EMPIRICAL DETERMINATION OF SITE EFFECTS FOR SEISMIC HAZARD ASSESSMENT IN KISHON GRABEN AREA NEAR THE CARMEL FAULT

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ABSTRACT

Ground motion amplifications due to soft soils, common in urban areas, are a major contributor to increasing damage and number of casualties. The great variability in the subsurface conditions across a town/city and the relatively high costs associated with obtaining the appropriate information about the subsurface, strongly limit proper hazard assessments. Direct information from strong motion recordings in urban areas is usually unavailable. This report summarizes the work done the over the last 10 years regarding the investigation of the site effects by H/V ratio from ambient noise and estimating the local seismic hazard in the Graben Kishon (western part of the Zevulun plain).

The possible site amplification effect, using ambient noise surveys, was estimated at 250 sites. The soil sites exhibit H/V amplitudes ranging from 2 to 8 on the frequency range 0.45 to 10 Hz. These data were used to constrain 1-D subsurface model developed using geological, geophysical data and borehole information. H/V spectral ratio observations were checked against theoretical subsurface transfer functions at locations where borehole information is available farther constraint the range of possible Vs velocities of the different layers and thus, by means of trial an error it was possible to conclude a systematic spatial distribution of the Vs velocity and thickness in the substrata that are also consistent with the spatial distribution of the fundamental resonance frequencies of the soft sediments obtained by means of the H/V spectral ratios, and other geological and geophysical information available at different locations in the study area.

The subsurface model serves as input for computing the expected Uniform Hazard Site-Specific Acceleration Spectra at the investigated sites. These evaluations are very important for realistic assessment of the vulnerability of all types of existing and newly designed structures and for urban and land use planning.

The ambient noise measurements allowed identifying, and estimating vertical displacement of faults, which are defined as a discontinuity in the subsurface model and associated with either a sharp change in the fundamental frequency and/or a change in the shape of the H/V ratio over a short distance. In our study we reconstruct the faults previously traced by geological data and reveal some new transversal faults. The modelling results are represented graphically in the geological cross sections and reflect our concept of subsurface structure that in the same case does not necessarily existing concept to the subsurface structure in the investigated region.
1. INTRODUCTION

Israel has a long documented history of destructive earthquakes (e.g. Amiran et al., 1994). This information, descriptive in its nature, is very useful for learning about the earthquake history of the region. However, questionable reliability of many historical "facts", the dramatic change in the demographic conditions, the changing engineering characteristics of the buildings and changes in geographical locations of towns and villages present great difficulties in using the macroseismic information to reliably assess the earthquake hazards.

Amplification of earthquake ground motion by near-surface geological conditions has been recognized as a major cause of damage in areas underlain on poorly consolidated sedimentary layers. The extraordinary damage to Mexico City due to the Michoacán earthquake (on Sept. 19, 1985, MS = 8.1) was as a result of site amplification unconsolidated deposits in a lake bed zone (Singh et al., 1988). Although the epicentre was over 350 km away, the resonance frequencies of sediment layers on which the buildings rests were nearly the same as the natural frequencies of buildings, and increased structural damage by double resonance. Damage from of destructive earthquakes during the last two decades, like the Spitak, Armenia, 1988 (Borcherdt et al., 1989), California, Loma Prieta, 1989 (Hough et al., 1990) and Northridge, 1994 (Hartzell et al., 1996), Kobe, Japan, 1995 (Iwata et al., 1996), Kocaeli (Izmit), Turkey, 1999 (Ozel et al., 2002), Algeria, 2003 (Hamadche et al., 2004) and many others, are clear reminders of the fact that soil dynamic parameters deserve more attention and consideration. This is particularly important for towns and engineering design located in Zevulun Plain because they are built on the sedimentary basin with strong impedance contrast between the soft sediments and underlying bedrock.

The Emek Zevulun area is characterized by major geological features including sub-parallel horsts and grabens dissected by faults; the absence of a common reflector for the whole area, and the presence of five lithological units, which may be considered as potential local reflector and overall sediments thicknesses varying from 10 m up to 600m. Over the past thirteen years, at the request of various private and public companies, over then fifteen sites in the Emek Zevulun have been investigated to determine the local site effects for the earthquake hazard assessment. We observed amplification factors of 3 to 6 at various frequencies of 0.5-5.0 Hz.
During 2004-2005, ambient noise measurements (Zaslavsky et al., 2006) were conducted at 480 locations in an area of about 50 km² (see Fig. 1), using the financial support of the Steering Committee for the National Earthquake Preparedness and Mitigation in the framework of microzoning study of the Haifa Bay and Qrayot. The result has shown two H/V peaks at frequencies related to resonances of deep and shallow structures. Spatial variations of the frequency 0.4-5 Hz for the first peak and 1-8 Hz for the second peak, and H/V amplitude level of 2-5 for the first peak and 2-10 for the second peak, reflecting the geological complexity that is presented in four distribution maps.

At the request of the Geological Survey of Israel from September to December 2006, we carried out a series of ambient noise measurements along three profiles: the first profile along the Hillazon graben in W-E direction; second extending from the Kishon graben to Hillazon graben in SSW-NNE direction and a third line along the Central Horst in W-E direction (see Fig 1). Total length of the lines is roughly 50 km. About 210 sites were instrumented for varying periods of time (Zaslavsky et al., 2007). Change of shape of the spectral ratios allows the differentiation of the reflectors, which change over the area. Frequencies of the first and second peaks in the H/V spectral ratios are used to define the thickness of sediments in the context to reconstruct multi-layer 1-D models. Sites, where sharp changes in the fundamental frequency and/or change in the shape of the H/V ratio over a short distance are observed, identified as fault. In some cases the faults defined as a result of geological interpretation of ambient noise measurements, do not coincide with existing geological representations. From September to November 2007, again at the initiative of the Geological Survey of Israel, we have conducted ambient noise measurements along four profiles (total length is 17.5 km, 76 sites of measurements) in the southern part of the Emek Zevulun (Zaslavsky et al., 2007b) for reconstruction of subsurface structure. The faults inferred from the H/V analysis significantly differ from those mapped previously by using surface geology information. It should be emphasized that measurements of ambient noise along profiles solely in the area, where detailed microzonation study was not previously performed, may hamper interpretation of results and affect their fidelity and stability. Microtremor survey with dense grid of measuring sites over the study area facilitates constructing the cross sections, tracing faults and developing isopach maps for different lithological units.

So, we started in 2004 a long term experiment to study the local site effects for the assessment of earthquake hazard to the Emek Zevulun. In this report we have concluded investigation of seismic hazard to the western part of the Emek Zevulun (Kishon Graben).
However we note that in industrial zones of urban area, it is not always possible to measure ambient noise for site effect estimation. The performed works consist of some phases:

1. Empirical evaluation of potential enhanced ground motion in soft sediments using dense grid recording of ambient noise. Reliable prediction of site amplification in the investigated area and producing maps of the distribution of the fundamental frequency and amplification.

2. Integrated analysis of microtremor measurement results and available geological, borehole to reconstruct the subsurface structure.

3. Identifying, and estimating vertical displacement of faults, which are defined as a discontinuity in the subsurface model and associated with: (1) a sharp shift in the fundamental frequency corresponding to a vertical displacement; (2) significant difference in all three characteristics of the H/V spectra, i.e. fundamental frequency, amplitude and shape corresponding to both vertical displacement and change in the velocity profile.

4. Use of the adequate analytical transfer functions and Stochastic Evaluation of Earthquake Hazard for prediction the site dependent Seismic Ground-Motion Hazard Maps in terms of ground motion parameters used for engineering purposes.

2. GEOLOGICAL BACKGROUND

Geological data used in the present study are collected from several sources. In particular, depth of the Top Judea Gr. is compiled from the structural maps of Mero (1983), Fleisher and Gafou (2003) and Bar Yossef et al. (2003). Borehole information and geological cross sections across the study area (Kafri and Ecker, 1964; Gvirtzman, 2006) are used to determine general subsurface conditions, local site stratigraphy and composition of the soils. The general geology is taken from the Geological Map of Israel. The geology of the shelf and continental margin offshore Haifa is largely described by Almagor and Hall (1980), Eytam et al. (1992), and Almagor (1993).

The area studied is located in the Zevulun Plain and occupies a structural block of the Kishon Graben. During 2004-2007 ambient noise measurements were performed in the different parts of the Zevulun Plain (Zaslavsky et. al., 2006, 2007a 2007b). The fragment of the geological map with study area and measuring sites locations is shown in Fig. 1.
Figure 1. Geological map and location of measuring sites.
The geological structure of the study area is rather complex. It explains considerable differences in definition of faults locations by Mero (1983) and Fleischer and Gafsou (2003) (see Fig. 2).

![Fault locations diagram](image)

**Figure 2. Scheme of fault locations according to different interpretations.**

The Kishon Graben came to existence in the Eocene. The deposition of Kishon Graben formations was governed by tectonic activity and sea level fluctuations causing transgressions and regressions. Two main phases of tectonic activity can be recognized in the Zevulun Plain.

An early Neogene phase of block faulting created the Kishon Graben. During the Miocene this graben was filled by calcareous sediments, by considerable thickness of conglomerates and by some evaporates. The Pliocene transgression was limited to the depression of the Kishon Graben, where a thick complex of clays and marls was deposited.

The second phase of tectonic activity was during the late Pliocene - Early Pleistocene...
resulting in a phase of uplift and faulting, accompanied by volcanic activity. As a result, the Kishon graben was deepened.

The main stratigraphic units of the sedimentary column in the study area are the Judea, Mt. Scopus, Avedat, Saqiye and Kurkar Groups (compiled from Kafri, 1964, and Mero, 1983).

The Judea Gr. of Cenomanian- Turonian age is represented mainly by the dolomites and limestones. Its depth of bedding in the investigated area varies from several meters near the Carmel Fault to 1500 meters at western central part of the Graben (Fleischer and Gafsou, 2003).

The Mt. Scopus Group is composed of Senonian to Paleocene formations, cropping out in area of cities Shefara’am and Qiryat Atta. The Group is composed of the Menuha, Ghareb, Mishash and Taqiye Formations. These formations are wholly exposed at the vicinity of Shefar'am and represented by chalk, marl sometimes bituminous, alternating with clay layers. The Avedat Group of Eocene age is composed of the Zor'a and Timrat Formations, which crop out in the southeastern part of the study area and cover all earlier formations. Zor'a Formation is subdivided into two members: Adulam and Maresha. The formation is represented by alternations of chalk and hard chalky limestone.

The Saqiye Group overlies the Mt. Scopus and Avedat Groups unconformably and is overlain by the Kurkar Group. The Saqiye Group is composed of the Bet Guvrin (Upper Eocene - Early Miocene), Lakhish (Oligocene - Early Miocene), Ziqlag and Mavkiim (Upper Miocene) and Yafo (Upper Miocene to Pliocene) Formations. Bet Guvrin and Lakhish Formations are represented by chalk and marl with intercalations of limestone layers. Ziqlag Formation is represented by bioclastic, reefal limestone with intercalations of marl and chalk. Lithology of Mavkiim Formation is massive layers of anhydrite. Yafo Formation is represented mainly by clays and marls of marine and continental origin.

The Kurkar Group consists of the Pliocene and Pleistocene age formations. Kurdane Formation of Upper Pliocene - Lower Pleistocene age is represented by sandy limestone to calcareous limestone, rich in fossils, shells and algae. Deposits of the Kurdane Formation are found only in the eastern part of the Kishon Graben and Central Horst. A number of marine transgressions of the Quaternary epoch produced a sequence of interbedded strata of dune sands and lagoonal clays in the subsiding graben structure. The general lateral variation of sediments in the Kishon Graben from NW to SE shows the following pattern:

- marine clays and silts in the western part of the graben;
• eastwards, marine and littoral calcareous sands as beach barriers and dune formations. These sand strata are commonly partly cemented and known as Kurkar;
• mainly lagoonal clays, silts and loams in the eastern part of the graben, developed behind the coastal dune formations.

From our experience and knowledge, accumulated from the former studies carried out in the Zevulun Plain in 2006 and 2007, we consider that the following lithostratigraphic units are potential reflectors owing to their geotechnical characteristics:
• Top Judea Gr. is identified as the deepest reflector;
• Top Mount Scopus Gr. or top Avedat Gr., which have close velocity characteristics, we presume as a shallow reflector in the eastern part of studied area;
• Top Mavkiim or Ziqlag Formation we consider as deep reflector in that part of graben, where Top Judea Gr. is so deep, that cannot serve as a reflector any more, and as a shallow reflector, while Top Judea Gr. is fundamental one;
• The impedance contract between sand/sandy loam and calcareous sandstone the Kurkar Gr. or/and clay of Yafo Fm. cause additional reflection that we have already fixed in our former investigations.

3. SPECTRAL RATIO TECHNIQUES FOR SITE EFFECT EVALUATION

The method for the assessment of site response function using ratio between the spectrum observed at a site of interest and the spectrum from the same source recorded at reference site was applied by Borcherdt (1970) and usually refers as the Standard Spectral Ratio (SSR). Many investigators (Satoh et al., 1995; Carver and Hartzell, 1996; Steidl et al. 1996; Reinoso and Ordaz, 1999; Zaslavsky et al., 2000; Lebrun et al., 2004 and others) use SSR to evaluate site response functions from moderate or weak motion recordings of earthquakes.

A common assumption in SSR is the comparison of ground motion at the site of interest with some "reference" site (usually a bedrock outcrop site). We should note that in many cases like a case of the weathered and cracked bedrock, signal recorded at reference site does using surface geology information not present the input motion of the base of the soil layers site, but has its own site response. In such a case, the use of these surface rocks as a reference sites often leads to underestimating of the amplification by a factor of 2-4 in frequency range which is within the range of engineering interest (Steidl et al., 1996;
Zaslavsky et al., 2002). Even with the borehole bedrock directly below the soil site, we have destructive interference between the up-going and down-going wave-fields which is a feedback altering the "true" input.

Kagami et al. (1982, 1986) proposed that microtremor generated by distant oceanic disturbances can be used as a measure of ground motion amplification by SSR method. In reality low frequency microtremor over relatively short distances should have similar source and path effects. The applicability of high frequency microtremor in site effect studies has been investigated by several studies (Field et al., 1990; Rovelli et al., 1991; Lermo and Chávez-García, 1993; Gaull et al., 1995; Zaslavsky et al., 1995; Ojeda and Escallon, 2000; Horike et al., 2001 and other). However, in urban and suburban areas, microtremor is generated by human activities and intensity of microtremor source may essential change from place to place. Therefore, this method can be used within limited areas only (the distance from reference station is some hundred meters).

Nakamura (1989) hypothesized that site response could be estimated from the spectral ratio of the horizontal versus vertical component of microtremor (HVSRN) observed at same site. The HVSRN technique is widely used for estimating site amplification factors of S wave due to an earthquake. Seekins et al. (1996) reported comparison of earthquake and microtremor using traditional station-par SSR method in order to clarify the applicability of microtremor data to ground motion prediction. They pointed out that microtremor station pair method may be used only for identifying the frequency of the fundamental resonance of soil site while Nakamura's method resulting are similar to those that derived from S-wave station-pair ratio. Zhao et al. (2000) also concluded that the H/V ratios of microtremor almost coincide with those of seismic motion. The experiment of Zhao et al. (2000) was based on simultaneous recording microtremor at basement and surface using borehole at several sites. From these results, H/V ratio coincides with the theoretical transfer function due to SH wave propagation in the surface soil layer better than the observed transfer function used simultaneous microtremor measurements between the basement and the surface. Mucciarelli and Gallipoli (2004) compared stability horizontal-to-vertical spectral ratios, composed of 674 triggered noise records and 132 earthquakes and showed that resonance peaks obtained with two different data sets are very similar as in frequency as amplitude.

Studies of Zaslavsky et al. (2005, 2008a,b) as well as many other investigators (Toshinawa et al., 1997; Chávez-García, and Cuenca, 1998; Mucciarelli et al., 2003)
showed that horizontal-to-vertical spectral ratio obtained from ambient noise can be used to obtain reliable information related to linear seismic behaviour of sedimentary layers.

4. AMBIENT NOISE RECORDINGS AND DATA PROCESSING

Ambient noise measurements were carried out from December 2007 to August 2008. The study areas are approximately 60 km2. The ambient noise was recorded at 250 sites (see Fig. 1). Ambient noise measurements are conducted using portable instruments (Shapira and Avirav, 1995) consisting of a multi channel amplifier, Global Positioning System (GPS) and a laptop with 16-bit analog-to-digital conversion card. 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. As a final test, all seismometers are placed at the same location and in the same orientation to record the same waves. It so happens that the differences between the seismic channels are marginal even without “correcting” for the instrumentation response. In fact, at frequencies below the natural frequency of the seismometers, correcting for the instrument response may increase variability and scattering. It is necessary to remind that all channels (horizontal and vertical) have practically the same frequency response function and amplifiers are set to the same gain level. Hence, spectral ratio may be calculated on the recorded signals. Moreover, it is possible to assess the predominant frequencies in the H/V spectra also at frequencies much lower than the natural frequency of the seismometer.

For each site we determine the average H/V spectral ratios and their corresponding standard deviations by applying the following process: Time windows each
of 30 sec long, sets of H and V ground motions that were Fourier transformed using cosine-tapering (1 sec at each end) before transformation. The spectra were then smoothed with a triangular moving Hanning window. More precisely, we applied “window closing” procedure (see Jenkins and Watts, 1968) for smart smoothing of spectral estimates so that any significant spectral peaks are not distorted. For each site we compiled a set of up to 50 selected time windows, each window providing an H/V spectral function.

The average spectral ratio for each of the 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:

\[
A(f) = \frac{1}{2n} \left[ \sum_{i=1}^{n} \frac{S_{NS}(f)_i}{S_V(f)_i} + \sum_{i=1}^{n} \frac{S_{EW}(f)_i}{S_V(f)_i} \right]
\]  

(1)

Where \(S_{NS}(f)_i\) and \(S_{EW}(f)_i\) are individual spectra of the horizontal components and \(S_V(f)_i\) is individual spectrum of the vertical component

Routine analysis and data processing are performed using the software SEISPECT developed in the Seismology Division of GII (Perelman and Zaslavsky, 2001). SEISPECT is a MATLAB application for spectral analysis and processing of ground motion, including seismograms recorded by short-period and broad-band seismic stations, as well as strong motion accelerometers. The main modules of the program are visualizing and editing of the input data; selecting time window and computing FFT and H/V spectral ratios; saving and displaying results.

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

The spatial distributions of the resonance frequency and its associated amplitude for two peaks characterizing H/V spectral ratios over the study area are presented in Figs. 3 and 4. Analysis of the results shows that the area mapped can be divided into two zones characterized by different subsurface structure. Division occurs along faults mapped by red color (see Fig. 3). A general correlation between the fundamental frequency and depth of the fundamental reflector, which is Top Judea Gr. for zone 1 and Top Mavqi’im and Ziqlag Fms. for zone 2, is reflected in the map of the spatial distribution of the first H/V resonance
frequency. Decrease of the fundamental frequency from 1.8 Hz to 0.45 Hz in NW and SW directions characterizes dipping of the Top Judea. Sharp shift in the frequency values from 0.45 Hz up to 0.7-1.4 Hz indicates sharp dipping of the Top Judea while Top Mavqi’im and Ziqlag Fms becomes a fundamental reflector. In a zone 2 decrease of the fundamental frequency from 1.4 Hz up to 0.5 Hz in the same directions proceeds. Close to Carmel fault frequency starts to increase and on distance, approximately, 200-500 m from a fault again occur sharp alteration of frequency that characterizes change of reflector.

In our study we reconstruct the faults previously traced by geological data and reveal some new transversal faults. Criteria of fault identification using ambient noise measurements may be formulated as follow: sharp changes in characteristics of the H/V spectral function, i.e. fundamental frequency, amplitude and/or shape of curve over the short distance are probably associated with vertical displacement and a change in the velocities. In the study area, we apply these criteria.

In Fig. 5 the faults detected by the H/V analysis are compared with those mapped by Mero (1983) and Fleischer and Gafsou (2003). We note that some directed NW-SE faults detected by microtremor analysis agreed with those studies. We could not trace faults up to coast in the northwest part of the area because the measurement sites are designed with a grid spacing of 500m. But in some cases the number of measurements is not enough. Moreover, we could not measure ambient noise for site effect estimation in industrial zones of urban area, and thus we could not locate accurately faults in a southwest part of the area.

In the vicinity of Shefar'am, direction of faults detected by microtremor analysis coincide with outcrops Menuha, Ghareb and Taqiye Formations. The microtremor analysis has allowed detecting faults having SW-NE directione. We suppose that the Nesher fault passes through Kishon graben. We trace a fault which passes parallel to the Carmel fault and was determined by Mero (1983) (Fig. 3).

Amplitude at the fundamental H/V peak reflecting impedance contrast between deposits and fundamental reflector varies from 2 to 2.5 in the first zone where a reflector is Top Judea Gr. and from 2 to 5 in the second zone where a reflector is Top Mavqi’im and Ziqlag Fms (Fig. 3). Spatial distribution of this parameter over the study area is influenced by lithological composition of sediments above the reflector and also reveals its depth.
Figure 3. Distribution of the first H/V resonance frequency and its associated amplitude

Fault detected using microtremor measurements
Line of reflector change
Figure 4. Distribution of the second H/V resonance frequency and its associated amplitude.
Amplitude of the fundamental frequency in the second zone is formed by the impedance contrast between soft sediments together with calcareous sandstone the Kurkar Gr. or clay, marl Yafo Formation with \( V_s = 650-850 \) m/sec and limestone Ziqlag Fm. with \( V_s = 1500 \) m/sec. Spatial distribution amplitude of the fundamental frequency in the second zone reflects the facial variation of soft sediments in the Kishon Graben from NW to SE.

The distribution of the second resonance frequency (Fig. 4) strongly depends on the thickness of soft sediments above a shallow reflector and varies from 1 Hz to 20 Hz. The analysis of microtremor measurement has shown that thickness soft sediments tends to increase according to dipping of a fundamental reflector. H/V spectral ratio obtained at the cropping of the Avedat Group deposits are characterized by the absence of the second
resonance frequency. H/V spectral ratio obtained at the sites, where soft sediments with $V_s=250-450$ m/sec overlies calcareous sandstone of the Kurkar Gr. or clay, marl of the Yafo Formation with $V_s=650-850$ m/sec and thickness of these layers are close does not show the second peak.

The amplitude of the second peak (Fig. 4) varies from 2 to 10. In the first zone the amplitude of the second peak is formed by the impedance contrast between soft sediments over chalk and chalky limestone of Avedat group or/and Limestone Ziqlag Fms. In the second zone this parameter reflects the impedance contrast between soft sediments and calcareous sandstone of the Kurkar Gr and/or clay, marl of the Yafo Formation.

6. SHEAR-WAVE VELOCITY PROFILE

The key parameters to evaluate site effects analytically by 1D model for vertical incidence of shear wave using SHAKE program (Schnabel et al., 1972) are the S-wave velocity of the unconsolidated sediments, thickness of each layers, density and specific attenuation in different lithological units as well as S-wave and density of the reflector. Densities and specific attenuation in different lithological units are chosen on the base of literature sources (Borcherdt et al., 1989; McGarr et al., 1991; Theodulidis et al., 1996; Reinozo and Ondas, 1999; Pergalani et al., 2000; and many others). Recently, Pratt and Brocher (2006) used spectral decay in the shear-wave spectral ratio with respect to reference site amplification curves and estimated Q-values for shallow sedimentary deposits. They concluded that range of Q values is 10-40. This is the range which was used in this study.

In previous microzonation studies in Zevalun plain (Zaslavsky et al., 2006, 2007a,b) limited data on sediment thickness and S-velocities available from a few refraction profiles and boreholes are used to constrain possible S-wave velocity structure via comparison with analytical transfer function. Table 1 summarizes the mechanical properties for the subsoil layers in investigated area.
Table 1. Mechanical properties of the materials used in the 1D model.

<table>
<thead>
<tr>
<th>Lithological unit</th>
<th>$V_s$ m/sec</th>
<th>Density g/cm$^3$</th>
<th>Damping %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Silt) Holocene</td>
<td>160-180</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>(Sand and sandy loam) Kurkar Gr., Pleistocene</td>
<td>250-400</td>
<td>1.6-1.7</td>
<td>3</td>
</tr>
<tr>
<td>(Gravels) Kurkar Gr., Pleistocene</td>
<td>400-500</td>
<td>1.7</td>
<td>3</td>
</tr>
<tr>
<td>Calcareous sandstone (Kurkar Gr., Pleistocene) (and clay) Pliocene</td>
<td>600-650</td>
<td>1.8-1.9</td>
<td>2</td>
</tr>
<tr>
<td>Sandy Limestone (Kurdani Fm., Pliocene-Pleistocene)</td>
<td>750-850</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>(Chalk) Avedat Gr., Lower-Middle Eocene</td>
<td>950-1050</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Marl-chalk (Mount Scopus Gr., Senonian-Paleocene)</td>
<td>850-950</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Limestone and dolomite (Judea Gr., Cenomanian-Turonian)</td>
<td>1900</td>
<td>2.2</td>
<td></td>
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</tbody>
</table>

7. RECONSTRUCTION OF SUBSURFACE STRUCTURE AND IDENTIFICATION OF FAULTS

Using the data of the observed resonance frequencies, their associated amplitude across the investigated area and the shear wave velocity values presented in Table 1, we can construct a subsurface multilayer model and estimate the thickness of the sediments at most of the measurement sites where borehole information is not available. The constructed subsurface models are based on available geological and geophysical data and these are constrained by the empirical H/V information. When we consider both the first and second resonance frequencies, the layer thickness may be estimated quite accurately, using the second resonance peak as additional limiter in selecting a plausible value.

The positions of the presented profiles are indicated in Fig. 6. In all presented cross sections we show for comparison the depth of Top Judea Gr. according to the structural maps of Fleischer and Gafsou (2003).

7.1. Profile 1

As indicated in Fig. 6, profile 1 of 12.0 km long passes in SW-NE direction. Cross section along profile 1 reconstructed on the base of H/V spectral ratio analysis is
shown in Fig. 7. The analytical transfer functions for representative points of profile 1 are shown in Fig. 8 superimposed on the spectral ratios obtained at these points.

Figure 6. Map showing positions of the profiles chosen to illustrate the application of H/V method for reconstructing subsurface structure.

Result of the integrated analysis of microtremor measurement and available geological information has shown that along profile 1 limestone and the dolomite of the Judea Gr. is a fundamental reflector. Majority of H/V spectral ratios shows two resonance peaks. The first, fundamental one is associated with the Judea Gr. The second resonance peak is associated with thickness of the soft sediments over chalk and chalky limestone of Avedat groups. For sites located at outcrop of the Avedat groups the second resonance peak disappears and we observe the fundamental peak only (Fig. 8 points 362, KL1, ZV90, ZV357, ZV354, ZV352). The amplitude of the second peak is formed by the impedance contrast between soft sediments over chalk and chalky limestone of Avedat group together with limestone and the dolomite of the Judea Gr. The amplitude of the second peak depends on the soft sediment S-velocities features (see Table 1).
Figure 7. Schematic cross section along profile 1. For position see Fig.6
Amplitude of the fundamental frequency is formed by the impedance contrast between chalk and chalky limestone of Avedat group with Vs=1050 m/sec and the limestone of the Judea Gr. with Vs=1900 m/sec. Amplitude of the fundamental frequency is also influenced by thickness and density (S-velocities features) of the soft sediments.

In the segment of profile 1 between points ZV238 and ZV225, which is located in the north-east part of profile, the sediments of the Mt. Scopus group are cropping out. The points at this segment show higher amplitude of the fundamental frequency in comparison with sites located at outcrop of the Avedat group. Amplitude of the fundamental frequency at this segment is formed by the impedance contrast between marl, chalk of Mt. Scopus group with Vs=800-850 m/sec and the limestone of the Judea Gr. with Vs=1900 m/sec. H/V spectral ratio at points ZV238, ZV156 and ZV225 show two resonance peaks. The second resonance peak is correlated with marl of the Taqiya Fm. (Vs=500-600 m/sec). The points ZV343 and ZV350 are located on outcropping Ahihud Member (Menuha Fm.). H/V spectral ratio at this points show two resonance peaks. Amplitude of the fundamental frequency is formed by the impedance contrast between rocks with Vs=1200 m/sec and the limestone of the Judea Gr. with Vs=1900 m/sec (Frieslander and Ezersky, 2002). The second resonance peak is correlated with marl and chalk of the Ahihud Member with Vs=650-690 m/sec (Frieslander and Ezersky, 2002).

The sharp shift in the fundamental frequency between some neighboring points along profile 1 is observed (Fig. 7 and 8). This corresponds to a vertical displacement of more than 70 m. In the segment of profile 1 between points ZV155 and ZV225 the fundamental frequency practically does not change. Nevertheless subsurface model suggests increasing reflector depth up to 70m at points ZV343 and ZV350 due to variation in Vs of the upper layers.

In the segment of the profile between points KL34 and KL31 the gradual decrease of fundamental frequency from 1.0 Hz to 0.85 Hz is observed. Top Judea depth changes from 153 m (KL38) to 210 m (KL37) and to 250 m (KL36). Shift in the reflector depth by 50 and 40 m respectively can indicate presence of faults or gradual dip of the Top Judea.
7.2. Profile 2

As indicated in Fig. 6, profile 2 of 11.0 km long passes parallel to profile 1 in the SW-NE direction. Cross section along profile 2, reconstructed on the base of H/V spectral
ratio analysis, is shown in Fig. 9. The analytical transfer functions for representative points of profile 2 are shown in Fig. 11 superimposed on the spectral ratios obtained at these points.

At point ZV35, the depth of the reflector, which is associated with the Judea Gr., is 190 m. Amplitude of the fundamental frequency is formed by the impedance contrast between chalk and chalky limestone of Avedat group with Vs=1050 m/sec and the limestone of the Judea Gr. with Vs=1900 m/sec. The second resonance peak associated with thickness of the soft sediments over chalk and chalky limestone of Avedat groups.

In the segment of profile 2 between points ZV349 and ZV122 (Fig. 11) we observe sharp increase in the amplitude values and also changes in the shape of both spectrum and H/V spectral ratio in comparison with point ZV35. Taking S-wave velocities from Table 1 and the data of Shefa Yamim 3 well shown in Figure 10, we obtain a good fit between the analytical transfer function and H/V spectral ratio at point KL55. H/V spectral ratios at other points of the segment practically do not differ from H/V spectral ratio at point KL55. Thus the soil-column model of point KL55 is valid for every point in this segment of the profile. Depth of the reflector associated with the Top Ziqlag Formation varies in the range 90-130 m. Amplitude of the fundamental frequency is formed by the impedance contrast between soft sediments together with calcareous sandstone of the Kurkar Gr or clay, marl Yafo Formation with Vs=650 m/sec over limestone of the Ziqlag Fm. with Vs=1500 m/sec. We consider that between points ZV35 and ZV349 the Top Judea is too deep, therefore Top Ziqlag Fm. becomes the fundamental reflector.

At point ZV93 again there are changes in the shape of a spectrum and H/V spectral ratio. The fundamental frequency and amplitude decrease to 0.45 Hz. and 2 accordingly. H/V spectral ratios show two resonance peaks. The first fundamental one is associated with the Judea Gr. Thus depth of the Top Judea decreases and again it becomes a fundamental reflector. Increase in the reflector depth accompanied by a fault. The impedance contrast between chalk and chalky limestone of Avedat group with Vs=1050 m/sec together with limestone of the Ziqlag Fm. with Vs=1500 m/sec and the limestone of the Judea Gr. with Vs=1900 m/sec explains low values amplitude of the fundamental frequency. The amplitude of the second peak is formed by the impedance contrast between soft sediments over limestone of the Ziqlag Fms.

The sharp change in the fundamental frequency between points ZV123, ZV144, ZV141, and ZV89, ZV40, ZV355 and ZV102, ZV53 and ZV133 corresponding to a vertical displacement of more than 70 m.
Figure 9. Schematic cross section along profile 2. For position see Fig.6

To Judea Gr. from Fleischer and Gafsiou.

Limestone, dolomite (Judea Gr.); Vs=1900 m/sec
Limestone (Mavqi'im and Ziqlag Fms., Miocene); Vs=1500 m/sec
Chalk-marl (Senonian -Eocene); Vs=850-1050 m/sec
Soft sediments; Vs=300-500 m/sec
Calcareous sandstone of the Kurkar Gr or clay, marl Yafo Fm with Vs=650 m/sec

Profile 5
Profile 6
Figure 10. (a) - Lithological section of Shefa Yamim-3 well and (b) - comparison between average H/V spectral ratio (red line) obtained at point KL55 and analytical transfer function for Shefa Yamim-3 well (black line).

Figure 11. H/V spectral ratios (red line) and analytical transfer function (black dashed line) for representative points located along profile 2.
Point ZV102, which is located on outcropping Mt. Scopus group, shows higher amplitude of the fundamental frequency in comparison with adjacent points on the profile. Amplitude of the fundamental frequency at this point is formed by the impedance contrast between marl, chalk of the Mt. Scopus group with Vs=800-850 m/sec and the limestone of the Judea Gr. with Vs=1900 m/sec.

7.3 Profile 3

The cross section along profile 3 of 8.0 km long, crossing parallel profiles 1 and 2 in SW-NE direction, is shown in Fig. 12. In the southwestern edge of the profile at point NS21 located on the outcrop of the Judea Gr. site effect is not observed. H/V spectral ratios at points NS24, NS19-1 and NS26 show two resonance peaks. Results of the integrated analysis of microtremor measurement and shallow seismic reflection and refraction (Frieslander and Ezersky, 2003) have shown that in the segment of profile 3 between points NS24 and NS26 limestone and dolomite of the Judea Gr. is the fundamental reflector. The change in the fundamental frequency from 1.1 Hz to 1 Hz between points NS24 and NS26 (Fig. 13) corresponds to the increase in the reflector depth from 220 m to 250 m. The amplitude of the second peak is formed by the impedance contrast between consolidated alluviums (Tel-Hanan-5 Well) with Vs=650 m/sec and the chalk and chalky limestone of Avdat group with Vs=980 m/sec together with limestone of the Judea Gr. with Vs=1750 m/sec.

H/V spectral ratios at points NS27 and ZV196 show one resonance peak at frequency 2 Hz (Fig. 13). In agreement with the seismic reflection survey data (Frieslander and Ezersky, 2003) we consider that between points NS26 and NS27 Top Judea is sharply dipping and shallow reflector, which is related to the limestone of the Ziqlag Formation becomes a fundamental. Amplitude of the fundamental frequency is formed by the impedance contrast between consolidated alluvium or calcareous sandstone of the Kurkar Gr with Vs=650 m/sec over limestone of the Ziqlag Formation with Vs=1500 m/sec.
Figure 12. Schematic cross section along profile 3. For position see Fig.6
At point ZV181 (Fig. 14) the fundamental frequency decreases to 1.25 Hz that corresponds to the dipping of Top Ziqlag Fm. to 115 m. Sharp change in the fundamental frequency between points ZV196 and ZV181 suggests the existence of a fault. The increase of amplitude at point ZV181 shows that the soft sediments with \( V_s = 250-350 \) m/sec overlay the Calcareous sandstone of the Kurkar Gr. or clay, marl Yafo Formation with \( V_s = 650 \) m/sec.

The sharp change in the fundamental frequency between points ZV181 and ZV183 corresponds to a vertical displacement. The second resonance peak appears at points ZV183, ZV176 and 689. It is associated with thickness of the soft sediments over the Calcareous sandstone of the Kurkar Gr. or clay, marl Yafo Formation with \( V_s = 650 \) m/sec.

In the segment of profile 3 between points DS4 and KZ1 the fundamental frequency practically does not change comparatively with point 689, but second frequencies decrease to 1.25 Hz and change shape of the spectrum and H/V spectral ratio. By calculations of the theoretical transfer function and comparison with the experimental spectral ratio we get soil column model where the deposits with \( V_s = 650 \) m/sec are overlies the deposits with \( V_s = 850 \) m/sec. Besides that H/V spectral ratios along the segment show third resonance peak at frequency 3-4 Hz which we relate to thickness (H=5-10 m) of the soft sediments with \( V_s = 150-200 \) m/sec.

Sharp increase in the both the fundamental and second frequencies from 0.7 Hz to 1.0 Hz and from 1.25 Hz to 1.5 Hz occurs between points KZ1 and ZV186 This corresponds to the decrease in the reflector depth from 315 m to 190 m respectively, which is accompanied by a fault.

At point ZV66 there is a change in the shape of a spectrum and H/V spectral ratio. The fundamental frequency and amplitude decreases till 0.45 Hz. and 2 accordingly. H/V spectral ratios show more than three resonance peaks. The first, fundamental one is
associated with the Judea Gr. Thus depth of the Top Judea decreases and again it becomes
the fundamental reflector. The decrease in the reflector depth is accompanied by a fault.
The impedance contrast between chalk and chalky limestone of Avdat group with \(V_s=1050\)
m/sec together with limestone of the Ziqlag Formation with \(V_s=1500\) m/sec and the
limestone of the Judea Gr. with \(V_s=1900\) m/sec, explains low values amplitude of the
fundamental frequency. Different seismic impedances between soft sediments with
\(V_s=150-200\) m/sec, soft sediments with \(V_s=250-350\) m/sec, deposits with \(V_s=650\) m/sec
and limestone of the Ziqlag Formation with \(V_s=1500\) m/sec create a complicated system of
resonance peaks.

The sharp change in the fundamental frequency between points 289 and ZV86,
420, 421 and 422, 401 and 402 is corresponding to a vertical displacement.

7.4 Profile 4

As indicated in Fig. 6, profile 4 of 7.5 km long passes parallel to the above
described profiles in SW-NE direction. Cross section along profile 4, reconstructed on the
base of H/V spectral ratio analysis, is shown in Fig. 15. The analytical transfer functions
for representative points of profile 4 are shown in Fig. 16 superimposed on the spectral
ratios obtained at these points.
Figure 15. Schematic cross section along profile 4. For position see Fig.6

- Soft sediments $V_s=300-500$ m/sec
- Limestone, dolomite (Judea Gr.); $V_s=1900$ m/sec
- Chalk-marl (Senonian -Eocene); $V_s=850-1050$ m/sec
- Limestone (Mavqi'im and Ziqlag Fms., Miocene); $V_s=1500$ m/sec
- Calcium sandstone of the Kurkar Gr or clay, marl Yafo Fm; $V_s=650$ m/sec
- Top Judea Gr. from Fleischer and Gafsou (2003)
In the southwestern edge of the profile at points 738 and 739 site effect is not observed. H/V spectral ratios at point 736 show two resonance peaks. The first, fundamental one is associated with the Judea Gr. The amplitude of the second peak is formed by the impedance contrast between consolidated alluviums with Vs=650 m/sec and the chalk and chalky limestone of Avedat group with Vs=1050 m/sec together with limestone of the Judea Gr. with Vs=1750 m/sec.

In the segment of profile 4 between points 737 and 749 (Fig. 16) we observe sharp increase in the amplitude values and also changes in the shape of both spectra and H/V spectral ratio in comparison with point 736. We presume that between points 736 and 737 there is a sharp dipping of the Top Judea and Top Ziqlag becomes a fundamental reflector.

A gradual decrease of the fundamental frequency from 0.63 Hz to 0.54 Hz is observed. Top Ziqlag depth changes from 250 m (737) to 280 m (777) and to 310 m (749).

![Graph](image-url)

**Figure 16.** H/V spectral ratios (red line) and analytical transfer function (black dashed line) for representative points located along profile 4.

A shift in the reflector depth by 30 m can indicate presence of faults or gradual dip of the Top Ziqlag. At points 751 and 752 the fundamental frequency decreases to 0.47 Hz that corresponds to the increase in the reflector depth to 350 m, which is probably accompanied by fault.

In the segment of profile 4 between points 753 and BZN6 we observe changes in the shape of both spectra and H/V spectral ratio. Though the depth of the reflector does not change, we suppose a fault between points 752 and 753.
The sharp change in the fundamental frequency from 0.7 Hz to 0.85 Hz between points BZN20 and GAZ1 corresponds to the vertical displacement of the Top Ziqlag of 50 m.

In the segment of profile 4 between points ZV213 and 475 both the fundamental and second frequencies increase and the shape of H/V spectral ratio changes too. This corresponds to the decrease in the reflector depth from 265 m to 205 m between points ZV169 and ZV213, which is probably accompanied by a fault.

At point 454 there is a change in the shape of a spectrum and H/V spectral ratio. The fundamental frequency and amplitude decreases to 0.75 Hz. and 2.7 accordingly. H/V spectral ratios show more then three resonance peaks. The first, fundamental one is associated with the Judea Gr. Thus depth of the Top Judea decreases and again it becomes the fundamental reflector. Decrease in the reflector depth accompanied by a fault. Different seismic impedances between soft sediments with Vs=250-350 m/sec, deposits with Vs=650 m/sec and sandy limestone of the Kurdane Formation with Vs=1200 m/sec create complicated resonance peaks.

7.5. Profile 5
As indicated in Fig. 6, profile 5 of 9.2 km long passes in the SE-NW direction. Cross section along profile 5 reconstructed on the base of H/V spectral ratio analysis is shown in Fig. 17. The analytical transfer functions for representative points of profile 1 are shown in Fig. 18 superimposed on the spectral ratios obtained at these points.

Result of the integrated analysis of microtremor measurement and available geological information has shown that in southeast part of the profile, between points ZV348 and KL73, limestone and the dolomite of the Judea Gr. are the fundamental reflector.

The sharp change in the fundamental frequency from 1.0 Hz to 0.75 Hz between points 658 and ZV190 corresponds to vertical displacement of the Top Judea of 100 m.

In the segment of profile 5 between points KL57 and 655 we observe sharp increase in the fundamental frequency, amplitude values and also change in the shapes of both spectra and H/V spectral ratio. We consider that between points KL73 and KL57 there is a sharp dipping of the Top Judea and Top Ziqlag Fm. becomes the fundamental reflector.
Figure 17. Schematic cross section along profile 5. For position see Fig.6
Amplitude of the fundamental frequency is formed by the impedance contrast between soft sediments together with calcareous sandstone of Kurkar Gr or clay, marl Yafo Formation with Vs=650 m/sec over limestone of Ziqlag Formation with Vs=1500 m/sec.

Sharp decrease in the fundamental frequency from 1.20 Hz to 0.95 Hz occurs between points 655 and ZV31. This corresponds to the increase in the reflector depth from 120 m to 160 m, which is probably accompanied by a fault.

At point 656 the fundamental frequency practically does not change in comparison with point ZV31, while shape of the H/V spectral ratio is different. The best fit between the analytical transfer function and H/V ratio has allowed to obtain the following a soil column model where soft sediments with Vs=350 m/sec overlay the deposits with Vs=850 m/sec and reflector depth is 240m. The increase in the reflector depth from 160 m at point ZV31 to 240 m at point 656 corresponds to the vertical displacement of the Top Ziqlag Fm. that agrees well with the data of Shefa Yamim 7 and Shefa Yamim 8 wells.

Sharp decrease in the fundamental frequency from 0.95 Hz to 0.6 Hz occurs between points 656 and ZY6. This corresponds to the increase in the reflector depth from 255 m to 385 m, which is accompanied by a fault.

In the segment of profile 5 between points KL67 and B5 shape of H/V spectral ratio changes in comparison with previous points of the profile. By calculation of the theoretical transfer function and comparing it with the experimental spectral ratio we have obtained a soil column model which includes soft sediments with Vs=450 m/sec, deposits with Vs=650 m/sec and Vs=850 m/sec are over limestone of the Ziqlag Formation with Vs=1500 m/sec.

The sharp increase of fundamental frequency up to 2 at points of the profile NS35, NS27 and NS14 indicates an uplifted block.

At points T29, T12 and T16 the shape of the spectrum and H/V spectral ratio changes in comparison with previous points of the profile (Fig.18) and correspondingly we derive different soil column models (Fig.17). We suppose a fault between point 371 and point T29 despite of the computed depth of a reflector practically does not change.
Figure 18. H/V spectral ratios (red line) and analytical transfer function (black dashed line) for representative points located along profile 5.

7.6. Profile 6

As indicated in Fig. 6, profile 6 of 10.0 km long passes in the SE-NW direction. Cross section along profile 6, reconstructed on the base of H/V spectral ratio analysis, is shown in Fig. 19. The analytical transfer functions for representative points of profile 6 are shown in Fig. 20 superimposed on the spectral ratios obtained at these points.

Results of the integrated analysis of microtremor measurement and available geological information have shown that in the southeast part of the profile, between points ZV106 and ZV185, limestone and the dolomite of the Judea Gr. are the fundamental reflector.

The sharp change in the fundamental frequency between points ZV85 and ZV84 and between points ZV126 and 662, correspond to a vertical displacement of the Top Judea about 100 m.

In the segment of profile 6 between points ZV186 and 334 we observe changes in the shape of both spectra and H/V spectral ratio. We consider, that between points...
Figure 19. Schematic cross section along profile 6. For position see Fig.6
ZV185 and ZV186 there is a sharp dipping of the Top Judea and Top Ziqlag becomes a fundamental reflector.

Figure 20. H/V spectral ratios (red line) and analytical transfer function (black dashed line) for representative points located along profile 6.

8. SEISMIC HAZARD ASSESSMENT

We use H/V measurements together with available geological and geophysical information to construct a subsurface model for the investigated region. This model, in turn, may be used for estimating the expected site effects due to earthquakes. In the engineering practice, the aseismic building design and assessments of the earthquake risk refer to the site-specific acceleration (or displacement) spectrum. The design acceleration spectrum is essentially a representation of the maximum acceleration amplitudes for a prescribed probability of occurrence developed for a set oscillators with one degree of freedom for a given damping ratio. Since seismic activity is low in areas like Israel, local acceleration data from strong earthquakes is insufficient to estimate directly the design acceleration spectrum; therefore, in areas covered by soft sediments, we must resort to the
use of synthetic data. For this purpose Shapira and van Eck (1993) developed the SEEH method (Stochastic Estimation of the Earthquake Hazard). In brief; SEEH produces a number of synthetic earthquake catalogues that represent the possible future seismic activity within 200 km of the investigated site. These catalogues adhere to the available information about the seismogenic zones in the area and their associated seismicity. The Monte Carlo statistics are used to generate different catalogues which reflect the uncertainty associated with the spatial and temporal parameters of the seismicity. For each earthquakes in a catalogue, SEEH implements the stochastic simulation method (see Boore, 2000) to generate synthetic S waves accelerogram for the surface of the bedrock which then propagates through the soil column of the site (using Shnabel, 1972; or Joyner, 1977) to the surface. The synthetic free surface accelerogram is used to calculate the acceleration response spectrum for a predefined damping. Here again, the Monte Carlo statistics are used to select the values of the parameters used in the ground motion simulations. For example; we assume a unified distribution for locating the hypocenter within a defined seismogenic zone and within a 5-20 km depth, and the estimated seismic moment of the event (and thus the energy at the source) are log-normally distributed around the expected value with an uncertainty factor of 3 and so forth. The parameters used are based on studies done in the area and reflect our current knowledge (and uncertainty) about the seismic activity and the main parameters that control the spectra of expected ground motions at a given site. The ensemble of these hundreds (sometimes thousands) of synthetic acceleration response spectra are statistically analyzed in order to assess the spectral amplitude level to be exceeded at least once in a certain exposure time (usually 50 years) and a certain probability (usually 10%).

Based on the comparative analysis of the acceleration spectra computed, the study area is divided into 20 zones (Fig. 21). Soil-column models and acceleration spectra generalized for each zone are given in Table 2 and Fig. 22. For comparison, the designs spectra, required in the same area by the current Israel Standard 413 (IS-413), are plotted and for ground conditions that meet the BSBC (1997) soil classification scheme. The shape of the hazard functions differ significantly from those prescribed by IS-413 code in Zones 6, 7, 8, 10, 11, 12, 18, 19 where the IS-413 code underestimate the acceleration in the period range from 0.3 to 0.5 sec. For the rest of the zones both curves practically coincide.
Figure 21. Map of seismic zonation in the study area.

Table 2. Soil column models for representative sites of zones.

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<th>Damping %</th>
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|   | 40  | 1.9| 650  | 2 |
| 9  | 60  | 2.1| 1500 | 1 |
| Half space | 2.3 | 1900 |

|   | 7  | 1.5| 160  | 4 |
|   | 50  | 1.7| 350  | 3 |
| 10 | 20  | 1.9| 650  | 2 |
| Half space | 2.1 | 1500 |

|   | 15  | 1.5| 200  | 3 |
|   | 65  | 1.7| 350  | 3 |
| 11 | 20  | 1.9| 650  | 2 |
| Half space | 2.1 | 1500 |

|   | 75  | 1.6| 260  | 3 |
|   | 100 | 1.9| 650  | 2 |
| 12 | 100 | 2  | 850  | 2 |
| Half space | 2.1 | 1500 |

|   | 230 | 1.9| 650  | 2 |
| Half space | 2.1 | 1500 |

|   | 15  | 1.5| 200  | 3 |
|   | 115 | 1.7| 350  | 3 |
| 14 | 90  | 1.9| 650  | 2 |

| Half space | 2.1 | 1500 |

|   | 10  | 1.5| 160  | 4 |
|   | 95  | 1.7| 280  | 3 |
| 15 | 100 | 1.8| 650  | 2 |
| Half space | 2.1 | 1500 |

|   | 25  | 1.7| 400  | 3 |
|   | 30  | 1.9| 650  | 2 |
| Half space | 2.1 | 1500 |

|   | 6  | 1.5| 200  | 4 |
|   | 20  | 1.7| 350  | 3 |
| 17 | 220 | 1.8| 650  | 2 |
| Half space | 2.1 | 1500 |

|   | 35  | 1.6| 250  | 3 |
|   | 65  | 1.9| 650  | 2 |
| 18 | Half space | 2.1 | 1500 |

|   | 12  | 1.5| 100  | 4 |
|   | 20  | 1.6| 270  | 3 |
| 19 | 85  | 1.9| 650  | 2 |
| Half space | 2.1 | 1500 |
Figure 22. Spectral accelerations for each zone. Spectrum according to the Israel Building Code (PGA of 0.093) is indicated by the dashed line (included for reference).

9. CONCLUSIONS

Ground motion amplifications due to soft soils, common in urban areas, are a major contributor to increasing damage and number of casualties. The great variability in the subsurface conditions across a town/city and the relatively high costs associated with obtaining the appropriate information about the subsurface, may significantly limit proper hazard assessments. Direct information from strong motion recordings in urban areas is usually unavailable. This report summarizes the work done over the last 10 years regarding the investigation of site effects using H/V ratio from ambient noise and estimating the local
seismic hazard in the Graben Kishon (western part of the Zevulun plain). In this study, we use noise recording conducted at 250 locations together with results obtained in measurements carried out previously.

Our conclusions may be summarized as follows:

- The application of the Nakamura's method, using ambient noise measurements, seems to be very useful to study the regions with low natural seismicity. The fundamental frequencies and their associated H/V levels are in good correlation with the surface geology, and they are sensitive to the change of thickness in the soft deposits.

- The structure and properties of the underlying soils inferred only from geological and geophysical information may still lead to wrong assessments of site response, especially when based on 1D model. Reliable modeling to be used in site response analysis is obtained by combining different empirical approaches, supplemented with geophysical and geological data.

- The ambient noise measurements enable identifying discontinuities in the subsurface and locate faults. These are associated with significant change in all three characteristics of the H/V spectra, i.e. fundamental frequency, amplitude and shape corresponding to both vertical displacement and change in the velocity profile. In our cases the faults defined as results of geological interpretation of ambient noise measurements, do not coincide with existing geological representation.

- The analysis of different kinds of geological, geophysical and seismic information, improved the knowledge of the structure of the Graben Kishon. This knowledge allowed the computation of theoretical seismic response of the Graben, which is very important for the estimation of the surface movement in the occurrence of a large event.

- Map of zones presented in the report in terms of the Uniform Hazard Site-specific Acceleration Spectra for a probability of exceedence of 10% during an exposure time of 50 years and a damping ratio of 5%, computed using SEEH procedure by applying the evaluated subsurface models may be useful for land use planning or making regional hazard decisions.
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