response.
Figure 1. Part of the Geological map (1:50,000) by A. Sneh and R. Weinberger (2003), also showing the location of the measurement points and reference places.
3. RECORDING SYSTEM AND DATA PROCESSING

A microzonation study to investigate possible site effect was carried out through ambient noise survey at 300 sites across the town using 250m grid between measurement points. Two methods are used to estimate site effects: H/V spectral ratio and H<br/_>site/H<br/_>bedrock

In our experimental set-up, each seismograph station consists of three (one vertical and two horizontal) L4C velocity transducers (Mark Products) with a natural frequency of 1.0 Hz and damping ratio 70% of critical. The recorded signals are sampled at 100 samples per second and band-pass filtered between 0.2 Hz and 25 Hz. All the equipment: sensors, power supply, amplifiers, personal computer and connectors are carried in a vehicle, which also serves as a recording centre. The seismometers are fixed on levelled metal plate placed directly on the ground. Prior to performing measurements, the individual seismometer constants (natural frequency, damping and motor constant) are determined using sine and step calibration signals, and then the frequency response functions of all channels are computed. This procedure allows evaluating change of natural frequency and motor constant (voltage sensitivity) during long time of measurements in harsh conditions in the free field.

The length of recorded ground motions (ambient noise) may affect the results and influence the reliability and applicability of the technique. In our experiments, the ambient noise is continuously recorded for 60-70 minutes, stored in a series of data files of 3 minutes each. We compile a set of up to 50 selected time windows and then average the spectral ratio.

To study the characteristics of spectra of ambient noise signals, we compute Fourier spectra and spectral ratios. The record length (time window) used for spectral calculations depends on the fundamental frequency.

The H/V spectral ratios are obtained by dividing the individual spectrum of each of the horizontal components [S<br/>NS(f) and S<br/>EW(f)] by the spectrum of the vertical component [S<br/>V(f)]:

\[
A_{NS}(f) = \frac{S_{NS}(f)}{S_{V}(f)} \quad A_{EW}(f) = \frac{S_{EW}(f)}{S_{V}(f)}
\]

The average spectral ratio for each of two horizontal components is computed, if the curves of average spectral ratios of the two components are similar then the average of the two horizontal-to-vertical ratios is defined as:

\[
A(f) = \frac{1}{2n} \left[ \sum_{i=1}^{n} \frac{S_{NS}(f)_i}{S_{V}(f)_i} + \sum_{i=1}^{n} \frac{S_{EW}(f)_i}{S_{V}(f)_i} \right]
\]
As already observed by many researchers, there is high scatter in the H/V spectra. The source of the scatter is debated between the researchers. Mucciarelli (1998), for example, claims that traffic is not a major reason for the scatter and Horice et al. (2001) used noise originated by passing traffic in their analysis. In a recent study, Parolai and Galiana-Merino (2006) showed that the influence of transients on the H/V spectral ratio is insignificant. Our observations indicate that the effect of transients is almost unnoticeable. In order to reduce the scatter and increase stability, our processing scheme involves a careful manual selection of the time windows from which we obtain the H/V functions. In selecting the time windows, the analysts follow the concept that sites with no site effect should exhibit spectra of the H and V components that are of the same level throughout the spectrum. At sites with significant site effect, the spectra of the two components should differ only within a certain limited frequency band, probably at the neighbourhood of the resonance frequency. Time windows with spectra that exhibit such or similar conditions are selected. Evidently, this practice has yielded an appreciated reduction in the H/V scatter.

In applying the second technique, one station that serves as a reference station is located on a basalt outcrop throughout the duration of the experiment, while the other station is moved from point to point. Due to practical limitations, we are able to carry out only three such sets of measurements, marked as R1, R2 and R3 (see Figure 1) where the reference station is within 400 meters from the investigated sites. Figure 2 shows the comparison between the average Hsite/Hbedrock and H/V spectral ratios for different points on those three places. The two functions showed similar peak values at the same fundamental frequency clearly indicating that the two methods reflect the same characteristics of the local site response. It is important to note that there are no significant differences in shapes of spectral ratios. The marked rise in the H/V spectral ratios observed at a frequency near 0.3 Hz (R2 place) is normally associated with ocean waves. Therefore, this peak is negligible in the Hsite/Hbedrock spectral ratios.
Figure 2. Comparison between average H/V (solid line) and Hsite/Hbedrock spectral ratios (dashed line) obtained at 3 places RL1, RL2 and RL3 indicated in Figure 1.

4. COMPARISON OF H/V SPECTRAL RATIOS FROM AMBIENT NOISE AND SEISMIC EVENTS

The theoretical background for use of ambient noise measurements in site response investigations is debated. Not likewise, the association of H/V spectral ratio from earthquake signals. The later clearly explains why H/V spectral ratios of S waves, often known as receiver functions, are also representing the site amplification. It is thus interesting to compare H/V spectral functions as obtained from ambient noise and earthquake recordings. In our studies we analyze the H/V spectral ratios from ambient noise measurements and from ground motion measurements generated by different sources of excitation: Local and regional earthquakes recorded by different sensors i.e.; accelerometers and seismometers. The strong motion station (Table 1) that recorded earthquake and used in this study is marked in the Figure 1. The recorded earthquakes are presented in Table 2.

Figure 3 presents the calculated receiver function of a site in Kiryat Shemona, as evaluated from the spectral ratio of strong motion recordings:

a. The H/V spectral ratio from two horizontal components of accelerograms of the Beirut earthquake. This H/V function shows prominent peak near 4 Hz (f_1) with an amplification factor of about 4.5 and with a second peak near 8.0 Hz.
b. The average spectral ratio obtained from eight earthquakes (events 1 to 8 in Table 1). The average function also yields two peaks at frequency 4.5 Hz (with amplitude 4.5) and 8.0 Hz.

c. The horizontal-to-vertical spectral ratio from ambient noise shows two prominent peaks near 4.5 Hz and 8.0 Hz in agreement with the resonance frequencies identified by the receiver function.

![Graph showing spectral ratios](image)

**Figure 3.** Average H/V spectral ratios for Kiryat Shemona strong motion station obtained from: two horizontal accelerograms of Beirut earthquake (thick line), seismogram of eight local and regional earthquakes (shaded line) and ambient noise (thin line).

**Table 1.** Parameters of earthquake recorded by accelerometer station and are used in this study. Distance is to the surface projection of the rupture.

<table>
<thead>
<tr>
<th>Site</th>
<th>Date yr/mo/dy</th>
<th>Origin time hr:mn:sec</th>
<th>M&lt;sub&gt;W&lt;/sub&gt;</th>
<th>Geographic coordinates</th>
<th>Distance (km)</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiryat Shemona</td>
<td>97/08/04</td>
<td>11:29:46</td>
<td>4.0</td>
<td>33.26</td>
<td>35.73</td>
<td>14</td>
</tr>
</tbody>
</table>
Table 2. List of earthquakes used in this study. Eq.- earthquake; Md – duration magnitude (Mw – moment magnitude).

<table>
<thead>
<tr>
<th>No.</th>
<th>Site</th>
<th>Date yr/mo/.dy</th>
<th>Origin time hr:mm:sec</th>
<th>M_d</th>
<th>Geographic coordinates</th>
<th>Distance km</th>
<th>Region</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td>99/03/27</td>
<td>13:42:29</td>
<td>3.6</td>
<td>34.61</td>
<td>33.25</td>
<td>270</td>
<td>Cyprus</td>
</tr>
<tr>
<td>3</td>
<td>Kiryat Shemona.</td>
<td>99/03/28</td>
<td>19:54:11</td>
<td>2.5</td>
<td>33.71</td>
<td>32.73</td>
<td>300</td>
<td>East Mediterr.</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>99/04/06</td>
<td>00:08:25</td>
<td>W5.2</td>
<td>39.50</td>
<td>37.90</td>
<td>700</td>
<td>Turkey</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>99/04/08</td>
<td>00:13:17</td>
<td>3.9</td>
<td>35.92</td>
<td>27.02</td>
<td>830-</td>
<td>Crete</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>99/04/10</td>
<td>22:46:09</td>
<td>3.4</td>
<td>35.68</td>
<td>28.16</td>
<td>740</td>
<td>East Crete</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>99/04/11</td>
<td>19:45:05</td>
<td>3.6</td>
<td>33.16</td>
<td>35.64</td>
<td>10</td>
<td>Golan</td>
</tr>
</tbody>
</table>

As mentioned above, site effect may be strongly influenced by soil structure interaction. In our case the strong motion station is located in a cellar of a two-stories building. The Fourier amplitude spectra from wind excitation recorded on the roof allowed establishing that f_2~8 Hz is the fundamental frequency of the building.

5. DISTRIBUTION OF H/V RESONANCE FREQUENCY AND THEIR ASSOCIATED AMPLITUDE LEVELS.

Examples of the individual and average H/V spectral ratios, obtained in different parts of study area are shown in Figure 4. In the most cases of the measurements the spectral ratios have one distinct peak, which is the resonance frequency of soil. Presence of only one peak of the resonance frequency characterizes of the uniform velocity section of the soft sediments covering the hard rock. The resonance frequency is proportional to the S-wave velocity in the soft layer and inversely proportional to its thickness. The height of the H/V peak depends on the seismic impedance between the soil and the hard rock.
Figure 4. Examples of the individual and average H/V spectral ratios in the Kiryat Shemona.

We have constructed maps displaying the distribution of the observed resonance frequencies (Figure 5.) and the associated H/V amplitude levels (Figure 6). The data exhibit peaks changing from 2 to 8, occurring at frequencies 0.7 - 14 Hz. We obtained almost flat H/V ratios at sites where basalt, conglomerates, limestone and travertine are outcropped. Exceptions are the site effects obtained on the basalt outcrop along the front of youngest the Hazbani basalt flows (Pleistocene), which covers the Meshki basalt flows (Pliocene). Probably this can be explained by decrease of the thickness and S-velocity in the margins of basalt lava. The erosion could be here the cause of decrease of the thickness and S-velocity. Whereas, the S-velocity of Meshki basalt, which is reflector here, increases probably to the south, farther from a source of volcanic flows. Our results show, with respect to the expected site effects, that the area can be divided into two zones separated by the Shehumit and Tel Hay faults. The first zone constitutes the built area of the town and is located in the Kiryat Shemona graben.
Figure 5. Distribution of the H/V resonance frequency in the Kiryat Shemona.

This zone is characterized by frequency anomalies of irregular shape with general trend to decrease from 14 Hz in the north to 1 Hz in the south. These variations seem to coincide with the variations in the depth to the basement. The significant increase of H/V ratios amplitudes, reaching 8 in the central part of Kiryat Shemona is probably associated with presence of loose alluvium deposits (i.e., low S-velocity) in this part of graben. Whereas the coarse deposits are predominating in the west in the vicinity of the outcropping of conglomerates and carbonate rock.
Figure 6. Distribution of the H/V amplitude level in the Kiryat Shemona.

The second zone is located to the east of the Shehumit and Tel Hay faults and south to the basalt outcropping. Gradual decrease of resonance frequency from 14 Hz to 0.7 Hz from the north near the outcrop of basalt to the south is correlated with dipping of the basalts. Thus in accordance to Hula 1 well that located in the southern part of the study area and reaching the basalt flow at the depth of 170m. The great part of this zone is generally characterized by
lesser variability and lower H/V spectral ratios (a level of 3-4). However, we observe a few spots of high amplitudes in the vicinity of the basalt outcropping.

6. ESTIMATION OF S-WAVE VELOCITY MODELS

Fourier spectra parameters and spectral ratios analysis over the study area show good correlation with variations in the subsurface geology and may be used to provide information about S-wave velocities and sediment thickness.

Measurements of ambient noise were carried out very close to drilling sites where geology data is available. We also used S-wave velocities and thickness of shallow sediments from seven seismic refraction lines (Ezersky, Shtivelman 1999, Frieslander, Medvedev, 2002). Locations of wells and refraction lines, used in this study, are shown in Fig.7. Limited data on S-wave velocities and sediment thickness obtained from seismic refraction surveys and boreholes enable calibration of the H/V spectral ratio with an analytical site response derived from a 1D subsurface model and then estimating the S-wave velocity profile at-depth. Then we extrapolate neighbouring sites model, using H/V spectral observations and information about the regional geology to constraint S-wave velocities of the lithological units present in the area.

Table 3 presents the S-wave velocities and thicknesses of sediments from refraction lines in the Kiryat Shemona (Ezersky, Shtivelman 1999, Frieslander, Medvedev, 2002). Proceeding from geological condition and locations of the refraction lines, we started to correlate S-wave velocities of the line 1: Vs=470m/s with the soil, Vs=760m/s and Vs=1120m/sec with two facies of tufa (travertine) (Sneh and Weinberger, 2003). In this area the tufa overlies the Hazbani basalt flows (Vs=1230m/s) (Sneh and Weinberger, 2003). S-wave velocities of the line 2 could be correlated with the soil (Vs=640m/s), the Hazbani basalt (Vs=970m/s) and the Meshki basalt (Vs~1500m/s). It is known that surface of basaltic lava is clinker and blister, while inside mass is more dense and massive. First (Vs=150-170m/s) and second layers with Vs= 350-730m/s of the lines 3, 4, 5, 6 corresponded to the alluvium sediments. Refraction line 7(0015) was carried out on the landslide scar, therefore, Vs=380-710m/s corresponded to the complex of slope movement material (loam, debris and talus breccias).
Figure 7. The Geological map of the Kiryat Shemona (1:50,000) by A. Sneh and R. Weinberger (2003), also showing the location of wells and refraction lines used in this study. The straight lines A and B show the position of the geological cross sections constructed in this study.

Table 3. Geotechnical data from refraction survey in the Kiryat Shemona.

<table>
<thead>
<tr>
<th>Refraction lines</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vs, m/s</td>
<td>Depth interval, m</td>
<td>Vs, m/s</td>
</tr>
<tr>
<td>1</td>
<td>470</td>
<td>0-3</td>
<td>760</td>
</tr>
<tr>
<td>2</td>
<td>640</td>
<td>5-7</td>
<td>970</td>
</tr>
</tbody>
</table>

- Well
- Accelerometer station
- Measurement point
- Refraction lines (Ezersky, Shitvelman, 1999, Frieslander, Medvedev, 2002)
- Geological cross section derived from H/V measurements
Third layer in all the refraction lines was correlated with the hard rock-basalt of Plio-Pleistocene age. S-wave velocity of basalt changes from 1200m/s in the north (the outcropping of basalt flows) to 2320m/s in the south of the investigated area. Within the area of obtained site response, refraction lines 3-7 showed velocities of basalt 1820-2320m/s. It supposed to be high seismic impedance producing the site effect.

As examples, Figs. 8 and 9 showed velocity-depth sections along refraction lines 3 and 5, correspondingly (locations see in Figure7), average H/V spectral ratios at points located on the lines.
As demonstrated by these examples, that resonance frequency has varied from point to point. Here, over a distance of only about 200m it changes from 3.8 to 7.5 Hz.

To construct a velocity models for point 102 located near QS well (location see in Figure7) we used boreholes data and Vs from Table 3.

Figure 8. a) Comparison between H/V spectrum ratios (red lines) and analytical transfer functions computed using refraction survey data (black lines) at sites along the refraction line3; b) velocity-depth section along the refraction line3.
Figure 9. a) Comparison between H/V spectrum ratios (red lines) and analytical transfer functions computed using refraction survey data (black lines) at sites along the refraction line 5; b) velocity-depth section along the refraction line 5.
Well QS is located on the landslide scar and reached the basalt at the depth 64 m. Lithological section presented by slope movement materials with the prevalence of debris of sandstone in the upper part and debris of the limestone in the low part (Figure 10a). Calculated analytical transfer function is compared with the empirical H/V spectral ratio at point 102 (Figure 10). We obtained similar velocities to those of refraction line 7, located at a distance of 1.5 km to the north in the similar geological conditions.

Figure 10. a) Lithological section of well QS; b) Vs-depth section of well QS, derived from interpretation of H/V spectra at point 102; c) comparison between H/V spectra at point 102 (red line) and the analytical transfer function (black line).

To estimate velocity model for point 86 (Hula-1 well), we used data Vs of alluvium and Vs of basalt from Table 3 and borehole data. Well Hula-1 is placed in the southern part of the study area (location see in Figure 7) and penetrates the basalt flows at the depth 170 m. Figure 11 shows the lithological section of the well Hula-1, Vs-depth section, analytical transfer function in comparison with observed H/V spectral ratio at point 86 located near the well. Both functions have the same resonance frequency. We obtained similar velocities for alluvium to those of refraction survey.
Here (Figure11) we used S-wave velocity of basalt 2300m/s obtained from the refraction line 6. When Vs=1800-2300m/s of basalt or its average value (Vs=2000m/s), was used the accuracy of modeling was about 10-15%. Therefore, for all models of the study area, we used Vs= 2000m/s of basalt flows, which is the main reflector.

As we noted above, the main reflector in the western part of study area may be the carbonate of Albian and Cenomanian age. Its velocity Vs=1900m/s was already defined in our previous works (Zaslavsky et al., 2001, 2004). Velocity of conglomerate (Miocene) also was taken from previous works.

Based on our results of site effect investigation we constrained the Vs range for main lithological units, present in the Kiryat Shemona area (Table 4). GEOLOGICAL MAP OF ISRAEL (METULLA) (A. Sneh and R. Weinberger, 2003) also was used.
Estimations of Vs velocities in the Kiryat Shemona area were constrained by borehole and seismic refraction survey data. This information helped us to develop Vs models over the study area, using H/V spectral ratios. It allowed us to construct the schematic map of the average S-wave velocity of the sedimentary layer (Figure 12) within the area where the site response was obtained. It is necessary to say that the upper layer with Vs=150-200m/s was not accounted in the average S-wave velocity, because its thickness is less than 20% of the depth to the reflector. As noted above, the spectral ratios have one peak of frequency in most cases of measurements, that is evidence of uniform lithological section, where velocity characteristics of the sediments change gradually. Therefore, we used the weighted average of soft layer velocity for constructing this map in the landslide zone and in the weathered basalt zone. The site effect is created by the seismic impedance between this soft layer and the hard rock (reflector).
Figure 12. The schematic map of the average S-wave velocity of the soft sedimentary layer, derived from H/V spectral ratio analyses. Positions of the refraction lines are shown by red lines.

The map (Figure 12) is characterized by increase of velocity of the soft sediments from northern and central parts of study area to the west of the town where slope movement material is accumulated and to the south-east where thickness of sediments is increased. Zone of $V_s=900-1000\text{m/s}$ is the weathered basalt, on which surface site effect with low amplitude was also observed.
7. RECONSTRUCTION OF SUBSURFACE STRUCTURE

To develop model of the subsurface and to estimate layer thicknesses, where borehole data or other data are not available, we used the derived Vs model of study area and H/V spectral information. The analytical transfer functions are consistent with the observed H/V functions of each site. It has to be emphasized that in order to obtain accurate depth estimations (within 30% of the real depth known from borehole data), it is required that the grid of measured sites will be dense and uniform. A dense grid helps us to obtain models that are consistent with all other geological information. In this study we have built the geological structures along of two profiles A and B (location see in the Figure 7). The directions of profiles are chosen while taking into account the distribution of the resonance frequency together with the goal to demonstrate geological structural elements derived from H/V measurements.

7.1 Profile A

Profile A crosses the study area from the north-west to the south-east (see Figure 7) and is presented in Figure13. Comparison between H/V spectral ratios and calculated transfer function at selected sites are shown in Figure14. H/V Ratios along the profile are characterized by one peak of frequency, except the point 69, which showed two frequencies with low amplitudes. The wide range of the resonance frequency (0.75-15Hz) reflects the varying depth to the reflector. The corresponding H/V amplitudes reach a level of 8 at the west (central part of the town). We could differentiate four tectonic blocks of the cross-section by different intervals of frequency.

According to our modeling and geology data, in the western block of the profile (points 99 and 37), conglomerate of Miocene age is the main reflector with Vs=750-900m/s. In this part of the study area (also see Figures 5, 6) seismic impedance between conglomerates, which thickness are more than 400m (Sneh and Weinberger, 2003) and alluvium of some meters thickness created the site effect with high resonance frequencies (6-14 Hz) and corresponding amplitudes 2.5-4. Point 99 does not show the site effect, because is located on the outcrop of conglomerate.

Sharp change of the resonance frequency from 13Hz to 6Hz and change in the amplitudes suggest the existence of the fault between points 37 and 170 (Figure 14). This fault may be the branch of the Muftalah fault which is situated in the similar direction about 500m west.
Figure 13. Schematic geological cross-section A constructed on the base of ambient vibration data analysis.
Figure 14. H/V spectral ratio at site 99, which shows absence of site effect, and comparison of the average H/V spectral ratios (red lines) with the analytical transfer functions (black lines) for other sites along profile A.
Next part of the profile, from point 170 to 52 shows wide range of the H/V ratios with single peak of frequency (3-8 Hz) and high amplitudes from 5 to 8. Here the increase of amplitudes level also reflects the change of the main reflector from conglomerate to basalt (Vs=2000m/s). Our modeling shows that the low velocities of the first soft layer (Vs=300m/s) provide the rapid change of the resonance frequencies but not the sharp change of the reflector depth. For example, frequency changes from 3 Hz (point 95) to 7.2 Hz (point 52) on distance of 0.5 km only.

As we noted above, we observed spectral ratios on some of local zones of the basalt outcropping, where the young and weathered basalt with Vs=900-1000m/s lies on the old basalt lava (Vs=2000m/s). H/V functions show a single peak at 6-14 Hz with low amplitudes (2-2.5) (Figures 5, 6). Point 57 of profile A (Figure 13) is a characteristic example. It locates on the Giv’at Shehumit and our model suggested 31m of the weathered basalt layer with Vs=990m/s (see Figure 14).

The analysis of H/V spectra shows the faults between points 52-57 (Tel-Hay f.) and 68-69 (Shehumit f.). These faults were detected by the geological survey (Picard, 1952, Glikson, 1966, Kafri, 1991, Ron, 1997, Zilberman, 2000) and concluded in GEOLOGICAL MAP OF ISRAEL (METULLA) by Sneh and Weinberger in 2003. We also detected these faults in the north and south of the study area, where the faults are concealed (Figures 5, 6).

The H/V ratio with two peaks was observed at the point 69. The first resonance frequency (4 Hz) is related to old basalt (reflector). Low seismic impedance between weathered basalt (Vs=980m/s) and the upper layer of soil with Vs=450m/s creates the second peak- 9 Hz with low amplitude.

The part of the profile (points 176-86) corresponds to zone of the increase of sediment thicknesses. This zone is characterized by single H/V resonance peaks, changing from 2.7 Hz to 0.7 Hz with amplitudes level of 3.5-5. The structure of this zone presents a simple two-layer model, when the soft layer of alluvium which is of uniform composition overlays basalt. Our models are confirmed by geological data from Hula-1 well (Figure 11, 13, 14), which penetrates the basalt flows from the depth 170 m. Clay (Vs=350-400m/s) alternating with gravel (Vs=600m/sec) does not create additional seismic impedance, that could be responsible for the second peak of frequency. We have to note that we also used the data from depth section along reflection line GP-0170 (Frieslander and Medvedev, 2002) which is attached to Hula-1 and stretches in the west direction.
7.2 Profile B

Profile B located in the western part of the study area (Figure 7), where “a complex of slope movement material and three overlying lobes of rock and debris flow deposits were identified” (A. Sneh and R. Weinberger, 2003). Our interpretation was performed using modeling at all sites in the landslide zone. Cross-section along profile B is presented in the Figure 15. H/V spectral ratios and corresponding analytical transfer functions at selected sites along profile are shown in Figure 16. H/V ratios at sites are characterized by single resonance frequencies, which changed in the wide range (2.6Hz-10Hz).

The important structural features of this profile are faults, derived from H/V measurements and dividing the blocks with different reflectors and depth to the reflector.

Point 102 (Figures 15, 16) presents the southern and downdip block of the profile. Point 102 is located near the QS well, which was mentioned above (Figure 10). According to the borehole data, basalt is the main reflector in this block.

Next updip block is represented by point 181 (Figures 15, 16). H/V ratio has peak of frequency at 8Hz with relatively high amplitude (a factor 5). According to GEOLOGICAL MAP OF ISRAEL (METULLA) (A. Sneh and R. Weinberger, 2003), sandstone of Barremian age or basalt Plio-Pleistocene age could be the main reflector. S-wave velocity of sandstone, as a rule, significantly below (Vs=600-750m/s), than Vs of basalt, and comparable with velocity of debris material. Assuming the basalt with Vs=2000m/s as main reflector we obtained good agreement between observed H/V function and calculated transfer function. Our models are confirmed by the data of the top Hasbani basalt from reflection line GP-0170 (Frieslander and Medvedev, 2002), western end of which is located 200m away from the point 181.

We have detected faults bordering this block, by a sharp shift of resonance frequency. These faults are striking in the W-E direction (also see Figure 17) in accordance with W-E oriented faults mapped by A. Sneh and R. Weinberger (2003) to the west on the Cretaceous beds exposition (Figures 1, 7).

The part of the profile (points 17-4) is characterized by resonance frequencies at 2.5-3 Hz with relatively low amplitudes (see Figure 16). Limestone with Vs=1900m/s is the main reflector for this block, as it follows from the geological data. Calculated depths to the reflector are 65-70m.
Figure 15. Schematic geological cross-section B constructed on the base of ambient vibration data analysis.

Figure 16. Comparison of the average H/V spectral ratios (red lines) with the analytical transfer functions (black lines) for sites along profile B.
Points 6 -29 are located at the northern part of profile, corresponded to the Kiryat Shemona graben where basalt is the main reflector. The small exposure of basalt exists to the north of point 29 at the distance of 200m. In this block we observed increasing of amplitude H/V ratios (a factor 4-5), possibly due to the loose sediments (Vs= 350-400m/s) dominating in the slope movement materials along the foot of the Cretaceous beds exposition (Figure 15).

We have detected fault between points 4 and 6, by a sharp change of H/V ratio amplitudes. We have identified this fault as Kiryat Shemona fault, which is concealed in the landslide zone.

### 7.3 Estimating the thickness of soft sediments.

Figure 17 shows a contour map of the sediment thickness, as inferred from the analysis of ambient vibration measurements. The sediment thickness changes from 20m at the north to 200m at the south of study area. We have obtained the data that allow us to distinguish the areas that correspond to different reflectors: area marked by red color is the area where basalt is the main reflector, by green color- limestone, by yellow color-conglomerate. It should be noted that we have traced the northern border of the basalt flow distribution. This was performed using H/V ratios with amplitude levels of less than 3.5. The faults derived from analysis of ambient vibration measurement are also presented. We have detected the parts of known faults covered by alluvium and slope movement material (the Kiryat Shemona fault) within the area where the site response was obtained (Figure 17). As we see the vertical displacement along the Shehumit fault reached 40m at the south part of the study area.

### 8. SEISMIC HAZARD MICROZONATION

In our studies we applied the SEEH procedure, developed by Shapira and van Eck (1993) (SEEH- Stochastic Estimation of the Earthquake Hazard) to predict the site specific acceleration response spectra computed for 10% probability of exceedence during an exposure time of 50 years and for a damping ratio of 5%. The SEEH computations require information on several seismological parameters such as spatial distribution of seismogenic...
zones and their seismicity characteristics, stress drop, Q-values, seismic moment – local magnitude relationships, etc. Estimation of these parameters are based on seismological data (local and regional earthquake) provided by the local seismic networks.

Figure 17. The schematic map of the sediment thickness, inferred from H/V spectral ratio analyses also shows the faults in the Kiryat Shemona
The SEEH applies Monte Carlo simulation to simulate the seismicity in the different seismogenic zones surrounding the investigated area over several thousands of years and applies the stochastic method to synthesize ground motions for each of the simulated events. At the final stage of the simulations, the synthetic horizontal accelerations propagate to the surface of the site through the soil layers constituting the site’s sub-surface. The SEEH also incorporates the uncertainties associated with almost every parameter needed in the computations. The response function of the soil column of the site is calculated by using the program SHAKE.

By comparison of the Uniform Hazard Acceleration Spectra calculated for 90 selected sites in consideration of the constructed subsurface models across the study area we divided the area into 8 zones (Figures 18, 19). Each zone is characterized by a generalized seismic hazard function representative the site within that zone (Table 5), computed under the assumption that the sediments are not susceptible to non-linear effects (black line).

The field observations of recent earthquakes using surface and downhole vertical array of accelerometers indicated that nonlinear behavior of the soils have great seismic engineering implications. In this study we used program of Joyner (1977) to calculate the ground response in strong motion in various conditions of the stress-strain relation. The physical properties of soil layers such as thickness, density and S-velocity were taken from the linear models. Estimates of the dynamic shear strength for different soils were inferred from the work of Hartzel et al (2004). The seismic acceleration spectrums allowing for non-linear behavior of the soil are presented by blue lines (Table 5). As shown in Table 6, there are significant differences when assuming linear and nonlinear soil behavior in all zones. The uncertainty in the parameters we used for assessing the hazard while allowing nonlinear effects is high. Consequently, our hazard assessments under nonlinear behavior of soil are only of an illustrative character.

The design spectra required in the same area for ground conditions by the current Israel Building Code 413 (IS-413) are also presented in Table 5.

It should be noted that the shape of the hazard functions (linear and nonlinear) differ significantly from those prescribed by the IS-413 code in all zones. In the zone I hazard assessment under nonlinear behavior of soil and the design spectra are comparable. In the Kiryat Shemona area the Israel Building Code underestimates the expected accelerations in different period ranges.
Figure 18. Seismic microzonation map of the Kiryat Shemona.

Figure 19. Generalized 1D soil columns for each zone.
Table 5. Parameters of generalized 1D soil columns and acceleration spectrums.

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CONCLUSIONS

Site effect is very important in the evaluation of seismic hazard. Subsurface impedance contrast can significantly amplify the shaking level, as well as increased duration of strong ground motion. Site effect investigations were carried out at 300 sites in the Kiryat Shemona area by using the horizontal-to-vertical spectral ratio of ambient noise. The horizontal-to-horizontal spectral ratios of ambient noise recorded simultaneously at the investigated site and the reference site also were used.

The analysis performed showed the following:

- The most part of the measurement sites produced H/V spectral ratios with single resonance peak, which indicate of uniform lithological section with velocity characteristics of the sediments changing gradually. In the most part of the study area the fundamental frequencies are associated with the basalt of Plio-Pleistocene age which is the main reflector. At the north-west of study area the carbonate and conglomerate are the main reflectors creating the site response.
- We observed distribution of the resonance frequencies in the range 0.7-14Hz and their associated amplitude levels in the range 2-8. The frequency and its amplitude maps were constructed. The fundamental frequencies correlate in general with dipping of the basement (reflector).
- H/V and H/H spectral ratios of ambient noise showed the consistent results. However, since the source of ambient noise in urban areas varies significantly from place to place, the H/H ratio technique can only be applied within a limited area and within 200-400 m from a reference site.
- We have developed S-wave velocities model for lithological units represented in the Kiryat Shemona area using ambient noise measurements, surface geology and refraction survey data and borehole data. The distribution of the velocity of the soft upper layer throughout the study area was mapped.
- Dense grid of measurements enabled estimating the depth to the main reflector (within areas corresponding to different reflectors) and detected the northern border of basalt flow distribution. On the basis of analysis H/V ratios two schematic geological cross-section were constructed.
• We defined more accurately the known fault locations. Parts of the Kiryat Shemona, the Tel- Hay and the Shehumit faults covered by alluvium and slope movement material were defined. The main direction of faults is N-S, but we have traced some new faults striking at W-E and NW-SE directions.

• We had presented the seismic microzonation map of the Kiryat Shemona area providing a realistic assessment of the site specific seismic hazard. Generalized model is proposed for each zone. The characteristic acceleration response spectra were computed using SEEH procedure on the bases of the generalized subsurface models under assumption non-linear and linear behavior of the sediments. Whereas non-linear hazard assessments had only an illustrative character.

• In all zones the shapes of the hazard functions differ significantly from those prescribed by the IS-413 code.
ACKNOWLEDGMENT

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