

MICROZONING OF THE EARTHQUAKE HAZARD
IN ISRAEL

PROJECT 7

**EMPIRICAL DETERMINATION OF SITE EFFECTS FOR THE
ASSESSMENT OF EARTHQUAKE HAZARD AND RISK TO
THE SOUTHERN SHARON
AND LOD VALLEY AREAS**

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ABSTRACT

Israel is a small country and its population centers are in close proximity to the seismically active Dead Sea Fault system, which is capable of generating earthquakes with magnitude as high as 7.5. Consequently, more than 90% of the population is vulnerable to earthquakes. Local variations of soil conditions did and will increase ground motion generated by earthquake and will increase the damage. Seismic microzonation and subsurface modelling are thus important in realizing the earthquake hazard across the populated areas.

The Seismology Division, Geophysical Institute of Israel, took the lead in site specific seismic hazard assessments in Israel. In 2001, thanks to a financial support of the Ministry for Absorption and the Earth Sciences Research Administration of the Ministry for National Infrastructure, a special team was formed in the Seismology Division to map site effects in Israel. In the present study forming part of project “Microzoning of the seismic hazard in Israel” 580 ambient noise measurements were carried out in the area of 165 km² including the towns of Qiryat Ono, Or Yehuda, Yehud, Shoham, partially Lod and more than 30 adjoining settlements. Hence, we finished seismic zonation in part of the Shefela region between the towns of Ramla and Kefar Sava.

Measurement results indicate site amplifications ranging from 2.5 up to 7-8 units decreasing from west towards east within the frequency band 0.27-12 Hz. The fundamental frequency has general trend to increase eastward. In the western part of the study area, at the Coastal Plain, sharp shift of the first resonance frequency from 0.3 Hz up to 1.2-1.3 Hz indicates a change of the fundamental reflector from the Judea Gr. to calcareous sandstone of the Kurkar Gr. The faults in the Top Judea Gr. previously traced by geological data are reconstructed and revealed some new transversal faults in the northern part of the study area.

Analysis of measurement results shows that correlation between shape of the Fourier spectra (H/V spectral ratio) and subsurface structure revealed formerly in the Petah Tikva area exists also in the Southern Sharon-Lod Valley. Spatial distribution of the ratio shapes allows us to judge spreading of the hard intermediate layer represented by chalk-marl and/or chalky limestone of the Judea Gr. to the east.

Data from representative boreholes and four refraction profiles integrated with H/V observations at corresponding locations are used to develop models of the subsurface at the measurements sites. S-wave velocity profile obtained in the Petah Tikva area is appropriate to

the Lod Valley, however V_s range for Eocene-Senonian marl-chalk layer is wider; and decrease of V_s to the south is observed. We have received additional confirmation that chalky limestone of the Judea Gr. is not the fundamental reflector almost everywhere and difference between estimations of the reflector depth according to the structural map of the Judea Gr. and from H/V analysis can reach a few hundred meters. Results of subsurface modeling are illustrated by geological cross sections.

By comparison of the Uniform Hazard Acceleration Spectra calculated for 120 selected sites and considering the subsurface models constructed across the investigated area, we divided the area into 7 zones. Each zone is characterized by a generalized seismic hazard function representative the sites within that zone. For many zones the Israel Standard (IS-413) underestimates the acceleration in the broad period range.

1. INTRODUCTION

Deformation of young sediments, paleoseismic and historical records indicates that the Dead Sea Fault has been continuously active and was the source of several destructive earthquakes that shook the entire region throughout geological times (Begin, 2005). Due to the small size of the country and proximity of population centres to the seismically active faults of the region, more than 90% of the population is vulnerable to the effects of severe earthquakes.

Over the past two centuries, large earthquakes with intensities reaching X on the MM scale occurred in the area. The earthquake of October 30, 1759, (Amiran et al., 1994), located probably in southern Lebanon, affected most of today Lebanon, Israel and Syria with damages extended as south as Jaffa. Some sources report a death toll of 10,000-40,000 people. According to Ambraseys and Barazangi (1989) losses were certainly considerable. The earthquake that occurred on January 1, 1837, was the strongest earthquake to occur in the region since the 19-th century (Amiran et al., 1994), where most of the damage is reported to occur in Safed and Tiberias. The July 11, 1927, earthquake, with magnitude $M=6.2$, was the most destructive regional seismic event in the 20-th century. The effects of the earthquake were devastating, particularly in Jerusalem and in the towns of Lod and Ramle. In Lod and Ramle, which at that time were small towns, many buildings were destroyed and 50 people were killed (Avni et al., 2002). The towns and settlements located in Southern Sharon and Lod Valley areas are relatively new constructions and we have no clear historical records of earthquake effects in vicinity of Lod. Nevertheless, based on similarity of the geological structure, we expect that these heavily populated urban areas may be seriously affected if a strong earthquake, with epicenter near the Dead Sea area, will occur in the near future.

Seismic wave amplification due to sedimentary deposits overlying hard rock is one of the more important parameters influencing seismic hazard. Site effects associated with ground motion amplification at resonance frequency of a building may have severe consequences. In the last decade, the Geophysical Institute of Israel has launched a number of projects to identify and map areas which are expected to amplify seismic ground motions across Israel (i.e., Zaslavsky et al., 1995, 2007a,b; Shapira et al., 2001). In those studies, we used various empirical methods to study the site response, including reference (Borcherdt, 1970; Kagami et al., 1982) and non-

reference (Lermo and Chávez-García, 1993) techniques as well as different sources of excitation: earthquakes, explosions and ambient noise (Zaslavsky et al., 2000, 2003).

Nakamura (1989, 2000) proposed a method to estimate the site effect by horizontal-to-vertical (H/V) spectral ratios of ambient noise. In a recent comprehensive study of the Nakamura's method by SESAME European project (Atakan et al., 2004; Bard et al., 2004) it has been concluded that H/V spectral ratio of ambient noise corresponds to first resonance frequency of the site but the H/V amplitude is not necessarily the expected amplification of shear waves but may serve as a lower bound of the expected amplification levels. Studies of Zaslavsky et al. (2000, 2005, and 2006) 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 define reliable information related to linear seismic behaviour of sedimentary layers.

In this report we analyze ground motion within the Southern Sharon and Lod Valley areas and its relation with subsoil ground condition. We recorded microtremor using single-station measurements at 580 points within the urban areas. Given the larger size of the investigated area we designed a measurement site grid of 500 m to give relative good coverage of the areas, considering different surface sedimentary deposits, thickness of sediments, and the shear wave velocity contrast between sediments and bedrock. Only in case of high variation in the observations led us to increase the density to a grid spacing of 250 m.

We obtain 1D models using geophysical and borehole data. We check the applicability of those models at sites where no borehole data are available. This enables understanding the spatial distribution of the expected amplifications and resonance frequencies over the study area and, as a result, revising the existing concepts of the subsurface structure.

The subsurface model serves as input for computing the expected Uniform Hazard Site-Specific Acceleration Response Spectra (Shapira and van Eck, 1993) at the investigated sites. The final stage is generalizing the hazard by mapping zones that feature similar seismic hazard functions.

2. GEOLOGICAL PATTERN

Geological information of the region is compiled from Gvirtzman (1969), Fleischer et al. (1993) and Fleischer (2000) and based on data from more than 160 wells including primarily

core descriptions and a few log data. Borehole locations are shown on the geological map (Fleischer, 1993) in Fig. 1. List of boreholes used is given in Appendix 1. The geological map is combined from the geological map of Kefar Sava (Sneh, 1993), Lod (Yechieli, 1997) to a scale of 1:50,000 and the geological map of Israel to a scale of 1:200,000 (Sneh, 1998). Surface geology in the study area is represented by chalky limestone and dolomite of the Judea Gr. (Cretaceous age) in the eastern part, by chalk and marl of Hashefela Gr. in the south-eastern part, and alluvial sediments of the Ayalon river (Holocene age), loam, sand and conglomerate of the Kurkar Gr. (Pleistocene age) in the central and western parts.

Generalized cross sections over the study area in the North-South (A-A') and east-west direction (B-B') are shown in Fig. 2. Its position is indicated in Fig. 1. General trend of the Judea Gr. to deepen from the sea level at the foot of the Shomron Mountains to 500-1200 meters at the Coastal Plain is seen in the cross section oriented west-east.

The fragment of the structural map of the top Judea Group (Fleischer and Gafso, 2000) in the study area is presented in Fig. 3a. Top Judea Group in the study area consists of the Bina Fm. (Turonian age) represented mainly by chalky limestone over the dolomite of Weradim and Negba Fms. As it is revealed in the Petah Tikva area, the contact between chalky limestone and the underlying dolomite produces site effect in the greater part of the area. This contact is also identified by a sharp break in resistivity and indicated as electric log marker "d" (Arkin and Hamaoui M., 1967).

In order to facilitate subsurface models developing isopach maps for every member of the stratigraphic sequence characterizing the whole Hashefela region, i.e. Hashefela, Saqiye and Kurkar Groups were constructed on the base of geological and borehole data in the study area.

The Judea Gr. is unconformably overlain by Hashefela Gr. (Campanian – lower Eocene) along the Lod syncline. It is represented by marl-chalk facies and has maximal thickness of 240 meters. In the western part, marl (Ziqim Fm.) of 200 m thick is occurred. Isopach map in Fig. 3b shows Hashefela Gr., marl Ziqim Fm. and also basalt-tuff of the National Park (Miocene age up to 300 m thick).

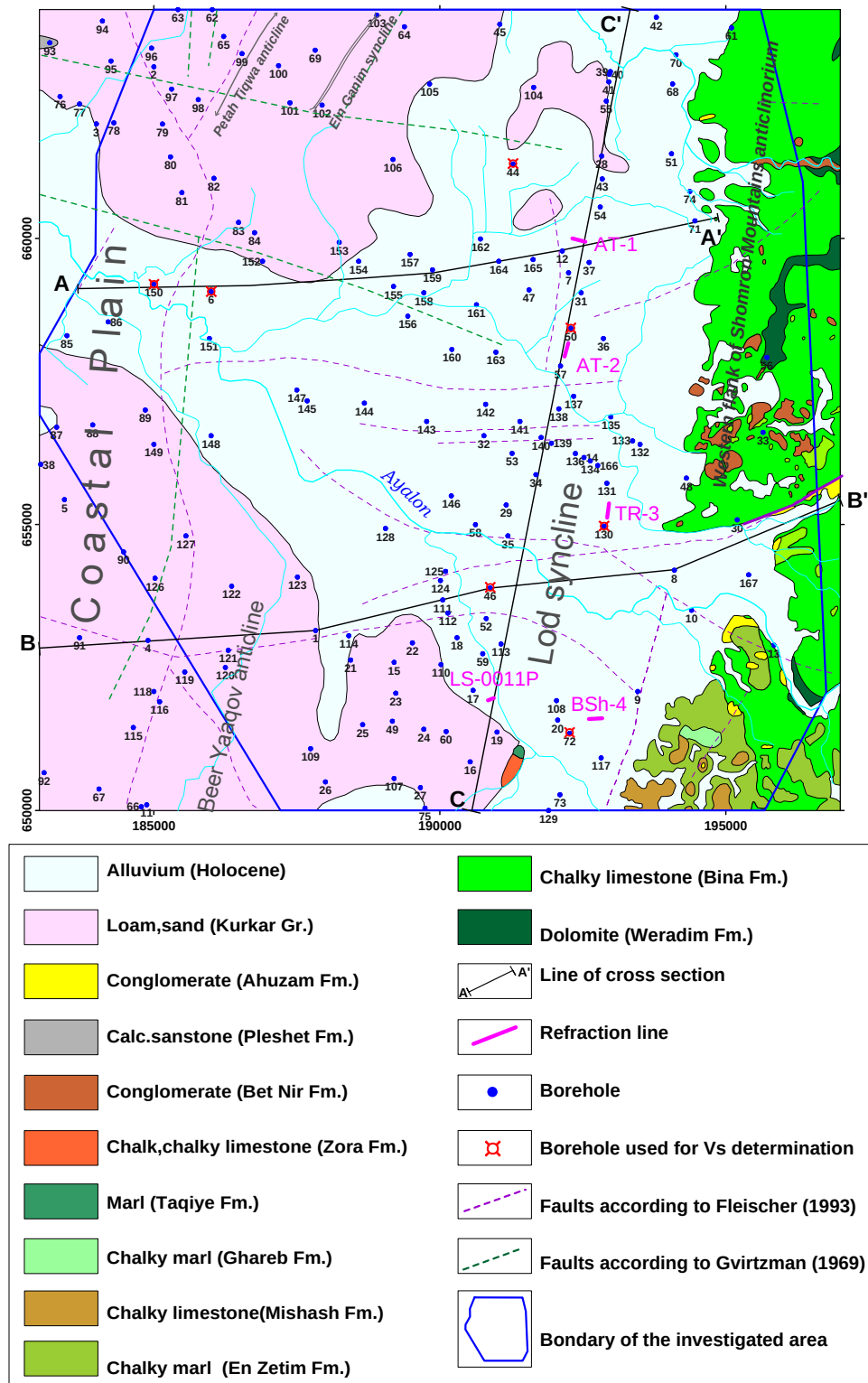


Figure 1. Geological map of the study area (scale 1:50,000). Numbers indicate wells as given in Appendix 1.

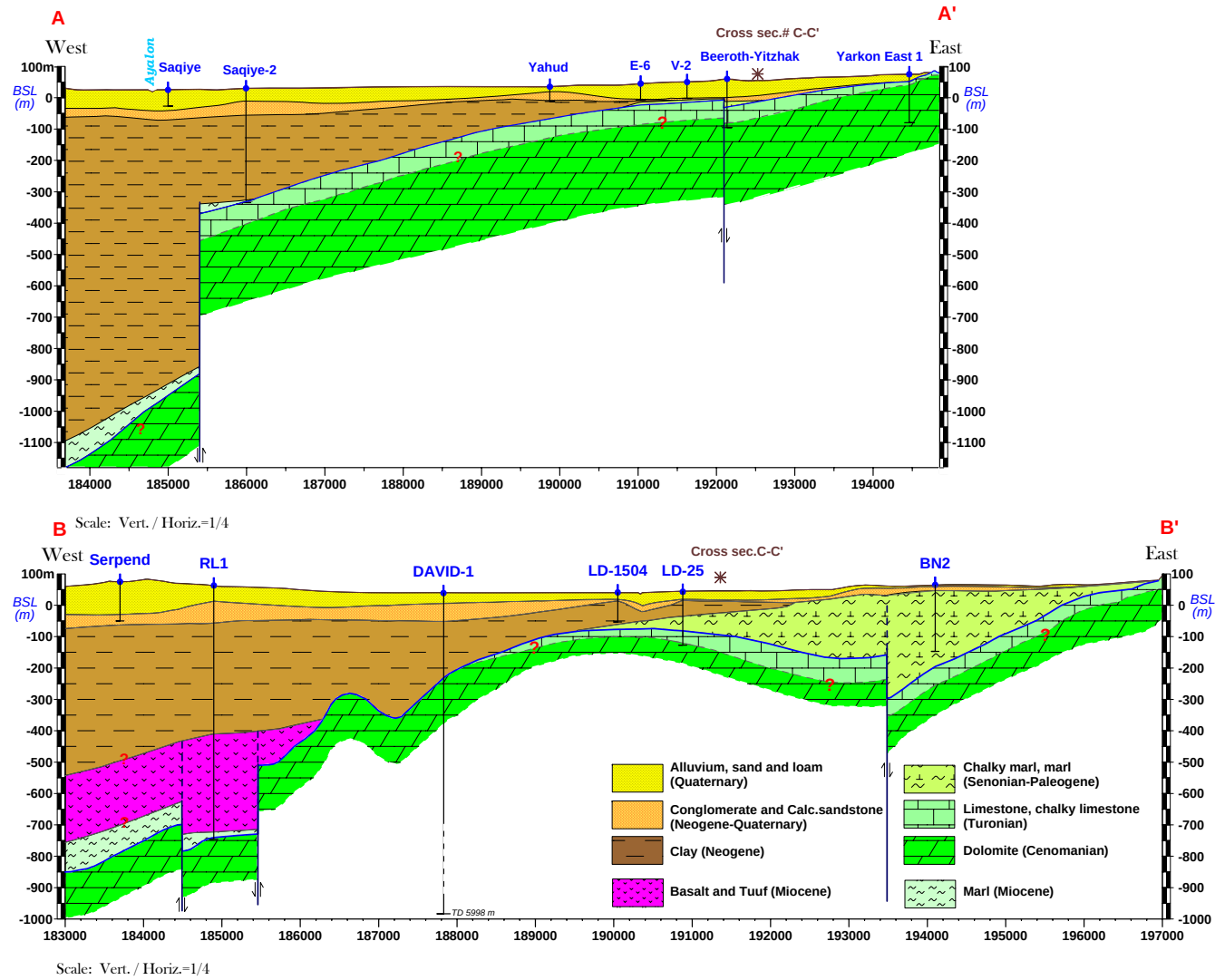


Figure 2. Schematic geological cross sections along profiles A-A' and B-B' indicated in Fig. 1. Blue line denotes top of the Judea Gr. according to the structural map (Fleischer and Gafso, 2000).

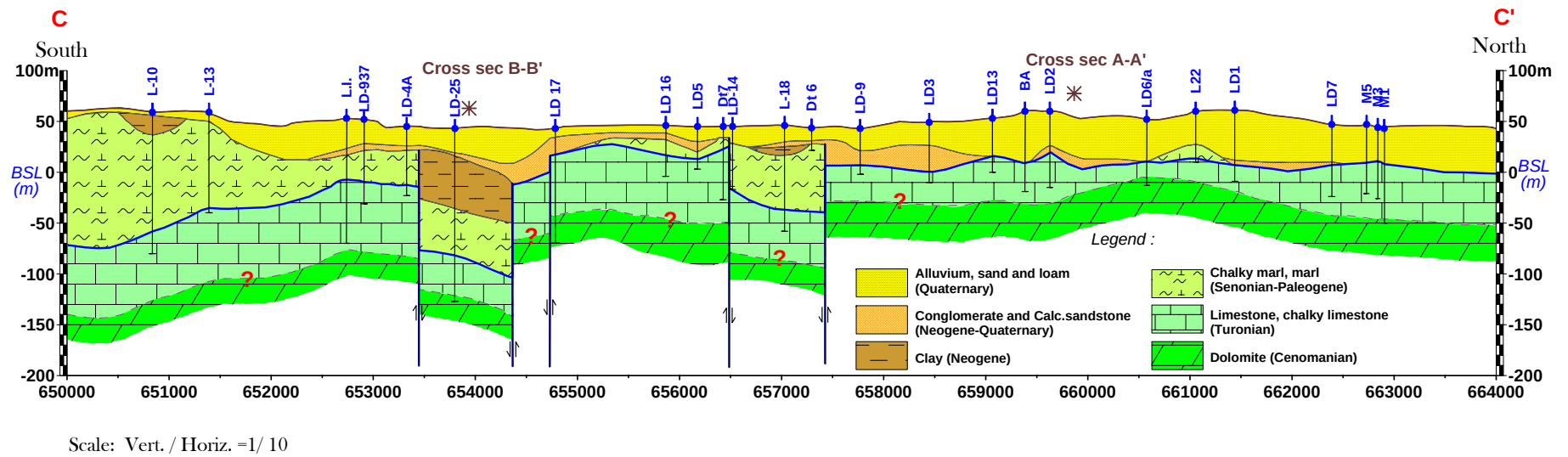


Figure 3. Schematic geological cross sections along profiles C-C' indicated in Fig. 1.

The Yafo Fm. can be generally separated into lower and upper part. The lower one comprises of clay, clayey marl and has thickness increasing from 0 m up to 750 m at the Coastal Plain. The upper Yafo Fm (Petah Tikva member) consists of calcareous sandstone and clay. Isopach map of the Yafo clay is shown in Fig. 4a.

The Kurkar Group of Pleistocene age conformably overlies the Sakiye Gr. The lower part of the Kurkar Gr. consists of marine and eolian calcareous sandstone ("Kurkar") of 0-165 m thick and conglomerates (Ahuzam Fm.) up to 30m thick. The total thickness of Kurkar Gr. increases toward the west. Fig. 4b shows isopach map of the calcareous sandstone and conglomerates of Kurkar Gr. The upper part of the Kurkar Gr. is characterized mainly by eolian sands and sandy loam of the Rehovot Fm. up to 138 m thick. To the east the upper Kurkar becomes more clayey ("hamra"). Total thickness of the Kurkar Gr. changes from 0 m in the east to 165 m in the west. The alluvium sediments of Holocene age outcrop in the southwestern part of the study area in upper basin of the Ayalon river, are represented by soil, loess, clay and gravel and have a maximum thickness of 30 meters. In Fig. 5a is displayed isopach map of the loose sediments of the Rehovot Fm., Kurkar Group and alluvium. The united lithologically homogeneous groups with corresponding thickness ranges are given in Table 1.

Table 1. United lithological units represented in the study area and their total thickness.

No.	Lithology	Thickness, m	Formation
1	Soil, loess, loam, sand	0 - 110	Alluvium, Rehovot
2	Conglomerate	0 - 30	Ahuzam, Bet Nir
4	Calcareous sandstone	0 - 166	Kurkar Gr.
5	Clay, clayey marl, marl	0 - 800	Ziqim, Yafo
6	Basalt and tuff	0-300	National Park Volcanics
7	Chalk-marl	0 - 123	Ziqim, Lachish, Beit Guvrin, Taqiye, Adulam, Ghareb, En Zetim
8	Limestone and chalky limestone	0 -91	Bina
0	Dolomite	~100	Bina, Weradim, Negba

Geological analysis shows that the investigated area may be divided into seven uniform zones based on both depth and structural configuration of the Top Judea Gr. and lithological composition of the sediments. The zones are defined as follow:

Zone 1 is an outcrop of the Judea Gr.

Zone 2 is exposed chalk and chalky marl (Hashefela Gr.) overlying directly the Judea Gr.

Zone 3 is loose sediments (alluvium, sand and loam) overlying directly the Judea Gr.

Zone 4 is located within the Lod and Ein Ganim syncline and is characterized by Kurkar Gr. and chalk-marl (the Hashefela Gr.) overlying the Judea Gr.

Zones 5 and 6 have the similar lithostratigraphic composition, i.e. Kurkar Gr. and clay-marl (Yafo Fm.) over the Judea Gr. However, maximal depth of the Top Judea Gr. is 260 meters and 500 meters correspondingly.

Zone 7 is located at the Coastal Plain, where the Judea Gr. deepens sharply down to a depth of 750-1100 meters and the calcareous sandstone (Kurkar Gr.) is the fundamental reflector.

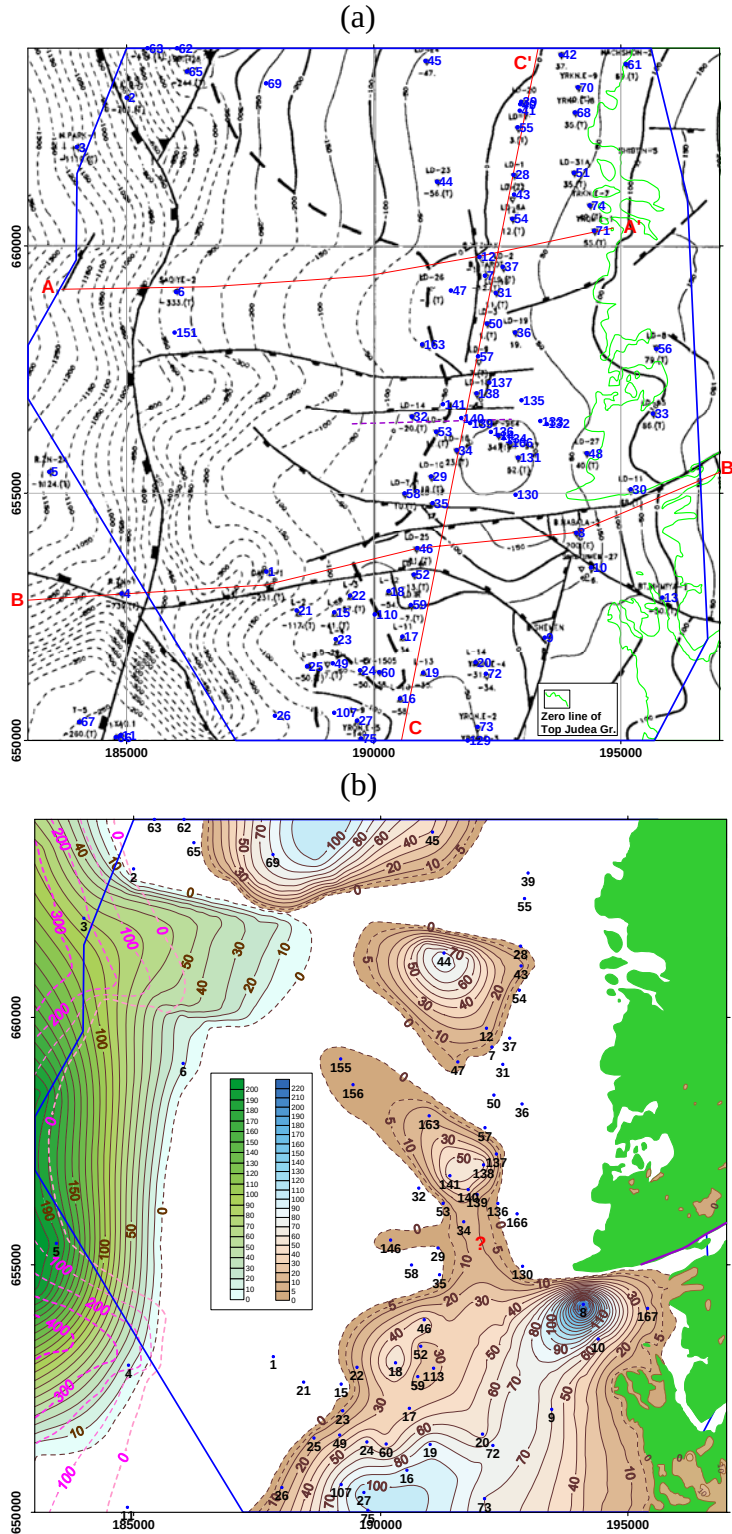


Figure 4. Fragment of the structural map of Top Judea Gr. (Fleisher, 1993) in the study area – (a); isopach maps of chalky marl (Hashefela and lower Sagiye Gr); marl of Ziqim Fm. and basalt of National Park (dotted pink lines) – (b).

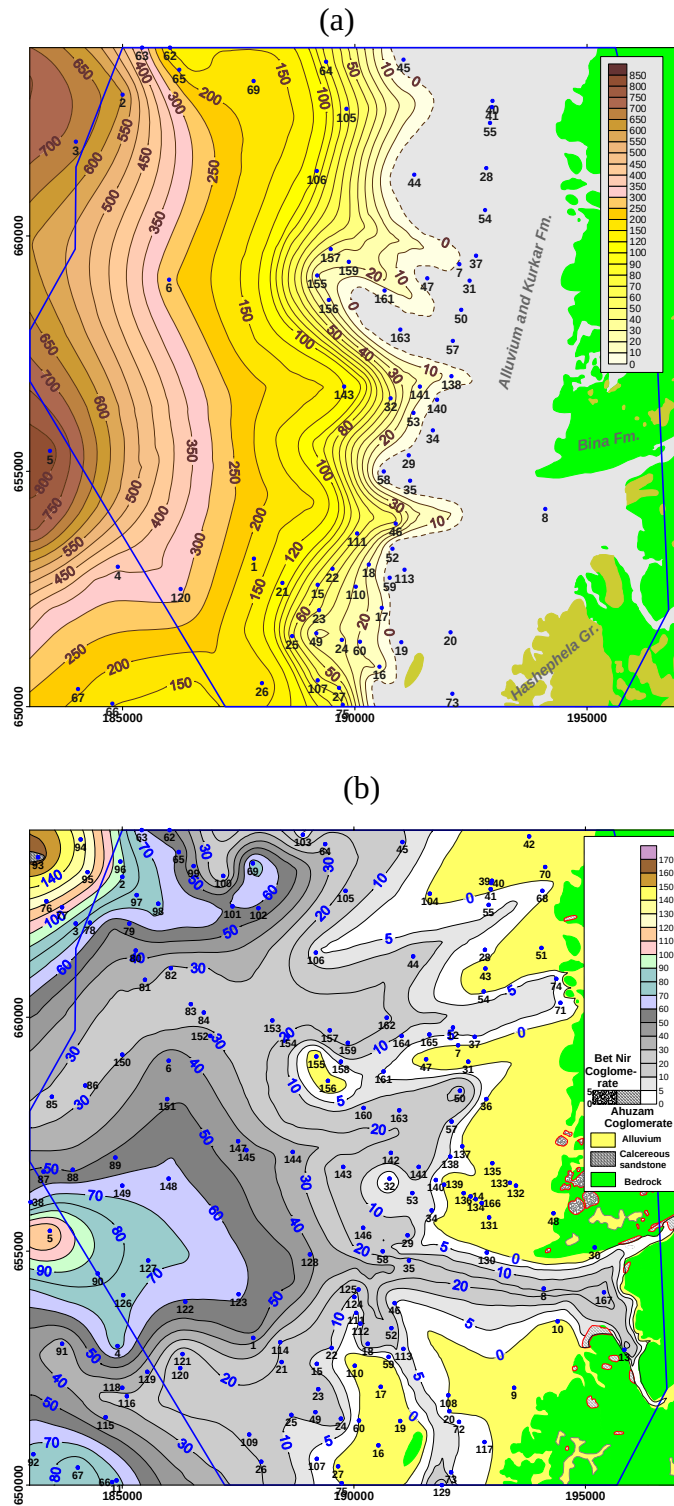
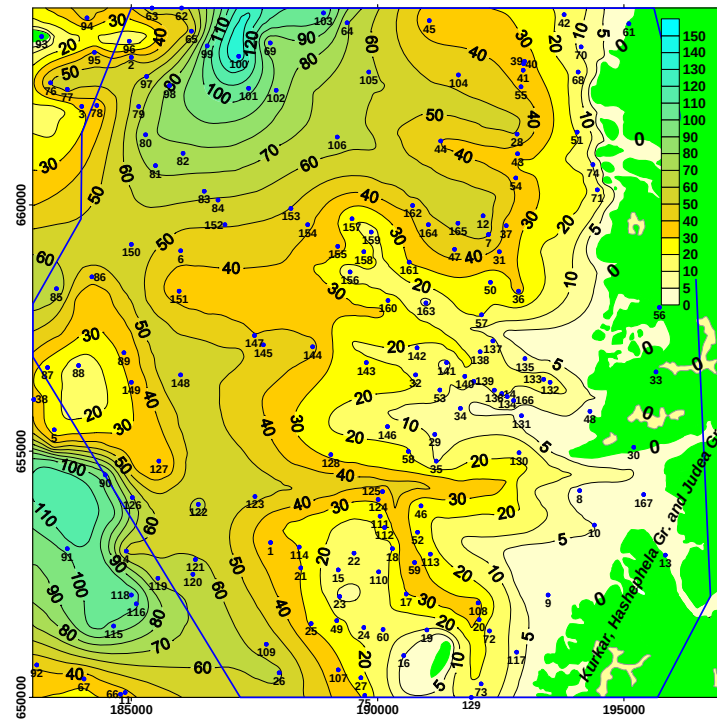


Figure 5. Isopach maps of clay (Yafo Fm.) – (a); calcareous sandstone and conglomerate (Kurkar Gr.) – (b).

(a)



(b)

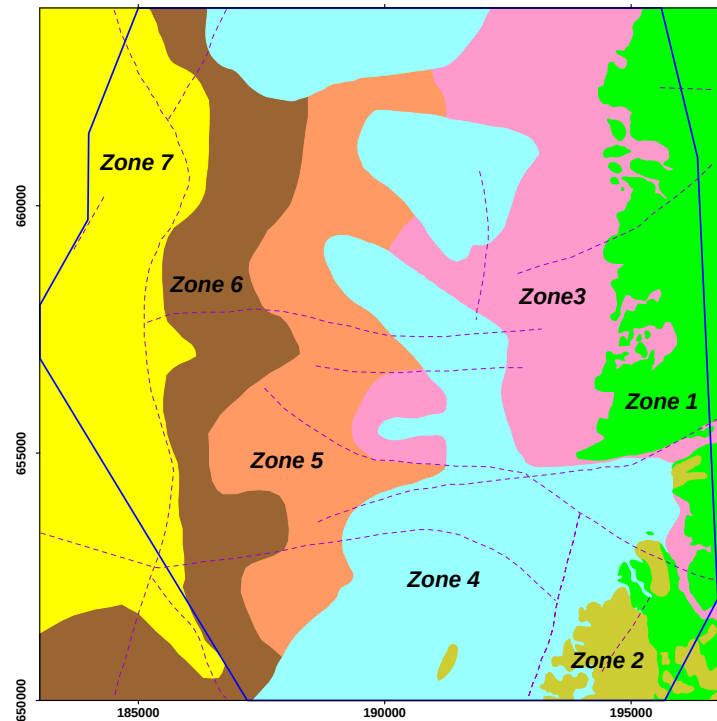


Figure 6. Isopach map of loose sediments (Rehovot Fm., the Kurkar Group) – (a) and geological divisions of the study area – (b).

3. OBSERVATIONS AND DATA PROCESSING

Figure 1 presents the map showing the locations of the measuring sites in the investigated area of 165 km². This study area includes the towns of Lod, Qiryat Ono, Or Yehuda, Shoham, and adjoining settlements like Elad, Ganey Tiqwa, Beit Dagan, Kefar Habad, Ben Shemen, Ginnaton and others. Ambient noise measurements were carried out in this area from January to October 2007. Many of the measuring sites were spatially distributed each 500 meters. High variations in the observations led us to increase the density to a grid spacing of 250 m and in some sites even 150 m. Based on many microzoning studies in the different areas of Israel, we note that reliable results can be obtained only using dense grid of measuring sites especially taking into consideration scarce geotechnical information such as S-wave velocities. We can compensate for the need of a dense grid of measured points of microtremor by drilling new borehole, conduct many geophysical surveys and monitor strong enough earthquakes at points across the area. These alternatives are by far more expensive, time consuming and may not always provide the necessary information.

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 computer 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.

Prior to performing measurements, the individual seismometer constant (free-frequency, damping and motor constant) are determined using sine and step calibration signals, and then the frequency response function of all channels are computed. As a final test, all seismometers are placed at the same location and in the same orientation to record the same waves.

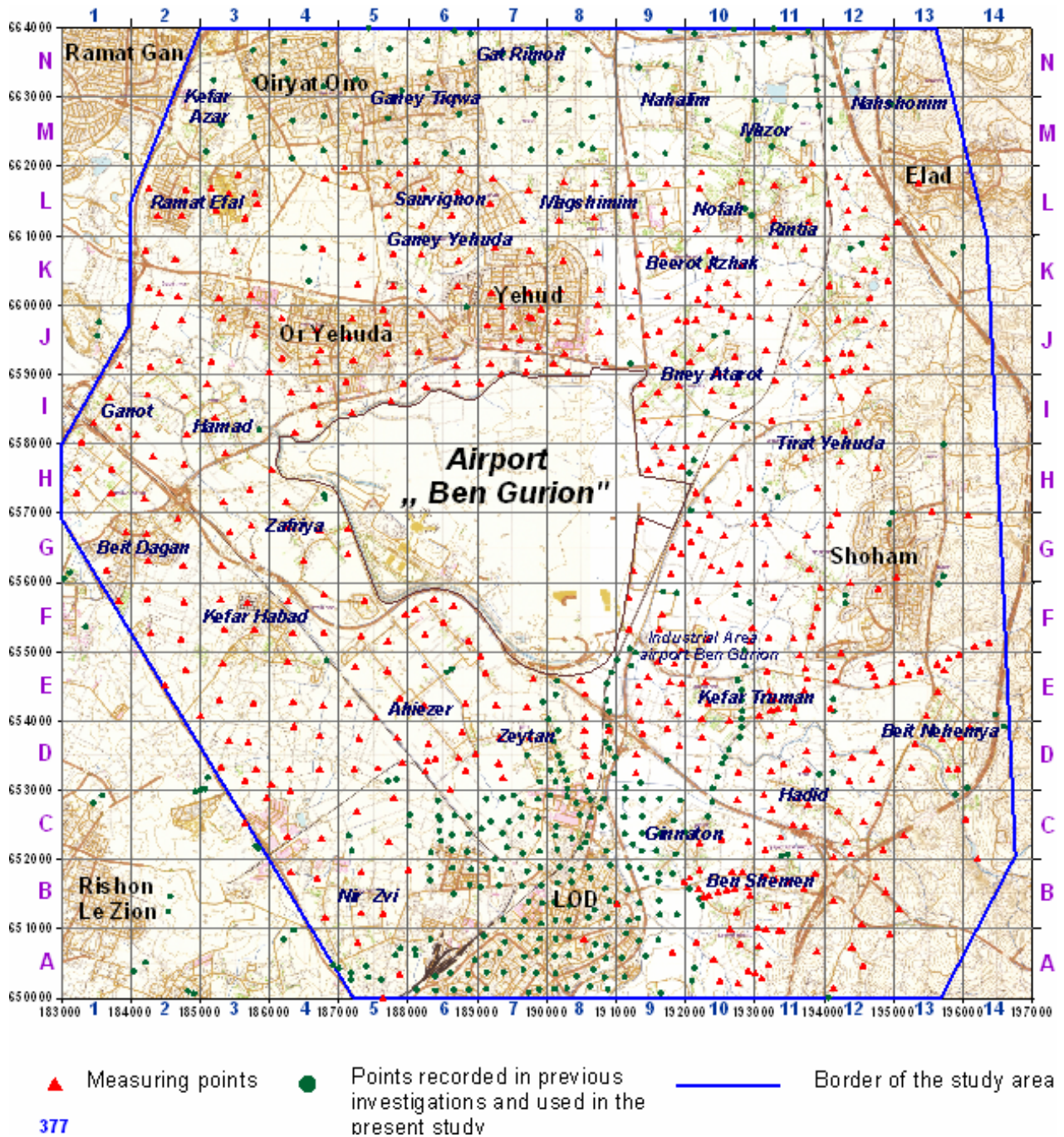


Figure 7. Location of the measuring sites in the study area

As already observed by many researchers, there is a 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, whereas Horice et al. (2001) used in their analysis recordings of microtremor originated by passing traffic. Recently, Parolai and Galiana-Merino (2006) showed

that influence of transients on the H/V spectral ratio is insignificant. Our observations also indicate that the effect of transients is almost unnoticeable. In order to reduce the scatter and increase stability, our processing scheme involved a careful selection of the time windows from which we obtained H/V functions. It followed the concept that at site with no site effects the amplitude spectra of the H and V components of the ground motions are of the same level throughout the spectrum. At sites with significant site effects, the spectral amplitudes of the two components will differ only within a certain limited frequency band, probably at the neighbourhood of the resonance frequency. Time windows that exhibit such or similar conditions were selected. The selection was made manually and yields an appreciated deduction in the H/V scatter.

Our results indicate significant dependence upon the experimental conditions, for example: duration of record on each point, presence underground structure in urban areas, soil-structure interaction because numerous measurements performed proximity to buildings, effect of rain, wind, coupling between seismometer and soil and other. Therefore, during field work it is necessary assessing the conditions of ambient noise waveform not only by visual inspection but also by computing spectra and H/V ratio several times for each case of measurement. Continuous record of ambient noise for 60-70 minutes enables to select sufficient number of suitable samples for analysis.

To study the spectral character of the ambient noise, we compute spectra and spectral ratios. The record length (time window), used for spectral calculations, depends on the fundamental frequency; 30 sec records at sites with frequencies above 1 Hz and 60 sec records for sites with frequencies less than 1 Hz. The selected time windows are Fourier transformed, using cosine-tapering (1 sec at each end) before transformation and then smoothed with a triangular moving Hanning window. More precisely, we apply “window closing” procedure (see Jenkins and Watts, 1968) for smart smoothing of spectral estimates so that any significant spectral peaks are not distorted.

The H/V spectral ratios were obtained by dividing the individual spectrum of each of the horizontal components [$S_{NS}(f)$ and $S_{EW}(f)$] by the spectrum of the vertical component [$S_V(f)$]. To obtain consistent results from the spectra of ambient noise, we use 60-70 time windows and then averaged the spectral ratios. When the $S_{NS/V}$ and $S_{EW/V}$ are similar, the horizontal-to-vertical spectral ratios is the average of the two spectral functions.

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

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. The program SEISPECT (Perelman and Zaslavsky, 2001) was specially developed for routine analysis in the frequency domain.

3. RESULTS

3.1. Variations of Fourier spectra and H/V ratio shape and its correlation with geological structure

Correlation between spatial distribution of the Fourier spectra (consequently H/V spectral ratio) from recordings of ground motion excited by ambient noise throughout the investigated area and geological structure revealed in the Petah Tikva takes place in the present study as well. We display below typical spectra and H/V ratios observed in the Lod valley and South Sharon area:

- The Fourier spectra and H/V ratios shown in Fig. 8 represent the case of one-layer model for sites adjoining the outcrop of the Judea Gr. on the western slope of the Shomron Mountains. Here, soft sediments overly directly limestone-dolomite of the Judea Gr. H/V spectral ratio at site 182 is formed by increase in the horizontal component, while the vertical one is almost flat. At site 297 we observe also a trough in the vertical component.
- The Fourier spectra and H/V spectral ratio in Fig. 9 represents the second type, characterized by wide frequency band where horizontal and vertical components deviate. For site 5 this frequency band is approximately 1-3 Hz and two inseparable resonance peaks are revealed in the H/V spectral ratios at frequencies 1.7 Hz and 2.1 Hz. The first resonance peak is correlated with the Judea Gr. and close-by second peak is related to intermediate marl-chalk layer. For site 30 this band is shifted toward low frequencies and H/V peaks at frequencies 0.55 Hz and 1.1 Hz are observed. Differently from the first two examples, which are actually fairly agree with our observations in the Petah Tikva, the last two ones demonstrate significantly higher frequency band of site effect. Two increases in the horizontal components at 3.5 Hz and 5 Hz for site 400 and 4.5 Hz and 7 Hz for site 403 define H/V ratio peaks. These results allow delimiting the spread of the marl-chalk layer to the east.

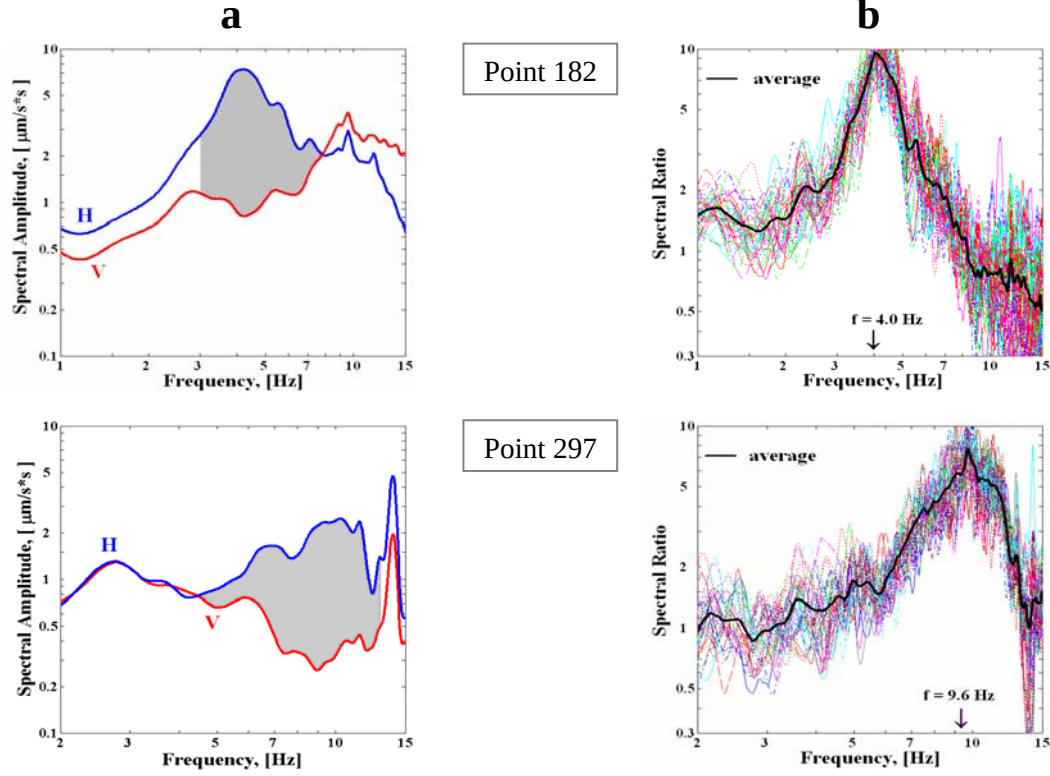
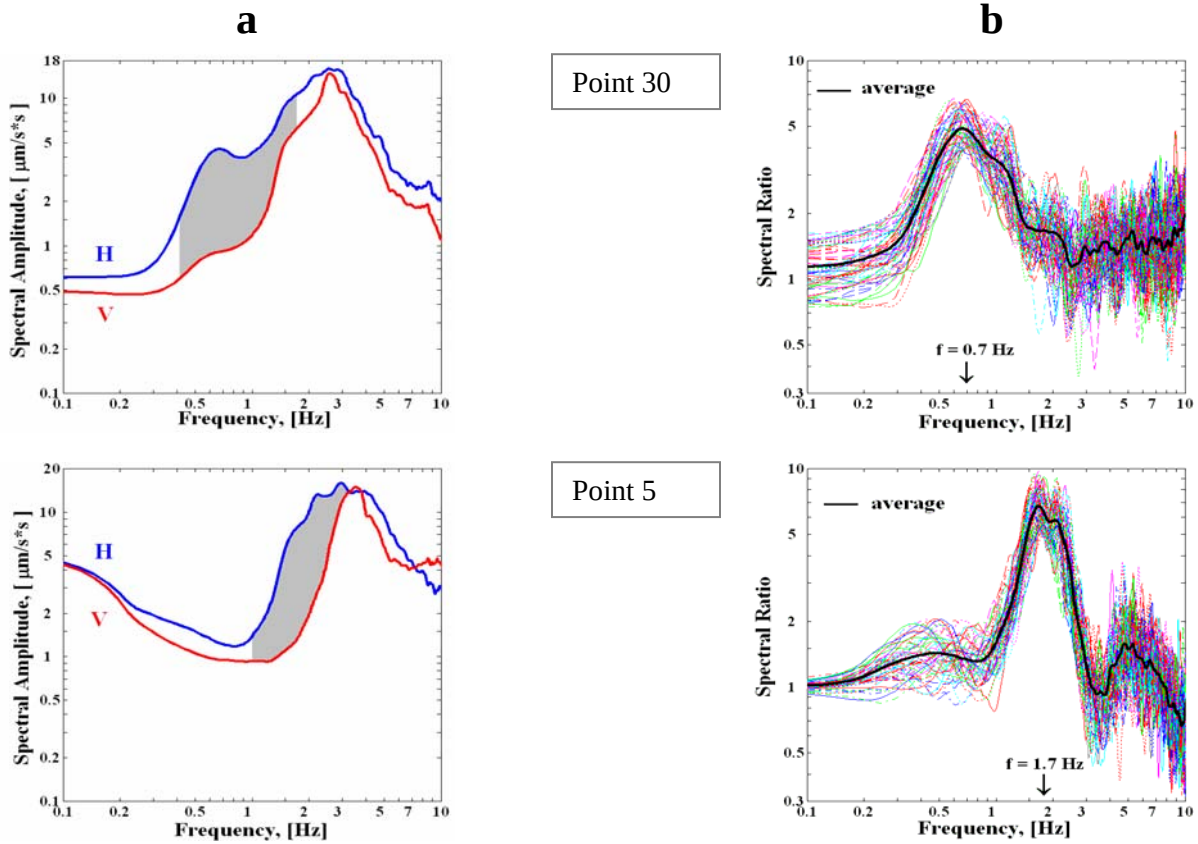


Figure 8. (a) Average Fourier spectra of horizontal (the blue line) and vertical (red line) components of motion obtained at points adjoining outcrop of the Judea Gr.; (b) H/V spectral ratios. The shaded area represents the frequency range of resonance motion.



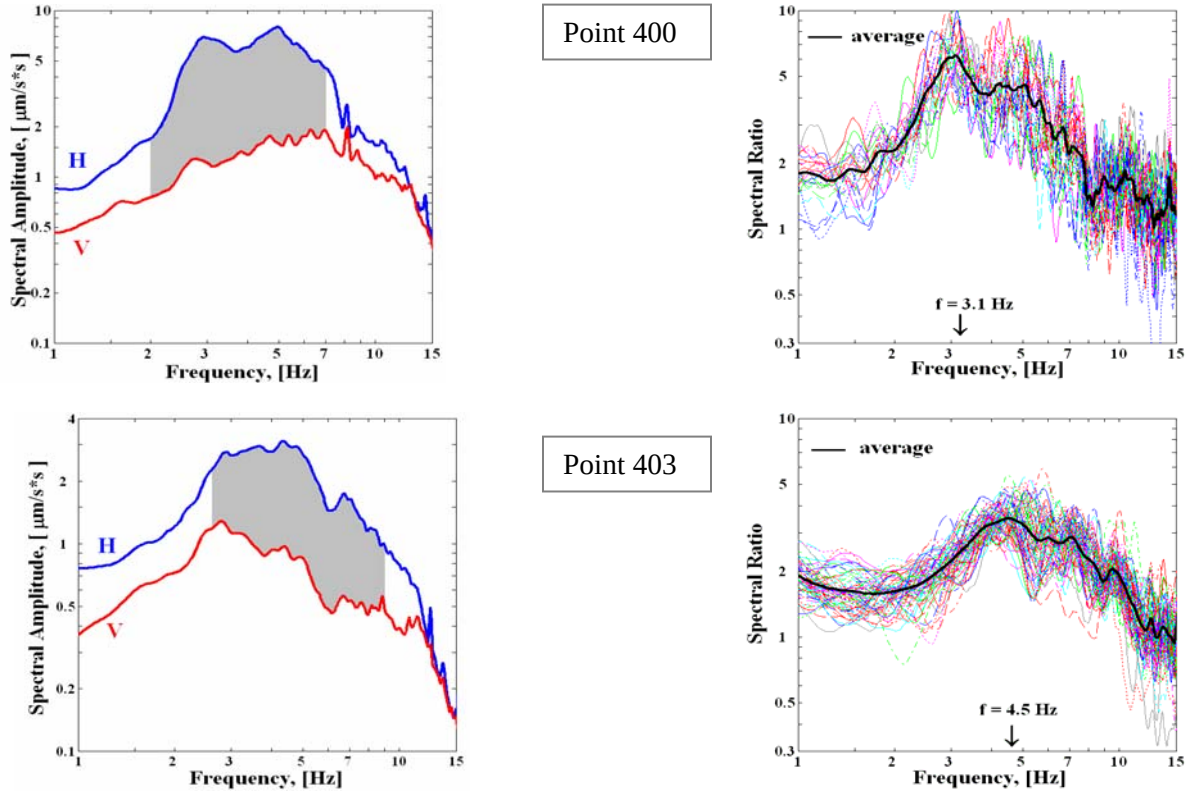


Figure 9. (a) average Fourier spectra and (b) individual and average spectral ratios for sites with subsurface structure including the intermediate marl-chalk and/or chalky limestone layer.

- Two separate motion amplification areas in the Fourier spectra in the frequency ranges 0.3-0.5 Hz for the first peak and 1.2-1.5 Hz for the second peak are typical for sites from the strip stretched SW-NE toward the coastline (see Fig. 10). Correspondingly, H/V spectral ratios reveal two separate low-amplitude but well-defined peaks. In this case the second peak of the spectral ratio is caused by the Yafo clay together with the calcareous sandstone of the Kurkar Gr. Their total thick reaches some hundreds meters.

Fourier spectra and H/V ratios for sites, located at the Coastal Plain where the Judea Gr. deepens to depth of more than 800 m and is not assumed as the fundamental reflector any more, are shown in Fig. 11. Decrease in the vertical spectral component forms single peak at frequency of 1.6 Hz with low amplitude of about 2 units characterizing impedance contrast between soft sediments and calcareous sandstone of Kurkar Gr., which is the reflector only

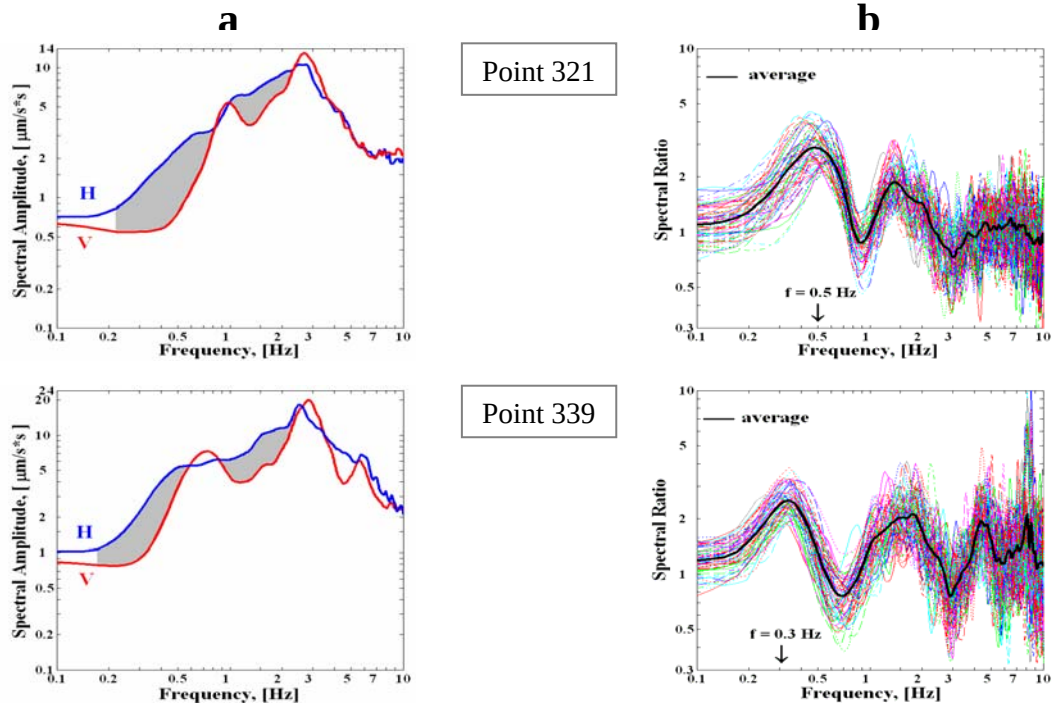


Figure 10. (a) average Fourier spectra and (b) individual and average spectral ratios for sites with subsurface structure including the thick Yafo clay layer.

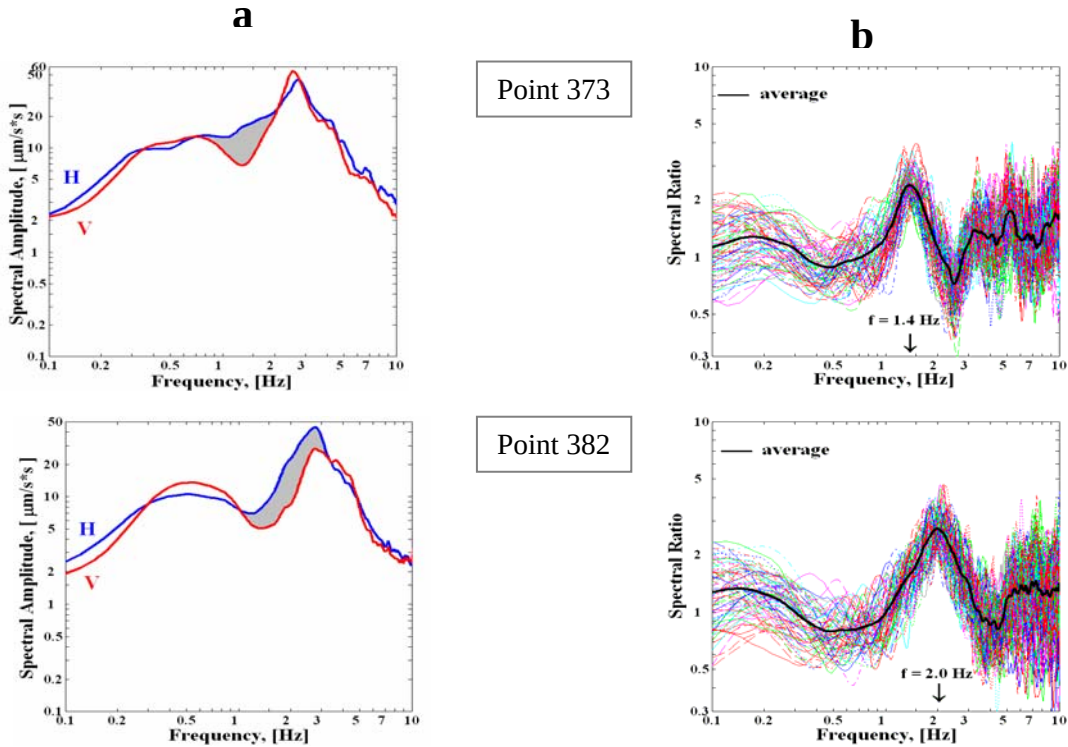


Figure 11. (a) Examples of average Fourier spectra and (b) H/V spectral ratios for sites located at the Coastal Plain and having calcareous sandstone of the Kurkar Gr. as fundamental reflector

- Additional type of the Fourier spectra (spectral ratio) is found in several limited areas in the eastern part of the Southern Sharon. The typical feature of the spectra and H/V spectral ratios for these sites is two separate amplification areas and correspondingly peaks. The first peak shows low both frequency and amplitude; and second, relatively high-frequency peak, reveals amplitude of 5-7 (see Fig. 12). Analyzing more thoroughly location of these type of H/V spectrum (ratio) we note that they are tied at the western slope of Judea and Samaria Mountains, where the recharge zone of the Yarkon-Taninim aquifer spreads (Frumkin and Gvirtzman, 2006).

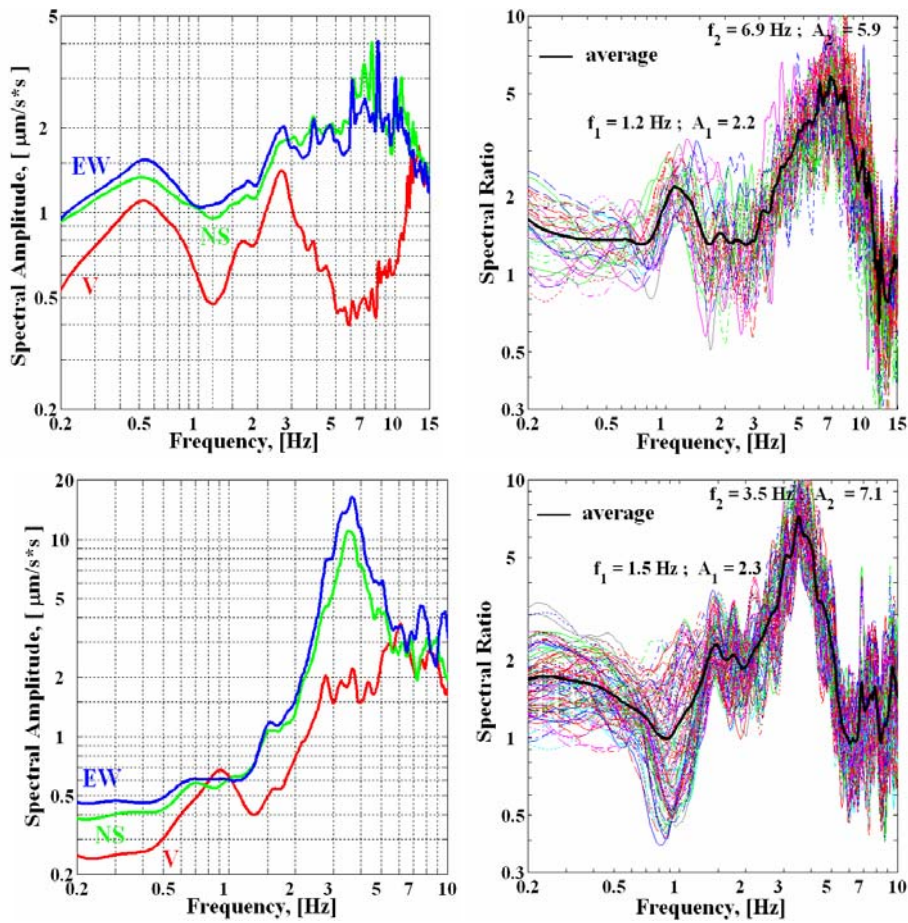


Figure 12. (a) Examples of average Fourier spectra and (b) H/V spectral ratios for sites located in the fractured zones of the Yarkon-Taninim aquifer.

Analysis of the Fourier spectra and H/V ratios in the Southern Sharon and Lod Valley we draw conclusion on consistent pattern in distribution of the site effect parameters and correlation

with subsurface structure throughout the whole Shefela region. This will justify the developing united velocity model, which in turn will be useful to constrain the possible geological models and contribute to seismic hazard assessment.

3.2. Distribution of the fundamental frequency and its associated amplitude

A general correlation between the fundamental frequency contours directed south-north and depth of the Top Judea Gr. is reflected in map of the spatial distribution of H/V frequency over the study area presented in Fig. 13. A decrease in the fundamental frequency from 10 Hz down to 0.3 Hz westward is in accordance with the dip of the Judea Gr. from the outcrop down to 500-1200 m.

Sharp shift in the frequency values from 0.25 Hz up to 1.2-1.4 Hz, which is detected in the west of the study area while the Judea Gr. keeps dipping, indicates the emergence of an additional shallower reflector. It is the calcareous sandstone of the Kurkar Gr. Conditional line of the reflector change mapped previously within the framework of Hashefela project is traced more accurately.

The frequency map shows different behavior of the frequency contours in the western and eastern parts of the study area. In the western part we observe smooth alternating wide areas of increase and decrease in the frequency field of latitudinal direction, which are connected probably with erosion channels or folding in the regions. In the eastern part of the area, where the Judea Gr. is significantly shallower than in the west, the character of the frequency field becomes mosaic due to irregularity of the reflecting surface and lateral lithological inhomogeneity of the sediments overlying reflector.

Several anomalies of 500-2000 m long and 500-700 m wide, characterized by the lower resonance frequencies of 1.0-1.3 Hz within the field of the medium-high (2-5 Hz) values, are distinguished in the northeastern part of the study area, on border of the western slope of Shomron Mountains anticlinorium and foothills of the Shefela region. According to Ben-Gai et al. (2007), complex interpretation of logs performed in the carbonates of the Yarkon-Taninm aquifer show presence of zones characterized by the high porosity and lower resistivity in this region. They can be defined as possible fractured zones. The upper horizon of these zones is stratigraphically attributed to the Bina limestone and the upper part of the Weradim dolomites. A

total thickness of the aquifer rocks consisting of Albian-Turonian carbonates of the Judea Gr. reaches 800 meters. We also note that the area, where measurements showing the low-frequency H/V peak are localized, is within the Ayalon Saline Anomaly (ASA). According to Frumkin and Gvirtzman (2006), the ASA phenomenon may be explained by a geothermal artesian karstic system with underground springs. The Yarkon-Taninim aquifer is extremely heterogeneous at both macro- and micro-scales, high porous and permeable media with the very complex flow field. The indicated above fractured zones are likely associated with the “upper sub-aquifer”.

We have shown typical examples of the Fourier spectra and H/V ratios from the indicated areas in Fig. 12. We assume that the lower fundamental frequency within the medium-high frequency field is related to the Weradim Fm. in the karsting, jointing and highly fractured areas. Carbonates from the karsting zone proper is an intermediate layer, which is characterized by $V_s=1200-1400$ m/sec obtained from the refraction survey.

The concept of the aquifer karsting fractured zone as a hypothesis could at the first approximation explain the distribution of the fundamental frequency within the northeastern part of the study area. However, in order to prove it we need additional investigations with significantly denser grid in the coordination with hydrologists.

Taking into account the significance of high amplitude associated with frequency 4-7- Hz for the second H/V resonance peak at sites situated in the zone of interest, we construct the maps of the predominant frequency and its amplitude disregarding position of this peak in the H/V spectral ratio (Fig. 15). The location of these fragments is indicated in the maps (Figs. 13 and 14).

We note that due to the absence of ambient noise measurements within the Ben Gurion airport area, frequency and amplitude contours within this area depicted in Figs. 13 and 14 are inferred.

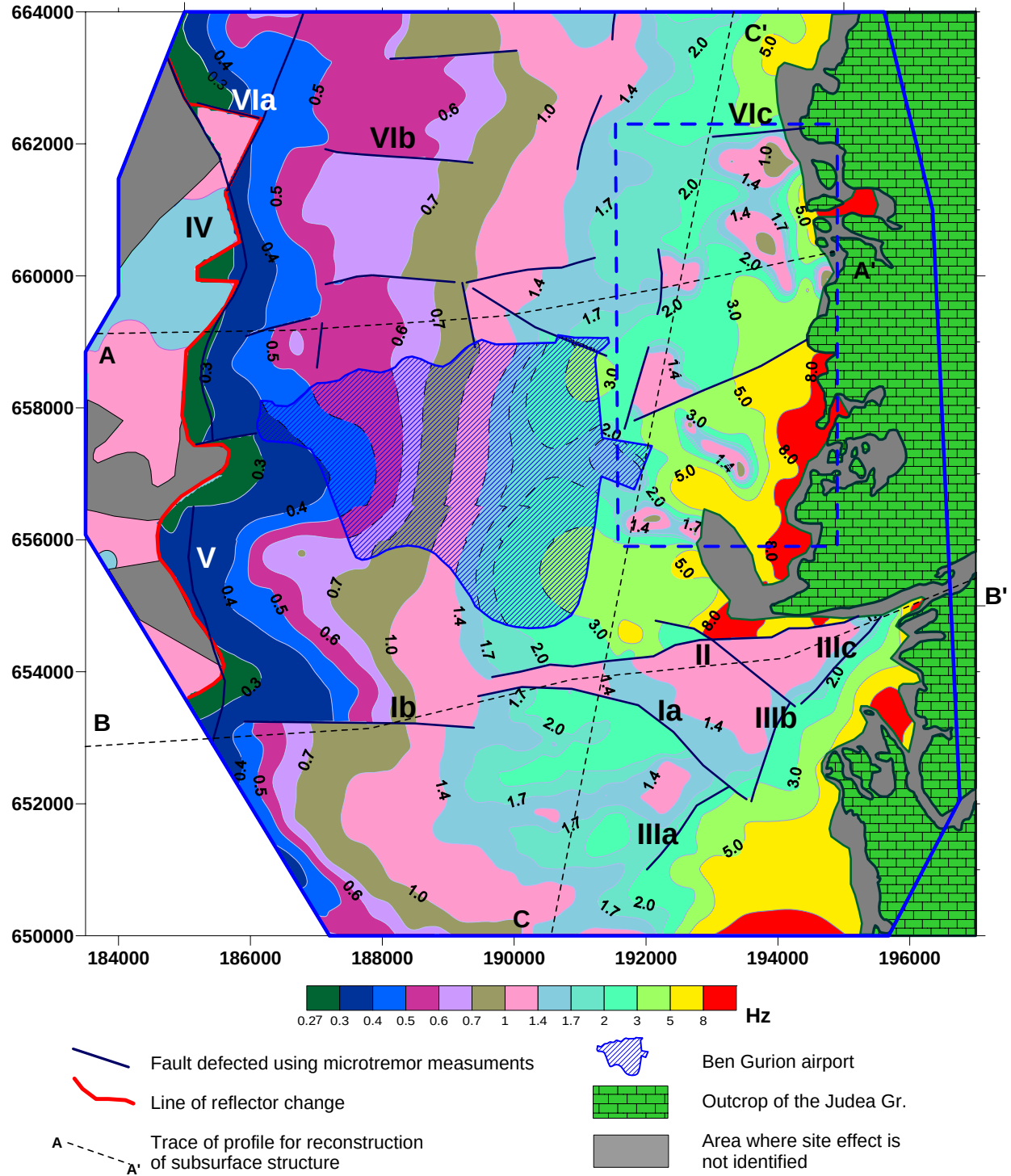


Figure 13. Distribution of H/V fundamental frequency over the study area. Another interpretation of the selected by the blue dashed line fragment of the map is shown below. Roman numerals indicate faults mentioned in the report

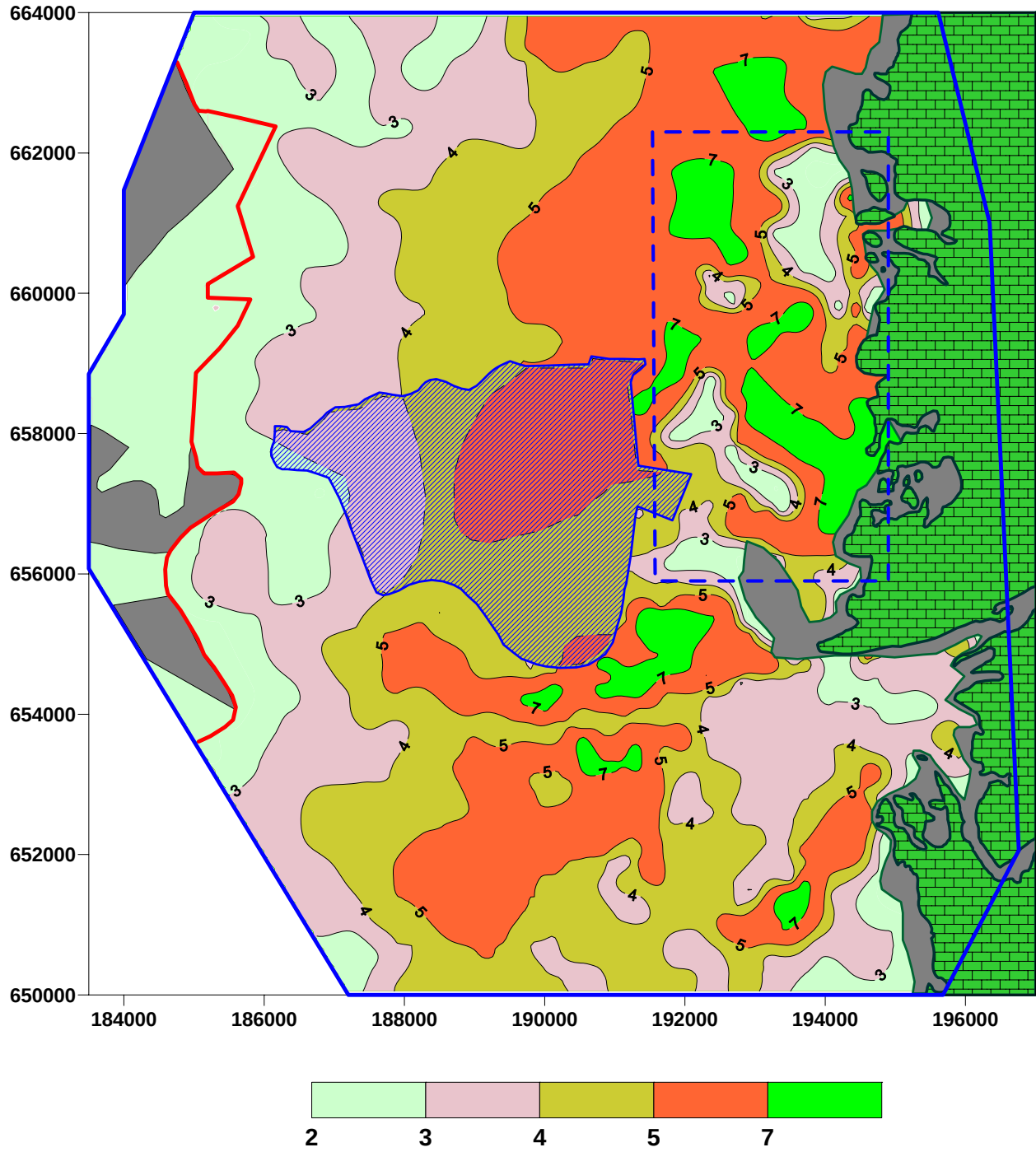


Figure 14. Distribution of amplitude associated with the fundamental frequency. Legend is the same as in Fig. 13.

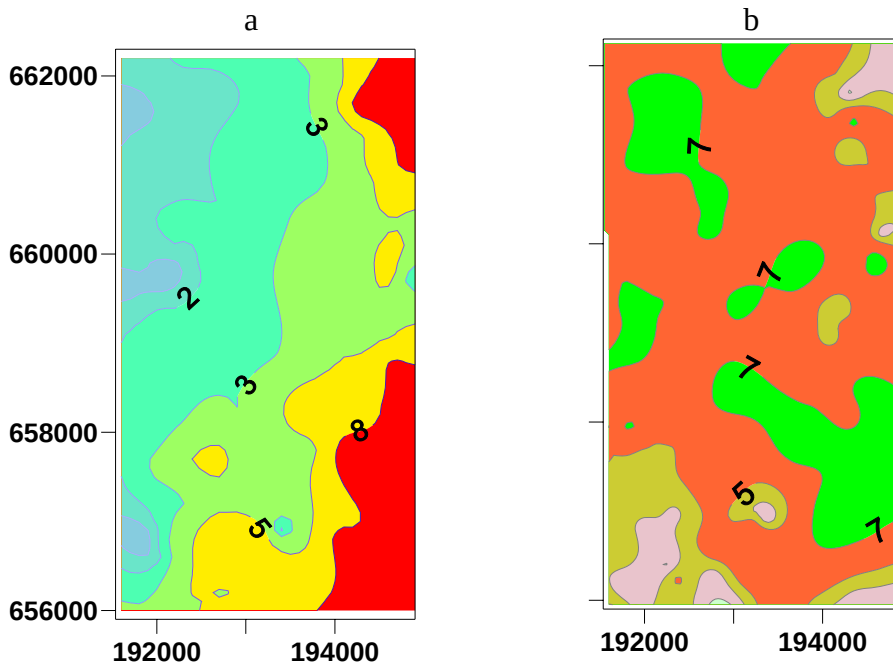


Figure 15. Distribution of predominant H/V frequency (a) and its corresponding amplitude (b) within the northeastern area, where the fractured zone is spread out. Position of this area is indicated in Figs. 13 and 14 by the dashed blue line.

The area of no resonance frequency and amplitude in the eastern side is wider than the outcrop of the Judea Gr. and extended at sites, where sediment thickness is too thin to produce site effect.

The area of the resonance frequency 1.1-1.4 Hz, trending E-W in the southeastern part of the study area, surrounded by faults Ia, II, and IIIb,c (Fig. 13). is associated with paleo-erosion channel of the Ayalon River. While the fault II limiting this structure in the north is detected in both the geological and structural maps of the Top Judea Gr., the faults I and IIIb are mapped on the structural map only. We note that the western segment of fault Ib is shifted northward.

Amplitude at the fundamental H/V peak reflecting impedance contrast between deposits and underlying reflector varies from 2 to 8 (see Fig.14). Spatial distribution of this parameter over the study area is influenced by lithological composition of sediments above the reflector and also reveals the general decrease in the direction of the dipping Top Judea Gr. Variations of Vs in the upper part of the geological section also control the amplitude value. Low amplitude areas in the eastern part of the study area correspond to the erosion channels. No direct correlation between distribution of the amplitude and fault location is revealed in the study area.

In our study we reconstruct the faults in the Top Judea Gr. previously traced by geological data and reveal some new transversal faults in the northern part of the study area. Criteria of fault identification using ambient noise measurements were developed in our previous investigations (Zaslavsky et al., 2007). Directed NS fault IV running throughout the whole area in the west and practically coinciding with the border between two reflectors is mapped by both Gvirtzman (1969) and Fleischer and Gafsou (2000). As it is already mentioned above, the lack of measurements within the airport area does not allow detecting faults. However, west of the airport a part of fault V is found (Fig. 13). Thus, the main conclusion 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 (possibly different material). In the study area, we apply these criteria. In Fig. 16 the faults detected by the H/V analysis are compared with those mapped by Gvirtzman (1969) and Fleischer and Gafsou (2000). We note that the northern latitudinal faults VI-a,b and c detected by microtremor analysis agreed with those determined by Gvirtzman (1969), however they have more complicated configuration.

3.2. Developing of S-wave velocity model

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 many studies (Borcherdt et al., 1989; McGarr et al., 1991; Theodulidis et al., 1996; Reinozo and Ordas, 1999; Pergalani et al., 2000; and 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 the range of Q values is 10-40. These values agree well with those, which are used in this study.

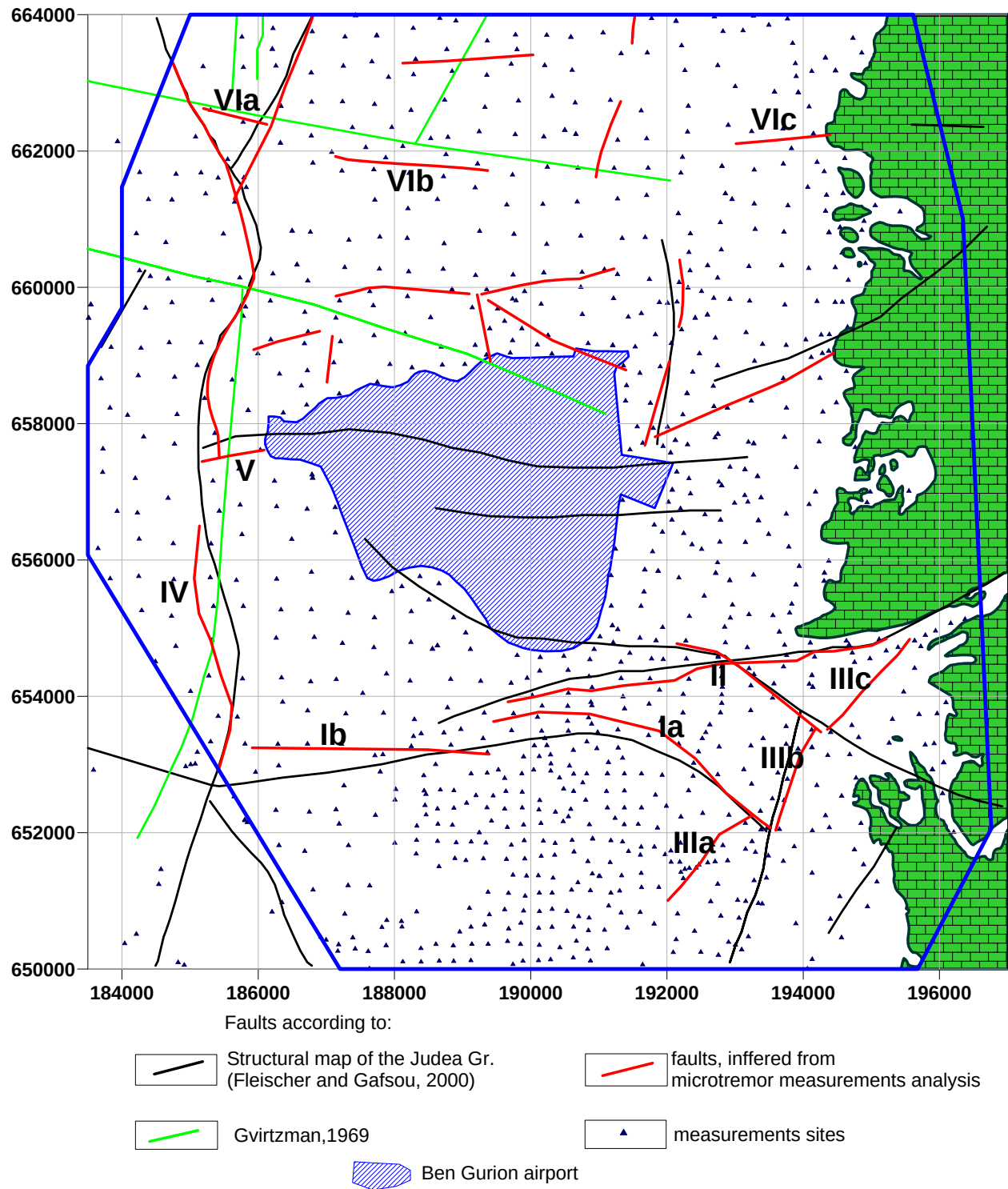


Figure 16. Map showing different interpretation of the fault locations. Roman numerals indicate faults mentioned in the report

Many authors assume ambient noise is primarily composed of surface wave (Lachet and Bard, 1994; Conno and Ohmatchi, 1998; Arai and Tokimatsu, 2004). Consequently, the comparison of H/V ratio from ambient noise with the transfer function of S waves is problematic. Others such as Nakamura (2000), Zhao et al. (2000), Enomoto et al. (2000) and Mucciarelli and Gallipoli (2004) claim that the H/V spectrum of ambient noise is dominated by the upward propagation of SH wave through the layered media. Whoever is right, both models agree that the H/V spectra and the site response function for SH waves are the results of the velocity structure of the media, with the same fundamental resonance frequencies and similar amplitudes at least when considering small motions. We demonstrate, through many previous studies when noise measurements were made near boreholes and/or near refraction surveys, that the fundamental frequency and its corresponding H/V amplitude derived from the analysis of ambient noise are practically the same as the fundamental frequency and its corresponding amplification level derived from the computed transfer function of SH waves at low strains propagating through a relatively simple 1-D model of the site, known from geo-technical and geophysical surveying. Thus, in order to construct models of the subsurface, we may start at sites close to refraction lines and boreholes, where we have subsurface information. Then propagate by means of extrapolation to neighbouring sites, using H/V spectral observations and information about the regional geology to constraint S-wave velocities of the lithological units present in the study area.

Using as a benchmark the S-velocity structure obtained in the Petah Tikva study area (Zaslavsky et al., 2006), we test all the velocity values at many borehole sites and four refraction profiles (Ezersky, 2007). Position of the refraction profiles are indicated in Fig. 1. To demonstrate the way S-velocities are tested, at the first step, we use location of KIT-3 refraction profile and Lod-32 well situated less than 1 km to the north. Lithological section of Lod-32 well is given in Fig. 17a and Table 2 together with velocity-depth section. Interpretation of refraction line suggests two layers: clay-silt and loam ($V_s=240$ m/sec) and layer with $V_s=1100-1300$ m/sec. According to the borehole data, the second layer is probably the chalky limestone of the Top Judea Gr., as we see in Petah Tikva, is normally underlain by dolomite and limestone with $V_s=1900$ m/sec. We calculate and compare the H/V ratios with the analytical functions for two

points 132 and 133 located at the refraction profile. Thickness for the second layer with $V_s=1360$ m/sec is fitted. Analytical functions compared with the H/V ratio are shown in Fig. 21b.

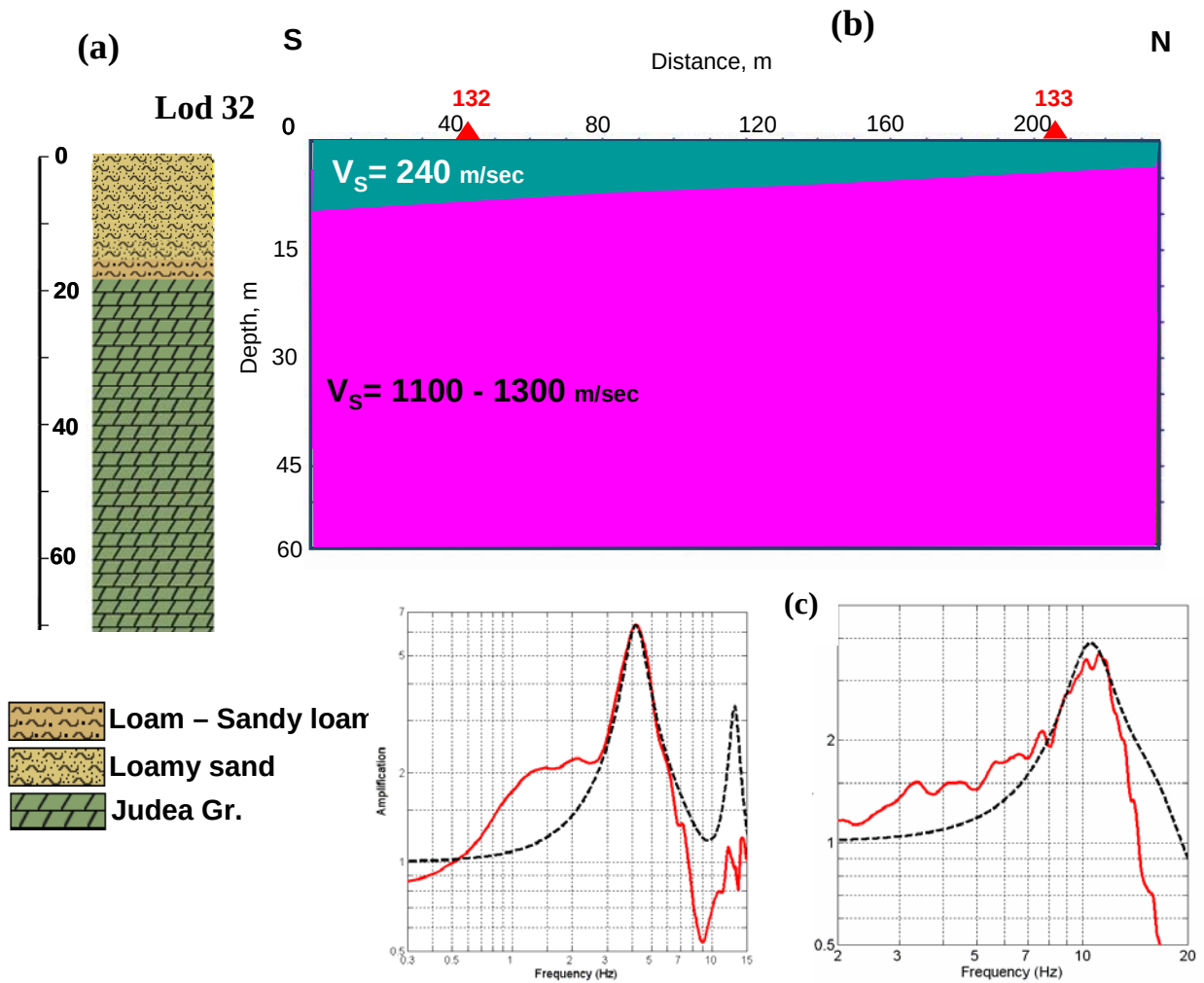


Figure 17. (a) Lithological cross section of Lod 32 well; (b) – Velocity-depth section along KIT-3 refraction profile; (c) - comparison between H/V spectral ratio (red line) and analytical transfer functions calculated using well and refraction survey data (black line).

Table 2. Geotechnical data and soil column model for sites located along profile KIT-3 close to Lod 32 well.

Lod 32 well data		Refraction survey data (KIT-3 profile)		Soil column model for sites 132 and 133	
Lithology	Depth interval, m	Depth interval, m	Vs, m/sec	Thickness, m	Vs, m/sec
Silt, clay and loam	0-18	From 0 to 5 -10	240	5-12	240
Chalky limestone (Judea Gr.)	Below 18	5-10 and below	1100-1300	30-50	1300
Dolomite (Judea Gr.)	?			-	1900

Lod-3 well is situated at one of the local decrease in the fundamental frequency revealed in the eastern part of the Southern Sharon, which we suppose to be correlated with fractured area in carbonates of the Judea Gr. within the Ayalon Saline Anomaly (Fig. 13). This well penetrates the Judea Gr. at a depth of 48 meters (see Fig. 18a). Three layers, differentiated by the refraction AT-2 profile, are correlated with sandy loam ($V_s=240$ m/sec), sand and calcareous sandstone ($V_s=550$ m/sec) and Turonian limestone of the Judea Gr. (1100-1400 m/sec). Calculation of the transfer functions for two sites, located along profile (Fig. 18b), show a fair match with corresponding H/V spectral ratios can be reached when thickness of the limestone and broken dolomite layer is 200-220 meters. In this case the reflector depth is 250-260 meters.

Similar V_s -depth section is obtained along AI-1 refraction profile, carried out in the analogous lithological conditions. Four layers: alluvium and loam-sandy loam ($V_s=200$ m/sec and 300 m/sec), sand and gravel ($V_s=460$ m/sec) and limestone of the Judea Gr. ($V_s=1200$ -1460 m/sec) are differentiated in Fig. 19a. Comparison between H/V ratio and analytical function calculated based on the AI-1 refraction line is shown in the same figure. Thickness of the limestone and broken dolomite layer providing a good fit is 165 meters.

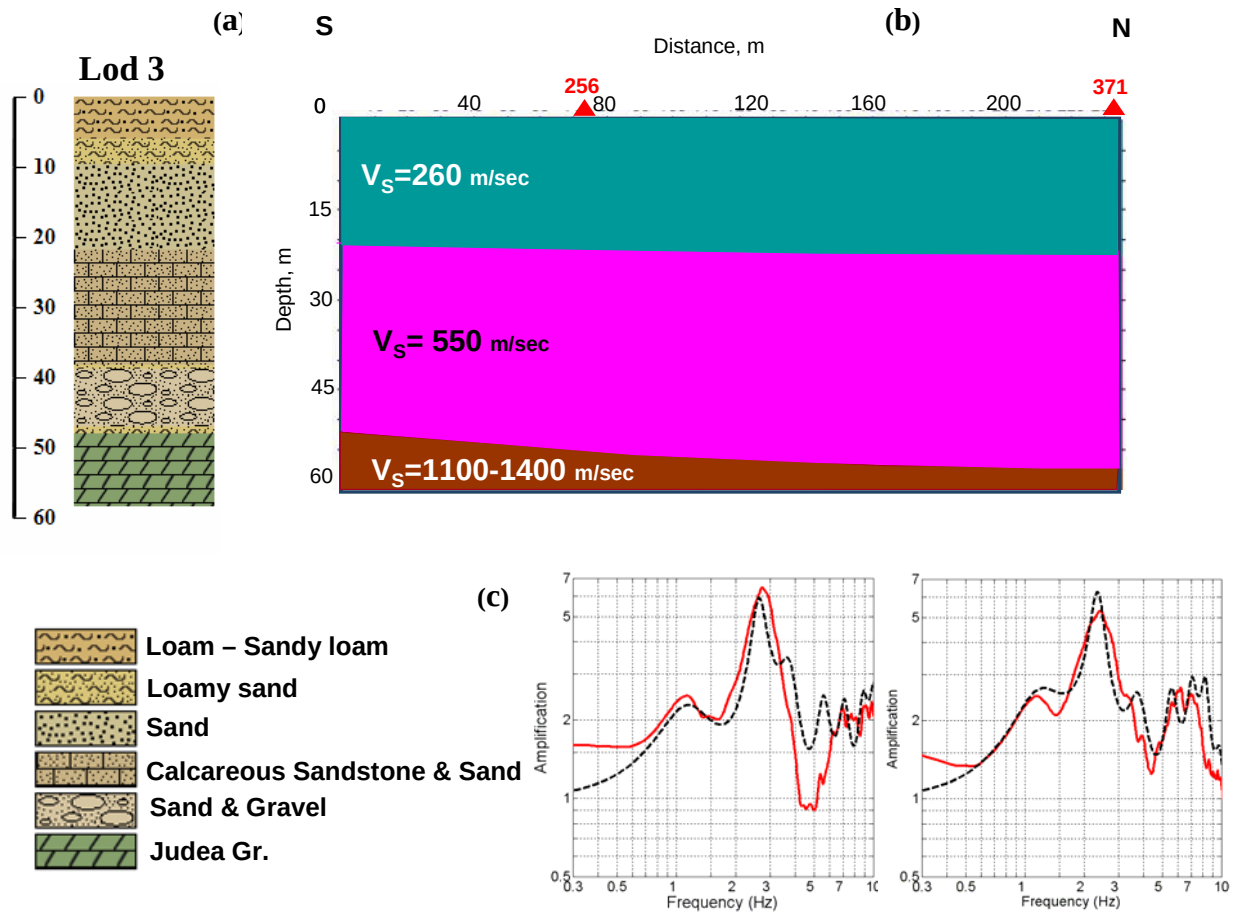


Figure 18. (a) Lithological cross section of Lod 3 well; (b) – Velocity-depth section along AI-2 refraction profile; (c) - comparison between H/V spectral ratio (red line) and analytical transfer functions for sites 256 and 371, calculated using well and refraction survey data (black line).

Table 3. Geotechnical data and soil column model for sites located along profile AI-2 close to Lod 3 well.

Lod-3 data		Refraction survey data (AI-2 profile)	Soil column models for sites 256 and 371	
Lithology	Depth interval, m	V_s , m/sec	Thickness, m	V_s , m/sec
Loam and silt	0-22	260	20-22	250
Calcareous sandstone and sand	22-48	550	22-24	600
Chalky limestone and broken dolomite (Judea Gr.)	48 and below	1100-1400	200-220	1100
Dolomite (Judea Gr.)	?	-	-	1900

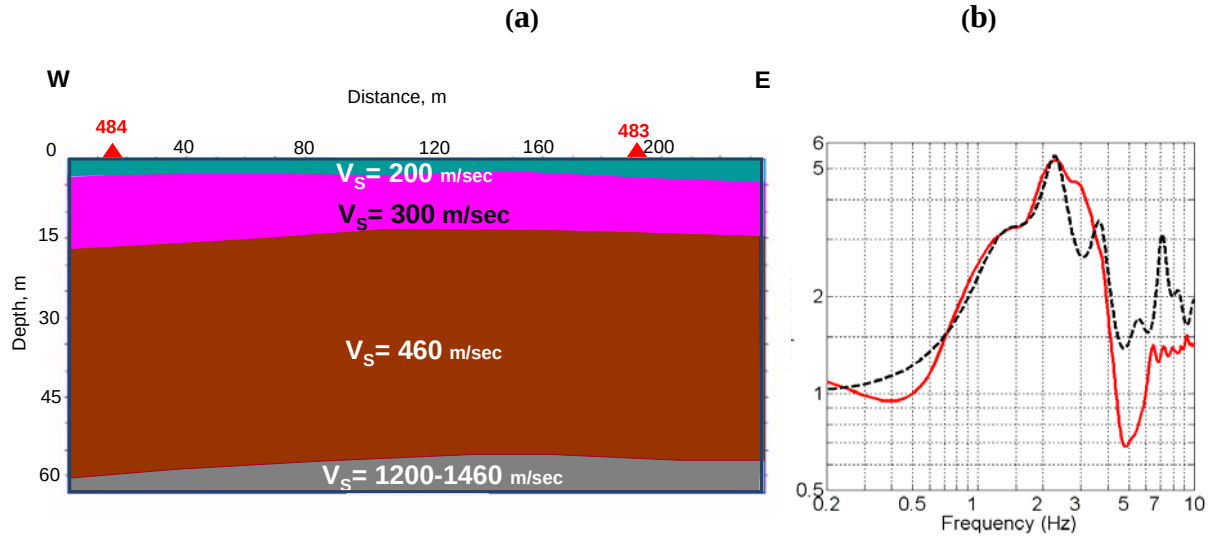


Figure 19. (a) Velocity-depth section along AI-1 refraction profile; (b) - comparison between H/V spectral ratio (red line) and analytical transfer functions for site 483 calculated using refraction survey data (black line).

Refraction profile BS-4 is carried out at a distance of 400 m eastward of YE-4 well, in order to obtain V_s for marl-chalk layer. BS-4 profile and YE-4 well are in similar geological conditions that enable using the lithological data from the well, while the thicknesses of the layers may be slightly varied. Interpretations of line BS-4, shown in Fig.20b, suggest a composition of four layers. Based on the data from YE-4 well, those layers are correlated with loam ($V_s=280$ and 490 m/sec), marl-chalk ($V_s=800$ m/sec) and limestone of the Judea Gr. ($V_s=1400$ m/sec). We note that YE-4 well penetrates the limestone layer and reaches the dolomites, that gives us the initial estimation of limestone thickness (Fig. 20a) for sites located along the refraction profile. The analytical transfer functions, which are in good agreement with the H/V spectral ratios (Fig. 20c), lead to the model presented in Table 4.

We note that modeling wells located at different parts of the study area demonstrate lateral heterogeneity of V_s for chalk-marl layer of the Mount Scopus Gr. Thus, for instance, in order to fit the analytical function to spectral ratio at Lod 23 well located in the northern part of the study area, we should use $V_s=950$ m/sec for the chalk layer. V_s value equal to $900-950$ m/sec is obtained in Petah Tikva area. This well also penetrates the Turonian limestone and reaches dolomite that again confirms our assumptions concerning the dolomites of the Judea Gr. as the

fundamental reflector. Comparison between H/V spectral ratio at borehole site and analytical model is shown in Fig. 21.

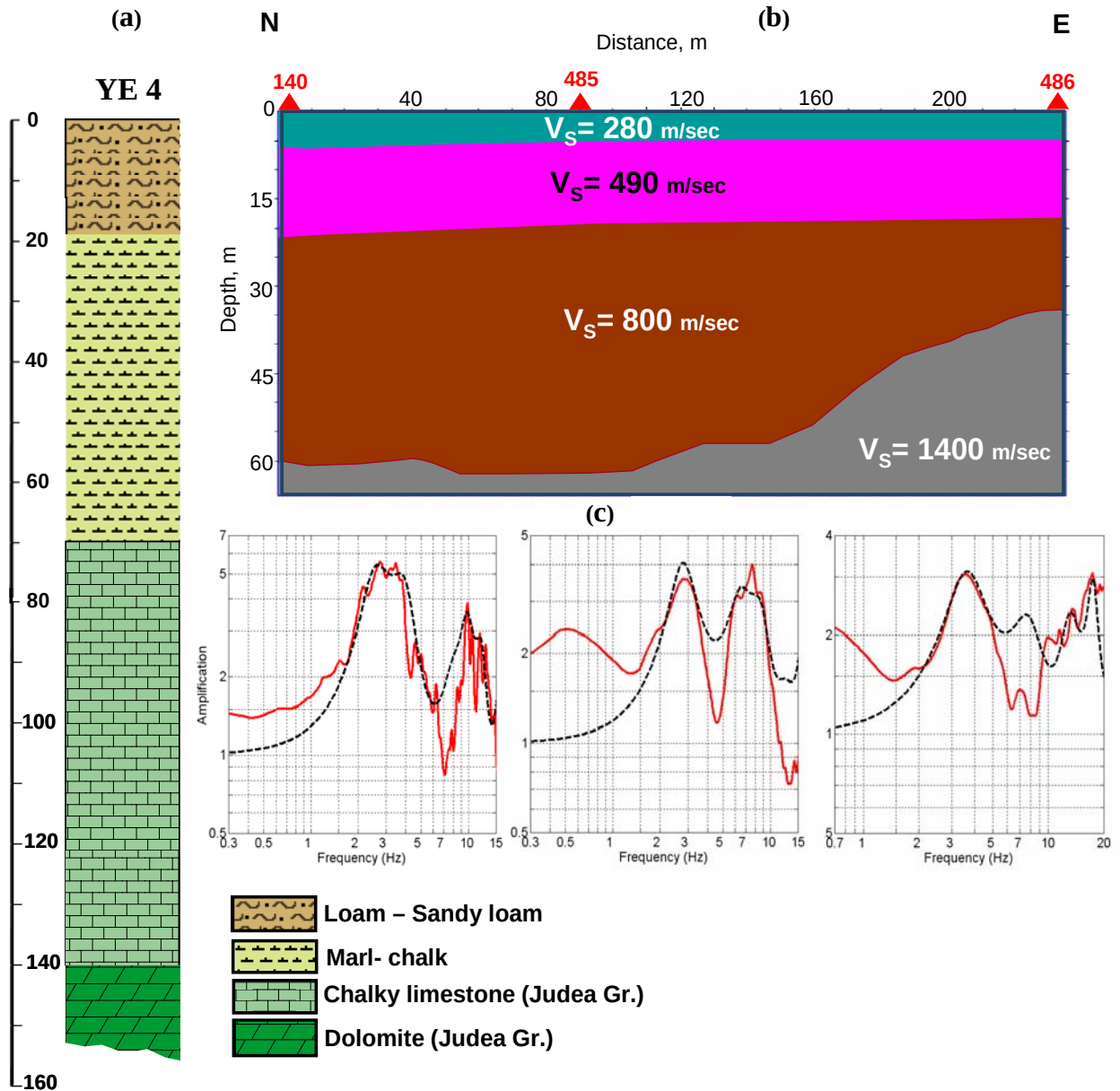


Figure 20. (a) Lithological cross section of YE-4 well; (b) – Velocity-depth section along BS-4 refraction profile; (c) - comparison between H/V spectral ratio (red line) and analytical transfer functions for sites 140, 485 and 486, calculated using well and refraction survey data (black line).

Table 4. Geotechnical data and soil column model for sites located along refraction profile BS-4 (400 meters from YE-4 well).

YE-4 well data		Refraction survey data (BS-4 profile)	Soil column models for sites 486, 485 and 140	
Lithology	Depth interval, m	Vs, m/sec	Thickness, m	Vs, m/sec
Clay and silt	0-20	280	5-12	240-290
		490	12-18	490-500
Marl	20-70	800	20-45	800
Chalky limestone (Judea Gr.)	70-140	1200-1400	25-45	1200-1400
Dolomite (Judea Gr.)	140 and below		-	1900

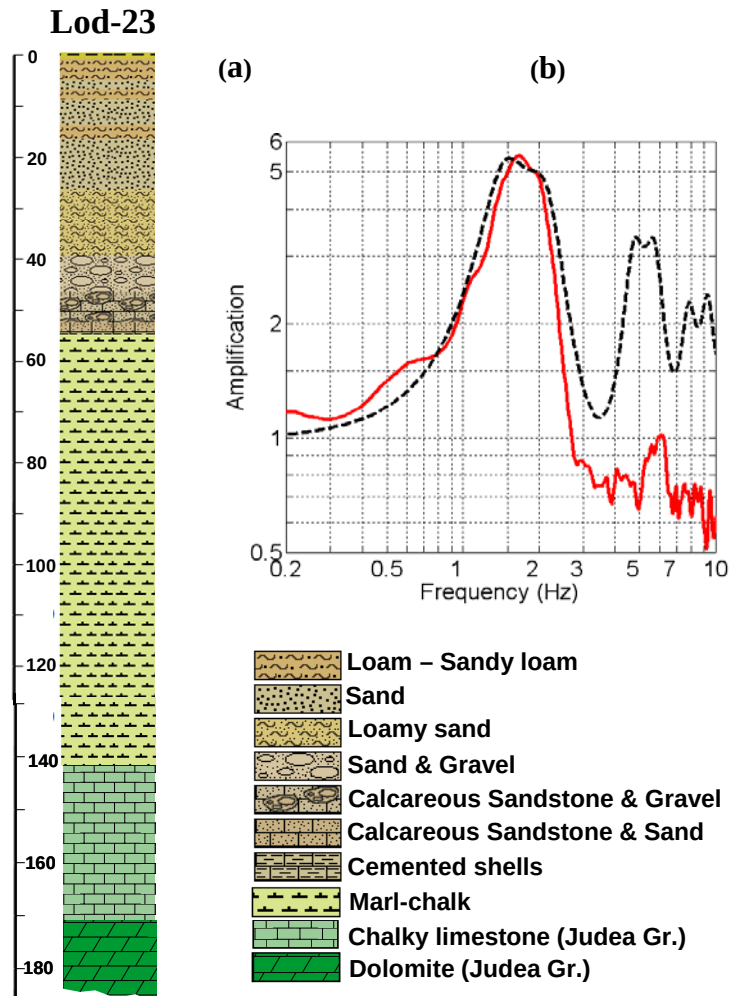


Figure 21. (a) Lithological cross section of Lod 23 well; (b) Comparison between H/V spectral ratio (red line) and analytical transfer functions for site 19 calculated using well data (black line).

Table 5. Geotechnical data and soil column model for Lod-23 well.

Lod 23 well data		Soil column model for site 19	
Lithology	Depth interval, m	Thickness, m	Vs, m/sec
Loam, sand	0-27	27	200
Sand, sandstone	27-40	13	550
Calcareous sandstone and gravel	40-55	15	750
Chalk	55-142	85	950
Chalky limestone (Judea Gr.)	142-172	30	1100
Dolomite (Judea Gr.)	172 and below	-	1900

Vs value for clay obtained in Petah Tikva is tested at several wells with varying thickness of this layer. We give two examples of Lod 25 and Sakiye-2 wells. The soil column models and comparison of the analytical functions with H/V ratios are presented in Table 6 and Fig. 22.

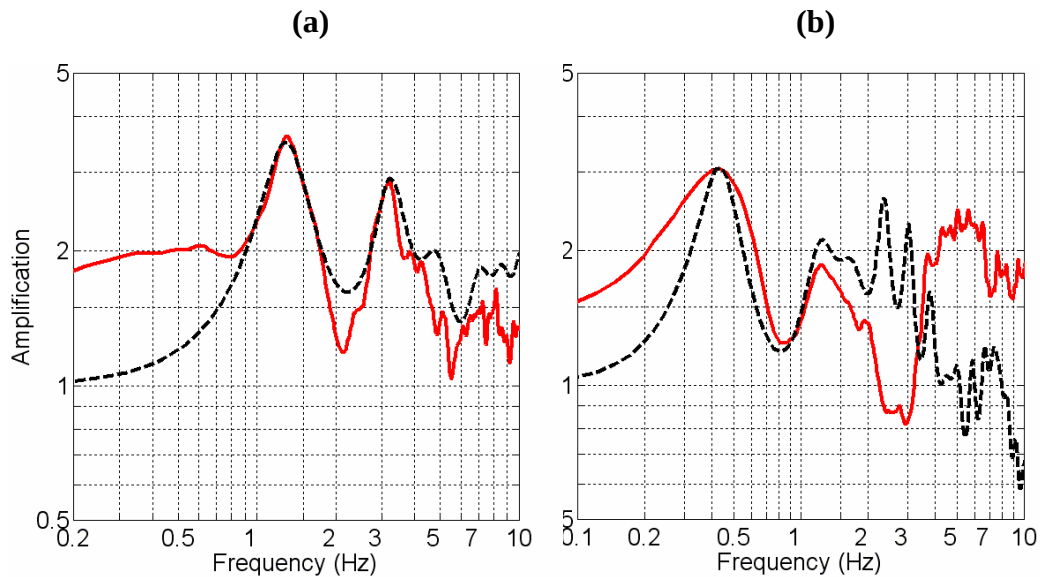


Figure 22. H/V spectral ratios for Lod 25 (a) and Sakiye 2 (b) wells superimposed the analytical functions calculated based on the well data

Table 6. Geotechnical data and soil column model for Lod-25 and Saqiye 2 wells.

Lod 25 well data		Soil column model for site 552	
Lithology	Depth interval, m	Thickness, m	Vs, m/sec
Loam	0-23	25	415
Conglomerate	23-28	7	500
Clay	28-80	55	600
Chalk	80-125	40	800
Chalky limestone (Judea Gr.)	125-164	40	1250
Dolomite (Judea Gr.)	172 and below	-	1900
Saqiye 2 well		Soil column model for site 364	
Lithology	Depth interval, m	Thickness, m	Vs, m/sec
Sandy clay	0-45	45	440
Gravel, loamy sandstone	45-90	45	740
Clay	90-365	250	620
Chalky limestone (Judea Gr.)	Below 365	200	1200
Dolomite (Judea Gr.)	?	-	1900

The last example represents sites located in the western edge of the study area, where the Judea Gr. is dipping to depth of 800-1000 m and calcareous sandstone of the Kurkar Gr. governs site response. As shown in Fig. 23a, the calcareous sandstone is found in Saqiye 53 well at a depth of 50 meters and overlain by sand and sandy loam $V_s=750$ m/sec for the reflector matches the analytical model to H/V ratio pretty well (Fig. 23b).

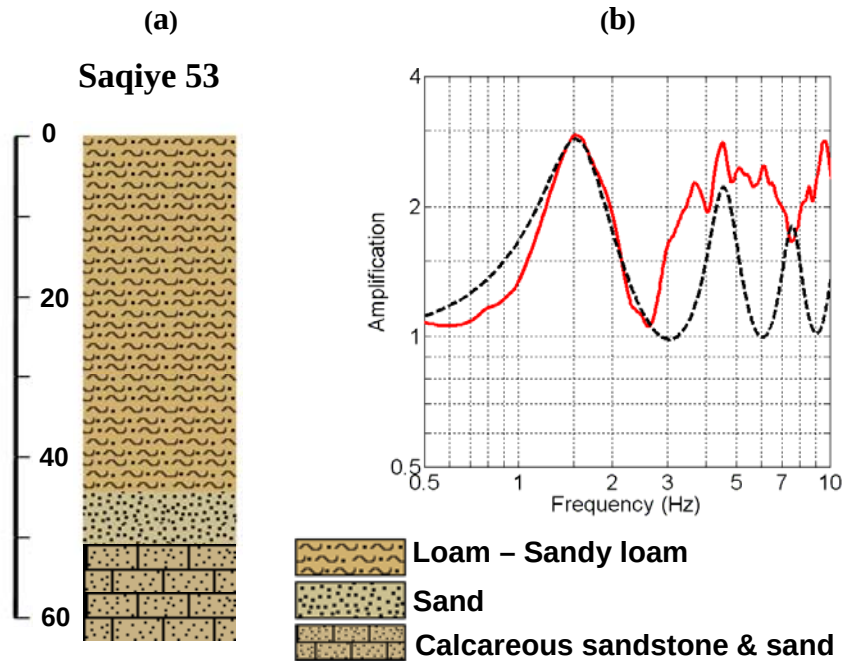


Figure 23. (a) Lithological section of Sagiye 53 well and (b) H/V spectral ratio for site 361 in comparison with the analytical function calculated based on well data.

The results of modeling at many boreholes with different lithological sections considering interpretation of the seismic refraction survey data show that S-wave velocity structure derived in the Petah Tikva area is suitable for the Lod Valley area as well. Vs ranges for the lithological units represented in the study area are summarized in Table 7.

Table 7. S-wave velocity structure for the study area

Material	Vs, m/sec
Alluvium, silt	150-250
Sand, loam	250-400
Sand, sandstone, gravel, conglomerate (Quaternary)	450-600
Calcareous sandstone (Kurkar Gr.), clay (Yafo Fm.)	600-700
Marl, chalk (Eocene-Senonian)	750-950
Chalky limestone and broken dolomite (Judea Gr.)	1100-1400
Dolomite and limestone (Judea Gr.)	1900

3.3. Estimation of subsurface structure along profile

Encouraged by the good fit between the H/V spectral ratios and the analytical response functions computed at well and refraction survey locations, we start at sites where we have subsurface information and then propagate by means of extrapolation to neighbouring sites, using H/V spectral observations as constraints. Since V_s is constrained by refraction data, H/V spectral ratio information contributes mainly in estimating layer thicknesses. Moreover, considering both first and second resonance peaks (if available), the layer thickness may be estimated quite accurately, using the second as additional constraint in selecting a plausible value.

The stochastic optimization algorithm (Storn and Price, 1995) is applied in order to fit an analytical transfer function to an observed H/V spectrum, giving the same weight at the fundamental and second natural frequencies and considering their amplitudes.

The practical relevance of ambient noise investigations may be illustrated by means of cross sections, whose positions are indicated in Fig. 1.

3.3.1. Profile AA

Profile AA', oriented EW and located in the northern part of the study area, is shown in Fig. 24. Along the whole profile AA' one can see the chalky limestone layer (the Judea Gr.) $V_s=1000-1400$ m/sec for this layer has been directly determined by refraction survey in different places. We demonstrate in the Petah Tikva study that chalky limestone of Turonian age is not a fundamental reflector but an intermediate layer. The fundamental reflector is the underlying Cenomanian dolomite and limestone and its $V_s=1970$ m/sec was already detected by refraction survey in the Parsa area located in the Dead Sea Rift system (Zaslavsky et al., 2000) and in the Dimona area (Zaslavsky et al., 2004).

In the western part of the profile the Judea Gr. dips at a depth of more than 1000 m, therefore we model only upper 40-50 m of deposits overlying the shallow reflector represented by calcareous sandstone of the Kurkar Gr. The spectral ratios for points from 369 to 447 show frequencies of 1.2-1.4 Hz and amplitudes of 2-3 (see Fig. 25). The fundamental frequency at point 365 sharply decreases down to 0.27 Hz with the same amplitude that is interpreted as the reflector change. From this point, the fundamental reflector is the Judea Gr. A fault between points 363 and 328 with the vertical displacement of 200 meters is also mapped in the structural map of the Judea Gr. (Fleischer and Gafsoy, 2000).

The segment of the profile between points 328 and 319 is represented by the H/V ratios with two separate peaks typical for soil column including thick layer of clay-marl (the Yafo Fm.). This uplifted block is limited by faults. The fault between points 319 and 318 with vertical shift of 100 m is associated with a decrease in the fundamental frequency from 0.6 Hz to 0.5 Hz, respectively. Saqiye-2 well, located at this block, penetrates chalky limestones of the Judea Gr. at a depth of 360 m.

The H/V spectral ratios in the next segment (up to point 52) are characterized by two inseparable peaks. Such shape indicates presence of high velocity intermediate layer, which is the Eocene-Senonian marl-chalk together with Turonian limestone. These deposits of 18 m and 66 m, respectively are found in Beeroth-Yitzhak well. Based on this well data we extend marl-chalk layer over the whole segment. Turonian deposits, as above mentioned, are traced also in Saqiye-2 well.

The eastern part of the profile is distinguished owing to local areas of H/V ratios with low amplitude fundamental peak at frequencies 1-1.3 Hz and significantly higher amplitude of the second resonance peak at frequencies 2-6 Hz. As already above indicated, these local areas are probably related to the fractured karstic zones within the Ayalon Saline Anomaly in the carbonate rocks of the Yarkon-Taninim aquifer. The calculated thickness of 200-230 meters for the broken dolomites provides a fair fit between the analytical and experimental estimations.

A series of faults divides the reflector into blocks of different depth. Two of five identified faults (points 365 vs. 363 and 52 vs. 484) are previously mapped in the structural map. Three faults in the central part of the profile are unmapped in the structural map and detected by H/V analysis only. Their strike is seen in the frequency distribution map (Fig. 13). The narrow uplifted block continues probably to the southeast; however lack of measurements within the Ben Gurion airport area does not allow us to trace the faults.

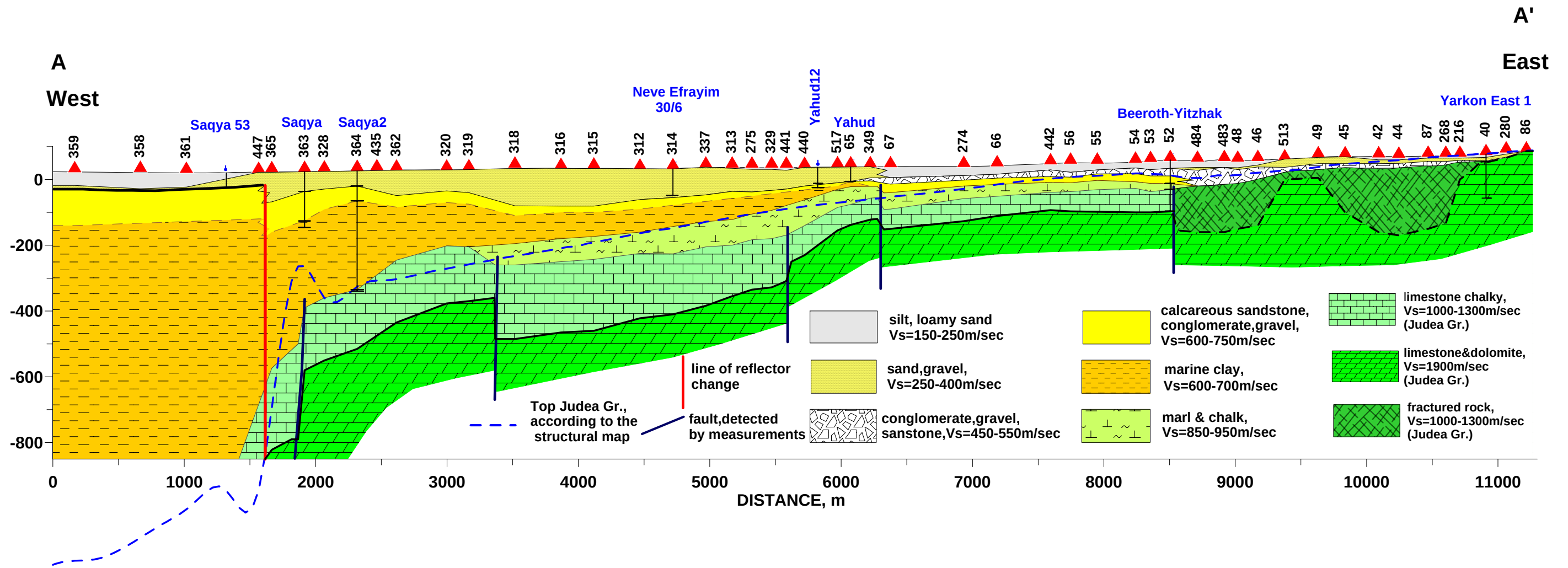


Figure 24. Schematic geological cross section along AA profile constructed on the base of H/V ratio analysis.

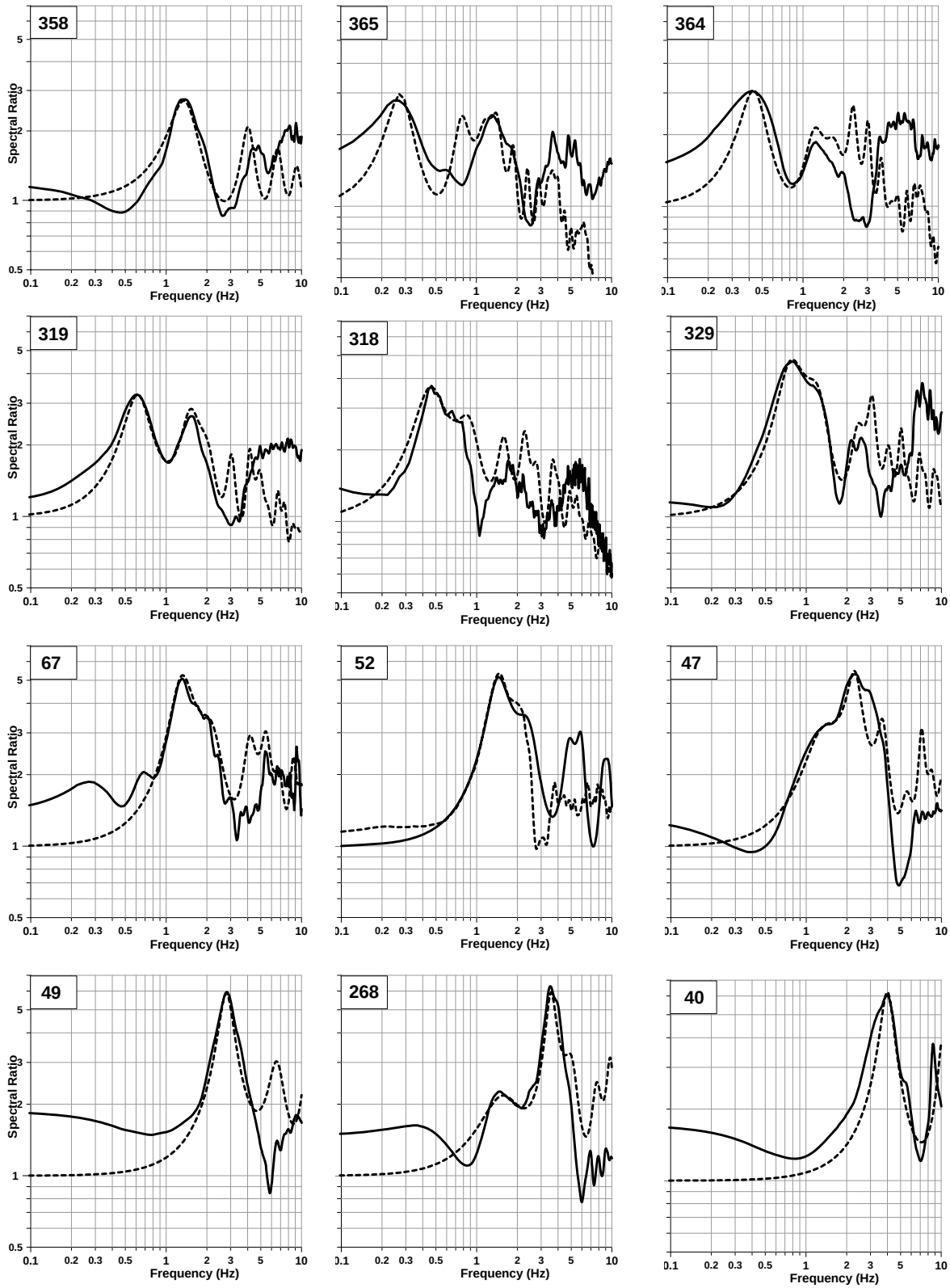


Figure 25. H/V spectral ratios (solid line) and analytical transfer functions (dashed line) for representative points along profile AA.

3.3.2. Profile BB'

Profile BB is located 12 km south of profile AA', is oriented in the EW direction and passes through paleo-erosion channel of the Ayalon River in the eastern part of the study area. The schematic geological cross section along the profile is displayed in Fig. 26, and representative H/V spectral ratios are shown in Fig. 27.

Site 563 located in the western edge of the profile shows low H/V peak amplitude at frequency 1.5 Hz. As in AA' profile, site effect is produced by sand and sandy loam over calcareous sandstone of the Kurkar Gr. At site 197, the sandstone crops out and no resonance frequency is observed. Change of fundamental reflector occurs between sites 197 and 561. The H/V curve at site 561 shows amplitude of 3 at frequency 0.3 Hz. The Top Judea depth, calculated by H/V ratio, is about 700 meters and agrees with the structural map data. Basalt-tuff of the National Park (Miocene age) of approximately 300 m thick is found in RL-1 well assumed as intermediate hard layer overlying the fundamental reflector. Its Vs derived from the modeling at site 177-1 is 1400 m/sec. The H/V ratios like at sites 561 and 177-1, with two separate low amplitude peaks, are typical for subsurface structure including the thick (300-400 m) Yafo clay-marl layer. Between sites 177-1 and 560 we observe an increase in the fundamental frequency from 0.35 Hz up to 0.4 Hz that corresponds to a vertical displacement of 150 meters. A fault is detected also in the structural map. We note that starting from site 560 the limestone of the Judea Gr. is intermediate hard layer. Shape of the H/V curve exhibiting two separate low-amplitude peaks typical for models including a thick Yafo clay layer, is observed from site 560 to 549. Slightly different shape of the H/V ratio at site 489 may be explained by a rise of the reflector and thinning of the clay layer. This observation is indicated in the structural map (Fig. 4).

Likewise AA' profile, the H/V ratio curves between sites 429 and 544 situated in the central segment indicate influence of high velocity layer. It is expressed in the second peak inseparable from the fundamental one. This segment is the uplifted block and the fundamental frequency for all the sites from this block varies in the range of 1.5-2.0 Hz. The Yafo clay layer is gradually thinning up to site 292. It is of interest that H/V ratio at well LD-25 (site 552) is different from that at 292 owing to two separate peaks. We suppose that the thickness of the clay layer has increased and affected the spectral ratio. This conclusion fully agrees with Lod-25 well data. Sharp decrease in the fundamental frequency from 2 Hz down to 1.3 Hz implies a vertical displacement of about 100 meters.

The next segment comprises sites from 544 to 277 located within the Ayalon River channel. The chalk-marl layer filling the paleo-channel influences the spectral ratios shape. Thickness of united chalk layer in Beit Nabala 2 well is 200 m. Sites 555, 296 (BN-2 well) and 277 show H/V ratios with two separate peaks. The first one of 1-1.2 Hz is produced by the Judea Gr. and the second is formed by impedance contrast between alluvium-conglomerate and marl-chalk layers. We note that the influence of the Turonian limestone layer on the model for sites from this block is negligible. Therefore this layer is supposed to be wedged out. The fault between sites 555 and 186 is identified by spatial distribution of the fundamental frequency (see map in Fig.13). The last two sites 277 and 278 are located on the different sides of the fault that also reflected in the ratio curves. We observe a single peak at site 278, where alluvium and conglomerate overlying directly the Cenomanian dolomites or the Turonian limestone with insignificant thickness. As for site 279, we observe amplitude 2.5 at frequency 7 Hz that corresponds to the conglomerate overlying the Judea Gr.

3.3.3. Profile CC'

To reconstruct subsurface structure along profile CC' (Fig. 28) of 14.5 km long, oriented north-south, we use also the results of measurements carried out within the framework of microzoning study in the town of Lod (Zaslavsky et al., 2001). The subsurface structure of the southern part of profile CC' up to point 530 is represented by sandy loam overlying marl-chalk layer, which is thinning to the north. The Judea Gr., underlying the marl-chalk, consists of Turonian chalky limestone, Cenomanian limestone and dolomite. Information on thickness of Turonian limestone is obtained from LI and LD-17 wells located directly at profile CC', also from YE-2, YE-5, LD-29, LD-25, LD-T1, LD-14 and others wells located in the vicinity. Analogously to two latitudinal profiles described above, the chalky limestone of the Judea Gr. is assumed as intermediate layer, while the dolomite is a fundamental reflector.

The spectral ratios in the southern part of profile CC', characterized by the typical shape with two inseparable peaks, shows a general trend of increase from 1.5 Hz (points 31) to 3.5 Hz (point 530), while the amplitude changes from 3 to 7, controlled mainly by the upper layer. We note that points 10 and 178 form local synclines. Two faults between points 506 and 241 and 528 and 179 limit a graben forming paleo-erosion channel of the Ayalon River, which is mapped in the structural map of the Judea Gr. However, by our estimation this graben is significantly narrower than by geological data.

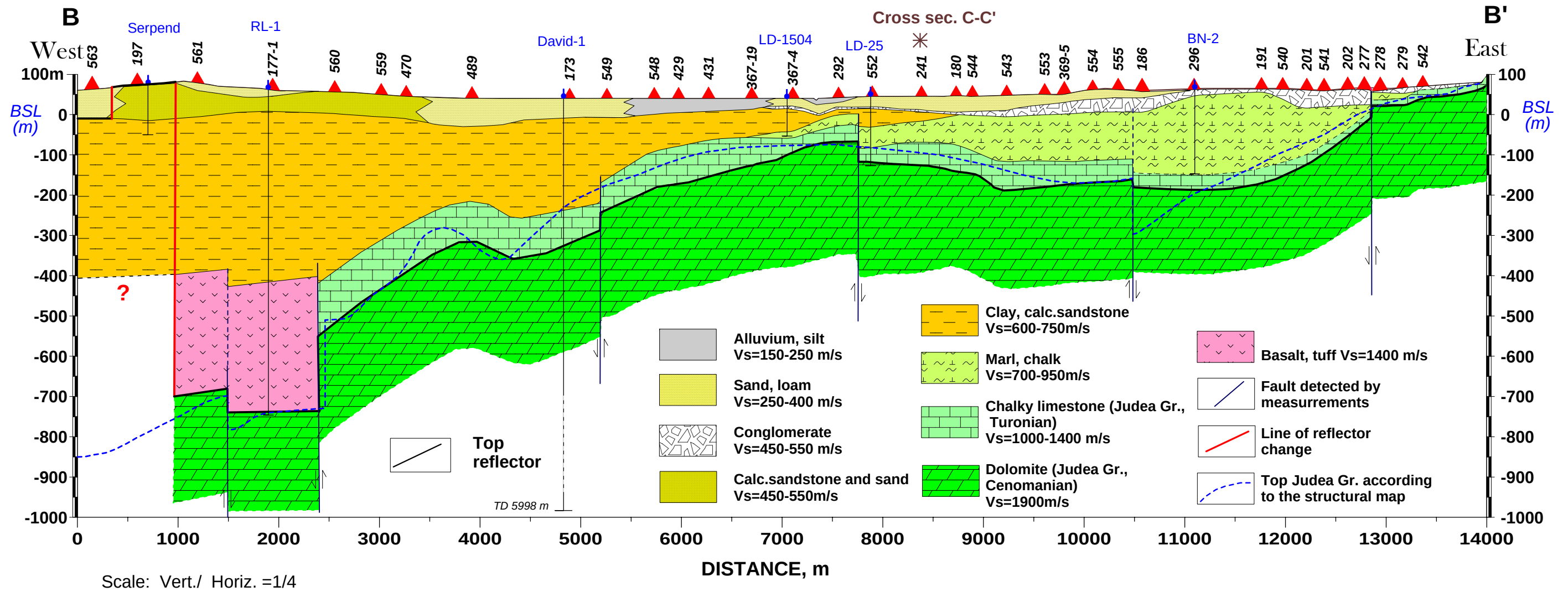


Figure 26. Schematic geological cross section along BB' profile constructed on the base of H/V ratio analysis

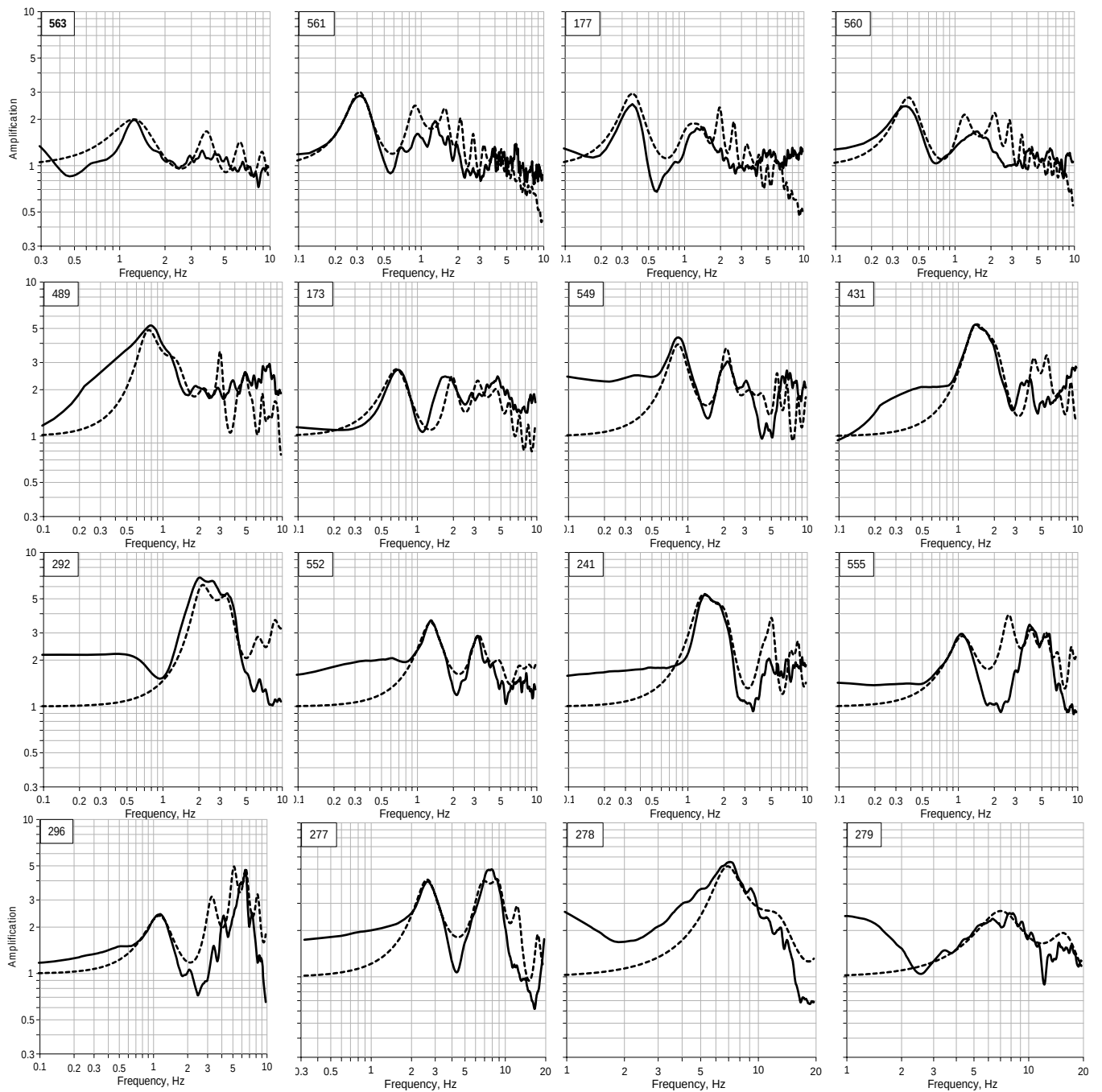


Figure 27. H/V spectral ratios (solid line) and analytical transfer functions (dashed line) for representative points along profile BB.

The vertical displacements are clearly identified by significant shifts in the fundamental frequency 2.05 Hz, 1.4 Hz, 2.6 Hz at points 506, 241 and 368 correspondingly. In our models we refer to the Lod-25 well data located in this graben not far from the profile, in which the Yafo clay layer of 55m thick and chalky limestone of the Judea Gr. of 40 m thick are found.

The segment of the profile from point 169 to the northern edge crosses a zone characterized by alternation of spectral ratios with single resonance peak at frequencies 2-3 Hz having amplitudes up to 8-9 and ratios showing two resonance peaks: the first one is at frequencies 0.96-1.3 Hz with amplitudes 2-2.5 and the second is at frequencies 2-4 Hz with amplitudes 5-8. This zone is indicated in the frequency and amplitude maps (see Figs. 13-15) and our interpretation is also given. Therefore, we briefly present our reasoning. We suppose the local areas with two frequencies to correlate with Turonian and Negba carbonates within the heterogeneous tectonically disturbed zones (fractured rocks), typically associated with karstic systems. The frequencies 0.95-1.3 Hz correspond to the Negba Fm. underlying the Turonian limestone at depths of 200-250 m. We note that $V_s=1000-1300$ m/sec for this rock obtained from the refraction survey are valid up to depths of 50-60m, whereas we extrapolate this velocities significantly deeper. Therefore, assuming possible errors in depth estimation, we show top reflector by the dashed line. Some examples from the fractured zone demonstrating H/V ratios with two resonance peaks (371 and 169) vs. single-peak ratios (211 and 373) are displayed in Fig. 29. Ratios at points 373, 51, 211, 500 and 501 yielding single peak with high amplitude are classic for sites with large impedance contrast between soft sediments and reflector, corresponding to Judea Gr. according to well data. There is chalky limestone in some wells. We note that the thickness of this layer is not exceeding 20-30% of the reflector depth and does not influence the model, and thus we have analytical function like point 211. Points 7 and 563, showing fundamental peak at frequency 2 Hz and second at 3 Hz, are located in the peripheral part of the anomalies.

A fault identified between points 373 and 257 is probably a continuation of the one mapped in the structural map (Fleischer and Gafsou, 2001) to the northeast. Whereas we do not detect two faults traced in the structural map between points 395 and 372; and 406 and 248 we do not detect due to small vertical shift.

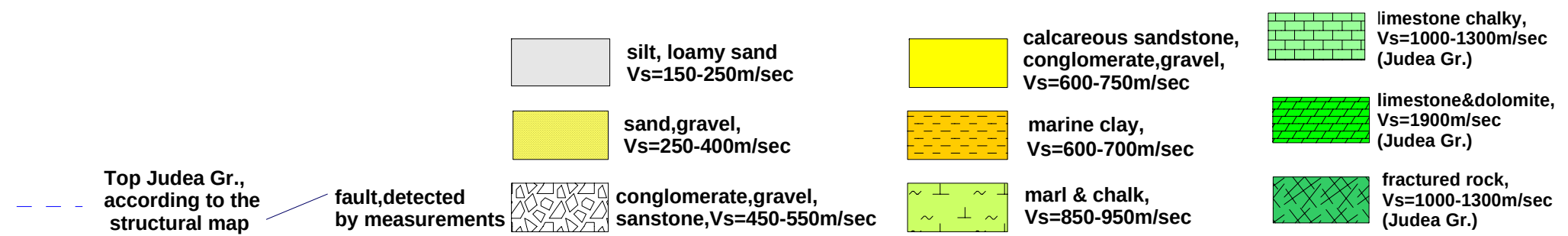
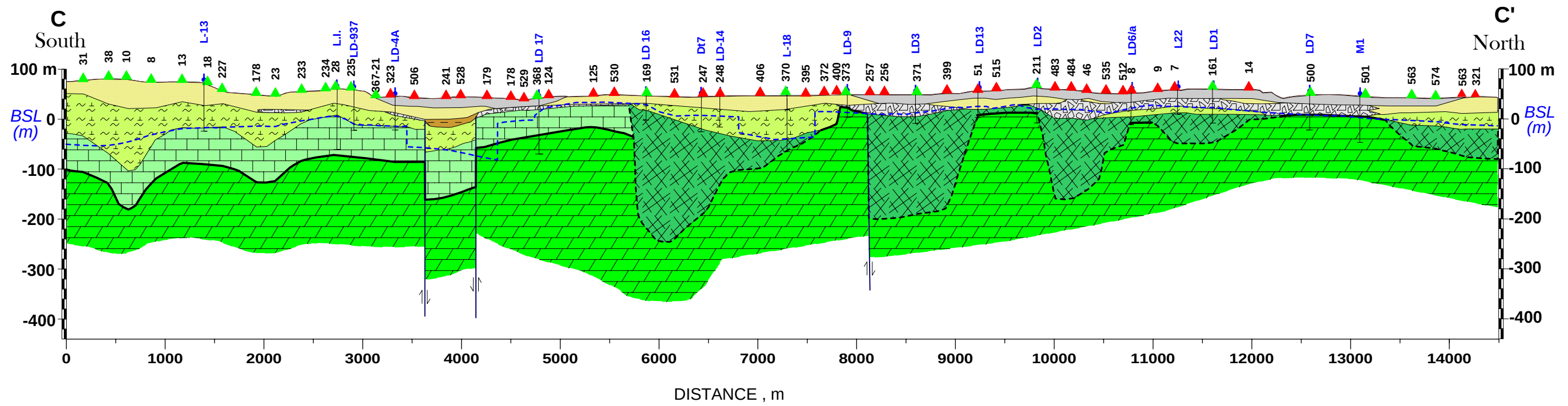


Figure 28. Schematic geological cross section along CC' profile constructed on the base of H/V ratio analysis.

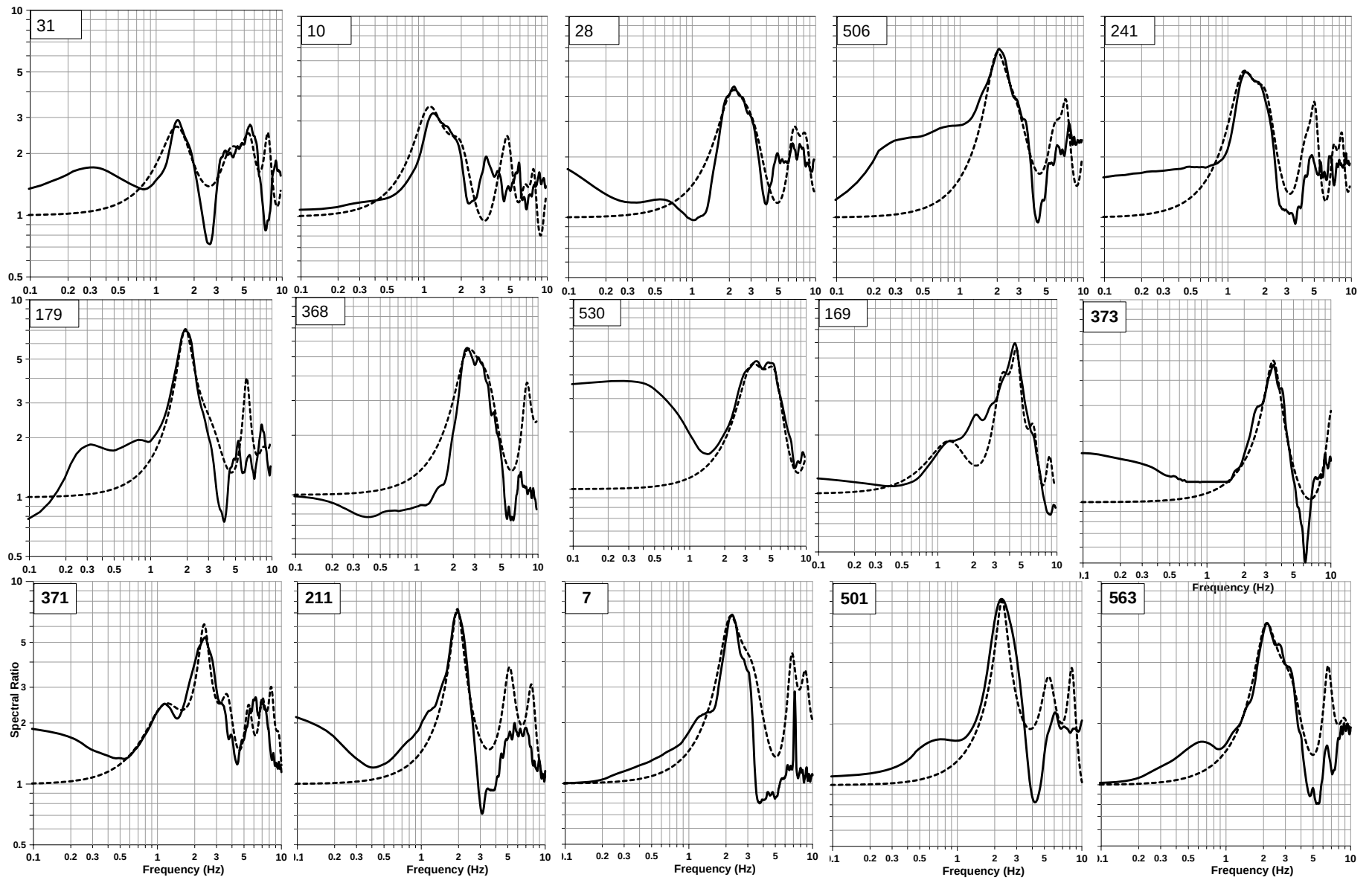


Figure 29. H/V spectral ratios (solid line) and analytical transfer functions (dashed line) for representative points along profile CC'.

4. SEISMIC HAZARD MICROZONATION

The design acceleration spectrum is essentially a representation of the maximum acceleration amplitudes for a prescribed probability of occurrence developed on a set of one degree of freedom oscillators with a given damping ratio. Since seismic activity in areas such as Israel is low, local acceleration data from strong earthquakes is insufficient to estimate directly the design acceleration spectrum. Neither do we have good reasons to assume that empirical attenuation functions of spectral accelerations that have been developed from observations in other parts of the world are applicable in Israel, let alone in areas where we expect geological site effects. Consequently, we prefer to resort to the use of synthetic data where local and regional characteristics of the geology and the seismicity are incorporated into the modelling.

The SEEH procedure (Stochastic Estimation of the Earthquake Hazard) developed by Shapira and van Eck (1993) and briefly described above, generates synthetic site specific acceleration response functions while considering; possible scatter of the attenuation parameters of S waves propagating the region, estimations of seismic moments from local magnitudes, possible stress drop values that are likely to be associated with earthquakes in the region etc. All mentioned uncertainties are incorporated in the process by using Monte Carlo statistics. The latter is also used to incorporate the uncertainty in estimating the seismic activity in the regional seismogenic zones located within 200 km of the investigated site. The response function of the soil column of the site is calculated by using the program SHAKE. The seismic hazard function, i.e., the uniform hazard site-specific acceleration response spectrum is computed for 10% probability of exceedance in an exposure time of 50 years and a damping ratio of 5%.

By comparison to the Uniform Hazard Acceleration Spectra calculated for 90 selected sites and in consideration of the constructed subsurface models across the investigated area excluding that part where no site effect is revealed, we subjectively divided the study area into 8 zones (see Fig. 30). Each zone is characterized by a generalized seismic hazard function representative of the sites within that zone. The characteristic acceleration response spectrum for each zone plus and minus one standard deviation is shown in Fig. 31.

For comparison, we also plot the design spectra required in the same area by the current Israel Standard 413 (IS-413) and for ground conditions that meet the BSSC (1997) soil classification scheme. The shape of the hazard functions differ from those prescribed by the IS-

413 code practically in all zones. The Israel code underestimates the acceleration in the different period ranges for the different zones.

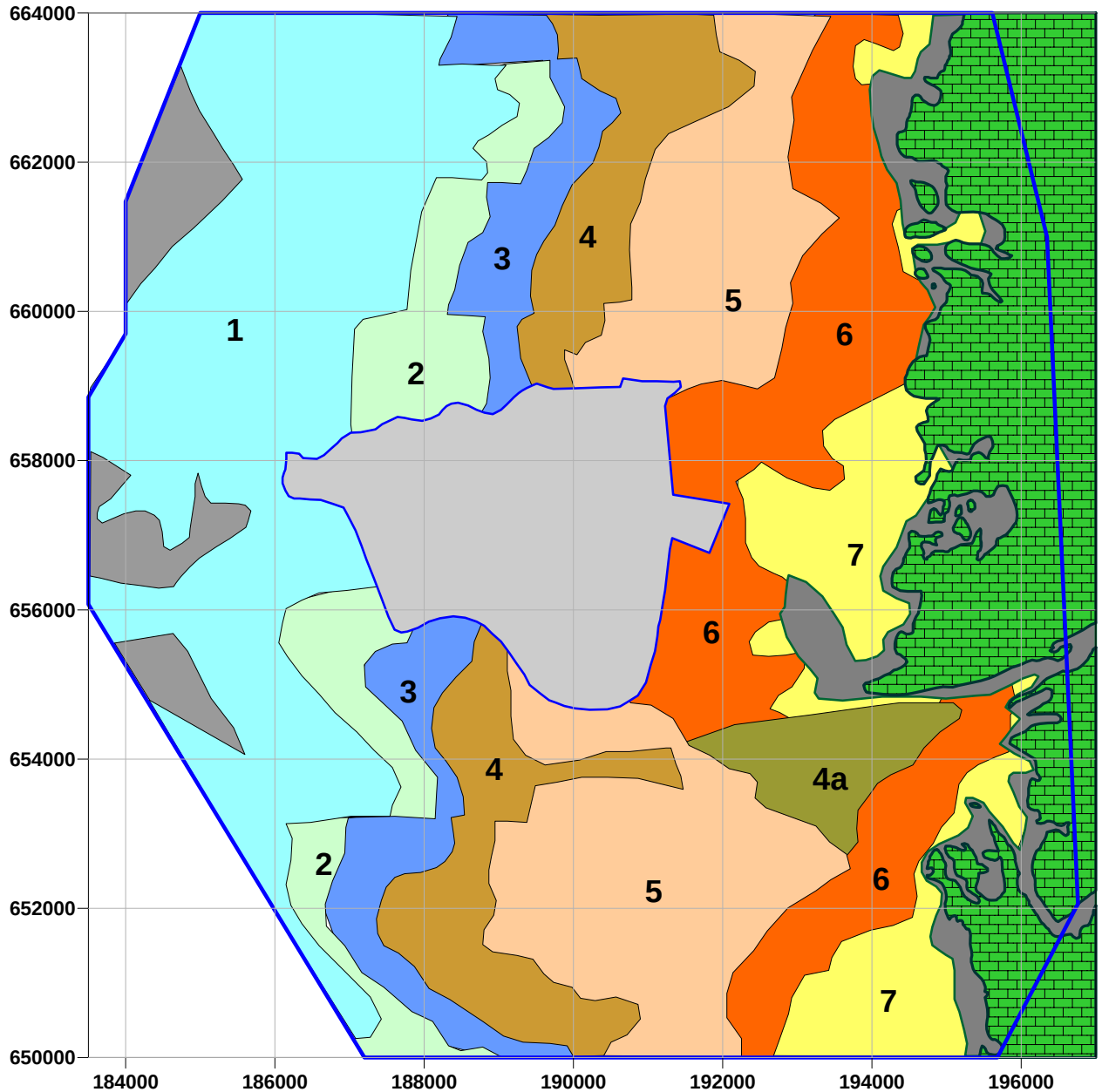


Figure 30. Microzonation map of the study area with respect to acceleration response spectra calculated by SEEH.

Each zone is characterized by a generalized seismic hazard function representative of the sites within that zone. The acceleration spectra for all zones are shown in Fig. 31. The soil column models leading to these generalized functions are given in Table 8.

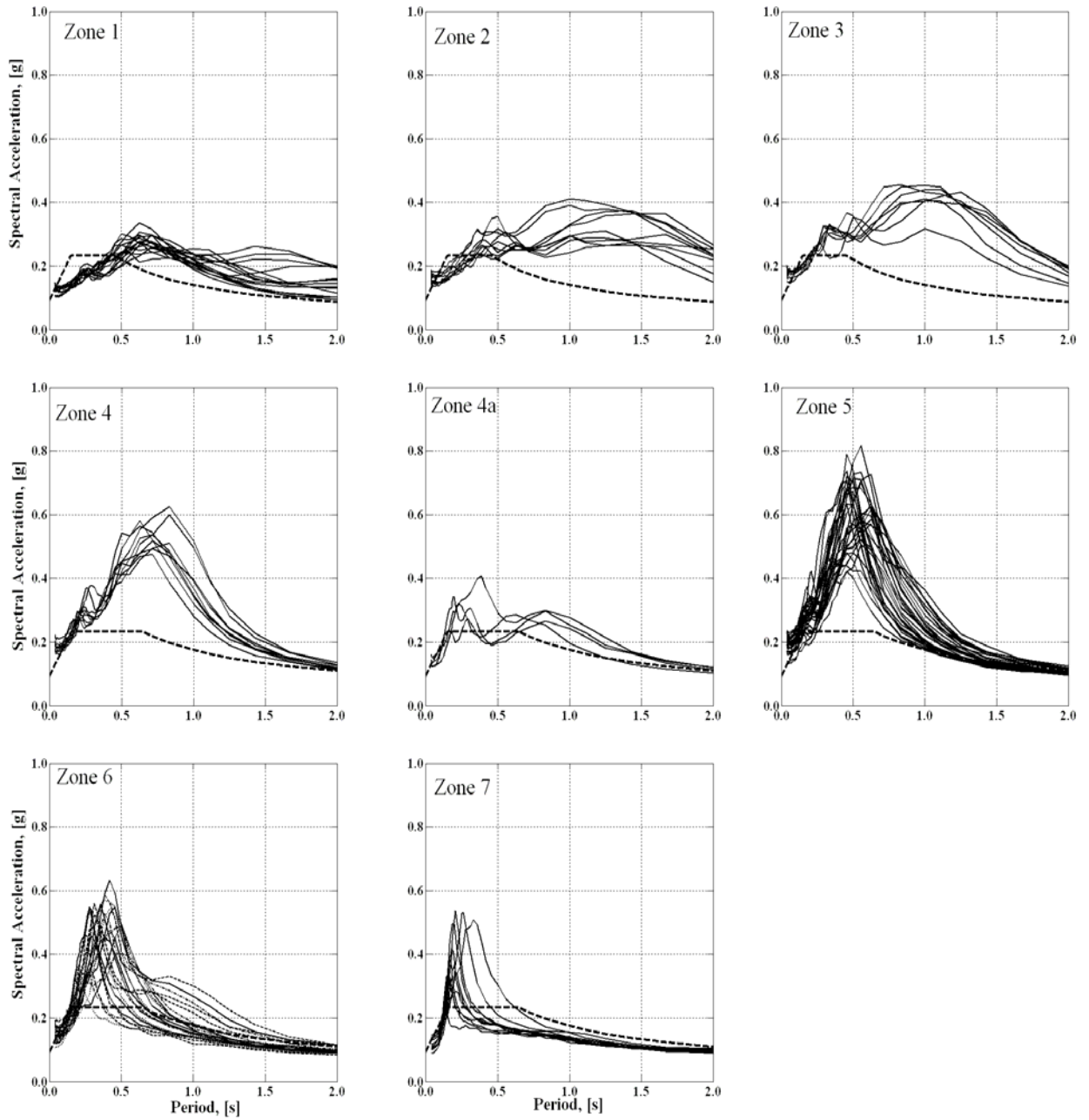


Figure 31. Uniform Hazard Site-specific Acceleration Spectra for different sites within selected zones. Spectrum according to the Israel Building Code (PGA of 0.093) indicated by the dashed line is included for reference.

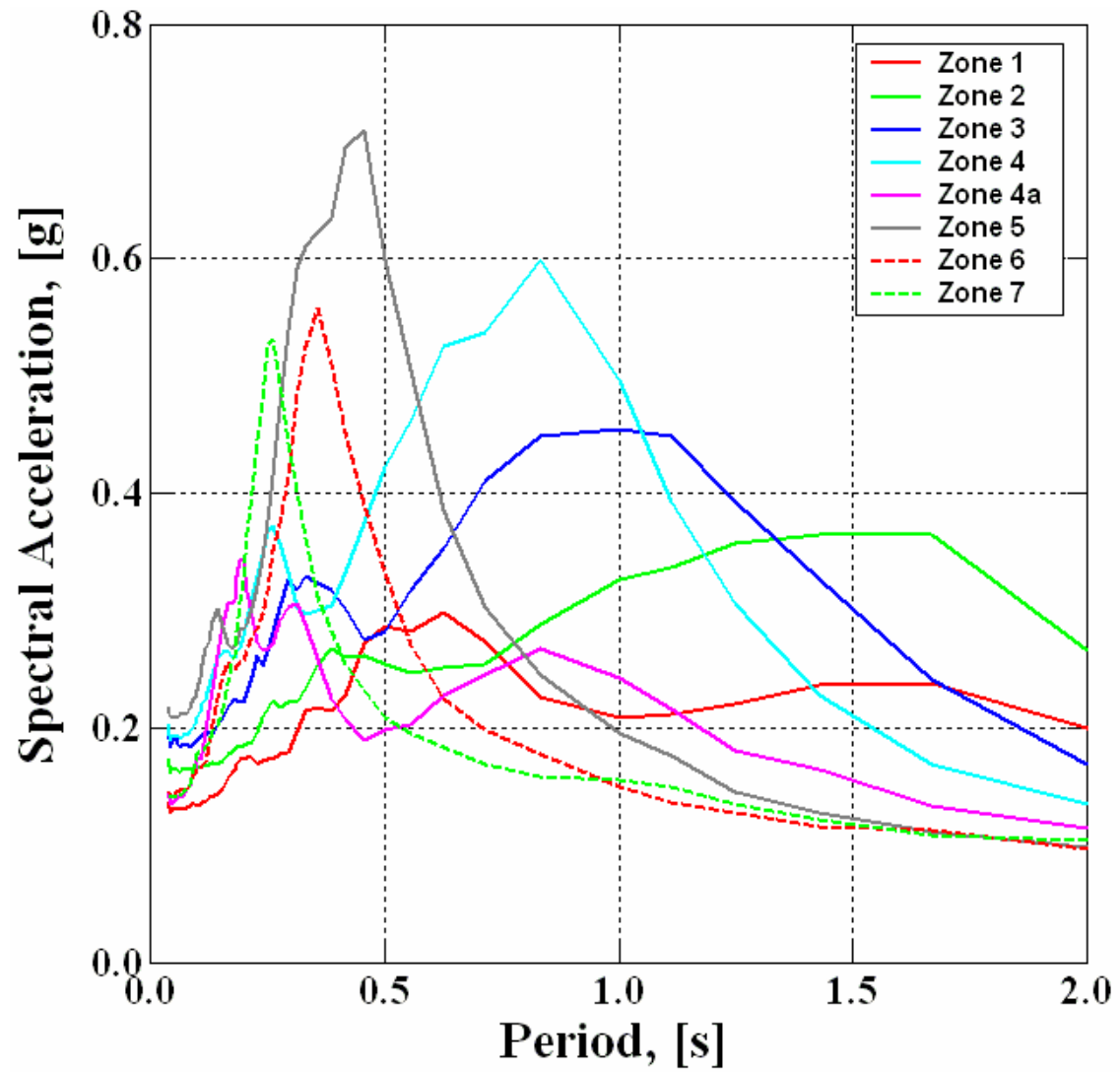


Figure 32. Generalized Uniform Hazard Site-specific Acceleration Spectra for all zones in the study area.

Table 8. Soil column models for calculating generalized acceleration response spectra for zones.

Zone	Thickness, m	Vs, m/sec	Density, g/cm ³	Damping, %	Zone	Thickness, m	Vs, m/sec	Density, g/cm ³	Damping, %
1	50	420	1.8	4	4a	10	250	1.6	4
	300	630	1.8	2		15	650	1.9	3
	180	1100	2.0	1		180	900	2.0	1
	-	1900	2.2			-	1900	2.2	-
2	90	320	1.7	4	5	20	250	1.6	4
	100	670	1.9	2		10	500	1.8	3
	65	980	2.0	1		15	900	2.0	1
	180	1200	2.0	1		65	1000	2.0	1
	-	1900	2.2	-		-	1900	2.2	-
3	60	260	1.6	4	6	15	250	1.6	4
	50	680	1.9	2		20	500	1.8	3
	90	950	2.0	1		20	1200	2.0	1
	135	1200	2.0	1		-	1900	2.2	-
	-	1900	2.2						
4	35	200	1.6	4	7	10	250	1.6	4
	15	550	1.9	2		10	340	1.7	4
	70	920	2.0	1		5	520	1.8	2
	85	1150	2.2	1		-	1900	2.2	-
	-	1900	2.2						

CONCLUSIONS

This report presents a study of the overall project on microzoning of Israel for the southern Sharon and Lod Valley.

The experiment, discussed in the present study, has the following goals:

- Empirical estimation of site effect applying H/V spectral ratio technique from microtremor;
- Improving theoretical site response determinations by comparing the empirical and the analytical assessments, selecting parameters of soil column models for satisfactorily predicting the transfer function by multi-layer 1-D models when linear behavior of the soil is assumed;
- Evaluating site-dependent seismic hazard in terms of ground motion parameters used for engineering applications.

The general conclusions may be summarized as follows:

- Predictions of ground motion based on models inferred from geological and geophysical information only may differ significantly from empirical estimates owing to the geological complexity of the site and the significant uncertainty associated with evaluating model parameters.
- A detailed comparison of the analytical and experimental site response functions obtained from the dense grid of ambient noise measurements allowed establishing shear-wave velocities of different lithological units and thickness of the sediments. Knowledge of these parameters enables us to reconstruct the subsurface structure.
- Our studies demonstrate the significantly added value of performing ambient noise measurements over a dense grid of measuring sites and improve possibilities to calibrate and correlate seismological information with information from different sources; e.g. surface geology, seismic refraction and reflection surveys, bore-hole data, geotechnical information and more. Such an integrated study is likely to produce a coherent and systematic assessment of the seismic hazard prevailing in the study area.
- The analytical transfer functions discussed in this study are only associated with weak motions in the range where the behaviour of the soils is linear. Therefore these functions do not represent the site effects under strong ground motion. The nonlinear characteristics of different site within study area are currently beyond the scope of this study. Nevertheless, based on the result presented above nonlinear site response can be determined by different mathematical models of soil nonlinearity, making use of the models developed for each zone. In that respect, the microzonation maps developed in this study are also relevant for the prediction of ground motions from earthquakes of high magnitudes
- In areas of low to moderate seismicity, microtremor measurements is the most practical approaches for assessing the site response functions to be implemented in earthquake seismic hazard and delineation of future locations of severe damage.

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Appendix A. Well data in the study area

EW	NS	Well number	Well name	Loose sediments	Sandstone and Conglomerate	Clay	Marl, chalk	Basalt	Chalky limestone	Top Judea depth	Well depth
187827	653145	1	David-1	32	58	189	0	0	0	279	5998
185000	663000	2	KA1	50?	90	605	0	0	>84	745	829
183994	662002	3	NP1	<182	?	678	80	210	>38	1150	1188
184897	652972	4	RL1	50	75?	355	13	310	0	803	809
183436	655434	5	RL2	25	120	822	195	13	0	1175	1187
186002	659070	6	S-2	43	47	260	12	0	3	362	365
192250	659400	7	BA	51	0	0	0		+	51	79
194100	654200	8	BN2	3.5	14	0	243?		+	260?	212
193460	652080	9	BS	1.4	0	0	>56?			57?	57
194400	653500	10	BS27	5	0	0	61?			66	57
184875	650100	11	BY -1	?	<100 ?	150 ?	0	0	+	260	>500
192140	659780	12	BY	<71	?	?	18		51	89	155
195840	652890	13	BN1	0	26	0	0		0	26	90
192520	656170	14	DT-964	15	0	0	0			15	32
189200	652590	15	L-1	16	7	61	0		36	84	184
190530	650850	16	L-10	5	0	19	93			117	139
190580	652100	17	L-11	<32		13	36			81	
190300	653020	18	L-12	5	13	19	63		>31	100	131
191000	651370	19	L-13	9	0	0	85			94	99
192060	651580	20	L-14	<30		0	55			85	125
188440	652630	21	L-2	31	19	110	0		>15?	160	184
189520	652930	22	L-3	18	10	58	14?			86/12 3?	174
189230	652050	23	L-4	7	18	51	6		>60	82	156
189720	651420	24	L-5	10	13	33	59			115	125
188650	651500	25	L-6	28	10	62	15		>40	115	155
188000	650500	26	L-7	62	20	>17 3	0?			>255	255
189660	650400	27	L-9	<30		61	109			200	210
192830	661440	28	LD1	50	4	0	0			54	70

191160	655340	29	LD10	9	16	0	0			25	82
195200	655080	30	LD-11	0	0					0	
192470	659050	31	LD13	37	0	0	0			37	53
190770	656550	32	Ld14	18	1?	50	0			67	96
195650	656610	33	L15	3	0	0				3	73
191680	655870	34	LD16	7	7	0	15		>21	29	50
191190	654800	35	LD 17	9	26	0?	0?		<77	35?	113
192860	658250	36	Lod10	33	0	0	0			33	53
192610	659580	37	LD2	36	5	0	0			41	75
183020	656050	38	MM1	40	64						107
192982	662916	39	M1	35	0		0		54	35	93
192964	662868	40	M3	33		0	0		>37	33	70
192954	662737	41	M5	<37	?	0	0		>31	37.5	68
193785	663865	42	L21	18	0					18	
192840	661040	43	L22	32		?	14		>4	46	50
191280	661300	44	L23	40	16	0	86		30	142	276
191048	663744	45	L24	34	11	0	40		45	85	257
190880	653890	46	LD-25	23.4	4.8	51	45		39	125	170
191560	659100	47	LD-26	46	0	0	6			52	
194310	655810	48	LD-27	3	0	0	0			3	107
189170	651560	49	LD-29	<35	?	26	27		72	88	221
192290	658430	50	LD3	22	26	0	0			48.5	59
194050	661480	51	L31a	19.5?						30?	155
190810	653355	52	LD-4A	21.5	5	0	32		>10	58	68
191263	656242	53	LD5	15	10	7	0		>10	32	42
192804	660549	54	LD6/a	40	0	0	0?		16	40	65
192910	662400	55	LD7	38	2	0	0			40	71
195720	657920	56	Lod8	5	0	0			0	5	107
192110	657770	57	LD9	21	7+	0	0			36	45
190623	654997	58	LD-T1	21	11	0	0		52	32	923
190750	652740	59	L. l.	35	1.3	0	24		>62	60	123
190110	651380	60	LD-1505	25?	0	18?	40			83	
195100	663680	61	N2	0.5	0	0				0.5	91
186020	664000	62	PT1	55	53	141	0			249	253
185420	664000	63	PT10	60	61	340	0		>6	461	467

189380	663700	64	Pt16	70	20+	80?					106
186220	663530	65	PT28	50	60	195	0		5	305	314
184780	650065	66	TU-1	35	76	151	0	0	<20	262	288
184040	650375	67	TU- 5	33	89	209			91	331	422
194070	662700	68	YE8	17.5	3.5					21	152
187820	663290	69	PT2	80	77	176	80?		25?	365	285
194130	663210	70	YE-9	7	0	0	0			7	150
194460	660307	71	Y E-1	18.5	4	0	0		0	22.5	154
192270	651350	72	YE4	15	4	0	75			94	202
192100	650275	73	Y E-2	18	5	0	69		40	92	177
194370	660820	74	Y E-7	10	6	0	0		?	16	130
189740	650040	75	Y E-5	29	0	74	99		72	202	437
183360	662480	76	H2	51	30+						79
183700	662350	77	KH	54	<84						118
184300	662020	78	RGNP	33	<100						92
185150	662000	79	TS6	34?	<101						138
185290	661425	80	TSH7	78	43?						106
185490	660800	81	TS30/4	73	35						120
186050	661050	82	TS	76	28?						90
186480	660280	83	H3	63	25						91
186760	660100	84	TS30/5	49+	37?						49
183480	658300	85	G	70	28						100
184200	658540	86	Sh	42							58
183300	656700	87	MH1	25	53						100
183930	656740	88	BD28/4	15	48						88
184850	657000	89	TM3	33	20?						52
184470	654520	90	SBD	96	8+						114
183700	653020	91	Serp	102	36?						125
183080	650660	92	Rish L	42	74						117
183180	663420	93	RY31/3	0	166						176
184100	663800	94	TI	46	132+						135
184250	663100	95	NY	45	120+						120
184958	663326	96	AG	8+	78+						78
185310	662610	97	KA	60	60?						120
185776	662425	98	RG	82	38+						126

186540	663230	99	KO	102	26+						126
187180	663020	100	QO	138	18						156
187380	662370	101	KO31/5	66+							66
187940	662330	102	GY	86	+						104
188900	663900	103	GR	105	3						109
191640	662640	104	N32/7	48	0						48
189820	662700	105	M32/6a	62	18	10+					88
189180	661380	106	GY31/6	66	5	3+					72
189200	650560	107	LD/ 6	33	3	64	82			182	
192040	651920	108	LD974	33?	0?	0					
187740	651080	109	NZ 26	+	6>						
190020	652550	110	WR999	12	0	28?				88?	89
190050	653680	111	LD-1504	21	4	+					147
190140	653450	112	LD-1503	<21	+						
191070	652910	113	LD-937	24	6	0	+				83
188408	653054	114	A 27/7	30	19						
184640	651450	115	WR-2900	95	38						
185100	651900	116	SARAF	<100	+						
192820	650920	117	LD/15	7	2	0					
185000	652080	118	Serp1	133+							133
185540	652420	119	Serp	64	13+						77
186250	652500	120	M 8	67	9.5	1+?					71+
186300	652800	121	SerpAA	62?	12+						78
186360	653920	122	M27/6	62+							62
187510	654080	123	Assafar	43+							43
190010	654020	124	L08	30+							30
190100	654180	125	L09	23?	10+?						33
185020	654060	126	Sifriay	<28?	11+						28
185560	654800	127	Sifriay016	32	28+						60
189050	654930	128	Yagel28/7	28	9+						37
191900	650000	129	BN	8?	31.5+					137!!	39.5
192870	654970	130	LD32	18	0		0			18	162
192920	655720	131	BN27(947)	3.5	0					3.5	38
193500	656400	132	Dt	14	0					14	38
193370	656460	133	Dt9	14	0					14	35

192630	656110	134	Dt3	8	0					8	37
192990	656880	135	Dt4	6	0					6	25
192370	656240	136	Dt5	11	0		0			11	17
192340	657240	137	Dt6	12	0		10+?			>22.4	22
192080	657020	138	L-18	<17	5?	8	58		>21.5	82.5	104
191950	656420	139	Dt7	10	0	0	12		>50	22	72
191770	656520	140	LD14	19	2	0	40			62	62
191400	656800	141	LMI1	5.2	16	13	59		>34	93	127
190800	657100	142	L044	19	3+						22
189770	656800	143	LD 29/7	22	15	31+ ?					68
188680	657120	144	KO	43	1+						44
187680	657160	145	KO1	41+							41
190200	655500	146	L AP	<17			3+				
187500	657350	147	Ts29/6	40	7+						46.5
186000	656550	148	S28/5	53	30+						71
185000	656400	149	BD	36+							36
185000	659200	150	S	52+							52
185970	658250	151	OE29/5	37	6+					315?	43
186900	659600	152	KO2	48+							48
188240	659930	153	KE30/6	50	30						80
188580	659600	154	KO3	39+							39
189190	659160	155	EE1	36	0	20	1+?				56
189440	658640	156	EE2	16	0	23	1+?				40
189480	659720	157	Y12	21	27.5	5+					62
189720	659050	158	TA	30	15+						45
189870	659450	159	Y	15	23	2+					46
190210	658060	160	E2	29	1+						30
190640	658840	161	V30/7	31	5	4+					44
190710	659990	162	E3	41?							42
190980	658010	163	V	5	15	0	20?			40??	125
191030	659600	164	E6	52+							52
191630	659630	165	V2	48.5+							48.5
192760	656030	166	Dt8	6	0	0	0			6	32
195400	654120	167	BN	<5?	23		+				?