SEISMIC HAZARD MAPS IN TERMS OF SPECTRAL ACCELERATION AT PERIODS OF 0.2 SEC AND 1 SEC FOR THE DESIGN RESPONSE SPECTRUM (TWO-POINT METHOD) IN THE NEW VERSION OF THE ISRAEL BUILDING CODE (SI 413)

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Abstract

Seismic hazard maps show the distribution of earthquake shaking levels that have a certain probability of exceedence. These maps were prepared in order to provide for the basic seismic requirements for the construction of safe buildings and bridges to withstand ground shaking from strong earthquakes. These maps will be implemented in the next revision of the updated Israel Building Code (SI 413).

In 2001, the Israel Geological Survey defined the regional seismogenic zones and these where approved in 2007, with minor changes, by experts from all neighboring countries. All together 27 seismogenic zones were defined. The seismic parameters associated with each of the seismogenic zones were defined by the Geophysical Institute of Israel. Those efforts have led to updating of the requirements in the Israeli Code 413 in terms of Peak Ground Acceleration, (PGA), for a probability of exceedence of 10% in 50 years (or return period of 475 years) for sites of generic rock with Vs=620 m/s.

In the process of updating SI 413, the new seismic requirements are based on earthquake response spectral acceleration at two specific periods – short (T = 0.2 sec) and long (T = 1 sec) - that have a probability of 10% of being exceeded in an exposure time of 50 years (475 years return period) and damping ratio of 5%. The assessment of the new hazard parameters is also based on using the empirical ground motion attenuation equations developed by Boore et al. (1997). The commercial program EZFRISK is used for computing peak ground acceleration and Spectral Acceleration (SA) under the assumption that earthquake occurrence, following the Gutenberg-Richter relationship, is time-independent and that the foci of earthquakes are uniformly distributed in each seismogenic zone.

The computations that were made for a rectangle are bounded by latitudes 29.5 °N and 33.5 °N, and longitudes 34 °E and 36 °E on a grid in steps of 0.02 degrees (about 2.2 km) and then contoured The 475 year hazard maps are computed for periods 0.2 sec (Ss) and 1 sec (S1) affected by values in the ranges 0.1g to 0.55g and 0.025g to 0.125g, respectively. Our results comply with the fact that that the seismicity of the region is relatively low and can be explained by very long return period (hundreds and thousands years) of strong earthquakes.
1. Introduction

The primary objective of all current seismic codes is to prevent collapse of the structure at the occurrence of a strong earthquake. The codes recognize that it is uneconomical to design a construction to behave elastically during strong shaking, and therefore it allows some degree of damage to occur.

The severity of vibratory structural response to seismic motion largely depends on the seismic ground motion characteristics and the structure's dynamic characteristics. One of the most important characteristic is the frequency content of the ground motion. The ground motion frequency content can be generally described as a measure of relative predominance of different frequencies present in the ground motion. In the Recommendation for Shape of Earthquake Response Spectra (Blume and Associates Engineers, 1973) on the basis of a number of significant records (accelerograms) of major earthquakes that occurred during 1934-1966 provided a "standardized" design spectrum shape to be used in the seismic design of nuclear power plant facilities in the US concept SA. Since earthquakes are complex phenomena and since it is not possible to exactly predict the nature of seismic ground motions, statistical analyses of recorded ground motion were used.

Using the seismic risk principles of Cornell (1968), Algermissen and Perkins (1976, 1978) developed isoseismic maps for horizontal peak ground acceleration (PGA) and velocities on rock having a 90% probability of not being exceeded in 50 years. These maps had been used for design response spectrums performed in American Association of State Highway and Transportation Officials (AASHTO) Bridge Design Specification 13th edition (1983). The same approach utilized in AASHTO current version (AASHTO 17th, 2002). In most engineering applications PGA is used for re-normalizing the "standardized" design response spectrum. The Applied Technology Council (ATC, 1978) used this map to develop similar maps for effective peak acceleration $A_a$ and effective peak velocity $A_v$ - related acceleration. These parameters based on a study by McGuire (1975). The $A_a$ and $A_v$ maps developed from the ATC study are in many ways similar to the Algermissen-Perkins map. The most significant difference is in the area of highest seismicity in California. Within such areas, the Algermissen-Perkins map has contours of 0.6g whereas the ATC maps have no values greater than 0.4g. This discrepancy is due to the difference between peak acceleration and effective peak acceleration and also to the decision by
the participants in the ATC study to limit the design value to 0.4g based on scientific knowledge and engineering judgment. The ATC maps were also provided with the contour lines shifted to coincide with the county boundaries.

In Israel estimations of the apparent annual probability of exceeding peak ground acceleration and composition potential earthquake risk maps for a reference peak acceleration of 0.1g, 0.2g, 0.3g and 0.4g were performed (Shapira, 1981). Seismic hazard map in terms of PGA for 10% probability during an exposure time of 50 years (return period 475 years) for the first time was computed by Shapira, 1987 (personal communication) for the updated Israel Seismic Code (SI 413) and then confirmed by Arieh and Rabinowitz, (1989). However, after more than 10 years of continuous monitoring of the local seismicity by the Israeli Seismic Network (ISN), the need to update the PGA map was evident. The PGA values predicted by the attenuation curves of Joyner and Boore (1981), which were used in the calculation of the seismic hazard map, were significantly lower than those that obtained from accelerograms of the Gulf of Aqaba earthquake. Map update process began in 1998 and included the following steps: selection of equation of ground motion estimation; update the catalog of earthquakes in Israel and the neighborhood for recent 2000 years (Amrat et al., 2001), identification of the seismogenic zones in the region (Shamir et al., 2001) according to tectonic, geophysical, geological and seismological data; determination seismicity parameters of the seismic zones (Shapira and Hofstetter, 2001). On the basis of these data in 2001 new seismic hazard map for the return period of 475 years was constructed (Shapira, 2002). In 2005, by request of Israel National Roads Company (MATZ), the Seismology Division prepared three new seismic hazard maps for the return periods of 125, 975 and 2475 years (Perelman et al., 2005). Those maps were computed for generic rock with grid 0.02 degree (2.2 km).

The 1991 Recommended Provisions for Seismic Regulations for New Buildings of the US National Earthquake Hazard Reduction Program (NEHRP) introduced preliminary spectral response acceleration maps developed by the United States Geological Survey (USGS) for a probability of exceedance 10% in 50 years and 250 years (return period 2,375 years). These maps, which include elastic spectral response accelerations corresponding to 0.3 and 1.0 sec periods, were introduced to present new and relevant data for estimating spectral response accelerations and reflect the variability in the attenuation of spectral acceleration and in fault rupture length (Two-Points Method).
In 1993, the USGS embarked on a major project to prepare updated national earthquake ground motion maps. The result of that project was a set of probabilistic maps published in 1996 (Frankel et al., 1996) that cover several rock ground motion parameters for of 10%, 5% and 2% probabilities during an exposure time of 50 years.

The 1997 NEHRP recommended provisions provide seismic maps for the spectral response accelerations at the short period range (approximately 0.2 sec) and 1.0 sec. The maps correspond to the maximum considered earthquake, defined as the maximum level of earthquake ground shaking that is considered reasonable for design of structures. In most regions of the United States, the maximum considered earthquake is defined with a uniform probability of exceeding 2% in 50 years (return period 2475 years). It should be noted that the use of the maximum considered earthquake was adopted to provide a uniform protection against collapse at the design ground motion. While the conventional approach in earlier editions of the provisions provided for a uniform probability that the design ground motion will not be exceeded, it did not provide a uniform probability of failure for structures designed for that ground motion.

The 1997 NEHRP Guidelines for the Seismic Rehabilitation of Buildings known as FEMA-273, introduce the concept of performance-based design. For this concept, the rehabilitation objectives are statements of the desired building performance level (collapse prevention, life safety, immediate occupancy, and operational) when the building is subjected to a specified level of ground motion. Therefore, multiple levels of ground shaking need to be defined by the designer. FEMA-273 provides two sets of maps (Two-Points Method), where each set includes the spectral response accelerations at short periods (0.2 sec) and at long periods (1.0 sec). One set corresponds to a 10% probability of exceedance in 50 years, known as Basic Safety Earthquake 1 (BSE-1), and the other set corresponds to a 2% probability of exceedance in 50 years, known as Basic Safety Earthquake 2 (BSE-2). The Basic Safety Objective is met when a building can satisfy two criteria: (1) the Life Safety Building Performance Level, which is the combination of the Structural and Nonstructural Life Safety Performance Levels, for the Basic Safety Earthquake 1 (BSE-1), and (2) the Collapse Prevention Performance Level, which only pertains to structural performance, for the stronger shaking that occurs less frequently as defined in the Basic Safety Earthquake 2 (BSE-2).

Now, the new version of Israel Standard (SI 413) intends to apply the same Two-Point Method. Therefore, the major objective of this study was to compute Uniform Seismic Hazard
Maps for periods of 0.2 and 1 second for 10% probability during an exposure time of 50 years and damping ratio of 5%. These maps are computed under the condition that all sites are composed of generic rock (Vs=620 m/s).

2. Basic concept for probabilistic seismic hazard analysis

The methodology used in most probabilistic seismic hazard analysis was first defined by Cornell (1968) and included the following steps whose are carried out in the preparation of new seismic hazard map in terms of peak ground acceleration for the return period 475 years (Shapira, 2002):

- Selection of equation of ground motion estimation.
- Update the catalog of earthquakes in Israel and the neighborhood for the last 2000 years (Amrat et al., 2001).
- Identification of the seismogenic zones in the region (Shamir et al., 2001), according to tectonic, geophysical, geological and seismological data.
- Determination seismicity parameters of the defined seismogenic zones (Shapira and Hofstetter, 2001).

The model for the prediction of the expected ground motion is an essential element of any seismic hazard assessment and has a strong influence on the hazard result. The limited strong motion data in Israel do not allow developing ground motion attenuation relationships. Therefore, we select three equations for estimation of PGA and spectral acceleration.

Boore et al. (1997) presented equations to predict horizontal response spectra:

\[
\ln Y = b_1 + b_2 (M - 6) + b_3 (M - 6)^2 + b_4 \ln r + b_5 \ln \frac{V_s}{V_A} \quad (1)
\]

where \( r = (r_{jb}^2 + h^2)^{1/2} \). In this equation

- \( Y \) = peak ground motion measure (peak horizontal acceleration or pseudo acceleration response in response spectra in g) for the random horizontal component at 5% damping;
- \( M \) = moment magnitude;
- \( r \) = closest distance from the surface of the ruptured fault to the station in km.
\( r_{jb} = \) closest horizontal distance from the rupture at the surface to the station in km.

\( V_S = \) average shear-wave velocity (m/s) to a depth of 30 m

\( b_1 = \) parameter related to fault mechanism:

\( b_1 = b_{1SS} \) for strike-slip earthquakes; \( b_{12} = b_{1RS} \) for reverse-slip earthquake; \( b_1 = b_{1ALL} \) if mechanism is not specified;

\( b_{1SS}, b_{1RS}, b_{1ALL}, b_2, b_3, b_5, V_A \) and \( h \) are regression coefficients provided in tabular form.

The coefficients in the equations for predicting ground motion are based on the selected 213 strong earthquakes from western North America with \( M_{w} \geq 5.0 \) and \( r \geq 20 \text{km} \) and were determined using a weighted, two-stage regression procedure and allow estimating response spectra in the period range from 0.0 sec to 2.0 sec.

From data set which consists of 595 strong motion records (magnitudes \( M_w \geq 5 \)) caused by shallow crustal earthquakes with magnitudes \( \geq 5 \) recorded in Europe and Middle East, Ambraseys et al. (2005) obtained the equation:

\[
\ln y = a_1 + a_2 M_w + (a_3 + a_4 M_w) \ln (d^2 + a_5^2)^{1/2} + a_6 S_S + a_7 S_A + a_8 F_N + a_9 F_r + a_{10} F_0
\]

(2)

where \( y \) is the acceleration response spectra for 5% damping (in cm/sec\(^2\)), \( S_S = 1 \) for soft soil site and 0 otherwise, \( S_A = 1 \) for stiff soil sites and 0 otherwise, \( F_N = 1 \) for normal faulting earthquakes and 0 otherwise and \( F_0 = 1 \) for odd faulting earthquakes and 0 otherwise. The set of ten coefficients of this equation \( \{ a_1 - a_{10} \} \) are regression coefficients provided in tabular form. This equation also allows assessing response spectra at period from 0.0 sec to 2.5 sec.

Bummer et al. (2007) presented equation for the prediction of acceleration spectral ordinates as:

\[
\log_{10}[\text{PSA}(T)] = b_1 + b_2 M_w + b_3 M_w^2 + (b_4 + b_5) \log_{10}[r] + f(S, F)
\]

(3)

where \( f(S, F) = b_6 S_S + b_8 S_A + b_9 F_N + b_{10} F_r \) and \( r = (R_{jb}^2 + b_6^2)^{1/2} \) in which PSA(T) is geometric mean of two horizontal components of 5%-damped pseudo-spectral-acceleration in cm/sec\(^2\) (and \( T \) is the period in sec); \( R_{jb} \) is the Joyner-Boore distance in km; \( S_S \) and \( S_A \) are dummy variables taking values of 1 for soft soil (\( V_{s30} < 360 \text{ m/s} \)) and stiff soil (360 m/s < \( V_{s30} < 750 \text{ m/s} \))
respectively, and zero otherwise; $F_N$ and $F_R$ are similar variables taking a value of unity for normal and reverse faulting events respectively, and 0 otherwise. The set of ten coefficients of this equation \{b_1 - b_{10}\} are regression coefficients provided in tabular form. This equation allows predicting of response spectral ordinates at periods from 0.0 to 0.5 sec.

3. Computation

Hazard map for Israel in terms of peak ground acceleration for return period of 475 years shows contours of PGA in the range of 0.075-0.3 g. (the minimum required acceleration is assigned 0.075g irrespective of the computed value). Using the map we have selected four zones changes of PGA (0.075-0.1g, 0.125-0.15g, 0.175-0.2g and 0.275-0.3g) and divided each zone to equal 52 segments along meridian. Thereafter, in each segment, one point is randomly selected and for its coordinates we calculate the PGA according to Equations 1, 2 and 3. In finale, for each zone we compute arithmetic average value PGA and associated standard deviation which are reported in Table 1. A few points are worth noting. First, for Boore et al. (1997) relationship we use two programs for hazard computation: EZFRISK (Risk Engineering Inc., 1995) and SEISRISKIII (Bender and Perkins, 1987) and obtain good coincidence of results. The second point is the discrepancy of peak acceleration estimated from different curves. Figure 1 shows prediction of PGA ordinates for different curves of peak acceleration versus distances for $M_W = 6.3$. We can see that application of Ambraseys et al. (2005) curve at near-source distance up to 20 km significantly exceeds assessment of PGA predicted by Boore et al. (1997) and Bommer et al. (2007) relationships. Moreover, the distance-dependent decay effect in Boore et al. (1997) is significantly smaller than those of Ambraseys et al. (2005) and Bommer et al. (2007). For Israel this is very important because many population centers are located in a distance range of 30-70 km from the seismically active Dead Sea Fault system.
Table 1. Average values of PGA and associated standard deviations obtained for four zones of PGA map of Israel using different attenuation relationships and the two programs EZFRISK and SEISRIAK III.

<table>
<thead>
<tr>
<th>Interval PGA of different zones g</th>
<th>Type of attenuation relationship</th>
<th>EZFRISK</th>
<th>SEISRIKIII</th>
<th>SEISRIKIII</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boore et al., 1997</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.089</td>
<td>0.076</td>
<td>0.102</td>
<td>0.063</td>
</tr>
<tr>
<td>σ</td>
<td>0.007</td>
<td>0.011</td>
<td>0.007</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>Ambraseys et al., 2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.148</td>
<td>0.016</td>
<td>0.199</td>
<td>0.217</td>
</tr>
<tr>
<td>σ</td>
<td>0.011</td>
<td>0.011</td>
<td>0.011</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td>Bummer et al., 2007</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.284</td>
<td>0.010</td>
<td>0.291</td>
<td>0.374</td>
</tr>
<tr>
<td>σ</td>
<td>0.005</td>
<td>0.014</td>
<td>0.026</td>
<td>0.041</td>
</tr>
</tbody>
</table>

Table 2 presents the spectral accelerations $S_8$ for period 0.2 and $S_1$ for period 1.0 sec are obtained using the attenuation relationships and the EZFRISK and SEISRIAKIII programs for four sites. Analysis of these data shows that application of Ambraseys et al. (2005) attenuation relationship significantly exceeds response spectra at 1.0 sec compared with values obtained by Boore et al. (1997). At short period (0.2 sec) predicted values spectral acceleration by Bommer et al. (2007) are always lower than values of Boore et al. (1997).

The small difference between results of computation PGA and spectral acceleration by two programs – EZFRISK and SEISRIKIII with the same attenuation equation by Boore et al. (1997) can be explained by distinction in format of input data of these programs. In EZFRISK the attenuation equation of Boore et al. (1997) is embedded, and the user must adjust the coefficients of this equation in the input file. In SEISRIKIII some attenuation equation represent as rectangle matrix that containing tabular values of mean peak acceleration (or other ground motion parameters) at respectively lists of distances and magnitudes. In addition, a distinction exists in the format input data of area sources (seismogenic zones): in EZFRISK the user can characterize the area sources by polygon in horizontal plane while in SEISRIKIII source area is define as a set which contains one or more subregions each must be defined as quadrangle.
Figure 1. Comparison curves of peak acceleration versus distance for magnitude $M_W = 6.3$ as given by Ambraseys et al. (2005), Boore et al. (1997) and Bommer et al. (2007) presented by the black, blue and red, lines, respectively.
Table 2. Comparison of the spectral acceleration for periods 0.2 and 1.0 sec obtained by different attenuation relationship using EZFRISK and SEISRISKIII programs for computations. BJF represents Boore et al. (1997); AM represents Ambraseys et al. (2005); and BO represents Bommer (2007).

<table>
<thead>
<tr>
<th>No.</th>
<th>Area</th>
<th>Equation Attenuation</th>
<th>Program</th>
<th>Spectral acceleration g</th>
<th>S_S</th>
<th>S_I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Haifa</td>
<td>BJF</td>
<td>EZFRISK</td>
<td>0.321</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SEISRISK III</td>
<td>0.336</td>
<td>0.089</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>AM</td>
<td>SEISRISK III</td>
<td>0.365</td>
<td>0.262</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BO</td>
<td>SEISRISK III</td>
<td>0.260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>North of Sea of Galilee</td>
<td>BJF</td>
<td>EZFRISK</td>
<td>0.556</td>
<td>0.143</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SEISRISK III</td>
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<tr>
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<td></td>
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<td>SEISRISK III</td>
<td>0.621</td>
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<td></td>
<td></td>
<td>BO</td>
<td>SEISRISK III</td>
<td>0.505</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>Jerusalem</td>
<td>BJF97</td>
<td>EZFRISK</td>
<td>0.242</td>
<td>0.064</td>
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<td></td>
<td></td>
<td></td>
<td>SEISRISK III</td>
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<td>0.070</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td>BO</td>
<td>SEISRISK III</td>
<td>0.197</td>
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<tr>
<td>4</td>
<td>Eilat</td>
<td>BJF</td>
<td>EZFRISK</td>
<td>0.428</td>
<td>0.105</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>SEISRISK III</td>
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<td></td>
<td>BO</td>
<td>SEISRISK III</td>
<td>0.360</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

So, for the sake of consistency, Boore et al. (1997) equation that was used for computation Hazard Map of Israel in terms of Peak Ground Acceleration (Shapira, 2002; Perelman et al., 2005) was used also for computation of Uniform Seismic Hazard Map in terms of spectral acceleration for periods 0.2 sec and 1 sec with 5% damping and 475 years return period. Hazard computations using EZFRISK (Risk Engineering Inc., 1995) have been performed for the area stretching from 29.5°N to 33.5°N, and longitudes 34.0°E to 36.0°E, using an approximately 0.02° x 0.02° regular grid interval (around 2.2 km) with a total number of 20301 computation nodes. Figure 2 shows maps of spectral accelerations for 0.2 and 1.0 sec in g units.

Two absolute maxima with elongated shape exist in the two maps, north of the Sea of Galilee, and around the Gulf of Aqaba. These most hazardous areas reflect active segments in the
Dead Sea Fault system, to the north of the Sea of Galilee and around the Gulf of Aqaba. Maximum spectral acceleration values at 0.2 s and 1.0 s are in the range of 0.55-0.6 g and 0.14-0.15 g, respectively that is smaller than in USA.

**Figure 2.** Hazard map of Israel in terms of earthquake response spectral acceleration in g, for 475 years return period and damping ratio of 5% computed for periods (a) 0.2 sec and (b) 1 sec.
4. Design response spectrum, construction using Two-Point Method

The 1997 National Earthquake Hazard Reduction (NEHRP 1997, Washington) provides two maps for response spectral accelerations at short periods $S_s$ at 0.2 sec and $S_I$ at 1.0 sec and proposed design response spectrum construction using the Two-Point Method. The principal parameters of this method are $S_{DS}$ and $S_{DI}$ which are defined as:

$$S_{DS} = F_a S_s \quad S_{DI} = F_v S_I \quad (4)$$

where $F_a$ and $F_v$ are the site coefficients described in NEHRP 1997. The values $S_s$ and $S_I$ may be obtained from the national ground maps defined by NEHRP (1997) or from CD-ROM published by the U.S. Geological Survey. In addition, for design response spectra construction the NEHRP 1997 allows application of the following equations:

$$S_{DS} = F_a \times 2.5 Z \quad S_{DI} = F_v \times Z \quad (5)$$

where $Z$ is peak ground acceleration (PGA). For rock with shear wave velocity $760 \text{ m/s} < V_S \leq 1500 \quad F_a = F_v = 1.0$. Consequently, Equation 5 can be presented as:

$$S_{DS} = S_s = 2.5 Z \quad S_{DI} = S_I = Z \quad (6)$$

According to the new version of Design provision for earthquake resistances of structures (Israel Standard, SI 413), it is also proposed to use the Two-Point Method. However, before the maps of $S_s$ and $S_I$ would be published The Standards Institution of Israel recommends using the following equations:

$$S_{DS} = S_s = 2.5 Z \quad S_{DI} = S_I = 1.25 Z \quad (7)$$

As a matter of fact our estimates of $S_s$ and $S_I$, are essentially lower than in USA and than those presented in Eq. (7). We assumed that the reason for the discrepancy is different PGA in Israel and USA. Therefore, we normalize response spectral acceleration at 0.2 sec period ($S_s$) and 1.0 sec period ($S_I$) with values of PGA taken from the PGA maps for Israel and USA with 10% probability during an exposure time of 50 years. Calculations were carried out in the PGA range 0.06 – 0.35 g which characterizes map of PGA for Israel. As noted
above the total number of computation nodes for Israel was 20,301 while for USA the total number of computation nodes was 99,718.

Figures 3 and 4 show $S_s$/PGA and $S_1$/PGA ratios for USA and Israel split into ranges according the PGA map of USA. A number of interesting observations can be made that are equally applicable to these figures. The main and most important observation is that the USA data vary significantly compared to the Israel one, so that for USA $1.6 \leq S_s$/PGA$ \leq 2.7$ and $0.4 \leq S_1$/PGA$ \leq 1.4$, while in Israel one gets $1.4 \leq S_s$/PGA$ \leq 2.0$ and $0.4 \leq S_1$/PGA$ \leq 0.6$. However, we should note that for each interval of PGA in Figures 2 and 3 in USA there are areas where $S_s$/PGA and $S_1$/PGA are identical to those in Israel.

Tables 3 and 4 show the averages and standard deviations of ratios of spectral acceleration at short period ($S_s$) and 1 second ($S_1$) versus PGA for different ranges computed for USA and Israel. In accordance with these tables the average for USA is:

$S_s$/PGA$=2.3\pm0.187$ and $S_1$/PGA$=0.701\pm0.140$.

And for Israel we get the following assessment:

$S_s$/PGA$=1.780\pm0.177$ and $S_1$/PGA$=0.492\pm0.023$.

We used the hazard map of USA in terms of peak ground acceleration for 475 years return period (Figure 5a,b) and marked areas where there the ratios of $S_s$/PGA and $S_1$/PGA for USA are similar to those in Israel. At the next stage of our research we used seismic hazard map of Canada (2005 National Building Code) in terms PGA, $S_s$ and $S_1$ and have implemented the above described calculations. As demonstrated in Figure 5, for a large part of the territory of Canada the level $S_s$/PGA and $S_1$/PGA coincide with values derived for Israel.

Following the above analysis we are confident that the levels $S_s$ and $S_1$ obtained for Israel are correct and reflect the seismic regime in Israel.
Figure 3. Comparison between ratios of response spectral accelerations at short period ($S_s = 0.2$ sec) versus PGA for: a) USA; b) Israel.
Figure 4. Comparison between ratios of response spectral accelerations at short period ($S_I = 1$ sec) versus PGA for: a) USA; b) Israel.
Table 3. Average and standard deviation of ratio of spectral acceleration at short period ($S_s$) and 1 second period ($S_1$) versus PGA for different ranges accordingly maps of Israel.

<table>
<thead>
<tr>
<th>PGA interval g</th>
<th>Number of Selected Points</th>
<th>$S_s$/PGA</th>
<th>S1/PGA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>σ</td>
</tr>
<tr>
<td>0.06 - 0.08</td>
<td>2593</td>
<td>1.699</td>
<td>0.046</td>
</tr>
<tr>
<td>0.08 - 0.10</td>
<td>2939</td>
<td>1.694</td>
<td>0.093</td>
</tr>
<tr>
<td>0.10 - 0.12</td>
<td>4200</td>
<td>1.688</td>
<td>0.101</td>
</tr>
<tr>
<td>0.12 - 0.16</td>
<td>4668</td>
<td>1.781</td>
<td>0.106</td>
</tr>
<tr>
<td>0.16 - 0.21</td>
<td>3282</td>
<td>1.796</td>
<td>0.114</td>
</tr>
<tr>
<td>0.21 - 0.27</td>
<td>2201</td>
<td>1.876</td>
<td>0.760</td>
</tr>
<tr>
<td>0.27 - 0.35</td>
<td>354</td>
<td>1.927</td>
<td>0.020</td>
</tr>
<tr>
<td>Total Average</td>
<td></td>
<td>1.780</td>
<td>0.177</td>
</tr>
</tbody>
</table>

Table 4. Average and standard deviation of ratio of spectral acceleration at short period ($S_s$) and 1 second period ($S_1$) versus PGA for different range PGA accordingly maps of USA.

<table>
<thead>
<tr>
<th>PGA interval g</th>
<th>Number of Selected Points</th>
<th>$S_s$/PGA</th>
<th>S1/PGA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>σ</td>
</tr>
<tr>
<td>0.06 - 0.08</td>
<td>27217</td>
<td>2.293</td>
<td>0.176</td>
</tr>
<tr>
<td>0.08 - 0.10</td>
<td>16083</td>
<td>2.299</td>
<td>0.193</td>
</tr>
<tr>
<td>0.10 - 0.12</td>
<td>13085</td>
<td>2.306</td>
<td>0.196</td>
</tr>
<tr>
<td>0.12 - 0.16</td>
<td>16392</td>
<td>2.323</td>
<td>0.177</td>
</tr>
<tr>
<td>0.16 - 0.21</td>
<td>13634</td>
<td>2.300</td>
<td>0.170</td>
</tr>
<tr>
<td>0.21 - 0.27</td>
<td>8902</td>
<td>2.295</td>
<td>0.174</td>
</tr>
<tr>
<td>0.27 - 0.35</td>
<td>4405</td>
<td>2.269</td>
<td>0.214</td>
</tr>
<tr>
<td>Total Average</td>
<td></td>
<td>2.298</td>
<td>0.187</td>
</tr>
</tbody>
</table>
Figure 5. Hazard map of USA in terms of peak ground acceleration PGA for 475 years return period. The black color indicates area of coincidence for a) $S_s$/PGA ratio and b) $S_l$/PGA ratio between USA and Israel.
Figure 6. Map of Canada. The blue and orange colors indicate areas of coincidence for: a) $S_s$/PGA ratio and b) $S_s$/PGA ratio between Canada and Israel.

5. Comparison of design response spectra obtained by different approaches

We chose four sites with different PGA (Table 5) and calculated the design response spectra using maps of $S_s$ and $S_1$ and according to the equations $S_s=2.5Z$ and $S_1$
= 1.25 \( Z \) (Amendment No. 3 of SI 413) when such information is not available. The results of calculations are represented in Figures 7-10, along with the spectrum according to SI 413 (1995) as a reference.

Table 5. Peak ground acceleration, 0.2-second and 1.0-second response spectral acceleration according to map calculated by program ESFRISK.

<table>
<thead>
<tr>
<th>Number</th>
<th>Area</th>
<th>PGA</th>
<th>( S_s ) (0.2 sec)</th>
<th>( S_1 ) (1.0 sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tel-Aviv-Jaffa</td>
<td>0.091</td>
<td>0.161</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>East Jerusalem</td>
<td>0.132</td>
<td>0.242</td>
<td>0.064</td>
</tr>
<tr>
<td>3</td>
<td>Haifa</td>
<td>0.185</td>
<td>0.321</td>
<td>0.083</td>
</tr>
<tr>
<td>4</td>
<td>To the North of Sea of Galilee</td>
<td>0.292</td>
<td>0.556</td>
<td>0.143</td>
</tr>
</tbody>
</table>

Figure 7. Comparison of the design response spectra constructed using two-point method for different site classes using maps of \( S_s \) and \( S_1 \) (red line) and \( S_s = 2.5Z \) and \( S_1 = 1.25Z \) (black dashed line) for Tel-Aviv. The spectrum of SI 413 (1995) is included as a reference (blue dashed line).
Figure 8. Comparison of the design response spectra constructed using two-point method for different site classes using maps of $S_s$ and $S_I$ (red line) and $S_s=2.5Z$ and $S_I = 1.25Z$ (black dashed line) for East Jerusalem. The spectrum according to SI 413 (1995) is included as a reference (blue dashed line).

Figure 9. Comparison of the design response spectra constructed using Two-Points Method for different site classes using maps of $S_s$ and $S_I$ (red line) and $S_s=2.5Z$ and $S_I = 1.25Z$ (black dashed line) for Haifa. The spectrum according to SI 413 (1995) is included as a reference (blue dashed line).
Figure 10. Comparison of the design response spectra constructed using Two-Point Method for different site classes using maps of $S_s$ and $S_I$ (red line) and $S_s = 2.5Z$ and $S_I = 1.25Z$ (black dashed line) for site north of the Sea of Galilee. The spectrum of SI 413 (1995) is included as a reference (blue dashed line).

If we look at the spectra, we can see that level of all response spectra obtained using maps of $S_s$ and $S_I$ substantially below not only of spectra constructed by recommendation of Amendment No. 3 of SI 413 (September 2009) but also spectra published in SI 413 (1995).

In a series of previous studies (see for example Zaslavsky et al., 2005; 2008a,b; 2009) we successfully applied the procedure developed by Shapira and van Eck (1993) to assess the site specific uniform hazard acceleration response. That procedure which we term SEEH (Stochastic Estimation of the Earthquake Hazard) is based on the stochastic method developed and used by Boore (1983), Boore and Atkinson (1987), Boore and Joyner (1991) among others. In brief, the SEEH process starts by performing Monte Carlo simulations of the expected seismic activity in seismogenic zones that may affect the study area. The seismicity and other regional parameters that characterize earthquake hazards in Israel are presented and discussed by e.g. Shapira and van Eck (1993), Shapira and Hofstetter (1993), Hofstetter et al. (1996), Shapira (2002), Sellami et al. (2003), Begin (2005) and Begin et al. (2005). These studies were used to specify the seismogenic zones affecting the region and their seismicity in the form of frequency-magnitude relationships.
Considering the uncertainty in estimating the frequency of occurrence, we generate several possible earthquake catalogues (artificial catalogues) for a long time span (thousands of years). These simulations are followed by synthesizing S wave ground motions at the investigated site from each of the earthquakes in the artificial catalogues using the stochastic method (e.g. Boore 1983, 2000). The site response due to the propagating waves from the base-rock to the site's surface are computed given the properties and structure of the subsurface at the analysed site. These wealth of synthetic free surface motions, representing what may happen in a long time span are used to compute the corresponding acceleration response spectra for a 5% damping ratio. In the final stage of SEEH all generated response spectra are assembled for estimating the spectral accelerations which correspond to a prescribed probability of exceedance and yield the uniform hazard, site specific acceleration response spectrum.

The SEEH approach has been applied to predict the acceleration response spectrum for areas presented in Table 5. Figure 11 shows the response spectrum obtained by the SEEH method and by the Two-Point Method using maps of $S_s$ and $S_l$. It is very important that two different methods, base on physical parameters of seismicity of Israel, show a good agreement above 0.5 sec. For periods greater than 0.5 sec there is disagreement between two curves because the change of amplitude of spectral accelerations obtained by the Two-Point Method is arbitrary as $1/T$, where $T$ is the period of vibration (sec).
Figure 11. Comparison between acceleration response spectrum obtained by SEEH (black line) the Two-Point Method using maps of $S_1$ and $S_f$ (red line) for four areas: a) Tel-Aviv-Jaffa; b) East Jerusalem; c) Haifa; d) North of the Sea of Galilee.

6. About of soil parameters for ground response characterization

The average shear wave velocity of the top 30 m of a soil profile ($V_{s,30}$) represents an usual parameter to classify soils in different categories in most National Building Codes (e.g. Italy, Israel, Switzerland, Eurocode-8, NEHRP, Canada, Japan, Uniform Building Code, IBC 97, ICC 2003 and many other). As shown in several studies (e.g. Borcherdt, 1994; Dobry et al., 2000; Parolai et al., 2001; Pitilakis et al., 2006; Mucciarelli and Gallipoli, 2006; Zaslavsky et al., 2009), soil classifications that account only for $V_{s,30}$ might lack precise definition of site classes and lead to erroneous evaluation of the ground amplification level, mainly in cases of deep soil deposits (deeper than 30 m) and abrupt stiffness changes (high seismic impedance contrast) between the bedrock and the overlying soil formations. Furthermore, the definition of the site effects by
means of soil classes which are assigned according to a sample parameter, such as $V_{s,30}$, is a source of variability of ground motion amplitude in attenuation relationships used for seismic hazard analysis. This is an acute problem for Israel. According to project "Microzoning of the earthquake hazard in Israel" (for example see Zaslavsky et al., 2003, 2006, 2007) most of population centers are built on young sediments with impedance contrast 4-8. The soil classification need more accurate description of soil types through fundamental frequency and amplification of soil column which was constructed by observing H/V spectral ratio of ambient noise along with geological and geophysical information.

The horizontal-to-vertical spectral ratio for these zones shows resonance frequencies of 0.8-1.7 Hz and H/V ratios from 4.5 to 7.0 (see Figure 12). Using as a benchmark the S-wave velocity structure obtained in Petah Tikva (Zaslavsky et al., 2006), we compared observed H/V spectra and computed site response functions for sites in southern Sharon and Lod valley using many borehole data and four refraction lines. Geotechnical data and soil column models for three zones in the town Yehud are summarized in Tables 6 and 7. Comparison between H/V spectral ratio with the analytical transfer functions of the soil column are presented in Figure 13. The site response functions are calculated using the program SHAKE (Schnabel et al., 1972). We can see very good agreement between the two functions.

![Figure 12](image-url)

**Figure 12.** Comparison between H/V spectral ratio (thick line) and analytical transfer function (dashed line) for: a) Zone 3; b) Zone 4; c) Zone 5.
Table 6. Geotechnical data and soil column model for site located in the southern Sharon and Lod valley area (Zone 3, Yehud area)

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thickness, m</td>
</tr>
<tr>
<td>Silt, loamy sand</td>
<td>70</td>
</tr>
<tr>
<td>Marine clay</td>
<td>60</td>
</tr>
<tr>
<td>Marl and chalk</td>
<td>90</td>
</tr>
<tr>
<td>Chalky limestone</td>
<td>150</td>
</tr>
<tr>
<td>Dolomite</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 7. Geotechnical data and soil column model for site located in the southern Sharon and Lod valley area (Zones 4 and 5, Yehud area).

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thickness, m</td>
<td>Vs, m/sec</td>
</tr>
<tr>
<td>Silt, loamy sand</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>Conglomerate</td>
<td>17</td>
<td>540</td>
</tr>
<tr>
<td>Calcareous sandstone</td>
<td>15</td>
<td>700</td>
</tr>
<tr>
<td>Marl and chalk</td>
<td>75</td>
<td>940</td>
</tr>
<tr>
<td>Chalky limestone</td>
<td>65</td>
<td>1130</td>
</tr>
<tr>
<td>Dolomite</td>
<td>—</td>
<td>1900</td>
</tr>
</tbody>
</table>

The subsurface models serve as input for computing acceleration response spectrum by SEEH method. The results of our computations are sown in Figure 13. The uniform hazard site specific response spectra for the three zones were computed for probability of exceedence of 10%
during an exposure of 50 years and damping ratio of 5%. We also plotted the acceleration response spectrum required in the same area by the Amendment No. 3, September 2009 (see formulae 5) of SI 413 for site class D. The shape of the spectra obtained for all zones differs significantly from those prescribed by the new version of SI 413.

![Figure 13](image.png)

**Figure 13.** Uniform Hazard Site-specific Acceleration Spectra for different zones in Yahud area. The spectrum according to the new version of Israel Building Code using $S_s=2.5Z$ and $S_1=1.25Z$, $F_a=1.52$ and $F_v=2.09$ is included for reference (black dashed line).

### 7. Discussion and conclusions

Curves of $S_s$/PGA (red) and $S_1$/PGA (green) versus magnitude for distances 10, 30, 50 and 90 km are depicted in Figure 14. We can see that for 475 years return period values of $S_s$/PGA and $S_1$/PGA affected by earthquakes with magnitude from 5.0 to 6.0. According to our opinion this is the main reason of significant differences in values $S_s$/PGA and $S_1$/PGA obtained for Israel and USA.
Figure 14. Curves of $S_s$/PGA (red) and $S_l$/PGA (green) versus magnitude for different distances. Shaded area shows values of the range $S_s$/PGA and $S_l$/PGA for Israel.

It should be noted that the Two-Point Method design spectrum is common practice in the USA, meanwhile other countries codes and some USA codes utilize different approaches. For example, UBC 1997 provide PGA-related (one-point) design spectrum that used to represent the dynamic effects of the Design Basis Ground Motion for the design of structures. This response spectrum may be modified to site-specific spectrum based on geological, seismological and soil characteristics associated with a specific site. National Building Code of Canada (2005) based on the Peak Ground Acceleration and spectral response acceleration on the period 0.2 sec, 0.5 sec, 1.0 sec, and 2.0 sec that can be obtained from tabled included in the code. New Zealand's code utilizes multi-section spectrum. The designer can use for the spectral values estimates detailed table "spectral shape factor" or calculate exact values by means of equation set.
The analysis of mentioned foreign codes leads us to the conclusion that design spectrum shape and values in each code are adapted to local geological and seismic conditions. Parameters $S_s$ and $S_1$ calculated for different codes varies and in many cases they are different from proposed $S_s=2.5$ and $S_1=1.25$ in Amendment No. 3 (September 2009).

Our conclusions may be summarized as follows:

- We checked that spectral accelerations for periods 0.2 and 1.0 sec provided by programs EZFRISK and SEISRISKIII are in good agreement. However, the results of SEISRISKIII obtained by using different equations to predict horizontal response spectra might vary significantly.
- Our results confirm that the predicted response spectral accelerations at short periods (0.2 sec) $S_s$ and at 1.0 sec $S_1$ correspond to the relatively low seismicity of Israel.
- Israel is vulnerable to strong earthquakes ($M \geq 7.0$), however, their frequency of occurrence is low. At the same time, we suppose that $S_s=2.5Z$ and $S_1=1.25Z$ proposed in the new version of SI 413 are very conservative values of spectral acceleration. Therefore, for design response spectrum construction by the Two-Point Method we suggest using the following values: $S_s=2.2Z$ and $S_1=0.9Z$ deducted from the current analysis.
- The fundamental frequency of vibration of soil column model and seismic impedance contrast should be more appropriate than $V_{S,30}$ for the characterization of the seismic response and, therefore, should not be disregarded in building code soil classification. In fact, we are convinced that using NEHRP $V_{S,30}$ amplification values are inappropriate for Israel and should be replaced.
- Now in Israel intensive construction of high-rise (15-25 storeys) buildings with fundamental period in the range of 0.8-1.5 sec is carried out. However, we have yet no experimental information about dynamic characteristics of buildings required to accurately determine their behavior during earthquakes. Therefore, for the sake of being on a safe side, we recommend for periods greater than $T_s$ (see the Two-Point Method) to utilize the $1/T^{2/3}$ dependency in building the Response Spectra Acceleration rather than the $1/T$, recommended in Amendment No 3 of SI 413.
8. Acknowledgement

Many thanks are due to Dr. Avi Shapira and Dr. Rami Hofstetter for fruitful discussions and constructive comments. Special thanks go to Eng. I. Minkin (TWIN Design and Consulting) who provided useful information about national building codes in different countries. We thank our colleges H. Dan, Y. Karmon, and Y. Menahem (GII) for their technical support throughout this report.
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