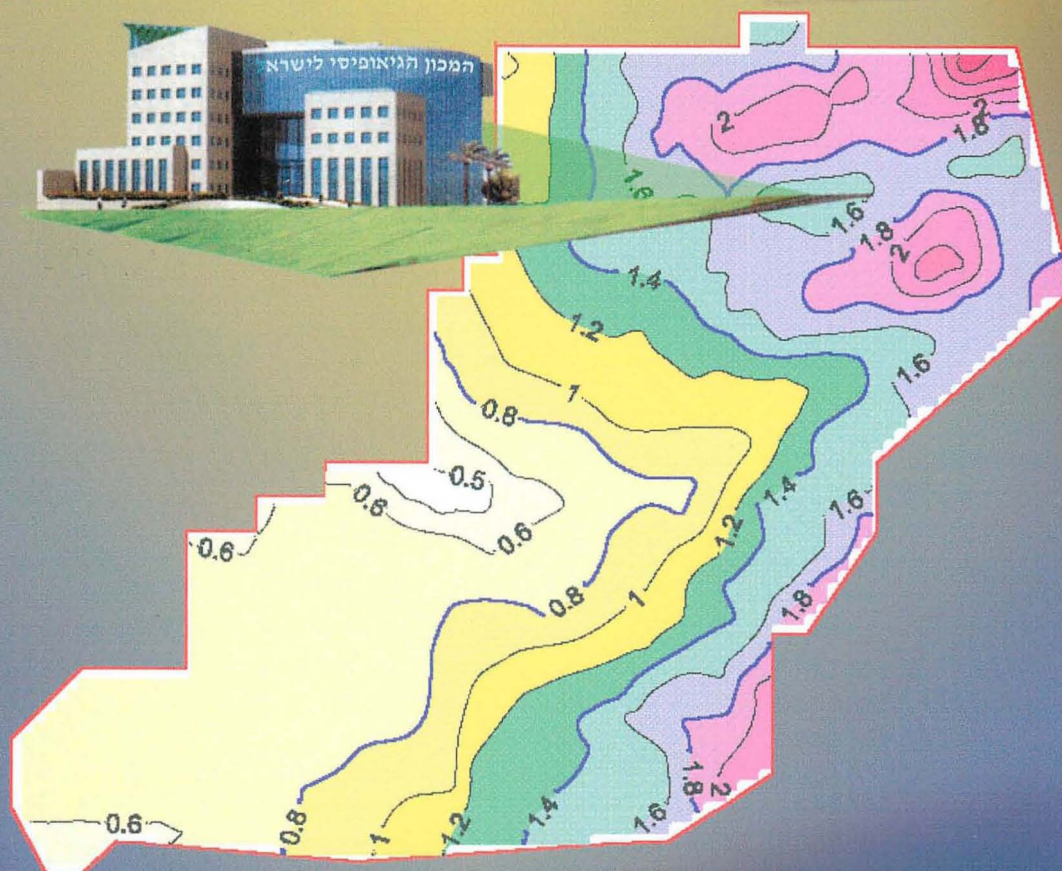


MICROZONING OF THE EARTHQUAKE HAZARD IN ISRAEL

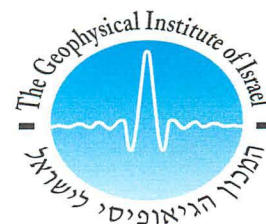
Project 1 SEISMIC MICROZONING OF LOD AND RAMLA

Submitted to:
Earth Sciences Research Administration
National Ministry of Infrastructures
and
The Ministry of Absorption



Principal Investigator:
Dr. Y. Zaslavsky

Collaborators:
M.Gorstein, M. Kalmanovich, V. Giller, I. Livshits, D. Giller,
I. Dan, Dr. A. Shapira, L. Fleischer, J. Leonov and U. Peled.



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Principal Investigator:
Dr. Yuli Zaslavsky

Collaborators:
**Marina Gorstein, Michael Kalmanovich, Vadim Giller,
Ion Livshits, Dagmara Giller, Ilana Dan, Dr. Avi Shapira,
Lorian Fleischer, Eng. Josseph Leonov and Uri Peled.**

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ABSTRACT

Throughout the history, Ramla and Lod were affected by strong earthquakes. The last destructive earthquake occurred on July 11, 1927 and caused the destruction of a great part of these cities reaching the seismic intensity of VIII on the MSK scale. Such a high intensity from a relatively distant earthquake of magnitude 6.2 is probably the result of the local site effects of the sedimentary layers that significantly enhance earthquake ground motions and thus the seismic intensities. An accurate evaluation of the site responses across Ramla and Lod to seismic ground motion, is of prime importance for urban developments, safer design of buildings and to the mitigation of the earthquake risk.

This study is focused on three steps: (1) detailed mapping of site response functions using microtremors recordings, (2) use geological information and borehole data with empirically obtained response functions to derive subsurface models for different sites across the study area and (3) estimate the seismic hazard in terms of Uniform Hazard Site-Specific Acceleration Spectra.

The Nakamura technique is used to empirically estimate the site response functions. 362 sites in Lod and in Ramla were instrumented for varying length of time. The site response of soil sites exhibit peaks of amplification factors ranging from 4 to 7 in the frequency range 0.5 to 2.5 Hz . These findings suggest that there are significant differences in the uppermost sedimentary layers. The shape of the empirical transfer functions determined in this study, as well as good agreement between both horizontal components, strongly suggest that the site response functions in this region are of 1-D nature, i.e. can be fairly inferred analytically from 1-D subsurface models.

The extensive database of microtremors recordings and the availability of boreholes data concerning thickness of the sediments, enabled a reliable comparison between the empirical and the analytical response functions. The shear-wave structures for different sediments were deduced by trial-and-error fitting of the calculated functions to the empirical transfer functions. Consequently we obtained the following values of share-waves velocities: in sand 350 m/s, in sandstone 600 m/s, in clay 500 m/s, in marl 700m/s, in chalk 800 m/s and in dolomite 2100m/s. In turn, fixing the S-wave velocities in the different materials, it became possible to

adjusted the thickness of the sedimentary layers to obtain a reasonable fit between the calculated and observed site response functions.

Once the site response functions are determined, it became possible to apply the SvE procedure to compute uniform hazard site-specific acceleration spectra that meets the criterion of accepted hazard in the Israeli Standard 413, i.e., a 10% probability of exceedence during an exposure time of 50 years and a damping ratio of 5%. The shape of the spectra obtained is significantly different from the one prescribed by Israel Building Code (IS-413). We thus conclude that the current requirements in the Israel standard 413 to design buildings to sustain earthquakes are inappropriate for Ramla and Lod and we provide an improved design spectrum to be applicable for building in Lod and in Ramla.

INTRODUCTION

The local geology and topography effects control the distribution of damages due to strong earthquakes. The amplification of earthquake ground motion by local site conditions has important implications in urban planning and development. In areas characterized by soft sediments, the amplification of the ground motion is common and lead to enhanced seismic hazard and risk.

Local site response may be evaluated by empirical and theoretical methods. The theoretical method allow detailed analysis of the parameters used in the evaluation; however, they require detailed geo-technical information about the materials through which the seismic waves propagate to the surface. The analytical response of plane SV waves impinging on a single layer overlying a half-space is well

1993). Empirical methods are based on seismic records on sites; thus, dominant frequency and amplification are determined directly. Empirical methods can be separated in two categories: those that use two sites and those that use only one site. Borchardt (1970) introduced the sediment-to-bedrock ratio (the most common approach) that consists of dividing the spectrum of the measured earthquake motions at a site by that of a nearby reference site (rock site). If the two sites have similar source and path effects, and if the reference site has a negligible site response, then the resulting spectral ratio constitutes an estimate of the site response. This approach identifies, in most cases, the fundamental resonant frequency and is considered to be the most reliable (Rogers et al., 1984, Singh et al., 1988, Jarpe et al., Darragh and Shakal 1991, Borchardt and Glassmoyer 1992, Gutierrez and Singh, S. K., 1992, Satoh, et al., 1995; Aguirre and Irikura, 1997; Su, et al., 1998; Beresnev, et al., 1998; Hartzell, 1998; Reinoso and Ordaz, 1999). Many investigators, among them Tucker and King (1984), McGatt et al. (1991), Field et al. 1992, Jongmans and Campillo (1993), Liu et al. (1992), Gagnepain-Beyneix et al. (1995), Zaslavsky et al., (1995), Carver and Hartzell (1996), Hartzell et al. (1996), Zaslavsky et al. (2000) evaluated site response function from moderate to weak motions of earthquake. However, this technique requires a number of earthquake records. In regions with relatively low seismicity, it would be necessary to wait for a significant period of time to obtain a usable data set.

Several studies (e.g., Otha et. Al., Yamanaka et al., 1994) applied the frequencies smaller than 0.5 Hz, seismic noise is categorized as microseisms and, for higher frequencies, as microtremors. The main advantage given by this approach is the fact that the spectral characteristics of microtremors have been recognized to be associated with the site conditions (Kanai and Tanaka, 1961; Katz, 1976; Katz and Bellon, 1978, Kagami et al., 1986; Zaslavsky, 1987; Gutierrez and Singh, 1992). It has been shown that with microtremors it is possible to identify the fundamental resonance frequency of nears surface soil deposits (see among others Otha et. Al., 1978; Lermo et al., 1988; Hough et al., 1991, 1992).

Nakamura (1989) proposed a method that requires only one recording station. Nakamura hypothesized that site response could be estimated from the horizontal-to-vertical ratio of microtremors. This technique was tested, experimentally and theoretically, at many sites all over the world, by different authors (Ochamachi et al., 1991; Lermo and Chavez-Garcia, 1993, 1994; Lachet and Bard, 1994; Field and Jacob, 1995; Zaslavsky et al., 1995, 1998, 2000; Malagnini et al., 1996; Seekins et al., 1996; Gitterman et al., 1996, Teves-Costa et al., 1996; Theodulidis et al., 1996; Konno and Ohamachi, 1998; Mucciarelli, 1998). Results obtained by implementing support such use of microtremors measurements for estimating the site response of surface deposits.

recordings of earthquakes and concluded that this approach is able to reliably estimate the frequency of the fundamental resonant mode and correctly predict the amplification level. This technique, know as the receiver function technique, is also

Ammon, 1991). Receiver functions were introduced by Langston (1979) to determine the velocity structure of the crust and upper mantle from teleseisms.

GEOLOGICAL BACKGROUND OF THE LOD-RAMLA AREA

The subject of the geological investigation in the Lod-Ramla area are the Bina carbonates of Judea Group, constituting the bedrock, and the sediment cover rocks overlying the carbonates.

Fig. 1 presents the geological map of the Lod-Ramla area.

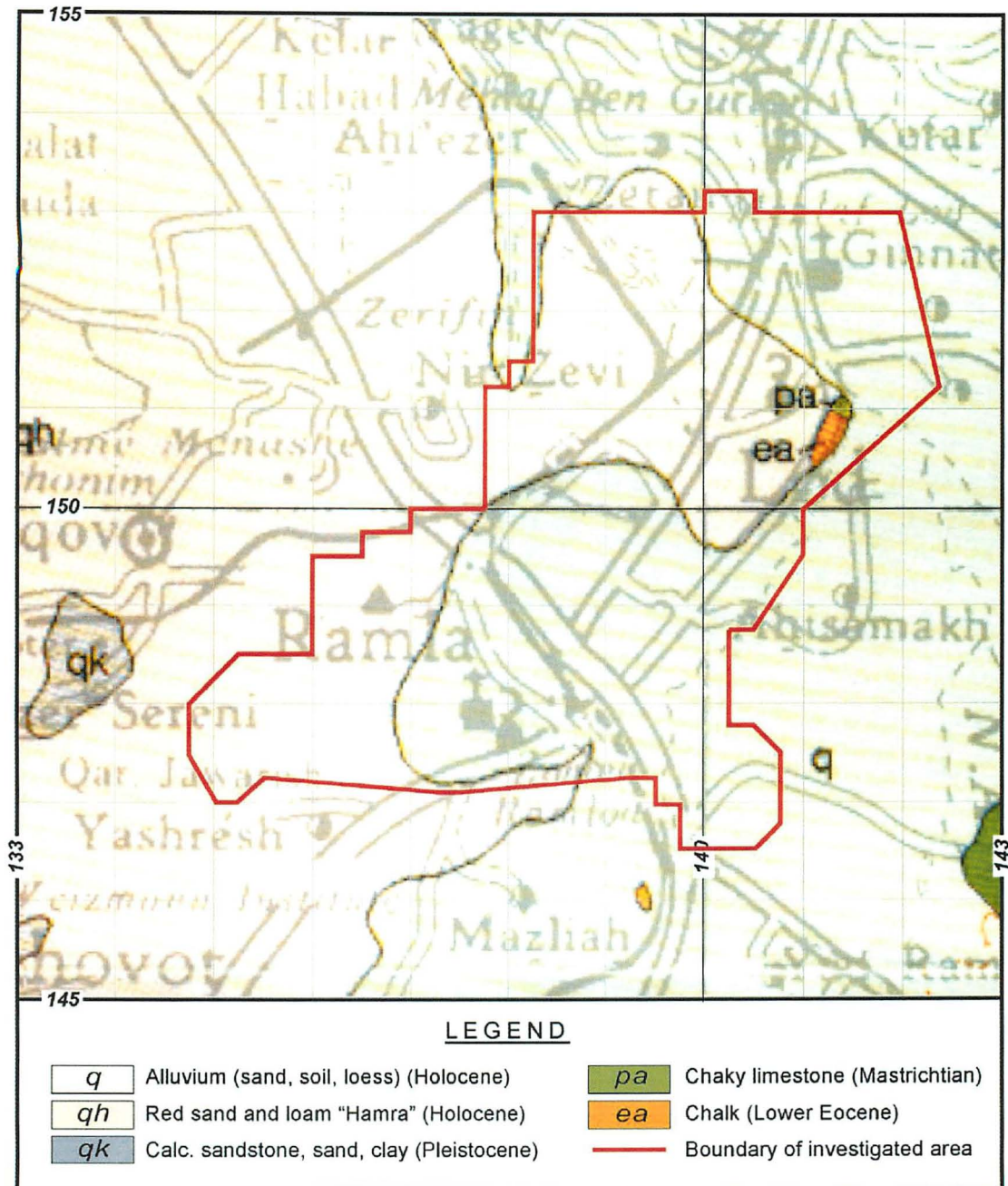


Figure 1. Geological map of the Lod-Ramla area

This map is a part of geological map of Israel to a scale of 1:200,000 (Sneh et al.). The surface comprises Quaternary sediment rocks and some remnants chalks of Eocene age.

Borehole data are provided by Gvirtzman (1969- PhD Thesis). The borehole data of the Lod-Ramla area are presented in the Table 1. Complementary geological information of the area under investigation, including boreholes data and well drillings is obtained mainly from the Geophysical Institute of Israel and the Hydrogeology Division of the Geological Survey of Israel.

Table 2 presents the basic lithological units of the rocks overlaying the carbonates of the Bina formation in the investigated area.

Bina formation, Shadmon, 1959. Bedrock. (by Fleisher L., Gelberman et al.)

Structure of the Top Judea Group is presented in Fig. 2B (Fleischer, Gelberman, and Wolf, 1993; Fleischer and Gafson, 2000). The Bina Fm. consists of white to gray limestone and dolomite, containing rudist and coral fragments. The upper contact of the Bina Fm. is unconformable

structural pattern of the Lod-Ramla area is marked by primary synclinal structure, crossed by normal fault along the axis. The depth of the top Bina Fm. increases from 60 m in the northeast part of the area to 350 m in the west part.

Mount Scopus group (Flexer, 1968)

-chalky facies. The formation is presented as a syncline in the eastern part of the area with 110 m maximum thickness and wedging out in the western part of the area.

There are few local lenses of Taqye and Ghareb fms. (3-15 m) that consist of shale and chalky limestone.

Avedat group (Braun, 1967).

The area of Lod and Ramla also contains the lower part of the Avedat Group, composed of silicified chalks (0-23 m). It has a local spreading in the central-east part

Saqiye Group (Gvirtzman and Reiss, 1965).

The Saqiye Group is associated with four major sedimentary cycles, each starting during a marine transgression and terminating with a sharp westward regression, accompanied by deeply cutting erosional unconformities caused by the tectonic and sea level movements (Gvirtzman, 1969). The group overlies, uncomfortably, the Avedat and Mt.Scopus group. The first cycle of Oligocene age consist of deep marine chalky marls Bet Guvrin Fm. and limestone of Lakhish Fm, deposited in a synclinal position from south to north. Thickness of marl and limestone vary from 0 to 80 meters and from 0 to 15 meters, respectively.

represented by marl facies. Therefore, for the purpose of site response modeling, they will be given as united lithological unit as displayed in Table 3. The isopach map of marl unit is presented in Fig. 2A.

The fourth sedimentary cycle of Pliocene age is represented by the transgressional Yafo Fm. (Gvirtzman, 1969). The Yafo Fm. consists of homogenous clay and clayed marl with some coquina beds and a few calcareous sand intercalations, in the upper part of the section. Clay fills the main syncline in the central part of the area. Thickness of clay varies from 0 m in the western part to 150 m in the eastern part of the area, as illustrated in Fig. 3B. The Yafo Fm. is overlaid by the diachronous Kurkar Group.

Kurkar Group (Gvirtzman, 1969).

Lower part of the Kurkar Group of Pleistocene age are characterized by (0-15 meters) and conglomerates of the Ahuzam Fm. (0-10 meters). The upper part is characterized by eolian sands of the Rehovot Fm. Holocene rocks, composed of reddish silty-clayey (0-10 m are present in the east and alluvium sediments (sand, soil, gravel, clay and loess with thickness of 0-10 m) are in the western part of the area, as shown in Table 2 and on the Fig. 3A.

On the basis of available geological data we selected lithologically homogeneous units (presented in Table 3) for geological modeling of the subsurface to be incorporated with microtremors measurements.

The share-wave velocity ranges were determined directly by seismic refraction surveys in different sites across Israel.

Table 1. WELL DATA IN THE LOD-RAMLA AREA

No	Well name	Coordinates		Quarter.	Yafo fm.	Lakh.fm.	B.Guv.fm.	En Zet.fm.	Total	Top
				Sand and			Chalky			Judea gr.
		EW	NS	sandstone	Clay	Limstone	marl	marl	marl	Carbonates
		Thickness in meters								Depts in m.
1	L1	139200	152590	23	61	0	0	0	0	84
2	L2	138440	152630	50	110	0	0	0	0	160
3	L3	139520	152930	28	58	3	11	0	14	100
4	L4	139230	152050	25	51	0	0	6	6	82
5	L5	139720	151420	23	33	12	0	47	59	115
6	L6	138650	151500	38	62	0	0			100
7	L7	138000	150500	82	>173	0	0			>255
8	L9	139660	150400	30	61			109	109	200
9	L10	140530	150850	5	19	8		85	93	117
10	L11	140580	152100	32	13	0		36	36	81
11	L12	140300	153020	23	14	5	38	20	63	100
12	L13	141000	151370	9	0	0	14	71	85	94
13	L14	142060	151580	30	0	0	0	55	55	85
14	T1	134780	150065	111	151	0	0	0	0	262
15	T2	137167	149007	75	80	11	17	23	51	206
16	T4	136130	149350	105	128	0	0	9	9	242
17	T5	134040	150375	122	209	0	0	0	0	331
18	T6	134115	148268	125	170	0	0	0	0	295
19	B1	134875	150100	100	160	0	0	0	0	260
20	B2	134686	149402	95	155	0	0	0	0	250
21	RL1	134897	152972	125	678	0	0	0	0	803
22	DAVID-1	137827	153415	90	189	0	0	0	0	279
23	GYC	137190	147055	65						
24	GYI	136680	146615	84						
25	GY8	137560	147290	45						
26	L.I.	140750	152740	35	0	0	3	22	25	60
27	LD1	140623	154997			0	0	0	0	32
28	LD4A	140810	153355	30	4	0	0	15	15	49
29	LD6	139200	150560	36	64	0		82	82	182
30	LD8	141680	149210	16	0	0	0	113	113	129
31	LD10	141160	155340	25	0	0	0	0	0	25
32	LD15	142820	150920	9	0		0	10+		
33	LD17	141190	154800	36	0				0	53
34	LD25	140880	153890	28	47	0	16	34	50	125
35	LD29	139170	151560	36	35	0	0	17	17	88
36	LD974	142040	151920	33	0	0	0	47+	47+	
37	LD-1505	140110	152380	25	18	8	8	24	40	83
38	YE2	142100	150275	23	0	0	0	89	89	112
39	YE3	142140	149825	10	0	0	0	127	127	137
40	YE4	142280	151320	19	0	0	0	75	75	94
41	YE5	139740	150040	29	74	3	20	76	99	202
42	NZ26	137740	151080	80+						
43	R-1268	139590	148380	43	40		30	24	54	107
44	R-1269	139422	146100	1	0	6	55+		55+	
45	INABA	142130	147500	9	0	0	0	5	5	14
46	R39	138790	145790	28	34	0	16	87	103	165
47	R20	138500	148300	44	71	0	9+			
48	R.AB.J.	138400	147500	48	41	0	71	40	111	200
49	R1303	138470	147180	51	67	0	36	40	76	194
50	MAZ24	138080	146400	40	0	0	9+			
51	R.ABD	135600	149200	115						
52	ALISA	136850	148900	97				0		
53	RAM	137700	149500	70						
54	RA	138600	149100	63						
55	W9	140020	152550	12	28					>40
56	LD1504	140050	153680	25	0	0				
57	LD-503	140140	153450	21						
58	LD937	141070	152910	30						
59	Ak	138408	153054	49						
60	WR-2900	134640	151450	133						
61	SARAF	135100	151900	100						
62	EINABA	141980	147120	0	0	0	0	25	25	25
63	AbuSh.	140730	146150	0	0	0	0	30	30	30
64	YASH	136262	147135	77						
65	R.Yash	135260	146490	75+						

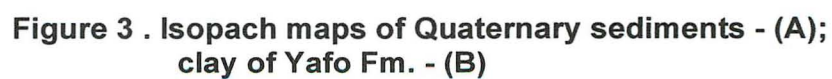
Table 2. STRATIGRAPHIC NOMENCLATURE OF THE SEDIMENTARY
ROCKS

N	Litology	Thickness (m)	Formation	Groups	Stage	Age	Abrev
1	Sand, soil, loess, clay, red sand and loam "Hamra"	0 - 15	Alluvium, "Hamra"		Holocene	Quaternary	<i>q, qh</i>
2	Sand and calcareous sandstone	0 - 110	Pleshet	Kurkar	Pleistocene		<i>qk</i>
3	Clay	0- 300	Yafo	Saqiye	Pliocene	Neogene	<i>ny</i>
4	Limestone	0 - 15	Lakhish		Oligocene	Paleogen	<i>ol</i>
5	Chalky marl	0 - 80	Beit Guvrin			Paleogen	<i>ue</i>
6	Chalk	0 - 23	Adulam	Avedat	Lower Eocene	Paleogen	<i>ea</i>
7	Marl	0 - 15	Taqiye	MT.Scopus	Paleocene	Paleogen	<i>pa</i>
8	Chalky limestone	0 - 15	Ghareb		Maastrichtian	Up. Cretaceous	<i>ma</i>
9	Marl	0 - 130	'En Zetim		Campanian	Up. Cretaceous	<i>ca</i>
	Dolomite	Half-space	Bina	Judea	Turonian	Up. Cretaceous	<i>t</i>

Table 3. MECHANICAL PROPERTIES OF THE ROCKS IN THE LOD-RAMLA
AREA

N	Litology	Formation	Thickness (m.)	Density (g/sm ³)	Range of Vs(m/s)
1	Sand and calcareous sandstone	Alluvium "Hamra" Kurkar	0 - 120	1.6-1.9	200 - 1170
2	Clay	Yafo	0- 300	1.6-1.7	300 - 620
3	Marl	Lakhish Beit Guvrin Taqie Ghareb 'En Zetim	0-120	1.7-1.8	400 - 1100
4	Dolomite-limestone	Bina(Ju gr.)		2.0-2.3	1100 - 2300

Figure 2. Isopach map of total marl - (A); Structural map of the top Judea Group (from the surface) - (B)



METHODS

Three main techniques are implemented:

1. Dominant frequency of the Fourier spectrum of microtremors.

When applying the assumptions that microtremors consist of vertically propagating S waves and that the source spectrum of microtremors is mainly white noise then the dominant frequency of the Fourier spectrum of the microtremors is a close approximation of the resonance frequency of the soils column. Good results were achieved by Lermo et al. (1993,1994) who applied this technique to determine dominant periods in Mexico City.

2. Sediment-to-bedrock spectral ratio.

This technique is based on comparing the spectrum of a seismic event recorded at the investigated site by the spectrum of the same event recorded in a nearby reference site (hard rock). This is also termed the classical technique. The classical technique requires that the propagation paths to the two sites are almost identical, i.e. the investigated site and the reference site are very close to one another with respect to the epicentral distance

3. The Nakamura technique.

An alternative method for removing the source effect was proposed by Nakamura (1984) and gained much interest because of its low cost, rapid field operations and simplicity of the analysis.

Fig.4 shows the simple model used by Nakamura. The Nakamura technique is based on the assumption that:

- (1) Microtremors are composed mainly of Rayleigh waves, propagating in soft surface layers overlaying an half-space;
- (2) The vertical motions are not affected by the soft soils.
- (3) The microtremors are originated by local surface sources (traffic and industrial noise) and they have no contribution from deep sources;
- (4) The amplification of the vertical component is exclusively associated with the depth dependence of the surface (Rayleigh) waves motion.

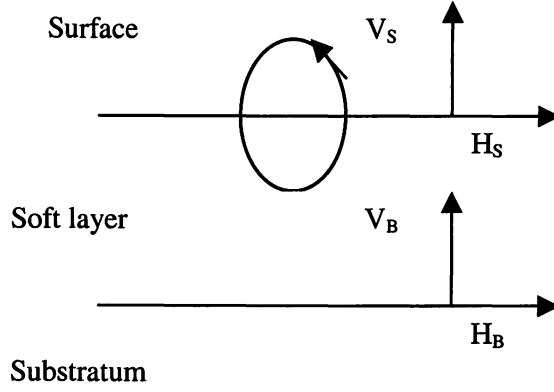


Figure 4. Simple model assumed by Nakamura (1989) to interpret microtremor measurements.

According to Nakamura, the transfer function (i.e., the site response function) for Rayleigh waves, and compensated for the source spectrum is:

$$S_M = \frac{Z_s}{Z_b} \quad (1)$$

Where $Z_s = H_s/V_s$ and $Z_b = H_b/V_b$. Under the prescribed assumptions, the vertical component is not amplified by the surface layer, i.e.,

$$\frac{V_s}{V_b} \sim 1 \quad (2)$$

we obtain

$$S_M = \frac{H_s}{V_s} \quad (3)$$

i.e. the vertical component of microtremors on the surface retain the characteristics of horizontal component of the hard rock.

DATA ACQUISITION AND PROCESSING

During the period February to October 2001, temporary networks of digital seismic data acquisition systems were installed in the Ramla-Lod area. The investigated area was bisected on a grid of 250m x 250m, each comprising a discrete measurement site. The map in Figure 5 shows the locations of the 362 observation points.

Ground motions were recorded by GII-SDA system which is a multi-channel, PC-based, digital seismic data acquisition system designed for site response field investigations (Shapira and Avirav, 1995). The seismometers used are sensitive velocity transducers with a natural frequency of 1.0 Hz. Digital records were obtained in the 0.2-25 Hz band-pass filter with a sampling rate of 100 samples per second. Each of the stations is equipped by one vertical and two horizontal seismometers (oriented north-south and east-west). Table 4 shows the time of measurements at the various sites. The length of recording for each measurement is an important parameter. Too short a period will result in an unreliable average spectral ratios, a too long period increases project efforts and costs.

At each site, the microtremors were recorded continuously, for two hours, creating data files of 3 minutes of microtremors data. Based on previous experience, we selected from each data file several segments of only 30 sec for spectral calculations. This time window is proven to be sufficiently long to provide stable results. The selected time windows were Fourier transformed using cosine tapering before transformation. The spectra were then smoothed with a triangular moving Hanning window (0.4 Hz) and re-sampled every 0.024 Hz in the 0.5-10 Hz frequency range. After data smoothing, and in order to obtain spectral ratios, the spectra of an EW and NS channel at a site were divided by the spectra of the vertical channel (Nakamura estimate). The arithmetical average of each individual ratios were also computed. We observed that there is practically no difference between arithmetical and geometrical averaging. If the averaged ratios of the NS and the EW component are similar, than the average of the two component ratios will be the site amplification function:

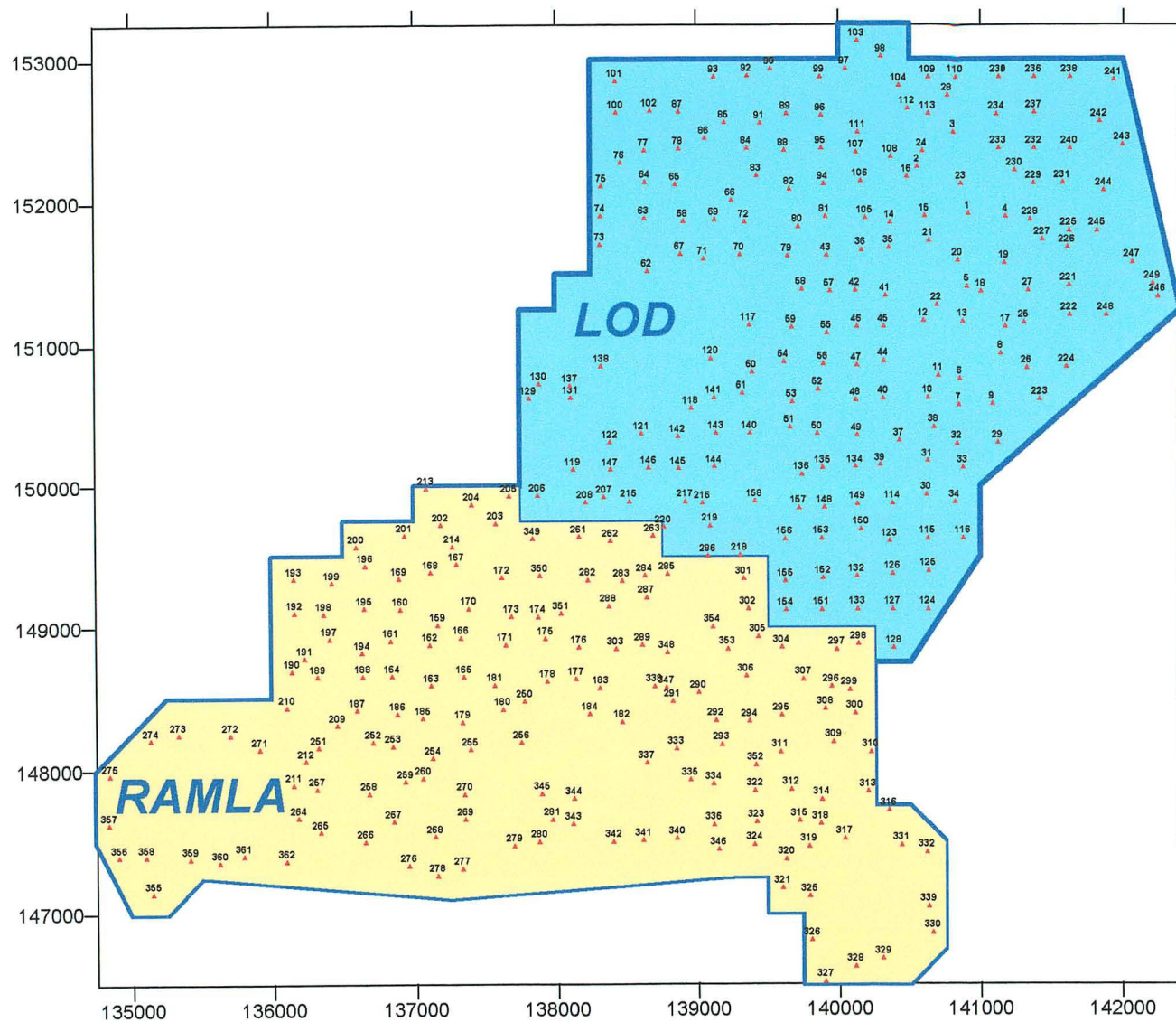


Figure 5. Location of the observation points

$$A = \frac{\sum_{i=1}^n S_{NS}(f)_i + \sum_{i=1}^n S_{EW}(f)_i}{2 \sum_{i=1}^n S_V(f)_i} \quad (4)$$

Table 4. TIME OF THE MEASUREMENTS IN THE DIFFERENT SITES.

POINT	COORDINATES		DATE	TIME	POINT	COORDINATES		DATE	TIME
	EW	NS				EW	NS		
p0001	140911	151919	2001/01/15	9:44 - 11:50	p0183	138310	148572	2001/05/24	07:53- 09:22
p0002	140553	152246	2001/01/16	9:18 - 13:58	p0184	138232	148390	2001/05/24	09:47- 11:16
p0003	140808	152488	2001/01/17	11:11 - 13:08	p0185	137057	148361	2001/05/29	06:10- 07:39
p0004	141177	151895	2001/01/18	10:53 - 12:59	p0186	136875	148392	2001/05/29	08:03- 09:35
p0005	140904	151407	2001/01/21	9:25 - 11:25	p0187	136594	148418	2001/05/29	10:00- 11:32
p0006	140857	150760	2001/01/22	7:33 - 09:39	p0188	136634	148655	2001/05/29	06:02- 07:28
p0007	140847	150576	2001/01/22	10:19 - 12:28	p0189	136320	148652	2001/05/30	08:07- 09:36
p0008	141144	150937	2001/01/28	07:06 - 09:09	p0190	136138	148691	2001/05/30	10:06- 11:36
p0009	141083	150582	2001/01/28	09:56 - 11:59	p0191	136230	148780	2001/05/31	05:58- 07:28
p0010	140630	150626	2001/01/29	07:31 - 09:34	p0192	136160	149099	2001/05/31	07:51- 09:20
p0011	140705	150781	2001/01/29	10:16 - 12:18	p0193	136154	149341	2001/05/31	09:47- 11:16
p0012	140599	151169	2001/01/30	06:50 - 08:50	p0194	136629	148821	2001/06/03	06:00- 07:29
p0013	140876	151161	2001/01/30	09:24 - 11:24	p0195	136645	149131	2001/06/03	08:20- 09:37
p0014	140358	151856	2001/01/31	06:42 - 08:49	p0196	136655	149431	2001/06/03	09:55- 11:12
p0015	140607	151899	2001/01/31	09:29 - 11:25	p0197	136403	148915	2001/06/04	05:52- 07:21
p0016	140477	152175	2001/01/31	12:01 - 13:54	p0198	136365	149092	2001/06/04	07:43- 09:12
p0017	141177	151126	2001/02/11	10:35 - 12:35	p0199	136420	149311	2001/06/04	09:32- 11:01
p0018	141002	151373	2001/02/12	13:08 - 15:04	p0200	136594	149568	2001/06/06	06:25- 07:54
p0019	141166	151574	2001/02/12	10:43 - 12:39	p0201	136934	149643	2001/06/06	08:15- 09:45
p0020	140838	151589	2001/02/12	13:11 - 14:06	p0202	137190	149721	2001/06/06	10:03- 11:26
p0021	140635	151729	2001/02/13	07:56 - 10:57	p0203	137580	149731	2001/06/07	2001/06/07
p0022	140693	151278	2001/02/13	11:50 - 13:44	p0204	137413	149866	2001/06/07	10:00- 11:29
p0023	140861	152128	2001/02/14	09:34 - 11:36	p0205	137673	149927	2001/06/10	05:28- 06:57
p0024	140588	152355	2001/02/14	12:22 - 14:22	p0206	137875	149930	2001/06/10	07:17- 08:46
p0025	141305	151156	2001/02/14	09:18 - 11:18	p0207	138340	149917	2001/06/11	05:45- 07:14
p0026	141326	150836	2001/02/19	11:57 - 13:29	p0208	138209	149880	2001/06/11	07:42- 09:11
p0027	141335	151380	2001/02/19	14:14 - 15:56	p0209	136455	148312	2001/06/12	06:23- 07:52
p0028	140764	152743	2001/02/19	10:02 - 11:47	p0210	136101	148437	2001/06/12	08:14- 09:46
p0029	141122	150309	2001/02/22	09:52 - 11:18	p0211	136146	147897	2001/06/17	06:11- 07:40
p0030	140619	149937	2001/02/25	09:22- 11:18	p0212	136233	148063	2001/06/17	07:58- 09:27
p0031	140625	150175	2001/02/25	11:52- 13:43	p0213	137090	149981	2001/06/19	05:47- 07:16
p0032	140834	150301	2001/02/26	09:04- 10:58	p0214	137271	149566	2001/06/19	07:41- 09:10
p0033	140878	150130	2001/02/26	11:33- 13:17	p0215	138520	149888	2001/06/20	06:07- 07:39
p0034	140820	149880	2001/02/26	13:53- 15:35	p0216	139038	149878	2001/06/20	08:24- 09:53
p0035	140351	151681	2001/02/27	09:09- 11:00	p0217	138915	149888	2001/06/20	10:09- 11:41
p0036	140154	151665	2001/02/27	11:29- 13:22	p0218	139302	149506	2001/06/21	05:45- 07:14
p0037	140427	150325	2001/02/27	09:21- 11:30	p0219	139092	149716	2001/06/21	07:36- 09:05
p0038	140670	150420	2001/02/27	12:17- 14:14	p0220	138763	149706	2001/06/21	09:30- 10:59
p0039	140292	150148	2001/03/01	09:37- 10:33	p0221	141621	151416	2001/06/24	05:53- 07:22
p0040	140313	150625	2001/03/01	12:10- 14:09	p0222	141626	151207	2001/06/24	07:39- 09:11
p0041	140328	151345	2001/03/04	08:57- 10:50	p0223	141419	150614	2001/06/25	06:04- 07:33
p0042	140112	151380	2001/03/04	11:22- 13:16	p0224	141607	150843	2001/06/25	07:49- 09:18
p0043	139912	151627	2001/03/04	13:41- 15:07	p0225	141621	151800	2001/06/28	06:20- 07:51
p0044	140315	150887	2001/03/05	09:51- 11:48	p0226	141609	151683	2001/06/28	08:12- 09:44
p0045	140314	151126	2001/03/05	12:18- 14:12	p0227	141435	151737	2001/06/28	10:04- 11:30
p0046	140126	151126	2001/03/06	09:18- 11:33	p0228	141348	151877	2001/07/01	05:52- 07:22
p0047	140128	150855	2001/03/06	12:06- 14:00	p0229	141373	152129	2001/07/01	07:37- 09:06
p0048	140117	150611	2001/03/07	09:13- 11:11	p0230	141238	152222	2001/07/01	07:49- 09:18
p0049	140126	150359	2001/03/07	12:06- 14:00	p0231	141577	152134	2001/07/02	05:51- 07:20
p0050	139850	150373	2001/03/11	09:16- 11:10	p0232	141375	152375	2001/07/02	07:49- 09:18
p0051	139660	150417	2001/03/11	11:40- 13:34	p0233	141125	152375	2001/07/02	07:49- 09:18
p0052	139855	150684	2001/03/12	08:56- 10:34	p0234	141112	152616	2001/07/03	07:58- 09:27
p0053	139675	150600	2001/03/12	11:03- 12:42	p0235	141125	152875	2001/07/03	09:48- 11:17
p0054	139618	150882	2001/03/12	13:07- 14:49	p0236	141375	152875	2001/07/04	08:36- 09:49
p0055	139918	151081	2001/03/13	09:47- 11:44	p0237	141375	152625	2001/07/04	10:14- 11:31
p0056	139895	150864	2001/03/13	12:09- 14:05	p0238	141625	152875	2001/07/05	05:32- 07:11
p0057	139939	151376	2001/03/14	09:04- 10:39	p0239	141125	152875	2001/07/05	07:26- 08:55
p0058	139740	151390	2001/03/14	11:01- 12:40	p0240	141625	152375	2001/07/05	09:12- 10:41
p0059	139673	151122	2001/03/14	13:07- 14:49	p0241	141929	152854	2001/07/09	07:05- 08:09
p0060	139393	150808	2001/03/15	09:28- 11:22	p0242	141831	152563	2001/07/09	08:27- 09:37

POINT	COORDINATES		DATE	TIME	POINT	COORDINATES		DATE	TIME
	EW	NS				EW	NS		
p0061	139324	150658	2001/03/15	11:52- 13:52	p0243	141991	152400	2001/07/09	09:55- 11:12
p0062	138653	151514	2001/03/19	10:03- 11:32	p0244	141860	152080	2001/07/10	05:52- 07:21
p0063	138632	151884	2001/03/19	12:56- 14:53	p0245	141815	151800	2001/07/10	07:51- 09:20
p0064	138637	152137	2001/03/20	09:47- 11:10	p0246	141625	151338	2001/07/10	09:45- 11:17
p0065	138851	152122	2001/03/20	11:34- 13:00	p0247	142060	151579	2001/07/11	05:48- 07:17
p0066	139245	152011	2001/03/20	13:26- 14:58	p0248	141880	151209	2001/07/11	07:36- 09:06
p0067	138887	151634	2001/03/21	08:55- 10:30	p0249	142203	151430	2001/07/11	09:29- 11:58
p0068	138906	151865	2001/03/21	10:56- 12:31	p0250	137778	148479	2001/07/12	06:09- 07:38
p0069	139126	151876	2001/03/21	12:54- 14:26	p0251	136323	148157	2001/07/12	08:13- 09:45
p0070	139306	151630	2001/03/22	08:50- 10:28	p0252	136703	148196	2001/07/12	10:02- 11:31
p0071	139049	151603	2001/03/22	11:39- 13:11	p0253	136842	148166	2001/07/15	05:57- 07:14
p0072	139342	151861	2001/03/22	13:38- 15:04	p0254	137125	148083	2001/07/15	07:30- 08:47
p0073	138319	151699	2001/03/25	08:55- 10:24	p0255	137393	148144	2001/07/16	05:50- 07:07
p0074	138324	151899	2001/03/25	10:48- 12:17	p0256	137750	148194	2001/07/16	07:24- 08:56
p0075	138329	152108	2001/03/25	12:46- 14:12	p0257	136310	147868	2001/07/16	09:17- 10:46
p0076	138464	152273	2001/03/26	09:03- 10:32	p0258	136673	147834	2001/07/17	06:19- 07:48
p0077	138631	152360	2001/03/26	10:58- 12:24	p0259	136930	147919	2001/07/17	08:09- 09:38
p0078	138872	152371	2001/03/26	13:02- 14:28	p0260	137057	147942	2001/07/17	10:01- 11:27
p0079	139644	151621	2001/03/27	09:09- 10:47	p0264	136181	147666	2001/07/22	06:54- 08:11
p0080	139716	151828	2001/03/27	11:19- 12:25	p0265	136333	147567	2001/07/22	08:27- 09:44
p0081	139904	151895	2001/03/28	13:25- 14:51	p0266	136648	147500	2001/07/22	10:01- 11:17
p0082	139567	152090	2001/03/28	09:06- 10:53	p0267	136845	147641	2001/07/23	06:04- 07:33
p0083	139424	152183	2001/03/28	11:24- 12:50	p0268	137140	147533	2001/07/23	07:48- 09:17
p0084	139358	152377	2001/03/28	13:26- 14:52	p0269	137355	147657	2001/07/23	09:36- 10:50
p0085	139196	152556	2001/03/29	08:55- 10:24	p0270	137350	147830	2001/07/24	06:09- 07:39
p0086	139059	152445	2001/03/29	11:00- 12:26	p0271	135908	148144	2001/07/25	08:14- 09:27
p0087	138872	152629	2001/03/29	12:56- 14:22	p0272	135702	148244	2001/07/25	09:53- 11:06
p0088	139617	152359	2001/04/01	09:15- 10:41	p0273	135334	148250	2001/07/26	05:49- 07:06
p0089	139636	152618	2001/04/01	11:08- 12:37	p0274	135136	148210	2001/07/26	07:21- 08:35
p0090	139525	152931	2001/04/01	13:04- 14:27	p0275	134843	147964	2001/07/26	08:52- 10:08
p0091	139449	152551	2001/04/02	09:01- 10:24	p0277	137332	147310	2001/07/29	07:59- 09:22
p0092	139361	152885	2001/04/02	10:57- 12:27	p0278	137156	147262	2001/07/29	09:39- 10:56
p0093	139125	152875	2001/04/02	12:50- 14:19	p0279	137697	147470	2001/07/30	05:50- 07:19
p0094	139895	152125	2001/04/03	09:20- 10:52	p0280	137874	147500	2001/07/30	07:43- 09:12
p0095	139875	152375	2001/04/03	11:27- 13:00	p0281	137967	147655	2001/07/30	09:27- 10:43
p0096	139875	152606	2001/04/04	09:31- 10:57	p0282	138222	149329	2001/07/31	06:29- 07:58
p0097	140044	152931	2001/04/04	12:53- 14:20	p0283	138466	149324	2001/07/31	08:16- 09:30
p0098	140296	153021	2001/04/04	13:24- 14:59	p0284	138638	149360	2001/07/31	09:50- 11:03
p0099	139870	152877	2001/04/05	08:52- 10:21	p0285	137786	149373	2001/08/01	06:41- 07:55
p100	138435	152624	2001/03/26	08:25- 09:55	p0261	1381362	149634	2001/07/18	06:24- 07:37
p101	138430	152849	2001/03/26	10:40- 12:55	p0262	138387	149607	2001/07/18	08:04- 09:18
p102	138673	152639	2001/03/26	12:25- 14:00	p0263	138686	149643	2001/07/18	09:34- 10:48
p10103	140126	153129	2001/04/05	10:55- 12:38	p0286	139076	149499	2001/08/01	08:18- 09:32
p10104	140423	152815	2001/04/05	13:18- 14:47	p0287	138640	149206	2001/08/01	09:59- 11:13
p10105	140185	151889	2001/04/15	09:07- 10:39	p0288	138373	149145	2001/08/02	09:18- 10:32
p10106	140150	152148	2001/04/15	11:03- 11:28	p0289	138608	148873	2001/08/02	10:50- 12:04
p10107	140120	152347	2001/04/15	12:57- 14:23	p0290	139005	148541	2001/08/06	06:37- 08:03
p10108	140363	152313	2001/04/16	09:20- 10:50	p0291	138820	148480	2001/08/06	08:16- 09:45
p10109	140631	152871	2001/04/16	11:21- 11:51	p0292	139127	148347	2001/08/06	09:59- 11:13
p10110	140822	152875	2001/04/16	13:21- 14:47	p0293	139166	148180	2001/08/07	06:37- 07:36
p10111	140132	152485	2001/04/16	06:53- 08:34	p0294	139366	148340	2001/08/07	08:14- 09:46
p10112	140483	152654	2001/04/16	09:15- 10:50	p0295	139595	148382	2001/08/08	06:16- 07:46
p10113	140630	152617	2001/04/16	11:23- 12:43	p0296	139941	148582	2001/08/08	08:12- 09:46
p10114	140375	149875	2001/04/17	08:53- 10:25	p0297	139981	148843	2001/08/08	10:08- 11:34
p10115	140625	149625	2001/04/17	10:50- 12:10	p0298	140132	148882	2001/08/09	06:11- 07:41
p10116	140875	149625	2001/04/17	12:36- 13:34	p0299	140069	148559	2001/08/09	08:05- 09:19
p10117	139374	151138	2001/04/18	09:02- 10:36	p0300	140106	148395	2001/08/09	09:38- 10:57
p10118	138958	150555	2001/04/18	10:59- 12:28	p0301	139329	149339	2001/08/12	06:06- 07:35
p10119	138123	150117	2001/04/18	12:53- 14:29	p0302	139360	149127	2001/08/12	07:59- 09:28
p10120	139100	150903	2001/04/18	06:20- 07:49	p0303	138423	148845	2001/08/13	06:13- 07:42
p10123	140355	149606	2001/04/19	08:51- 10:20	p0304	139528	148857	2001/08/13	08:32- 09:46
p10124	140625	149125	2001/04/19	10:42- 12:21	p0305	139430	148932	2001/08/13	10:03- 11:32
p10125	140628	149394	2001/04/19	12:41- 14:13	p0306	139343	148656	2001/08/16	06:41- 07:55
p10126	140375	149375	2001/04/22	09:05- 10:38	p0307	139748	148634	2001/08/19	06:04- 07:37
p10127	140375	149125	2001/04/22	10:58- 12:33	p0308	139898	148428	2001/08/19	07:51- 09:20
p10128	140382	140853	2001/04/22	12:57- 14:41	p0309	139957	148196	2001/08/19	09:51- 11:05
p10129	137816	150624	2001/04/22	07:55- 09:48	p0310	140217	148125	2001/08/20	06:23- 07:58
p10130	137887	150725	2001/04/24	07:05- 08:46	p0311	139585	148125	2001/08/20	08:36- 10:05

POINT	COORDINATES		DATE	TIME	POINT	COORDINATES		DATE	TIME
	EW	NS				EW	NS		
p0131	138110	150628	2001/04/22	10:25- 12:18	p0312	139659	147864	2001/08/20	10:25- 11:51
p0132	140127	149357	2001/04/23	09:29- 11:29	p0313	140197	147850	2001/08/21	06:06- 07:22
p0133	140125	149125	2001/04/23	11:51- 13:35	p0314	139872	147795	2001/08/21	07:39- 08:56
p0134	140114	150135	2001/04/24	09:19- 10:48	p0315	139717	147644	2001/08/21	09:16- 10:29
p0135	139886	150128	2001/04/24	11:16- 12:45	p0316	140343	147718	2001/08/22	05:54- 07:23
p0136	139740	150079	2001/04/24	13:03- 14:35	p0317	140031	147519	2001/08/22	07:48- 09:17
p0137	138103	150709	2001/04/24	09:25- 11:12	p0318	139865	147624	2001/08/22	09:34- 11:00
p0139	139420	150175	2001/04/29	09:04- 10:36	p0319	139872	147465	2001/08/23	06:01- 07:30
p0140	139375	150375	2001/04/29	10:58- 12:26	p0320	139625	147375	2001/08/23	07:52- 09:21
p0141	139123	150627	2001/04/29	12:46- 14:18	p0321	139596	147173	2001/08/23	09:38- 11:07
p0142	138864	150352	2001/04/30	06:19- 07:48	p0322	139403	147855	2001/08/26	05:59- 07:28
p0143	139136	150375	2001/04/30	08:12- 09:44	p0323	139414	147636	2001/08/26	07:44- 09:13
p0144	139122	150135	2001/04/30	10:13- 11:45	p0324	139399	147478	2001/08/26	09:29- 10:58
p0145	138870	150123	2001/05/01	06:29- 07:55	p0325	139786	147115	2001/08/27	06:14- 07:28
p0146	138057	150128	2001/05/01	08:15- 09:44	p0326	139800	146808	2001/08/27	07:44- 09:14
p0147	138391	150114	2001/05/01	10:04- 11:33	p0327	139894	146517	2001/08/27	09:32- 10:58
p0148	139898	149843	2001/05/02	06:27- 07:56	p0328	140105	146622	2001/08/28	07:26- 08:35
p0149	140128	149871	2001/05/02	08:15- 09:44	p0329	140300	146678	2001/08/28	08:51- 10:20
p0150	140152	149689	2001/05/02	10:06- 11:35	p0330	140653	146860	2001/08/29	05:55- 07:12
p0151	139875	149120	2001/05/03	05:55- 07:24	p0331	140434	147476	2001/08/29	07:38- 09:07
p0152	139887	149344	2001/05/03	07:44- 09:13	p0332	140614	147425	2001/08/29	09:24- 10:56
p0153	139877	149625	2001/05/03	09:34- 11:03	p0333	138843	148149	2001/09/03	06:13- 07:43
p0154	139626	149118	2001/05/06	06:20- 07:49	p0334	139109	147902	2001/09/03	07:58- 09:27
p0155	139625	149325	2001/05/06	08:08- 09:37	p0335	138941	147931	2001/09/03	09:41- 10:54
p0156	139623	149621	2001/05/06	09:53- 10:46	p0336	139110	147617	2001/09/04	06:05- 07:34
p0157	139719	149842	2001/05/07	07:18- 08:47	p0337	138636	148049	2001/09/04	07:52- 09:21
p0158	139411	149890	2001/05/07	09:13- 10:57	p0338	138692	148585	2001/09/04	09:39- 10:59
p0159	137165	149015	2001/05/08	06:29- 07:58	p0339	140626	147044	2001/09/06	08:12- 09:44
p0160	136899	149126	2001/05/08	08:18- 09:47	p0340	138846	147522	2001/09/09	06:16- 07:45
p0161	136829	148903	2001/05/08	10:10- 11:36	p0341	138609	147508	2001/09/09	08:02- 09:31
p0162	137108	148875	2001/05/09	06:18- 07:47	p0342	138400	147500	2001/09/09	09:48- 11:05
p0163	137117	148591	2001/05/09	08:23- 09:52	p0343	138114	147624	2001/09/06	06:12- 07:44
p0164	136838	148656	2001/05/09	10:15- 11:44	p0344	138118	147800	2001/09/06	08:02- 09:44
p0165	137350	148652	2001/05/10	08:35- 09:33	p0345	137896	147834	2001/09/06	09:55- 11:04
p0166	137330	148326	2001/05/10	09:51- 10:49	p0346	139143	147443	2001/09/11	06:38- 08:07
p0167	137302	149443	2001/05/17	06:16- 07:45	p0347	138776	148575	2001/09/11	08:42- 10:11
p0168	137116	149386	2001/05/17	08:06- 09:38	p0348	138784	148820	2001/09/11	10:25- 11:38
p0169	136890	149339	2001/05/17	10:07- 11:36	p0349	137837	149622	2001/09/12	06:20- 07:49
p0170	137387	149129	2001/05/20	06:21- 07:50	p0350	137887	149361	2001/09/12	08:04- 09:14
p0171	137644	148876	2001/05/20	08:09- 09:38	p0351	138034	149094	2001/09/16	05:59- 07:28
p0172	137622	149348	2001/05/20	10:03- 11:35	p0352	139411	148036	2001/09/16	09:52- 11:24
p0173	137685	149074	2001/05/20	05:56- 07:25	p0353	139212	148846	2001/09/20	07:45- 09:14
p0174	137872	149072	2001/05/20	07:47- 09:16	p0354	139105	149001	2001/09/20	09:29- 10:58
p0175	137922	148919	2001/05/20	09:37- 11:06	p0355	135149	147138	2001/09/23	06:18- 07:32
p0176	138158	148857	2001/05/22	05:59- 07:28	p0356	134906	147395	2001/09/23	07:57- 09:13
p0177	138136	148636	2001/05/22	07:46- 09:15	p0357	134836	147620	2001/09/23	09:32- 10:45
p0178	137937	148619	2001/05/22	09:37- 11:19	p0358	135099	147395	2001/09/25	07:01- 08:15
p0179	137338	148335	2001/05/23	06:11- 07:37	p0359	135414	147380	2001/09/25	08:31- 09:47
p0180	137623	148425	2001/05/23	07:58- 09:27	p0360	135622	147353	2001/09/25	10:04- 11:20
p0181	137658	148592	2001/05/23	09:56- 11:15	p0361	135792	147402	2001/09/30	08:31- 10:00
p0182	138462	148334	2001/05/24	06:03- 07:32	p0362	136094	147364	2001/09/30	10:22- 11:51

Prior to the recording of microtremors, we checked and determined the transfer functions of the instrumentation. This information is essential to facilitate transformation of the recorded signals into ground motion data, i.e., particle velocity. The individual seismometer constants (free-period, damping and motor constant) were determined from sinus and step calibration signals. The instrument characteristics of the stations are given in Table 5.

In addition, all seismometers were placed at the same location and in the same orientation to record the same waves (Fig. 6). These measurements provide relative

calibrations between the different channels of the entire monitoring system. Figure 7 presents, as an example, the seismograms and the corresponding spectra of vibration of 8 horizontal and 4 vertical seismometers. The amplitude spectra show that the measured motions and thus the transfer functions of the seismic channels, are practically identical.

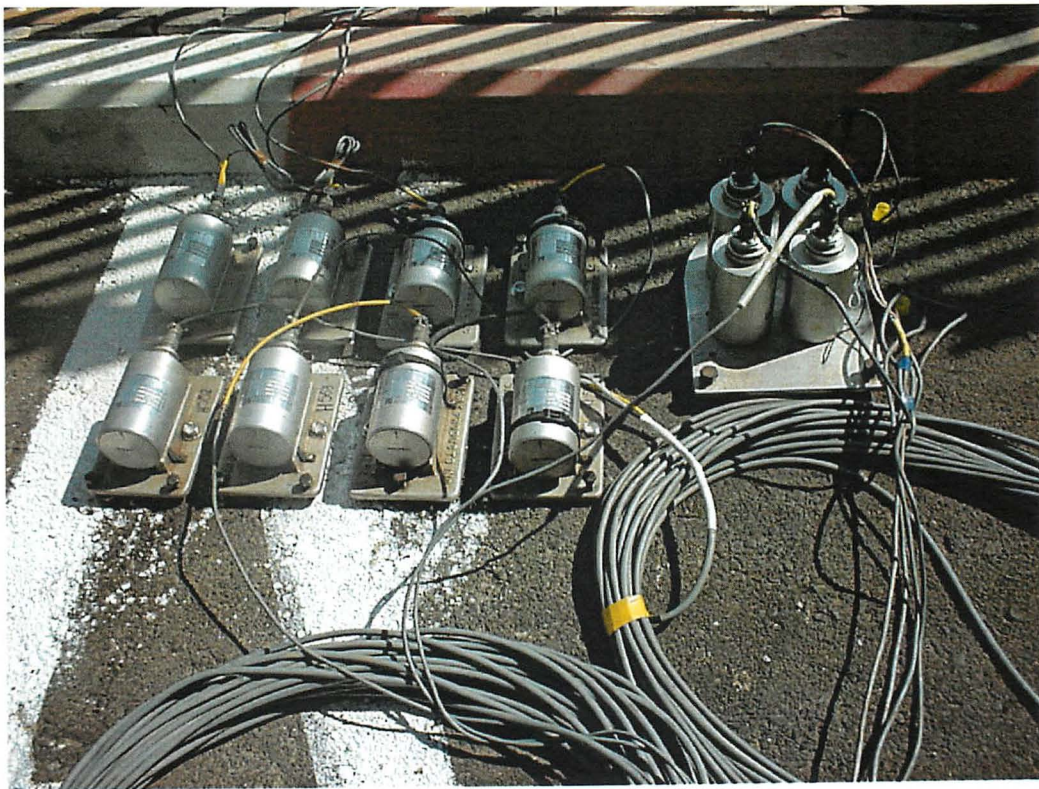


Figure 6. Experimental verification of identity of seismic channels.

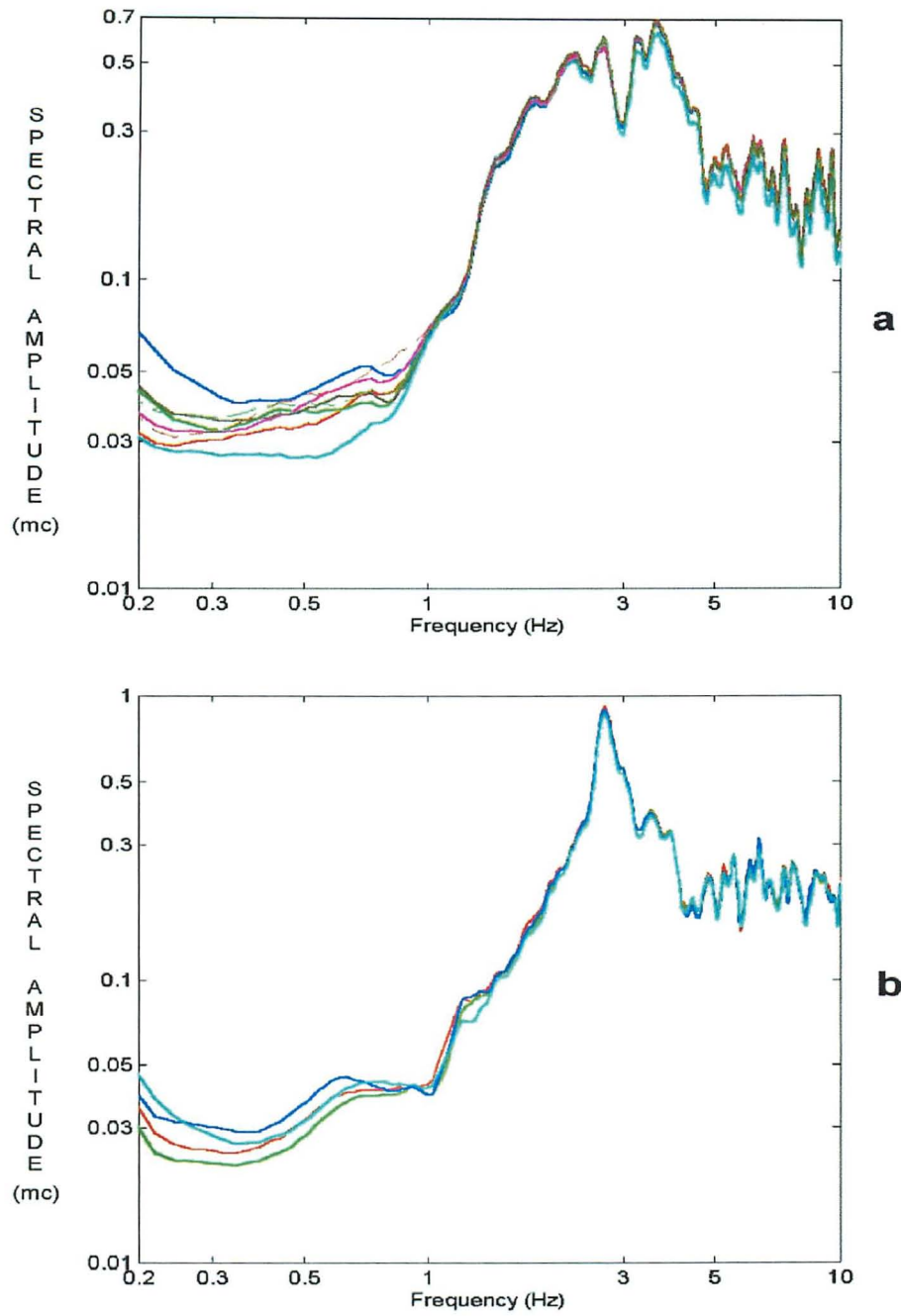


Figure 7. Spectra of simultaneously recorded ambient noise by (a) eight horizontal and (b) four vertical seismometers

Table 5. STATION CHARACTERISTICS

Sensor Number	Code	Trans-duction V/m/sec	Frequency Hz	Damping %	Component
1686	V686	123	1.00	0.73	Vertical
1558	H558	129	1.00	0.72	Horizontal (NS)
1559	H559	134	1.00	0.71	Horizontal (EW)
1687	V687	118	1.00	0.76	Vertical
1560	H560	127	1.00	0.69	Horizontal (NS)
1561	H561	118	1.00	0.68	Horizontal (EW)
1689	V689	126	1.00	0.67	Vertical
1562	H562	121	1.00	0.72	Horizontal (NS)
1563	H563	120	1.00	0.65	Horizontal (EW)
1690	V690	127	1.00	0.68	Vertical
1564	H564	125	1.00	0.66	Horizontal (NS)
1565	H565	127	1.00	0.70	Horizontal (EW)
2752	V752	117	1.00	0.67	Vertical
2746	H746	111	0.98	0.66	Horizontal (NS)
2745	H745	103	1.00	0.70	Horizontal (EW)
2751	V751	117	1.00	0.67	Vertical
2743	H743	111	0.98	0.66	Horizontal (NS)
2744	H744	103	1.00	0.70	Horizontal (EW)

Fig. 8 shows locations of seismometers during various sets of site investigations



Figure 8. Locations of the seismometers during various sets of the site investigation

EMPIRICAL SITE RESPONSE FUNCTIONS

The seismic noise (microtremor) field is controlled by several parameters including source distribution, propagation effects and site conditions. Common microtremor sources include, but are not limited to, cultural activity, wind, weather fronts and sea waves. Variations between microtremors spectra for different components used to obtain the average spectra at Point 176 are shown, as an example, in Figure 9A.

While the details of spectra of different time windows vary, their shapes are similar. These spectra are relatively flat between 0.2 and 1.0 Hz, but increase in amplitude near 3 Hz and decay with an approximately constant decay rate to 10 Hz. Figure 9b presents individual and average horizontal-to-vertical spectral ratio for this point No. 176 (i.e. the empirical transfer function as estimated with the Nakamura technique). As shown, the transfer function has a dominant peak near 1.0 Hz. The observed amplification factor is about 5. Examples of different time windows of the horizontal and the vertical components of microtremors at Point No. 88 are shown in Figure 10A. The solid lines presents the average. All of the spectra show a well-defined peak at about 3.0 Hz, while spectral ratios (Figure 10B) clearly exhibits the resonant peak at about 1.9 Hz with amplification up to 7. Figure 11A shows individual and average spectra of microtremors at Point No. 208. Two spectral peaks are visible in all horizontal spectra: a peak centered around the low frequency of 0.6 Hz and a peak centered near the higher frequency of 3.0 Hz. The peak at frequency 0.6 Hz is probably associated with the site response characteristics. Figure 11B presents individual and average horizontal to vertical spectral ratios. These curves show prominent peak at about 0.6 Hz with amplification of about factor 4 in a fair agreement with the spectra of the horizontal components. However, in most cases, due to the influence of sources from the dense population, high traffic and various industries the resonance frequency cannot be directly identified from microtremors spectra (Zaslavsky, 1988, Zaslavsky et al., 1998).

The individual and average horizontal-to-vertical spectral ratios obtained from microtremors for Points 91 and 261 are shown in Figure 12. These figures also demonstrate a similarity among the individual functions not only in terms of the peak position and magnitude, but also in the whole shape. The dominant feature of all spectral ratios for Point 91 is the high spectral ratio level at a frequency of about 1.8

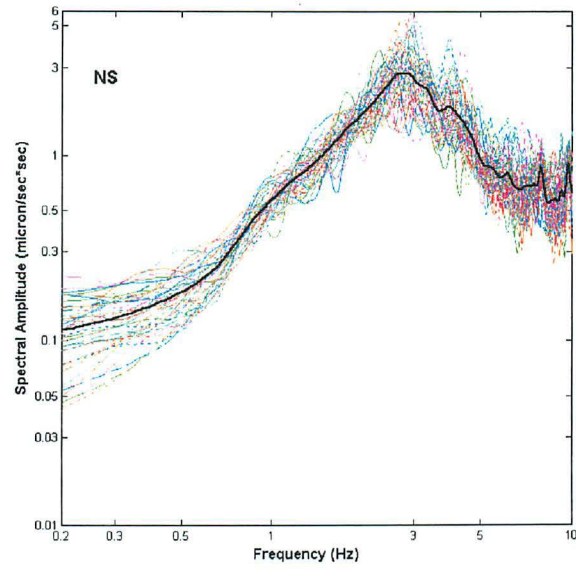
Hz with amplification up to a factor 7.0. In the case of Point No. 261 we can see prominent peak at about 0.6 Hz with amplification up to factor 4.5. The shape of the empirical site response functions, as well as good agreement between both horizontal components strongly suggest that site response functions in the Lod-Ramla region are of 1-D nature.

Examples of the average experimental site response functions obtained by Nakamura technique for the northeastern, central and southwestern parts of the region under study are displayed in Figures 13 through 15. We noticed that parameters of site effects are remarkably robust: Comparing two neighboring points we find that the differences in the location of the fundamental frequencies and amplification level are small and the general shapes of the two horizontal components are similar. These findings significantly increase the reliability of the obtained information and emphasize the importance of a dense grid of observation points in microzoning studies.

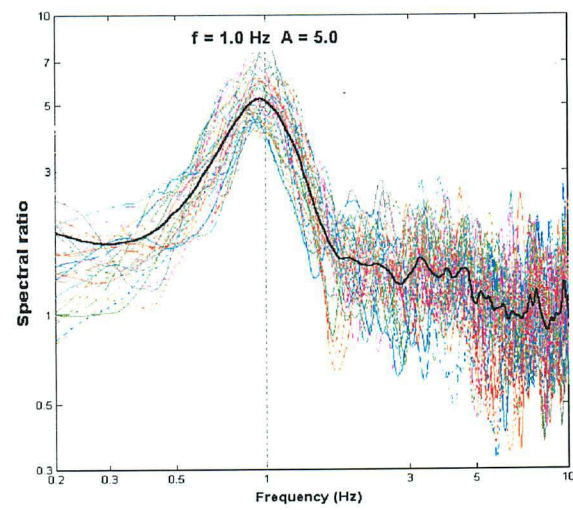
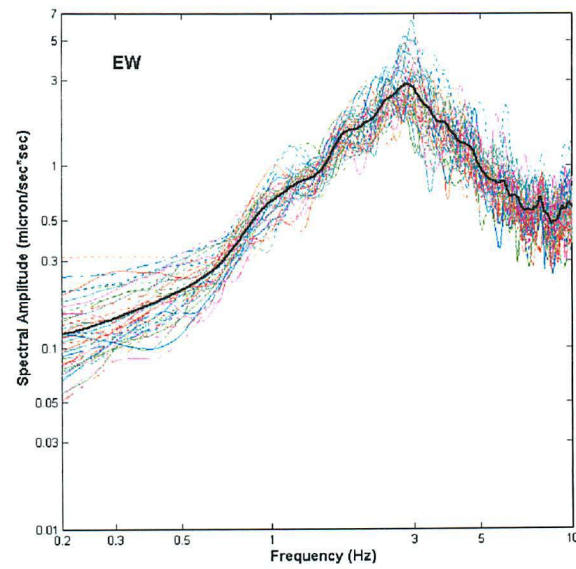
The microtremors measurements yield a series of parameters that can be used to estimate the expected ground motion during earthquake. The key elements for seismic hazard scenarios (Shapira et al., 2001) are maps of the predominant frequency and maximum relative amplification of ground motion. The map in Figure 16 shows the distribution of the fundamental frequency across the Lod-Ramla region. This figure integrates all the experimental data obtained in this study. The site response functions of the soil sites exhibit peaks at dominant frequencies between 0.6 to 2.5 Hz which, in turn, are correlated with the total sediment thickness. The lower resonance frequencies (range from 0.5 to 0.9 Hz) are attained at those sites in West-central part where the depth bedding of the top Bina Fm. is 350 meters, at most. The higher resonance frequencies (range from 2.0-2.7 Hz) are attained at those sites in Northeast part of the area, where the depth of the top Bina Fm. is only 60-80 meters from the surface.

The map of maximum amplification (Figure 17) reflects the variation of the impedance between the bedrock (carbonates of Bina Fm.) and the overlying sediments. The highest amplifications (range from 5-7) are attained at areas where the deposits (clay Yafo Fm.) are lying directly over the rock basement. The lower amplification (range from 3-4) correspond to areas where the marl deposits are placed over the bedrock.

Dominant frequency and amplification maps for Lod and Ramla are prerequisite for generating earthquake scenarios for these towns. These maps can help state and local governments to set priorities in managing land use, enforcing building codes, conducting programs for reducing the vulnerability of existing structures and planning for emergency response and long-term recovery.

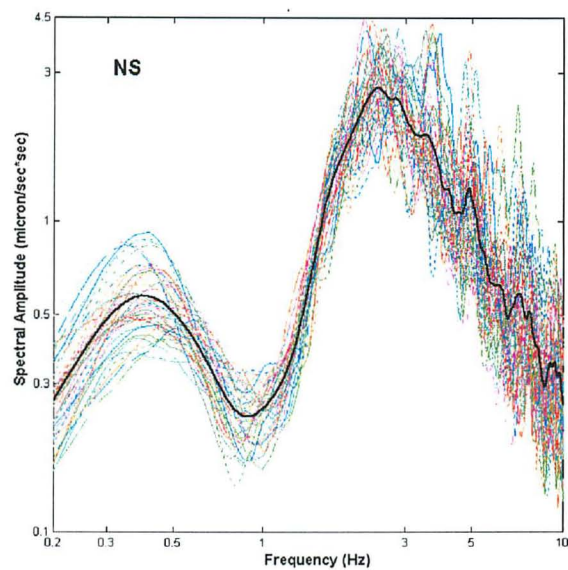


A

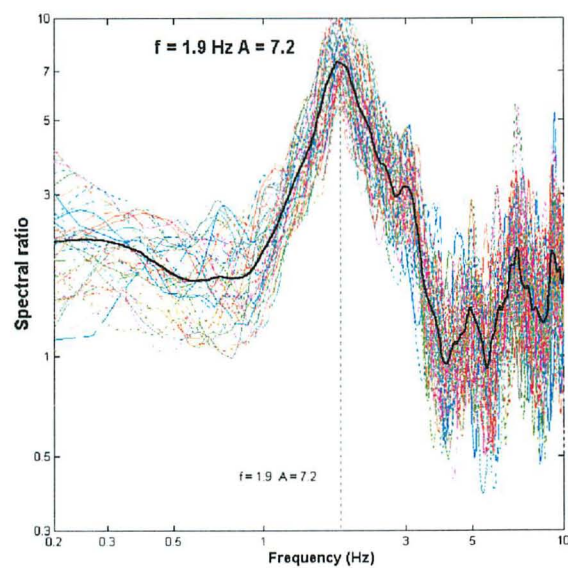
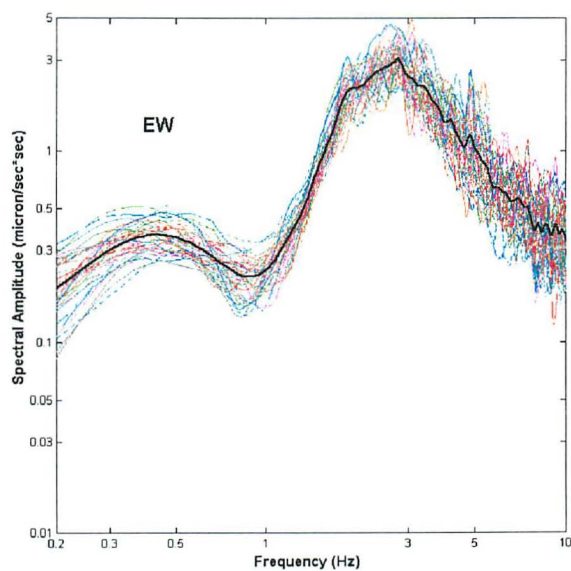


B

Figure 9. Spectral functions of microtremor measured in Point No.176: (A) Fourier spectra (B) horizontal-to-vertical spectral ratio.



A



B

Figure 10. Spectral functions of microtremors measured in Point No. 88. (A) Fourier spectra (B) horizontal-to vertical spectral ratio.

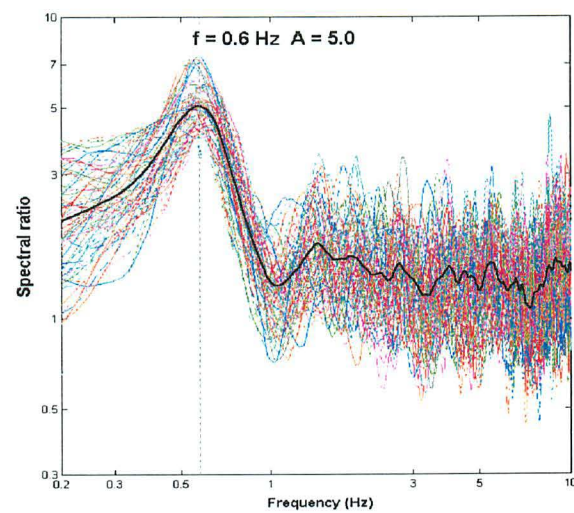
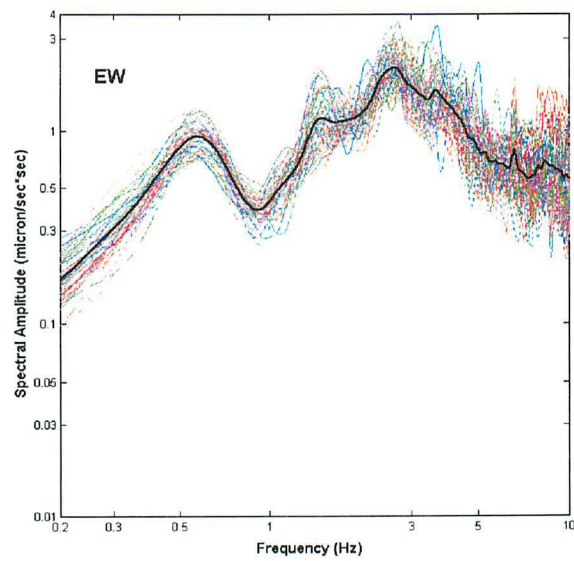
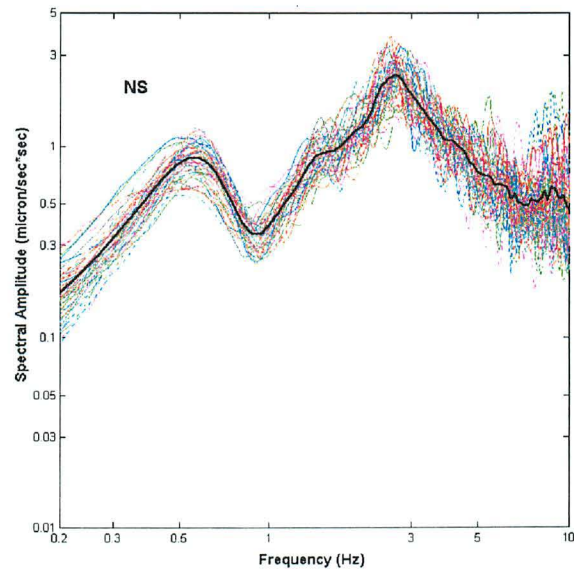


Figure 11. Spectral functions of microtremors measured in PointNo.208 .(A) Fourier spectra (B) horizontal-to-vertical spectral ratio.

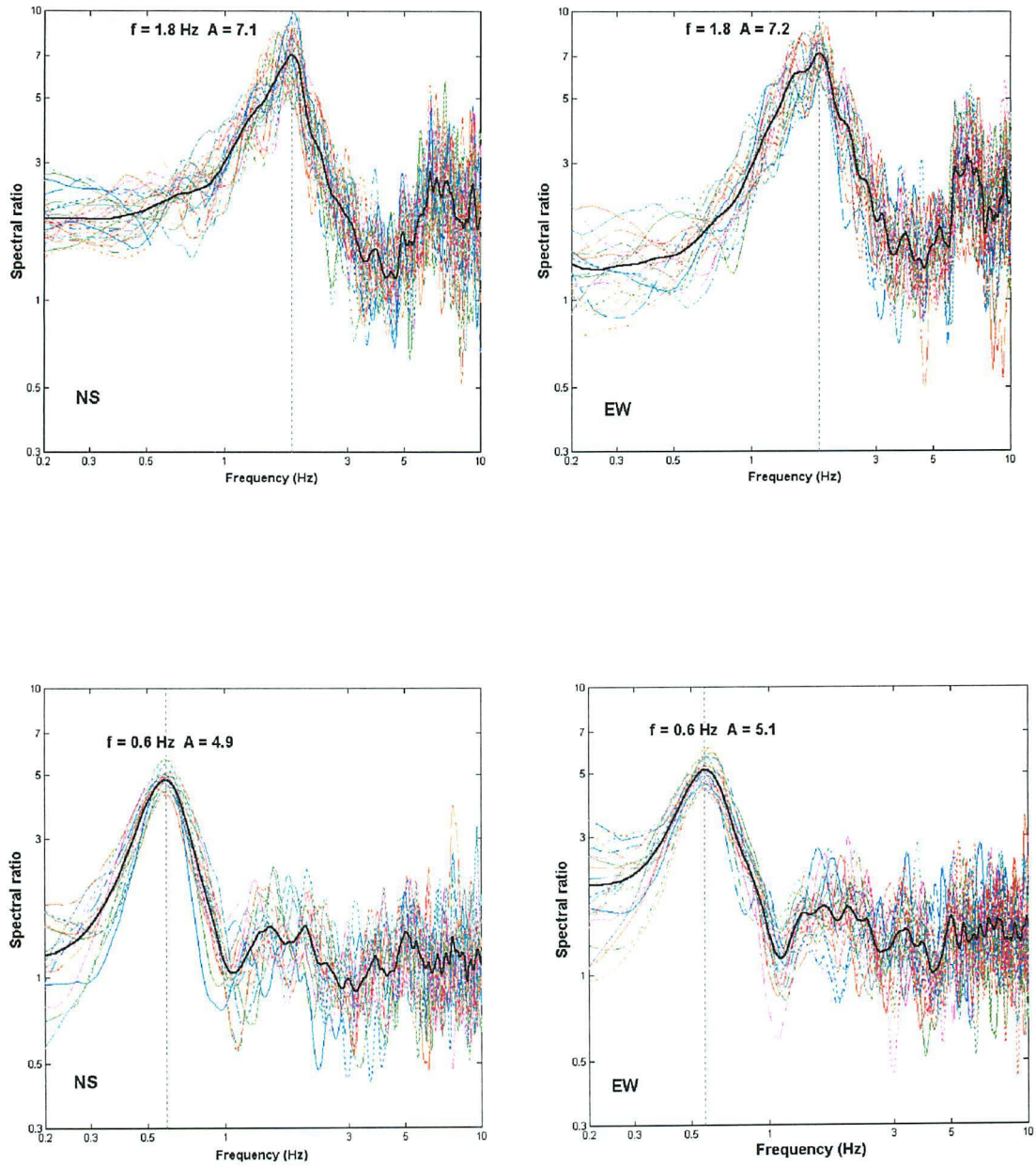


Figure 12. Horizontal-to-vertical spectral ratios obtained from microtremors at the Points No. 91 and 261

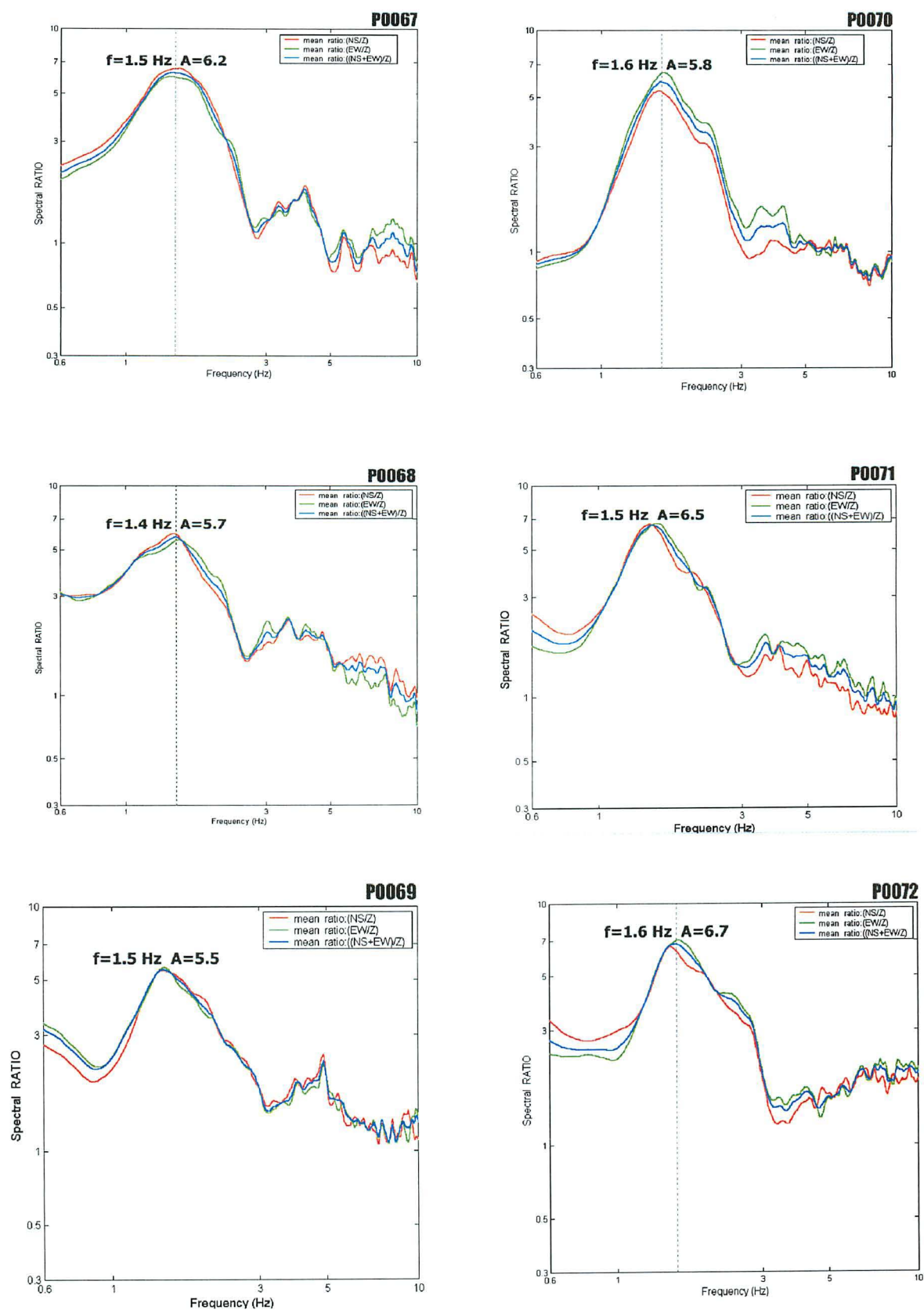


Figure 13. Empirical transfer functions of measurement points in the northwestern region of the Lod-Ramla area as determined by applying the Nakamura technique.

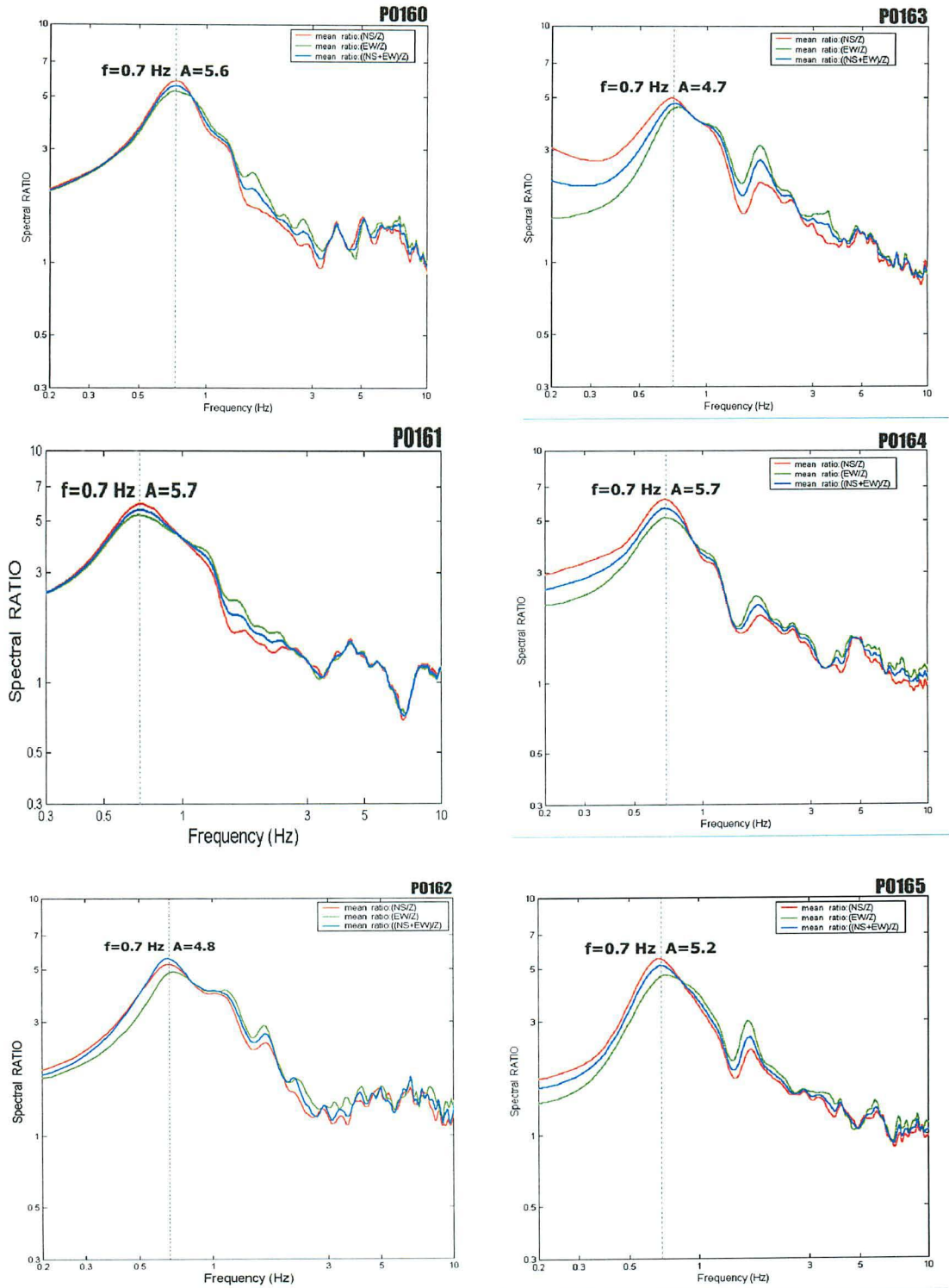


Figure 14. Empirical transfer functions of measurement points in the southwestern region of the Lod-Ramla area as determined by applying the Nakamura technique.

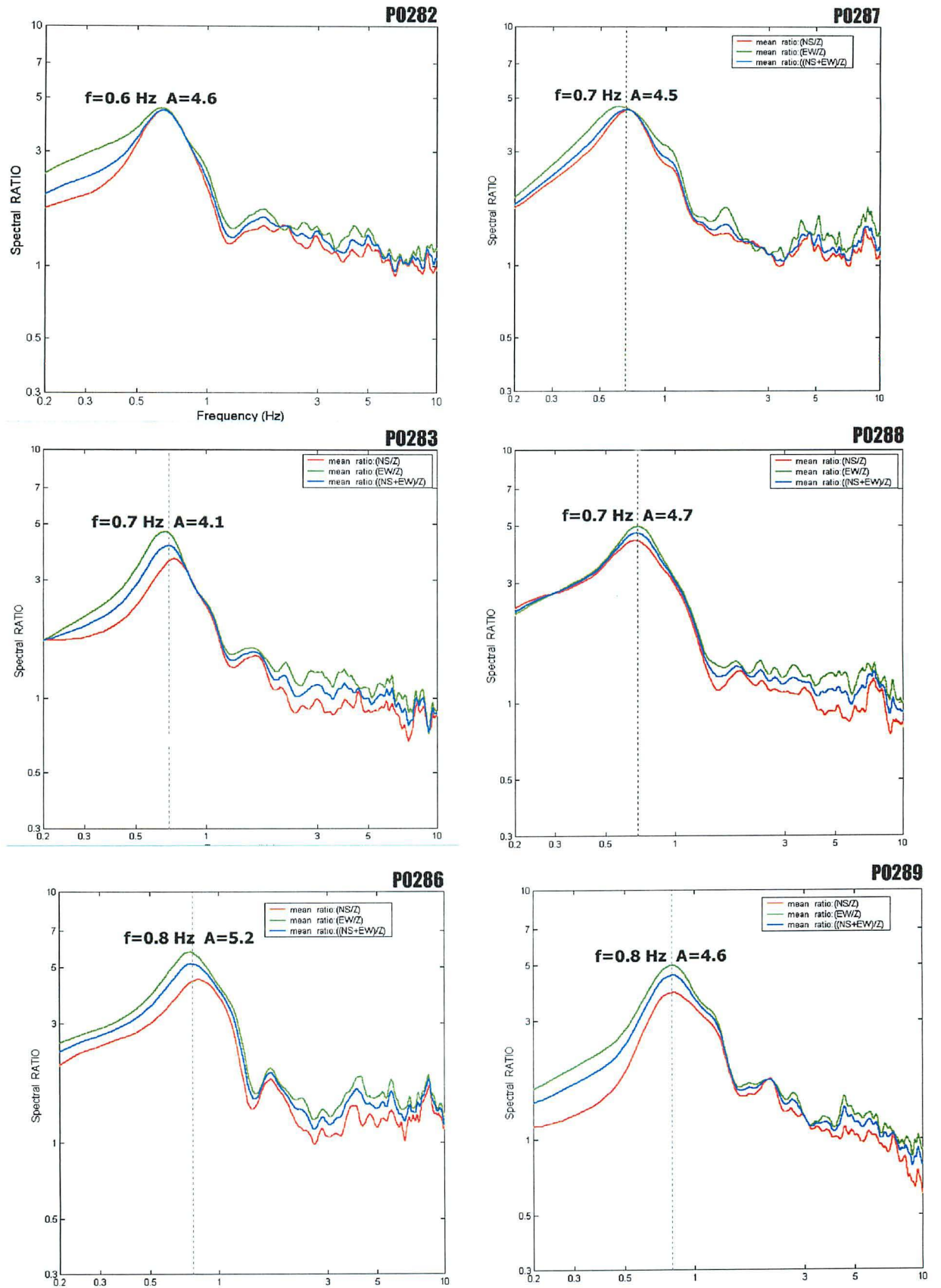


Figure 15. Empirical transfer functions of measurement points in the central region of the Lod-Ramla area as determined by applying the Nakamura technique.

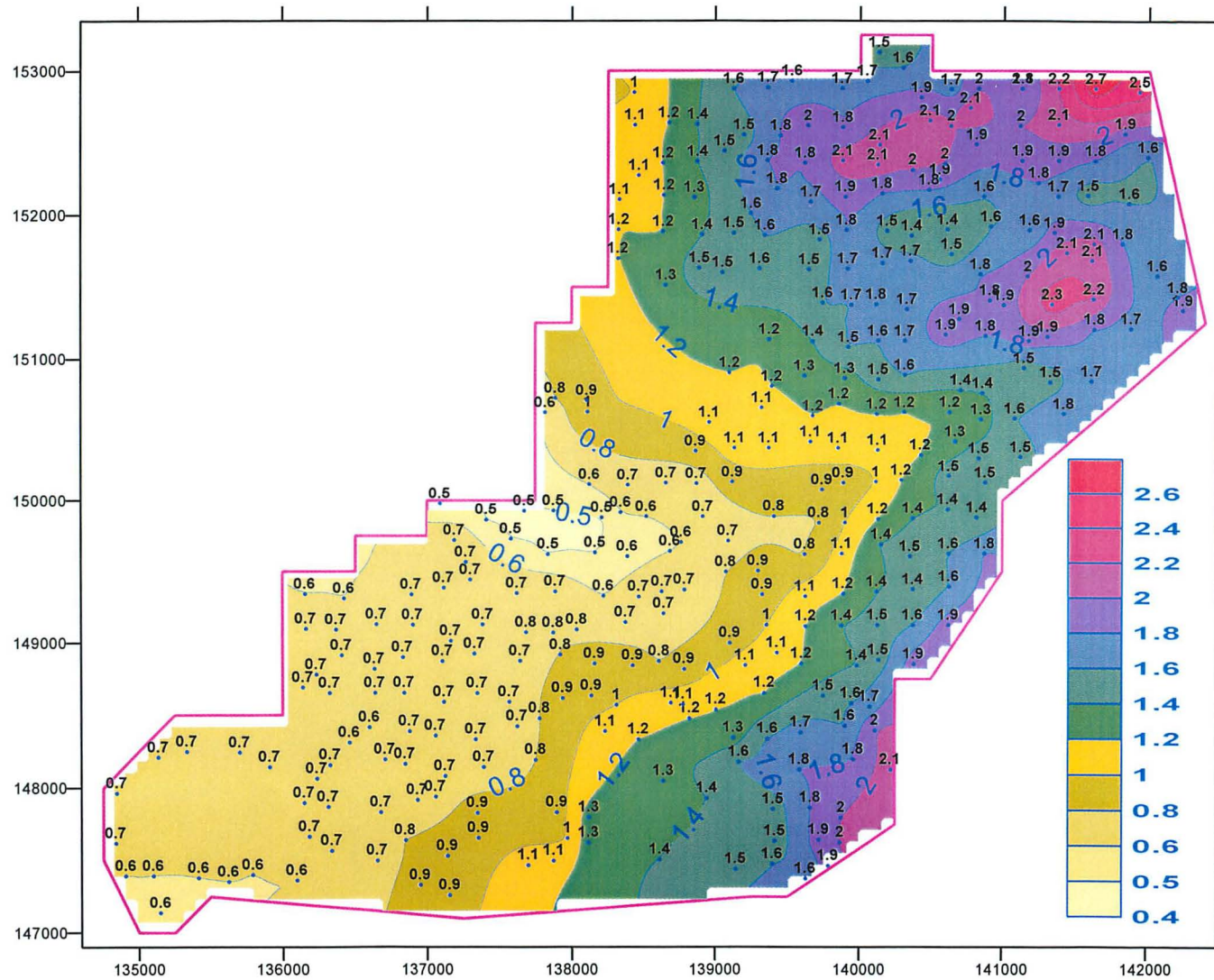


Figure 16. Distribution of the fundamental frequency for Lod-Ramla estimated from horizontal- to- vertical ratio of microtremor. (Frequency is given in Hz)

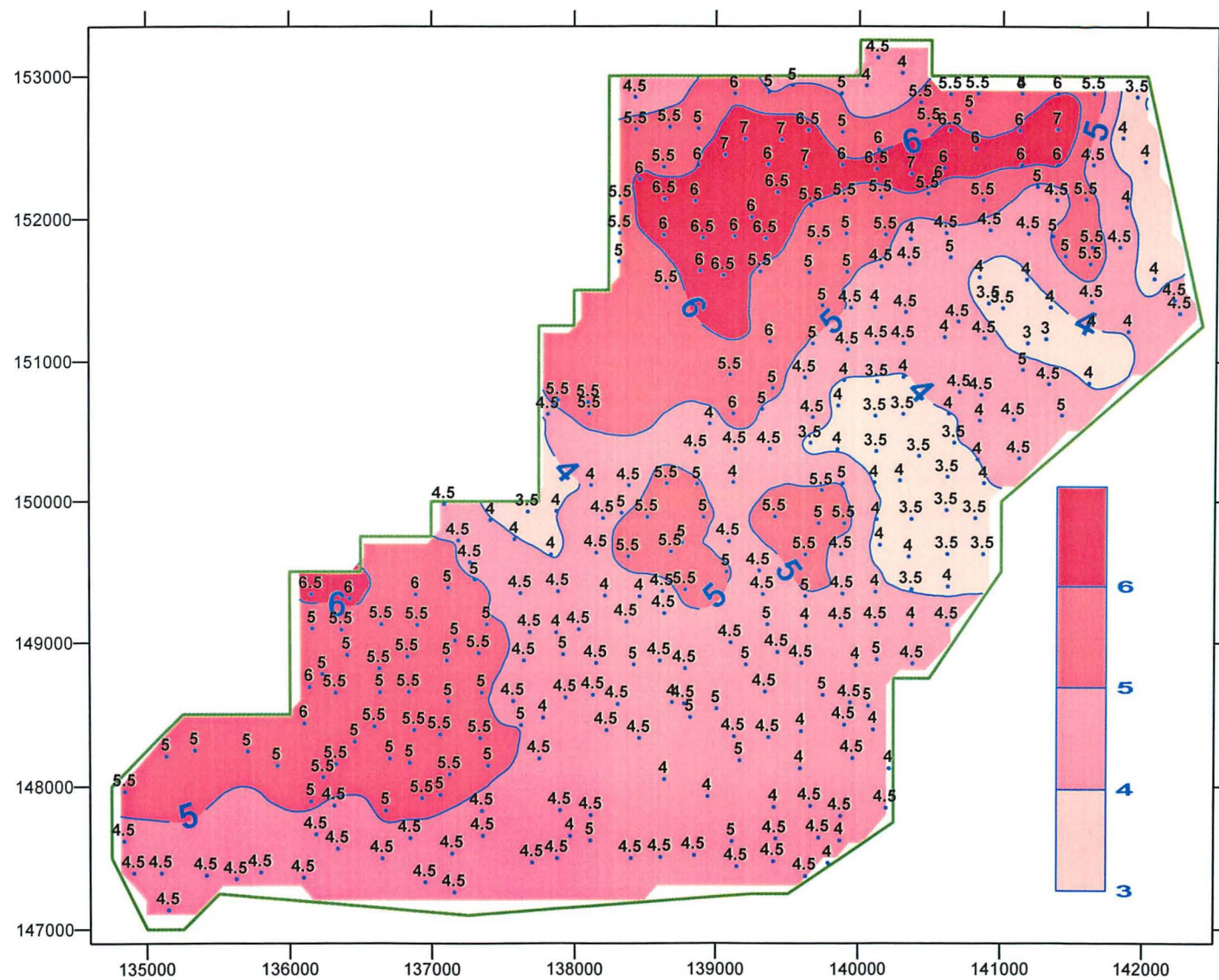


Figure 17. Distribution of the maximum amplification factor for Lod-Ramla estimated from the horizontal- to- vertical ratio of microtremor

DEVELOPING 1-D MODELS OF THE SUBSURFACE AND ANALYTICAL DETERMINATION OF THE SITE RESPONSE FUNCTIONS.

A. S-waves velocities in the sedimentary layers

In order to facilitate analytical site response determinations we need 1-D models of horizontally layered soils. The analytical response functions are computed -linear site response determinations (see Joyner, 1977). The program requires geotechnical parameters and thickness of the material each layer. Lithology and thickness were taken from borehole information, but the required S-wave velocity is vastly not known and may vary considerably across the area (see Table 3).

Measurements of ambient noise have been carried out very close to or directly at drilling sites where detailed information about the subsurface structure, namely the thickness of the sediments, is available. At those point, we could combine the borehole information with the observed site response functions to develop a 1-D model of the subsurface and also suggest S-wave velocity estimations for the soils that characterize the investigated region.

Initial parameters were chosen in accordance with geological information about the area investigated. Analytical response functions, computed for multi-layers, 1-D models, were compared with the empirical determinations (horizontal-to-vertical spectral ratios of microtremors). By means of trial-and-error we found the S-wave velocities that yield the best similarity between the analytical and the observed fundamental resonant frequency and maximum amplification.

The sediment rocks of the investigated area and the some characteristic geotechnical parameters are presented in the Table 3. As a first step, data from table 3 (including velocities) were used to compute the analytical functions. This trial yield unsatisfying results, as demonstrated in Fig. 18 and in Table 6 (Model 1).

In order to obtain more detailed and reliable information about the subsurface structures, we incorporated available logging data. Considering both the logging analysis and the detailed description of the wells, the upper layer (characterized in the Table 3 as sand and calcareous sandstone) were separated into three layers: hamra, sand and sandstone. Fig. 19 and Fig. 20 show the inferred depth maps of hamra, sand and sandstone. It should be emphasized that the inferred isopach maps in Figs. 19 and 20 are based primarily on the information from the boreholes logs. The corresponding S- velocities in these layers are: 200-250 m/s, 300 550 m/s and 600 1100 m/s.

Fig. 18 illustrates the selection of the optimal model for borehole L-11.

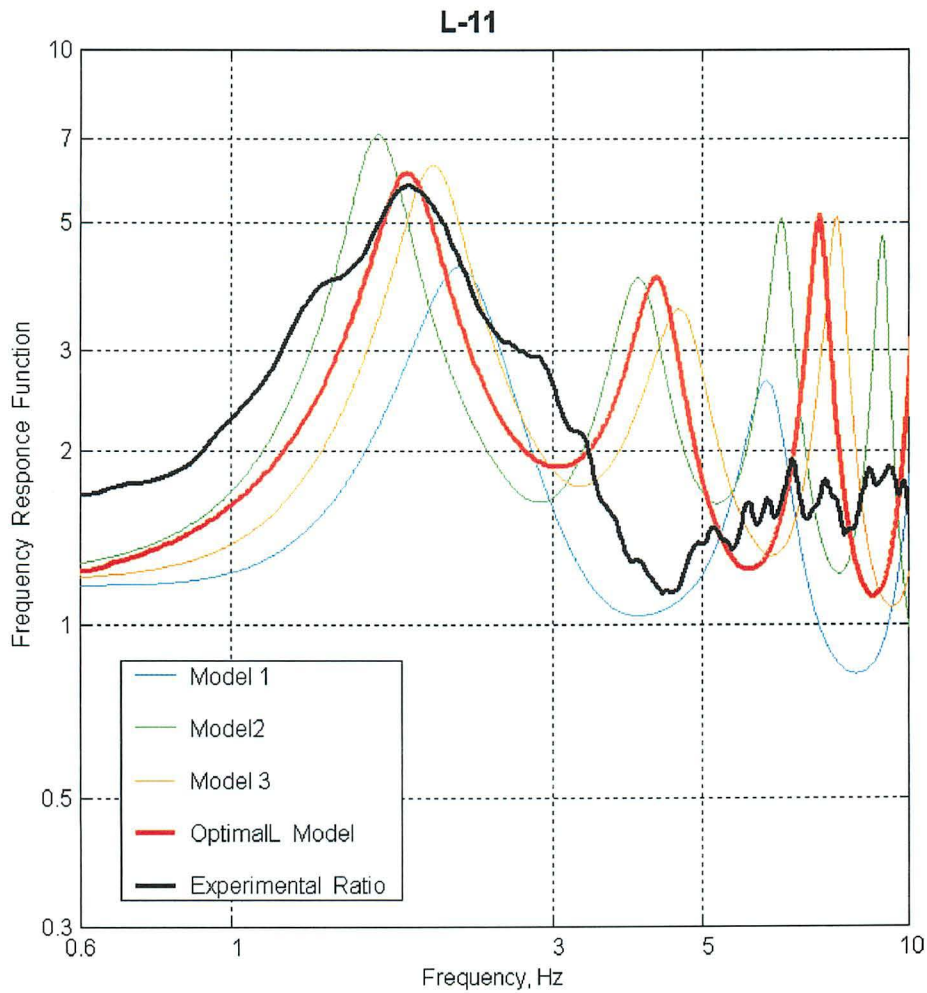


Fig. 18. Best fit model of the subsurface at the location of borehole L-11.

There is a good agreement between the empirical response function (i.e., the average spectral ratio) and the analytical function calculated by using the optimal model. The different models are given in Table 6.

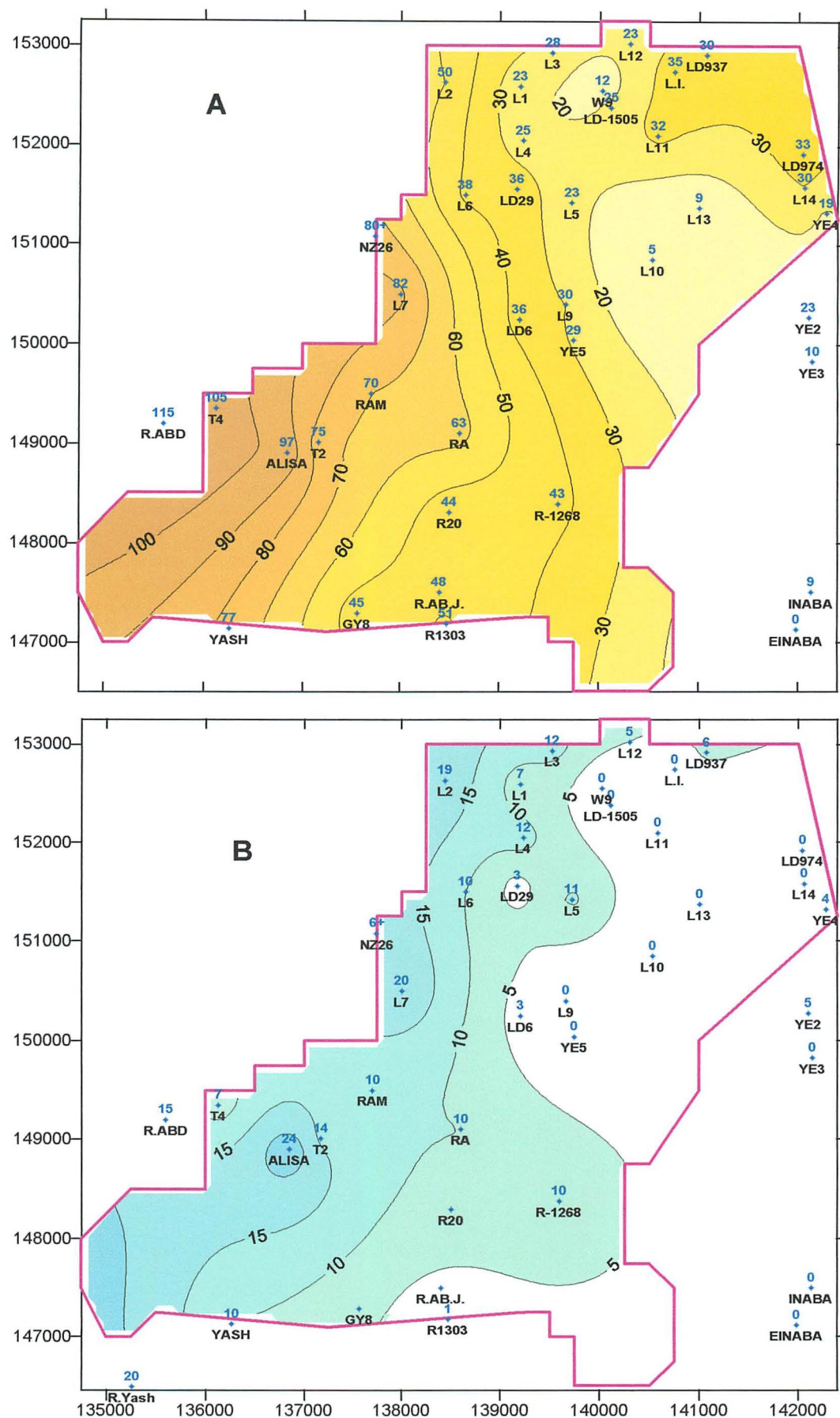


Figure 19. Isopach maps of the Quaternary sediments - (A) , Calcareous sandstone (Pleshet Fm.) and conglomerates (Ahuzam Fm.) - (B)

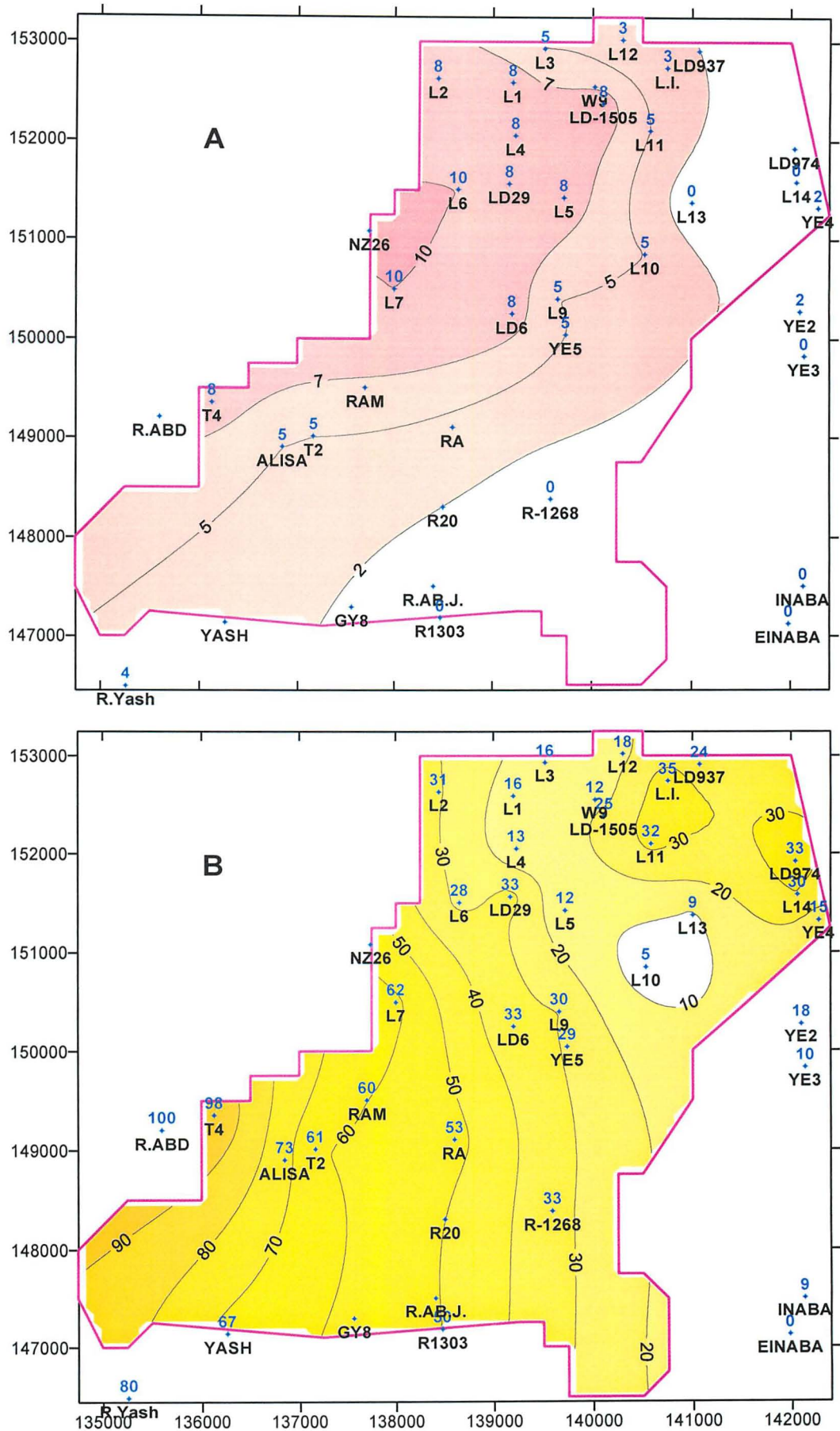


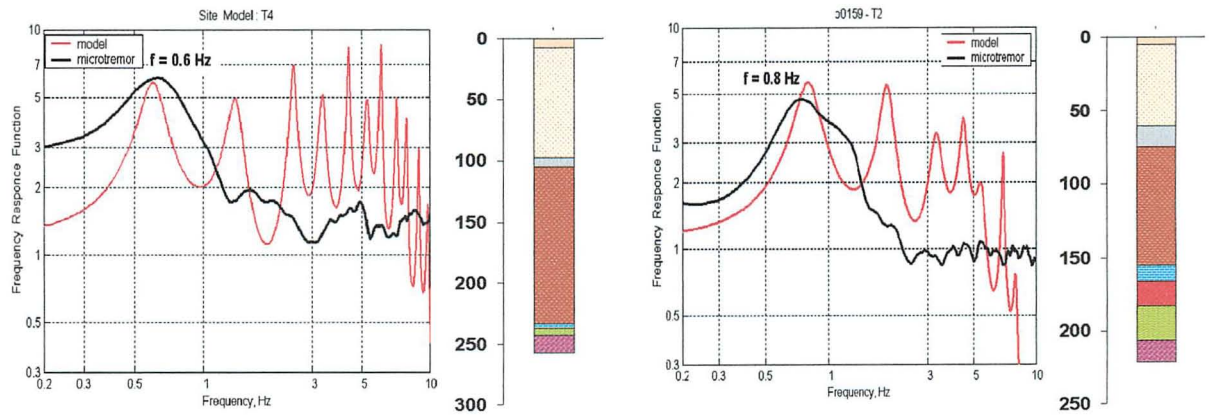
Figure 20. Isopach maps of hamra and soil -(A); sands (Rechvot Fm.) - (B)

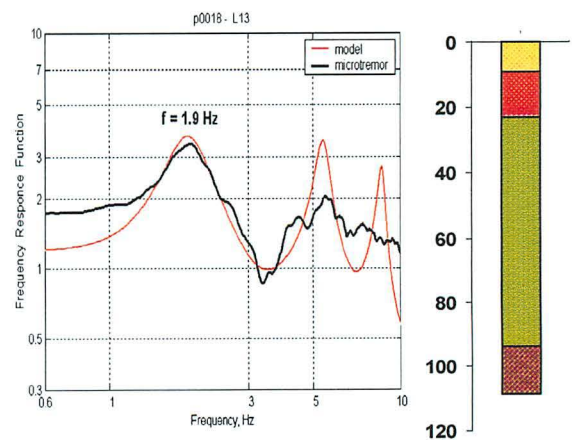
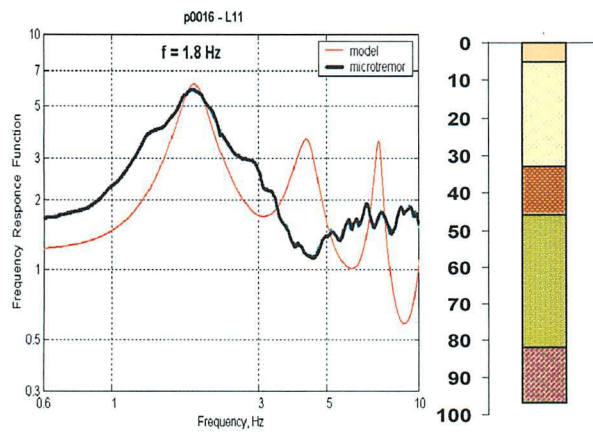
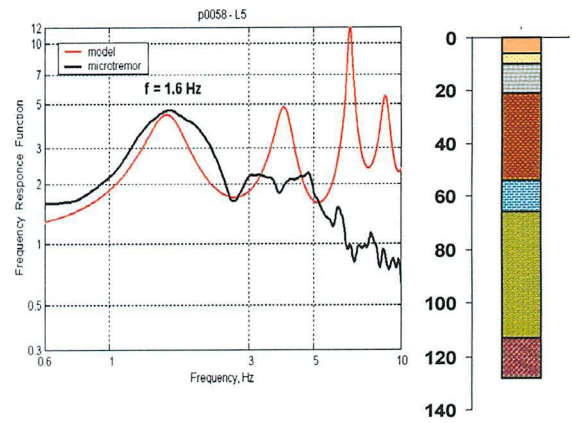
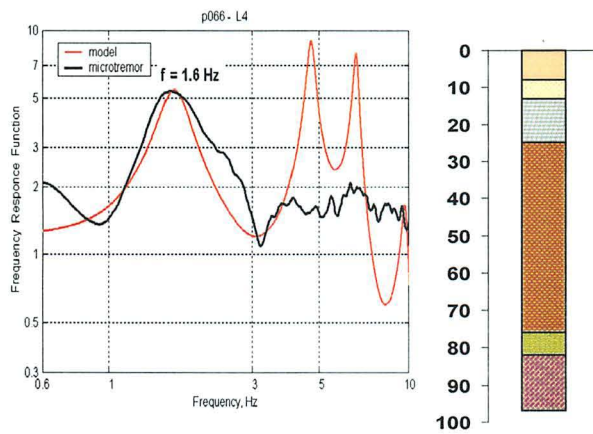
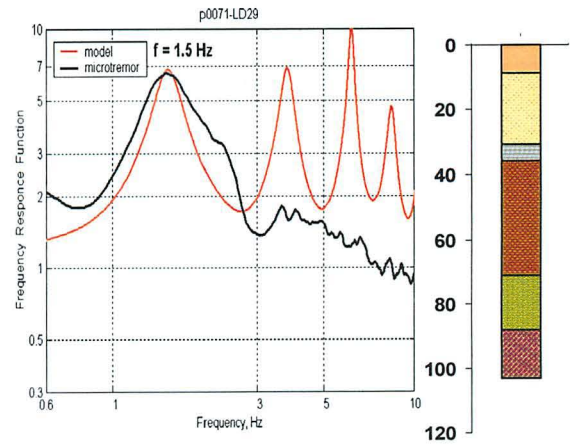
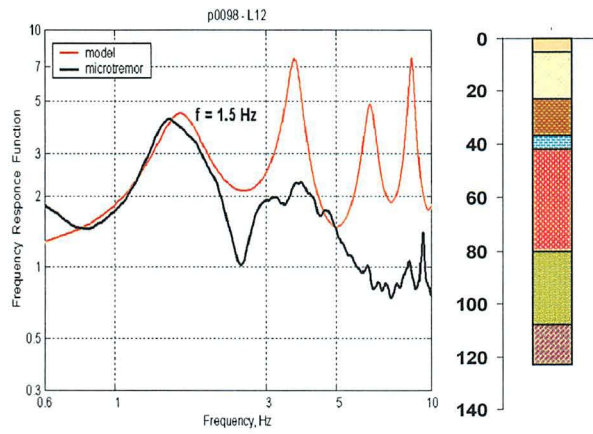
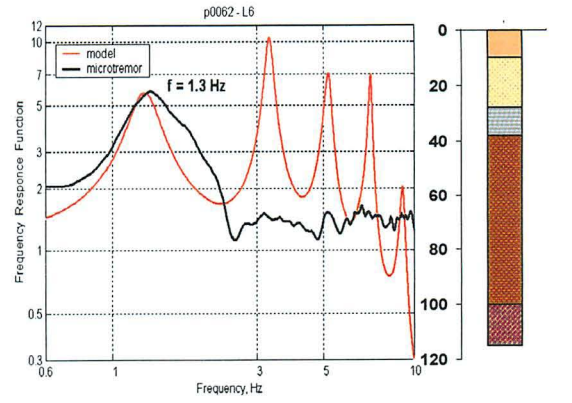
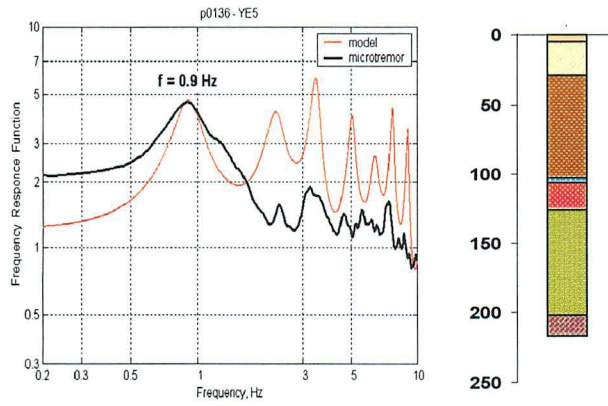
Table 6. MODEL PARAMETERS FOR THE BOREHOLE L-11 (LOD)

Layer	Thickness, m	Density, g/cm3	Measure ments		Model 1			Model 2			Model 3			Optimal model		
			f, Hz	A	V, m/c	f, Hz	A	V, m/c	f, Hz	A	V, m/c	f, Hz	A	V, m/c	f, Hz	A
Kurkar	32	1.6	1.8	5.8	700	2.1	4.2	300	1.6	7.0	350	2.0	6.3	350	1.8	6.1
Clay	13	1.7			500			400			550			500		
Marl	36	1.8			700			650			750			700		
Dolomite		2.1			2100			2000			2100			2100		

The chosen S-velocities are also used to derive optimal 1-D models for other borehole sites. We display in Fig. 21 the results of modeling 12 boreholes. The models are presented in Table 7.

The range of the fundamental frequencies of the computed response functions is 0.6 - 2.0 Hz. It corresponds to a depth range of 60 m to 240 m of the bedrock, which is characterized by dolomite of Bina formation of the Judea group.





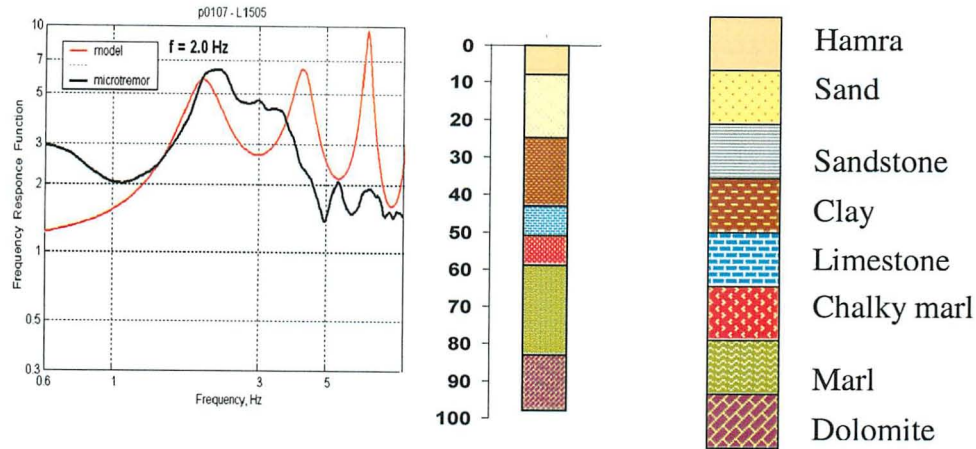


Figure 21. Comparison of the analytical and the empirical site response functions near boreholes in the Lod-Ramla area.

In all of these cases the main frequencies of the models are in agreement with amplification levels observed through the analysis of microtremors.

Table 7. GEOTECHNICAL PARAMETERS USED TO CALCULATION OF RESPONSE FUNCTIONS AT DRILLING SITES IN THE LOD-RAMLA AREA.

Site	Well	Layer Number	Material	Layer Thickness (m)	Depth (m)	Density (g/cm ³)	Shear-wave velocity (m/sec)
28	LI	1	Sand	35	0-35	1.6	350
		2	Marl	25	35-60	1.7	700
			Bedrock	Half space	> 60	2.1	2100
16	L-11	1	Sand	32	0-32	1.6	350
		2	Clay	13	32-45	1.7	500
		3	Marl	36	45-81	1.8	700
			Bedrock	Half space	> 81	2.1	2100
66	L-4	1	Hamra	8	0-8	1.6	200
		2	Sand	5	8-13	1.6	350
		3	Kurkar	12	13-25	1.7	600
		4	Clay	51	25-76	1.7	500
		5	Marl	6	76-82	1.8	700
			Bedrock	Half space	> 82	2.1	2100
107	L-15-05	1	Hamra	8	0-8	1.6	200
		2	Sand	17	8-25	1.6	350
		3	Clay	18	25-43	1.7	500
		4	Limestone	8	43-51	1.9	1000
		5	Marl	32	51-83	1.7	700
			Bedrock	Half space	> 83	2.1	2100
85	L-1	1	Hamra	8	0-8	1.6	200
		2	Sand	8	8-16	1.6	350
		3	Kurkar	7	16-23	1.7	600
		4	Clay	61	23-84	1.7	500
			Bedrock	Half space	> 84	2.1	2100
247	L-14	1	Sand	30	0-30	1.6	350
		2	Marl	55	30-85	1.8	700
			Bedrock	Half space	> 85	2.1	2100

71	LD-29	1	Hamra	8	0-8	1.6	200
		2	Sand	22	8-30	1.6	350
		3	Kurkar	5	30-35	1.7	600
		4	Clay	36	35-71	1.7	500
		5	Marl	17	71-88	1.7	700
			Bedrock	Half space	> 88	2.1	2100
18	L-13	1	Sand	9	0-9	1.6	350
		2	Marl	85	9-94	1.7	700
			Bedrock	Half space	> 94	2.1	2100
246	YE-4	1	Sand	19	0-19	1.6	350
		2	Marl	75	19-94	1.7	700
			Bedrock	Half space	> 94	2.1	2100
62	L-6	1	Hamra	10	0-10	1.6	200
		2	Sand	18	10-28	1.6	350
		3	Kurkar	10	28-38	1.7	600
		4	Clay	62	38-100	1.7	500
			Bedrock	Half space	> 100	2.1	2100
90	L-3	1	Hamra	5	0-5	1.6	200
		2	Sand	11	5-16	1.6	350
		3	Kurkar	12	16-28	1.7	600
		4	Clay	58	28-86	1.8	500
		5	Marl	14	86-100	1.8	700
			Bedrock	Half space	> 100	2.1	2100
98	L-12	1	Hamra	5	0-5	1.6	200
		2	Sand	18	5-23	1.6	350
		3	Clay	14	23-36	1.7	500
		4	Limestone	5	36-41	1.9	1000
		5	Marl	66	42-108	1.7	700
			Bedrock	Half space	> 108	2.1	2100
58	L-5	1	Hamra	6	0-6	1.6	200
		2	Sand	4	6-10	1.6	350
		3	Kurkar	11	10-21	1.7	600
		4	Clay	33	21-54	1.7	500
		5	Limestone	12	54-66	1.9	1000
		6	Marl	32	66-98	1.8	700
		7	Marl	15	98-113	1.8	800
			Bedrock	Half space	> 113	2.1	2100
44	L-10	1	Hamra	5	0-5	1.6	200
		2	Clay	19	5-24	1.7	500
		3	Limestone	8	24-32	1.9	1000
		4	Marl	68	32-100	1.7	700
		5	Marl	17	100-117	1.8	800
			Bedrock	Half space	> 117	2.1	2100
100	L-2	1	Hamra	8	0-8	1.6	200
		2	Sand	23	8-31	1.6	350
		3	Kurkar	19	31-50	1.7	600
		4	Clay	50	50-100	1.7	500
		5	Clay	60	100-160	1.7	600
			Bedrock	Half space	> 160	2.1	2100
141	LD6	1	Hamra	8	0-8	1.6	200
		2	Sand	28	8-36	1.6	350
		3	Clay	64	36-100	1.7	500
		4	Marl	82	100-182	1.8	800
			Bedrock	Half space	> 182	2.1	2100
51	L-9	1	Hamra	5	0-5	1.6	200
		2	Sand	25	5-30	1.6	350
		3	Clay	61	30-91	1.7	500
		4	Marl	59	91-150	1.8	800
		5	Marl	50	150-200	1.8	900
			Bedrock	Half space	> 200	2.1	2100
136	YE-5	1	Hamra	5	0-5	1.6	200

		2	Sand	24	5-29	1.6	350
		3	Clay	74	29-103	1.7	500
		4	Marl	43	103-146	1.7	800
		5	Marl	56	146-202	1.8	900
			Bedrock	Half space	> 202	2.1	2100
159	T-2	1	Hamra	5	0-5	1.6	200
		2	Sand	56	5-61	1.6	350
		3	Kurkar	14	61-75	1.7	600
		4	Clay	25	75-100	1.7	500
		5	Clay	55	100-155	1.7	600
		6	Marl	51	155-206	1.8	900
			Bedrock	Half space	> 206	2.1	2100
193	T-4	1	Hamra	8	0-8	1.6	200
		2	Sand	90	8-98	1.6	350
		3	Kurkar	52	98-150	1.7	600
		4	Clay	83	15-233	1.7	700
		5	Marl	9	233-242	1.8	900
			Bedrock	Half space	> 242	2.1	2100

The suggested S-wave velocities are similar to those obtained from the single refraction line conducted in Lod. The refraction line yields a 3-layers model with shear-wave velocities of 210 m/s, 320 m/s and 630 m/s. We interpreted these layers as hamra (soil sediments), sand and marl, respectively. Velocity values for different materials in the area of Lod and Ramla are given in Table 8.

Table 8. VELOCITY MODELS FOR THE LOD-RAMLA AREA

Layer's number	Material	Shearwave velocity m/sec			
		Depth 0-100m	Depth 100-150m	Depth 150-250m	Depth >250m
1	Hamra and soil sediments	200	—	—	—
2	Sand, loam	350	—	—	—
3	Calcareous sanstone and conglomerates	600	—	—	—
4	Clay	500	600	700	750
5	Marl	700	800	900	950
	DOLOMITE AND LIMESTONE	2100			

The S-wave velocities given in Table 8 refer to five lithologically homogeneous layers. The fifth layer, total marl, unites layers presented by marl facies. It includes m Fm.) and

chalk (Adulam Fm.). Limestone and chalk have limited spread and small thickness varying from 0 to 12 m for the limestone and from 0 to 25 m for the chalk.

B. Thickness of sedimentary layers

Shear waves velocities, derived from modeling at the borehole sites, were summarized and fixed for five selected sediment layers (see Table 8). These fixed velocity values and the microtremors measurements are used for estimating the thickness of the sediments at every point of measurement.

The procedure of 1-D modeling at borehole site is repeated for sites where no borehole information is available. In the trial-and-error process of adjusting the analytical response function to the empirical one, the soil thickness varied until an acceptable match is observed. Results for 51 selected sites are presented in Table 9 (layer thickness) and in Table 10 (main response parameters).

The thickness of hamra, sand and sandstone were taken from isopach maps, presented on the Figs. 19 and 20. We used the 1-D models of near-by borehole sites (where the information is highly reliable) to provide the initial values of thickness of the clay and marl.

In the trial-and-error process we altered the thickness of clay and marl (and consequently also of the depth of top Judea group). Fig. 22 presents isopach maps of clay, created on the basis of boreholes data (Fig. 22B) and on the basis of our measurements (Fig. 22A). The new subsurface models yield a thickness of the synclinal area to be 40 m more than is given in Fig. 22B and reaches a thickness of 270 m. In the southwest part of the area, the thickness of clay is 140 m, i.e. 40 m less than inferred from contouring the boreholes data.

Fig. 23A displays the isopach map of the marl, which is the sum of marly facies of Lakhia. In the eastern part of the area, the estimated thickness of marl is 25-30 m more than initially estimated. Also, at syncline B we estimate a thickness of 95 m which is 45 m thicker than estimated from the initial isopach maps.

Comparing the structural data given in the map of Top Judea Group (Fleischer & Gafson, 2000) (depth taken from the surface) with our estimates, we can note, that structural elements generally coincide but the depth of occurrence of the Top Judea Group in the central part of the area is 50 m deeper than that on the Fleischer map.

Two anticlinal crests A and B were well distinguished in our map, as shown on the Fig. 24A.

Based on the discussed above we may conclude that microtremors measurements can be a powerful tool to obtain quantitative estimations of layer thickness and useful for mapping interfaces of sedimentary layers.

Table 9. SEDIMENT THICKNESS AND DEPTH OF THE TOP JUDEA GROUP CALCULATED BY MODELING OF MEASUREMENT DATA.

NN	NN Point	Total Quaternary sediments	Clay (m)	Total Marl (m)	Depth of Top Judea group (m)
1	1	20	-	95	115
2	10	5	20	130	155
3	12	10	12	90	112
4	15	30	10	80	120
5	18	9	-	85	94
6	26	-	-	125	125
7	27	-	-	80	80
8	28	35	-	25	60
9	34	10	10	110	130
10	58	21	33	60	115
11	62	38	62	-	100
12	64	41	80	-	120
13	66	25	51	6	82
14	83	23	47	-	70
15	85	23	61	-	84
16	90	28	58	14	100
17	98	23	14	71	108
18	107	25	18	40	83
19	120	40	40	65	145
20	146	65	130	30	225
21	154	40	50	60	150
22	157	30	85	90	205
23	175	65	85	65	215
24	178	55	50	60	165
25	184	50	45	65	160
26	186	85	70	75	230
27	191	100	90	35	225
28	193	105	128	9	242
29	205	80	240	40	360
30	213	90	270	10	370
31	229	25	-	85	110
32	231	30	-	85	115
33	238	30	-	30	60
34	239	30	-	50	80
35	246	19	-	75	94
36	256	50	55	105	210
37	263	64	180	60	304
38	265	80	120	55	255
39	269	60	80	80	225
40	272	100	95	25	220
41	275	110	140	10	260
42	278	65	90	60	210
43	280	50	50	110	210
44	299	35	5	67	107
45	309	30	-	70	100
46	310	20	-	60	80
47	312	35	10	60	105
48	315	30	-	60	90
49	324	30	5	70	105
50	355	100	140	20	260
51	362	90	135	35	260

TABLE 10. COMPARISON OF EMPIRICAL AND THEORETICAL
RESPONSE FUNCTIONS

NN	Number of point	Observed		Calculated	
		Resonance frequency	Amplification	Resonance frequency	Amplification
1	1	1.6	4.5	1.6	4.2
2	10	1.2	4.0	1.2	3.3
3	12	1.9	4.0	1.9	3.9
4	15	1.4	5.0	1.4	4.8
5	18	1.9	3.5	1.9	3.7
6	26	1.5	5.0	1.5	3.4
7	27	2.3	4.0	2.3	3.6
8	28	2.1	4.5	2.1	7.1
9	34	1.4	3.5	1.4	3.5
10	58	1.6	4.5	1.6	4.5
11	62	1.3	6.0	1.3	5.8
12	64	1.2	6.5	1.2	5.1
13	66	1.6	5.5	1.6	5.5
14	83	1.8	6.5	1.8	5.5
15	85	1.5	7.0	1.5	5.5
16	90	1.6	5.0	1.4	5.1
17	98	1.6	4.0	1.6	4.5
18	107	2.1	6.0	2	5.9
19	120	1.2	6.5	1.2	5.3
20	146	0.7	5.0	0.7	5.1
21	154	1.2	4.0	1.2	5.4
22	157	0.8	5.0	0.8	4.7
23	175	0.8	5.0	0.8	5.1
24	178	1.1	5.0	1.1	5.4
25	184	1.1	5.0	1.1	5.2
26	186	0.7	5.5	0.7	5.2
27	191	0.7	5.0	0.7	6.2
28	193	0.6	6.0	0.6	5.9
29	205	0.5	4.0	0.5	4.2
30	213	0.5	4.0	0.5	3.6
31	229	1.7	4.5	1.7	4.5
32	231	1.5	5.0	1.5	4.6
33	238	2.7	6.0	2.7	6
34	239	2.1	4.0	2.1	5
35	246	1.9	4.5	1.9	4.3
36	256	0.8	5.0	0.8	4.6
37	263	0.6	5.5	0.6	4.6
38	265	0.7	4.5	0.7	5.1
39	269	0.8	5.0	0.8	4.9
40	272	0.8	4.5	0.8	6.1
41	275	0.7	5.0	0.7	5.3
42	278	0.9	4.5	0.8	5.4
43	280	1.1	4.0	1.1	5
44	299	1.7	5.5	1.7	4.5
45	309	1.8	4.5	1.8	4
46	310	2.1	5.0	2.1	3.8
47	312	1.7	7.0	1.7	4.8
48	315	1.9	7.0	1.9	5
49	324	1.6	6.0	1.6	4.8
50	355	0.6	4.0	6.3	5.5
51	362	0.6	5.0	0.6	5.3

2

Figure 23. Comparison of the isopach map of Marl concluded from (A) microtremors measurements and (B) the borehole information.

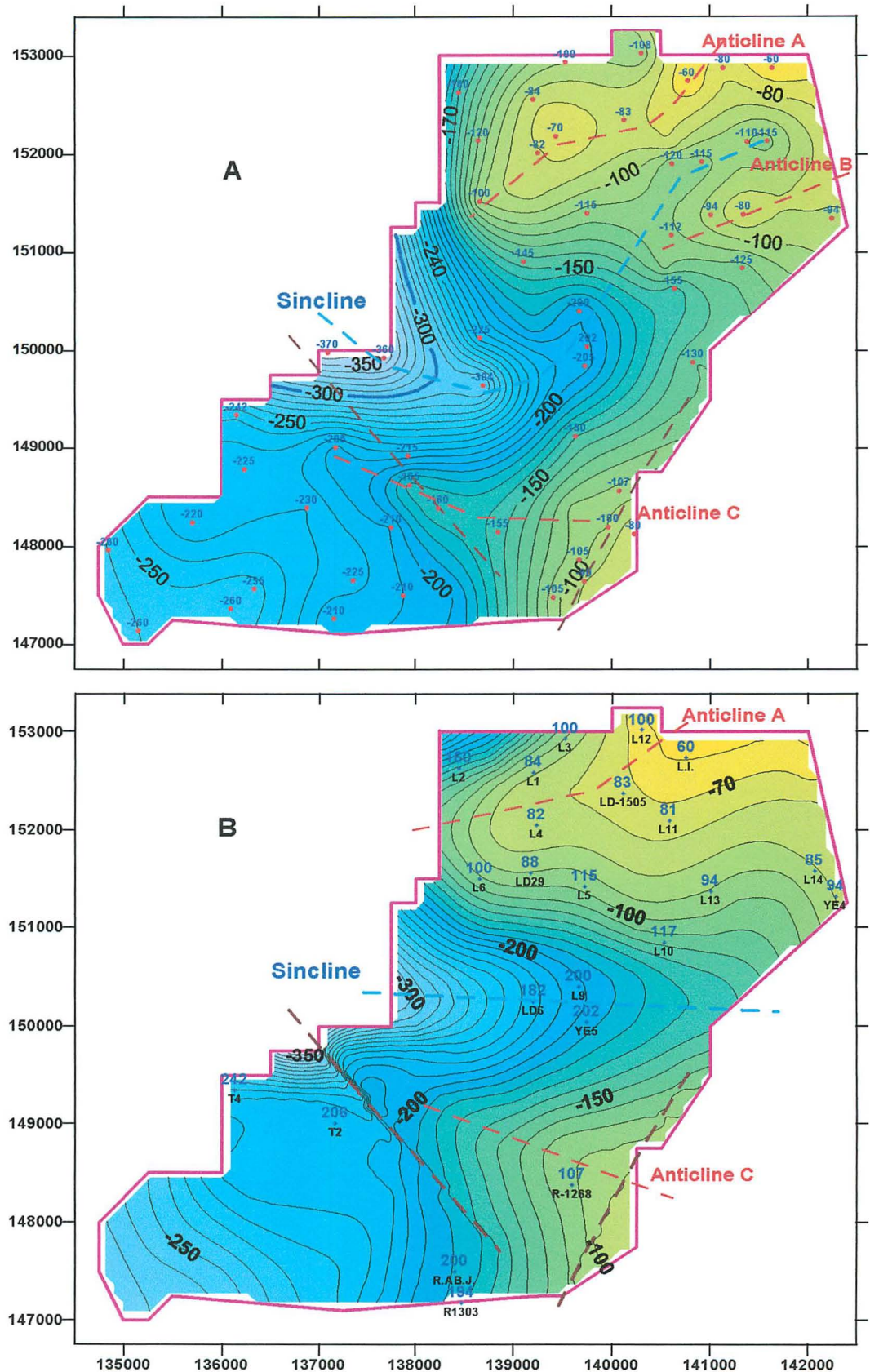


Figure 24. Comparison of structural maps of top Judea Group concluded from microtremor measurements and (B) the borehole information.

SEISMIC HAZARD ASSESSMENT FOR THE LOD-RAMLA AREA

For design purposes, the common engineering practice is to re-normalize a standard response spectrum by multiplying the spectral function by the horizontal peak ground acceleration (PGA) that characterizes the area where the building to be designed is located. The Israeli Code/Standard 413 (IS-413) provides the standard response spectra for different, but generalized, soil conditions (assuming a damping ratio of 5%) and provides the PGA for hard-rock site conditions. The PGA values in the IS-413 are computed for a probability of occurrence of 10% in an exposure time of 50 years.

The concept of a standard response function raises some seismological difficulties. The most significant among them are:

1. The probability of exceeding PGA is not necessarily the same as the probability of exceeding the frequency dependent accelerations obtained from the re-normalized response spectrum.
2. The response spectrum must depend on the spectra of ground motions from earthquakes of different magnitudes, mechanisms and distances from the investigated site.

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conditions are often found to be non-realistic.

In an attempt to overcome these significant difficulties, Shapira and van Eck (1993) developed the SvE approach. The SvE flowchart is shown in Figure 25. As described in this flowchart, SvE computations are based on regional parameters such as distribution of seismogenic zones, frequency-magnitude relationships, stress drop, Q-values, seismic moment - magnitude relationship, etc. which have been evaluated and routinely updated by the Seismology Div. of GII from local and regional earthquakes (see, for example van Eck and Hofstetter, 1989, Shapira and Hofstetter, 1993, Shapira and Shamir, 1994, Hofstetter et al., 1996, Shamir et al., 2001). The uncertainties associated with those parameters are incorporated in the SvE by applying Monte-Carlo statistics, i.e., simulating several possible lists of earthquakes over a very long time and synthesizing many accelerograms (an accelerogram is the acceleration time history on the free surface of the investigated site). The regional information is used to synthesize accelerograms for the surface of the

THE SvE APPROACH

Simulate Earthquake Catalogs for several thousand years.

Constrain: Events within seismogenic zones, $j=1,J$

Adhere to the freq._mag. relationship for each zone.

$$\log N(M)_j = \Phi(a_j - b_j M, \sigma_j)$$

For each catalog

For each event (Lat.Long., Depth, M)

ASSUME

Φ = Normal distribution
 ψ = Uniform distribution

$$\log M_o = \Phi[c + dM, \sigma]$$

$$\text{stress drop} = \psi[v_1, v_2]$$

$$f_{\max} = \psi[\xi_1, \xi_2]$$

$$Q_value = \psi[\kappa_1, \kappa_2]$$

Zero frequency Displacement = Ω_o

Hypocentral distance = R

$$\Omega_o = f(M_o, R) \text{ [Empirical relation !]}$$

COMPUTE A SYNTHETIC ACCELEROGRAM FOR
 AN *HARDROCK SITE*, FROM A *MAGNITUDE M*
 EARTHQUAKE AT *DISTANCE R*.
[Apply the Stochastic Method]

USE SUBSURFACE INFORMATION OF THE *SITE*
 TO **COMPUTE THE NON-LINEAR SITE RESPONSE**
 output:
FREE FIELD GROUND MOTION

COMPUTE & STORE:
SITE SPECIFIC RESPONSE SPECTRUM
PEAK ACCELERATION, VELOCITY, DISPLACEMENT

yes → more events ? → no

DO STATISTICS:
Uniform Hazard Site Specific Response
Spectrum
Peak Horizontal Ground Motion

Figure 25. Flowchart of SvE method

underlying bedrock and then they are convolved with the response function of the site under investigation, to yield the expected accelerations on the free surface of that site. Following our practice and that of many investigators world wide, the site response functions must be evaluated empirically.

As stated above, the SvE method was used to evaluate the seismic hazard for the area of Lod and Ramla.

Three hundred sixty measurements of microtremors were registered to produce the distribution map of the predominant frequency of site response. Based on our observations we divided the study area into four zones, each characterized by a fundamental resonance frequency of the soil column (see Figure 26).

The four zones are:

Zone 1. Characterized by a resonance frequency between 0.5 and 0.8 Hz.

Zone 2. Characterized by a resonance frequency between 0.8 and 1.4 Hz.

Zone 3. Characterized by a resonance frequency between 1.4 and 1.8 Hz.

Zone 4. Characterized by a resonance frequency between 1.8 and 2.5 Hz.

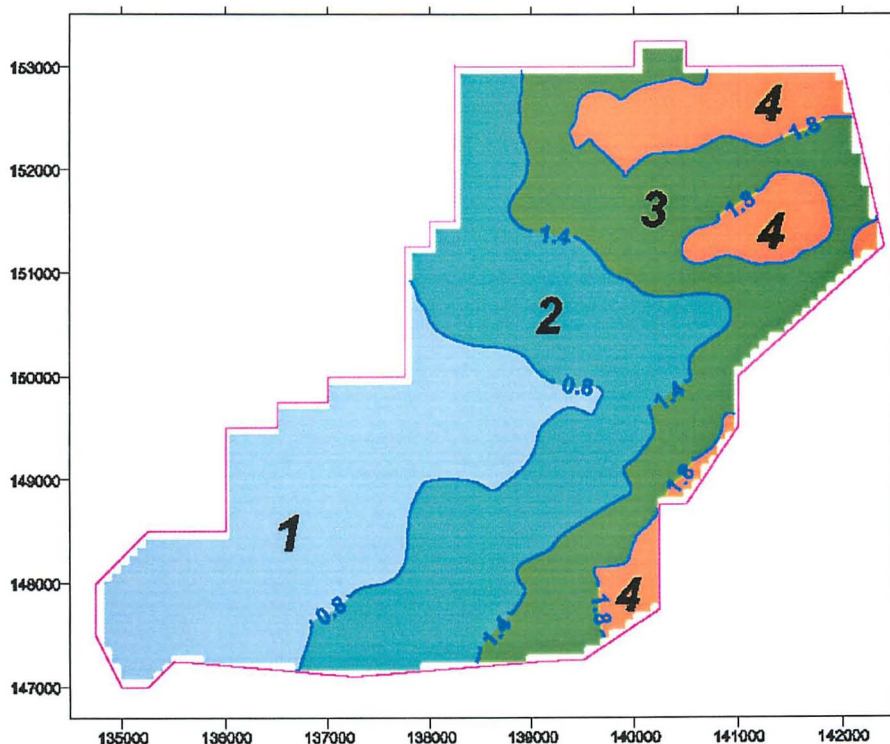


Figure 26. Map showing the four Zones division of the Lod-Ramla area

The Uniform hazard site-specific acceleration spectra for the 4 zones was computed for a probability of exceedence of 10% during an exposure time of 50 years and damping ratio of 5%. For each zone we used 10-15 analytical response functions. The results of our computations are shown on the Figs. 27-30. We also plotted the acceleration response spectrum that is required in the same area by the current IS-413 for ground types S2 and S3 with the required design horizontal Peak Ground Acceleration (PGA) value of 0.1g. The shape of the spectra obtained for all zones are significantly different from the ones prescribed by IS-413, in that IS-413 underestimates the accelerations in the period range from 2 sec. to 0.1 sec.

The Lod-Ramla area is characterized by moderate irregularities of soils yielding an overall amplification of earthquake ground motions with no remarkable differences from one zone to another (see Figs. 27 to 30) . In other words, although the study area can be divided into 4 zones with respect to the resonance frequency, the seismic hazard functions do not show a distinctive difference from one zone to the other. Consequently, it is suggested to adopt an overall response spectrum, which accounts for amplification effects throughout the whole investigated area. From the engineering standard point, the area of Lod and Ramla can be characterized by the uniform hazard site-specific acceleration spectra shown in Fig. 31.

We strongly recommend that estimations of earthquake loss scenarios should be based on our results. The other functions are presented for reference and information purposes only.

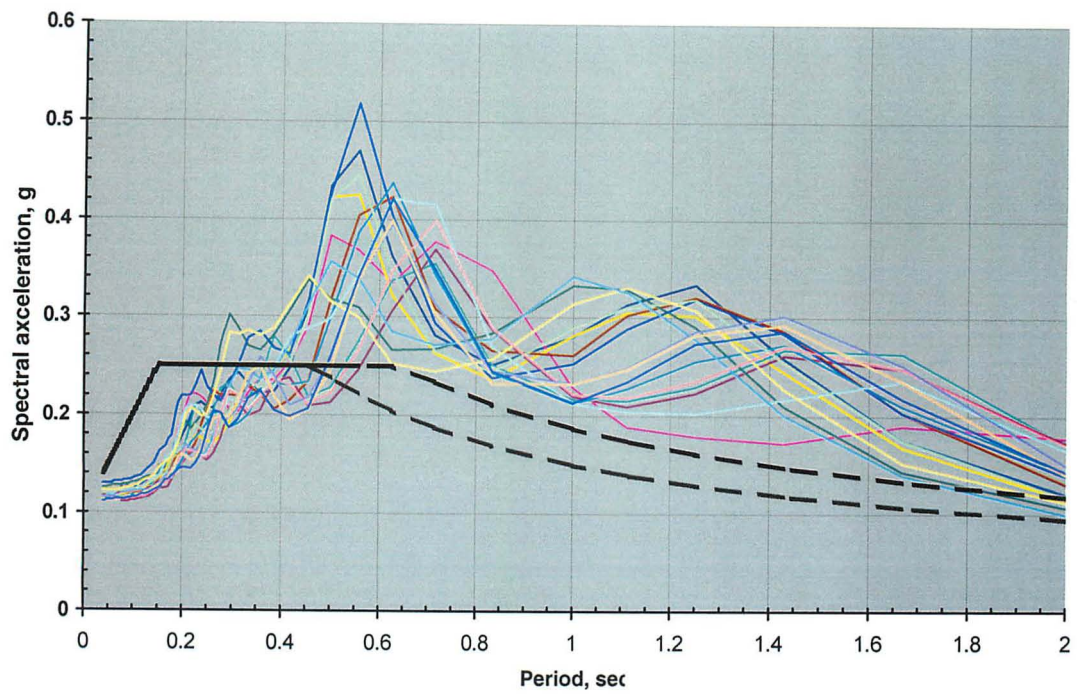


Figure 27. Uniform hazard site-specific acceleration spectra for different sites of Zone 1 of the Lod-Ramla area. Spectrum according to the Israel Building Code (Peak Ground Acceleration of 0.1g) is included for reference.

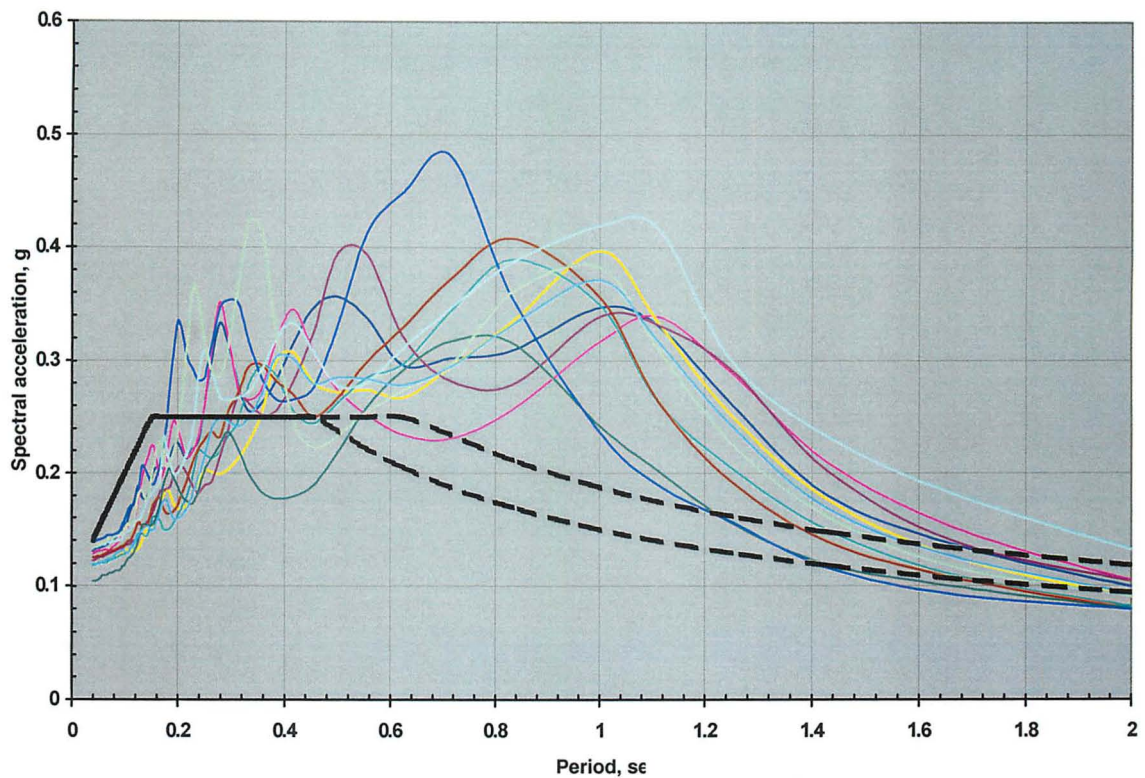


Figure 28. Uniform hazard site-specific acceleration spectra for different sites of Zone 2 of the Lod-Ramla area. Spectrum according to the Israel Building Code (Peak Ground Acceleration of 0.1g) is included for reference.

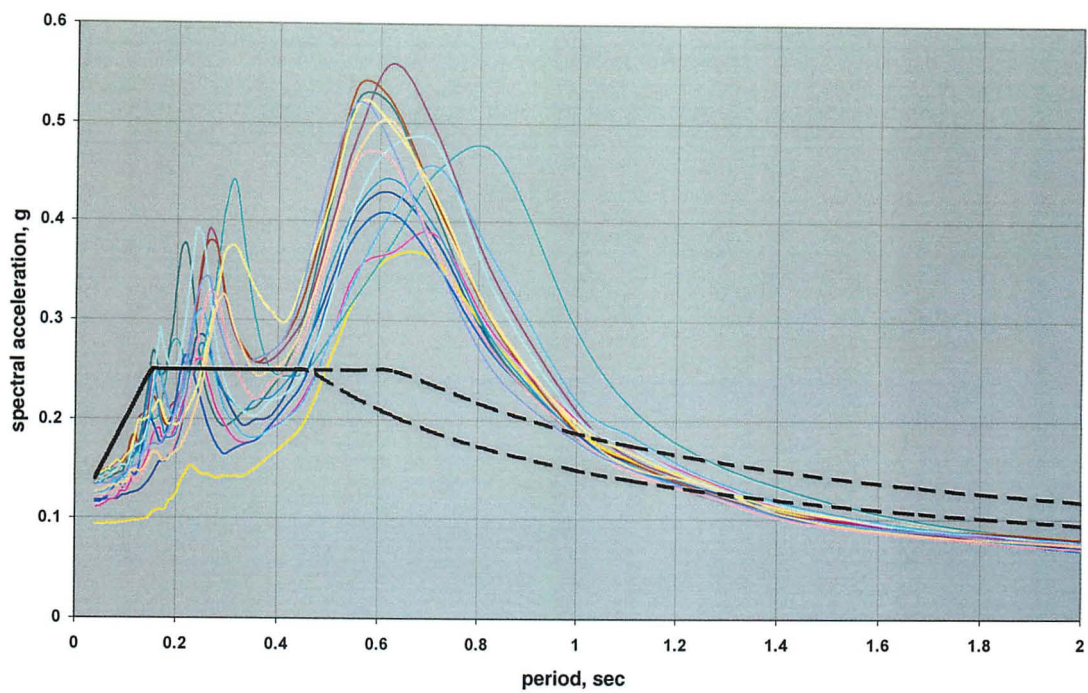


Figure 29. Uniform hazard site-specific acceleration spectra for different sites of Zone 3 of the Lod-Ramla area. Spectrum according to the Israel Building Code (Peak Ground Acceleration of 0.1g) is included for reference.

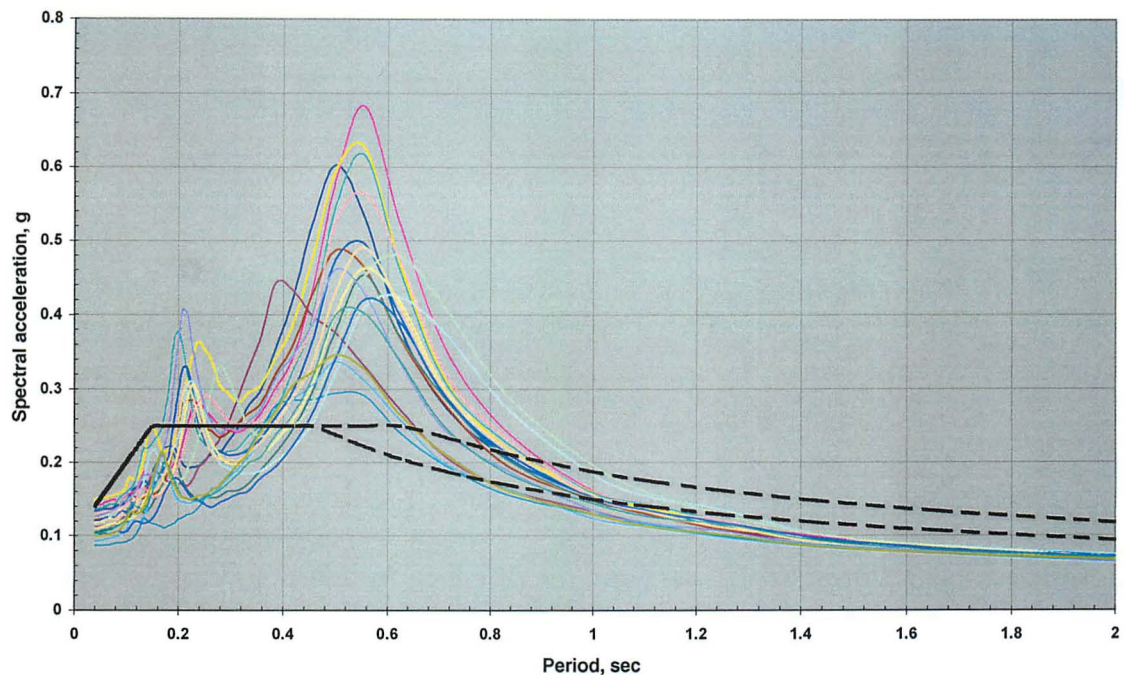


Figure 30. Uniform hazard site-specific acceleration spectra for different sites of Zone 4 of the Lod-Ramla area. Spectrum according to the Israel Building Code (Peak Ground Acceleration of 0.1g) is included for reference.

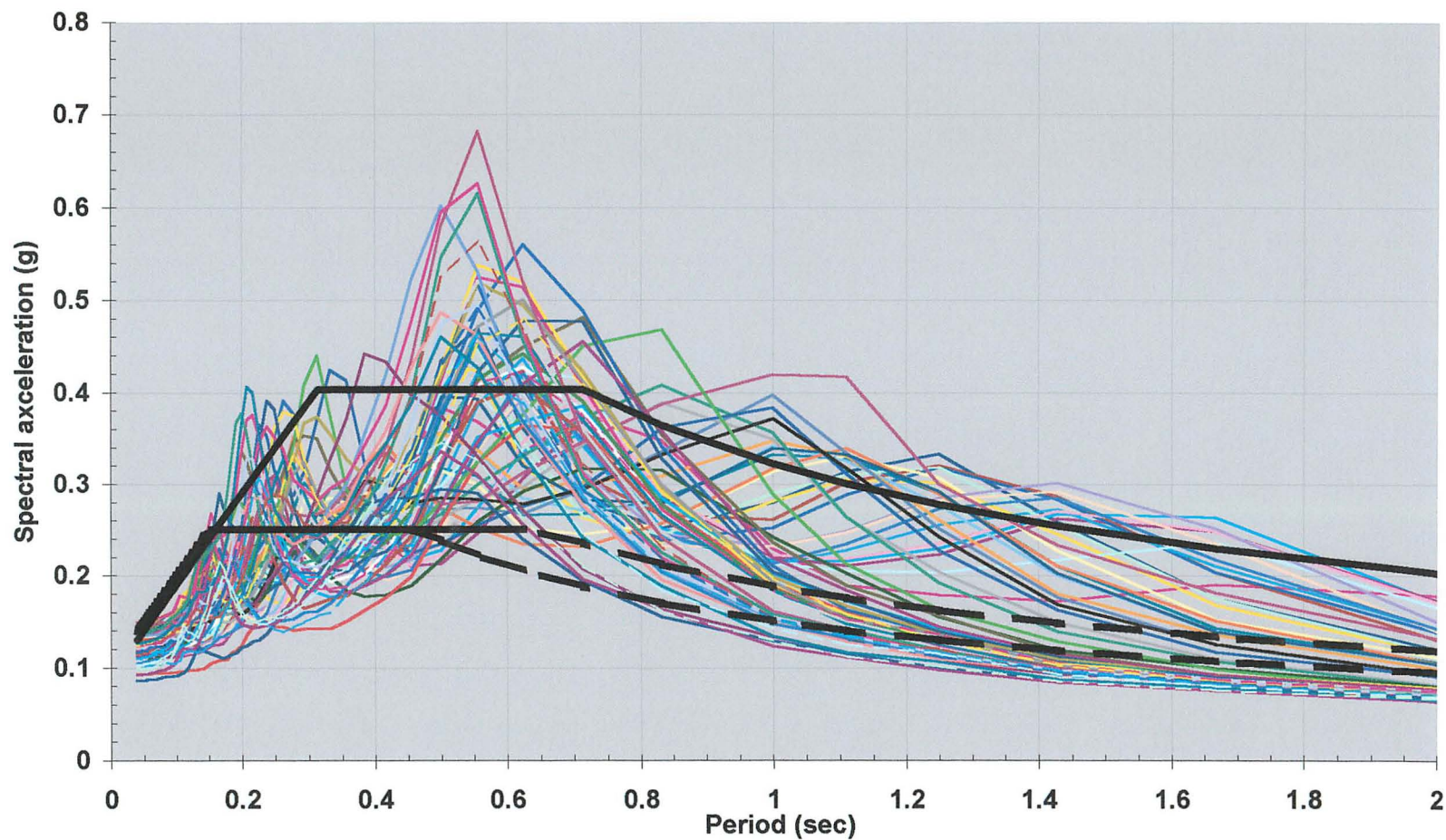


Figure 31. Uniform hazard site specific acceleration response spectra for all zones of Lod-Ramla area.
 Dashed lines show spectrum according to the Israel Building Code (Peak Ground Acceleration of 0.1g)
 Continuous line is the spectrum suggested for Ramla-Lod

DISCUSSION AND CONCLUSIONS

We have presented a seismic hazard microzoning study for the towns of Lod and Ramla. According to historical reports, several strong earthquakes intensively affected this area. The last big earthquake occurred on July 11, 1927 and caused the destruction of a great part of these cities reaching, in some sites, a seismic intensity of VIII (MSK scale). This is a high intensity for the magnitude (6.2) and the epicentral distance (90 km) of that earthquake. Such high intensities were possibly the result of local site effects in the towns.

A methodology for using microtremors spectral ratios as an aid to perform earthquake hazard microzoning in intensely populated areas of Israel has been developed. This method requires the accumulation of microtremors data at a grid of sites over the region of interest. The horizontal-to-vertical spectral ratios obtained from microtremors (Nakamura technique) proved to be valuable tool determine frequencies of deep and shallow soft soils with multi layer distribution and linear behaviors. We obtained a good correlation between the empirical and the analytical evaluations of the fundamental frequencies as well as for the amplification levels. The site response spectra exhibit peaks between 0.5 and 2.0 Hz with typical amplification factors of 4-6. We propose two maps that reflect the fundamental characteristics of possible site effects in the area: dominant frequency and maximum amplification.

The acquired data demonstrated that while the spectra of microtremors varied with time due to varying noise conditions, their shapes, for all the sites, are similar and characterized by relatively flat levels between 0.4 and 1.5 Hz. The amplitudes increase at about 3 Hz. Consequently; we conclude that the identification of the fundamental frequency of soil from the observed maximum Fourier amplitude of microtremors is misleading and probably incorrect.

The Nakamura technique proved to be valuable tool to determine the dominant resonance frequency of shallow and deep soils with a multi layer distribution. Results from simple numerical simulations indicate that there is a good agreement between the empirical and analytical assessments obtained from 1-D model computations. These findings strongly suggests that the technique of Nakamura effectively compensates for source effects in microtremors

measurements, which eliminates major limitations to their applications in earthquake engineering.

The relatively large database of microtremors recordings and the availability of logs of borehole information facilitated the comparison between the empirical and the analytical assessments. The shear-wave structures, for different sediments, were deduced by trial-and error fitting of observed and theoretical transfer functions. This in turn, helped to adjust the thickness of the sedimentary layers at locations where no borehole information is available. The practical relevance of the investigation is illustrated by means of map of depth to the bottom of the sediments and maps of thickness of different layers of sediments.

The fundamental frequencies determined in the present study were found to correlate well with the thickness of the sediments in Lod-Ramla area. The sediments are deeper on the southeastern part of Lod-Ramla (site response spectra exhibit peaks at 0.5-0.8 Hz), while they are shallower on the northwestern part (predominant frequency of site response at 0.9-2.0 Hz). The sites in Lod and Ramla show significant amplification. Thus, we divided the study area into four zones, each characterized by a fundamental resonance frequency of the soil column.

Modern practice in designing buildings to withstand earthquakes is to apply a modal analysis, while taking into account the expected ground accelerations that will shake the building. This practice is also applied in many modern buildings codes. The SvE method (Shapira van Eck, 1933) was deployed to comply with such needs under situations when no real acceleration data are available. The computations in the SvE are based on the stochastic method (Boore, 1983, Boore and Atkinson, 1987) and then convolve the synthetic accelerations with the response function of the site. The analytical response functions of the sites are computed by using the computer code of Joiner (1977).

The Uniform Hazard Site-Specific Acceleration Spectra were computed for a probability of exceedence of 10% during an exposure time of 50 years and damping ratio of 5%. The shapes of the spectra are significantly different from the one prescribed IS-413, in that IS-413 significantly underestimates the requirements (accelerations) across the period range 0.1 sec to 2.0 sec. From engineering standard point it is therefore proposed, that the whole area of Lod and Ramla be characterized by the uniform hazard acceleration spectrum shown in Fig. 31.

Apart from the comments directly related to the Ramla-Lod area, we would like to add the following comments:

1. M

be a powerful tool to map sedimentary cover layers. In regions of unknown basement morphology, such a procedure may be a way to quickly obtain a general idea of the subsurface structure. The dense grid of site measurements facilitated the development of isopach maps for the marl and top Judea group.

2. The joint application of analytical and empirical techniques for assessing soil response functions can provide useful feedback to improve the reliability of the obtained results. A detailed comparison of the analytical and empirical values constitutes a low-cost, efficient and fast procedure in order to establish the spatial dependence of both suitability and reliability of the method, improvement of models assumed and delimitation of those areas for which in-depth surveys are needed for proper assessment of soil response.
3. As demonstrated in this study, the site response variations are significant over very short distances, thus we strongly recommend that estimation of earthquake loss scenarios should be based on the site response functions obtained over a relatively dense grid of measurement points.
4. It must be realized that the applicability of the Nakamura technique is heavily depended on the amount of data. Analysis of ambient seismic noise encounters significant limitations primarily associated with the great variability of interfering sources of seismic energy. It is therefore essential to monitor the microtremors for a number of hours, sometimes preferably during different hours of the day, to increase the chances of selecting the appropriate time windows (of only 30 sec) that are used in the analysis. Here, quantity is a necessity to achieve quality.
5. An important issue that was raised before and during the investigations is the question of how dense should the grid of measured points be ?

The Lod-Ramla project was the first in Israel where site response functions are determined over a dense grid. In retrospective we may state that we gained reliability to the obtained results ONLY because we had a dense grid of measured sites. Again, it has to do with the application of the Nakamura Technique. Further more, in most of Israel there is very limited availability of

densely distributed geotechnical information such as S-wave velocities and densities of the materials, especially at depth. We could compensate for the need of a dense grid of measured points of microtremors 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.

The results described in this study calls for the need to continue microzoning the seismic hazard across Israel, practically by using measurements of microtremors for the assessment of the site response functions.

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