CHAPTER

14

Deterministic Seismic Hazard Computations (Hybrid Method) Applied for Two Cities in the Territory of Hungary

Katalin Gribovszki[1,2], Franco Vaccari[3], Sándor Szalai[1], Lili Czirok[4], Péter Varga[1] and Giuliano F. Panza[5,6,7,8]

Between 2002 and 2008, K. Gribovszki had the opportunity to stay in Trieste for several months and to participate in the research of the Seismological Group of the Department of Earth Sciences, University of Trieste, using data taken with her from Hungary. In this summary paper, we briefly report the results of the deterministic seismic hazard computations carried out during these years.

The primary objective of our work in Trieste was to prepare seismic hazard and risk maps for the cities of Debrecen and Budapest, capital of Hungary. In order to achieve this goal, synthetic seismograms were computed by the so-called hybrid technique by using different earthquake scenarios along several profiles.

The response spectra ratio values (RSR) along the investigated 2D profiles (at the predefined set of points) versus frequency and the epicentral distance have been automatically provided by the hybrid technique for the vertical, transversal, and radial components. Similarly to the RSR, curves of ratios of peak ground accelerations (PGA(2D)/PGA(1D)) were automatically provided as well at the predefined set of points at the surface along the investigated profiles. Besides these maps and curves, unique earthquake hazard curves have been produced too, such as Effective Peak Acceleration (EPA) curves for the inner town of the city of Debrecen. EPA curves made it possible to compare our results using our scenario No. 1 to the macroseismological intensity map of a devastating historical earthquake in 1834, thus it was able to validate our computations.

As the results of the computations peaked, ground acceleration grid maps for the territory of the downtown of Budapest and Debrecen for the three different components came into existence as well. Furthermore, for both cities, special seismic risk maps have been prepared. These special seismic risk maps were created based on the combination between the maximal amplitude frequencies of

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[1] Institute of Earth Physics and Space Science, Hungarian Research Network
[2] Institute of Geomatics and Civil Engineering, Faculty of Forestry, University of Sopron
[3] Department of Earth Sciences, University of Trieste, Italy
[4] Hungarian Meteorological Service
[5] Accademia Nazionale dei Lincei, Rome, Italy
[6] Earthquake Administration, Beijing, China
[7] International Seismic Safety Organization (ISSO), Arsita, Italy
[8] Beijing University of Civil Engineering and Architecture (BUCEA), Beijing, China
* Corresponding author:

spectral acceleration of synthetic seismograms and the building's eigenfrequencies at every 0,1 km^2 or even less areas at the downtown of Budapest and Debrecen.

1. Introduction and Objectives

Deterministic seismic hazard assessment (DSHA) computations have been done for the inner town of two Hungarian cities: Debrecen and Budapest. Synthetic seismograms were computed by the so-called "hybrid technique".

The computations for the area of Debrecen were motivated by the fact that Debrecen, the second most populated city in Hungary (its population is about 200, 000), is located in the eastern part of the country and is close to the Érmellék seismo-active region, where one of the largest earthquakes ever occurred in Hungary in the first half of the 19th century (Szeidovitz et al., 2002). The seismically active fault system, the Gálospetri graben, together with its continuation in Hungary: the Mobile zone, principally determines the seismic hazard of Debrecen.

In our initial computations in 2001 (Gribovszki & Vaccari, 2004), 2-scenarios (2 different computations along 2 different profiles, scenarios No. 1 and No. 2, Figure 1) have been used, assuming that the earthquakes occurred in the Gálospetri graben (Gálospetri village), which is part of the main quake zone of the Érmellék region, or in the Mobile zone (Hosszúpályi village).

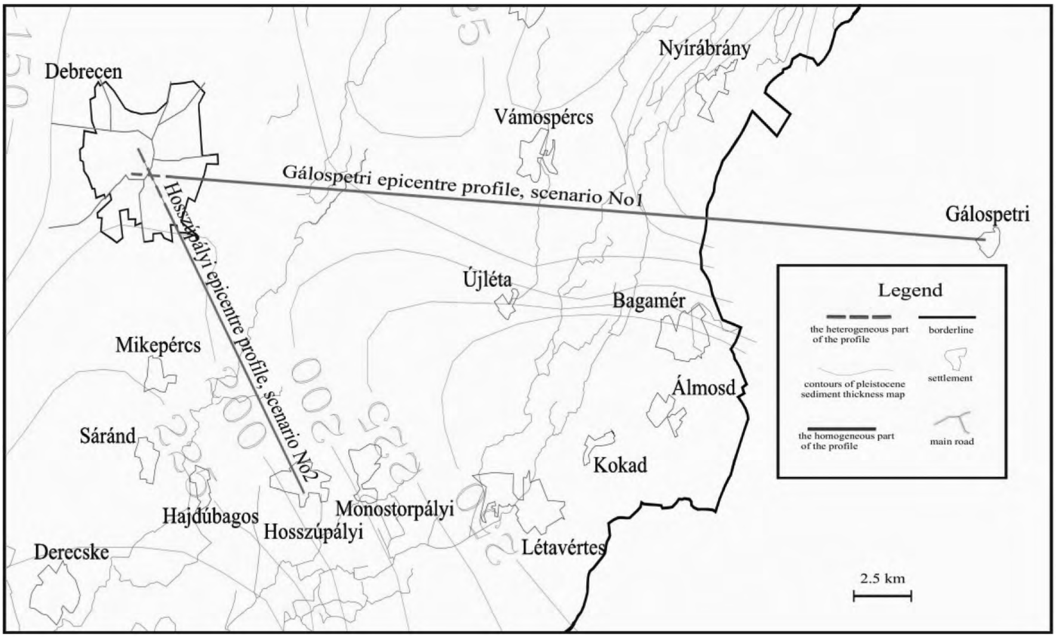

Fig. 1 Profiles between the city of Debrecen and the assumed epicentres in Gálospetri and Hosszúpályi villages, scenarios No. 1 and 2 (Figure 2 in Gribovszki and Vaccari, 2004).

We had the opportunity to compare our computations (scenario No. 1) with the macroseismic effects observed at the site of Debrecen in 1834, when the most devastating earthquake occurred in Érmellék seismo-active region (Zsíros, 1985).

One-and-a-half years later in 2003, as the continuation of our initial computations, a detailed one, was carried out using the same scenario as scenario No. 2 (Gribovszki & Panza, 2004). In that case, the initial computation using scenario No. 2 has been completed with developed input data (using more borehole data than before) at the 2D laterally heterogeneous profiles (Figure 2). Furthermore the computations were extended to the whole territory of Debrecen along 11 different laterally heterogeneous profiles, in order to prepare the synthetic scaled accelerograms along the profiles and the curves and maps derived from them (the ratio of maximum acceleration values: PGA(2D)/PGA(1D), response spectra ratio: RSR). These synthetic scaled accelerograms could be expected for the entire territory of Debrecen in the case of the highest earthquake hazard (assuming the nearest epicentre in the Mobil zone fault system). Another aim of the computations was to generate a special seismic risk map that, beyond the synthetic seismograms, takes into account the number of floors of the city's building in Debrecen as well (Gribovszki & Panza, 2004).

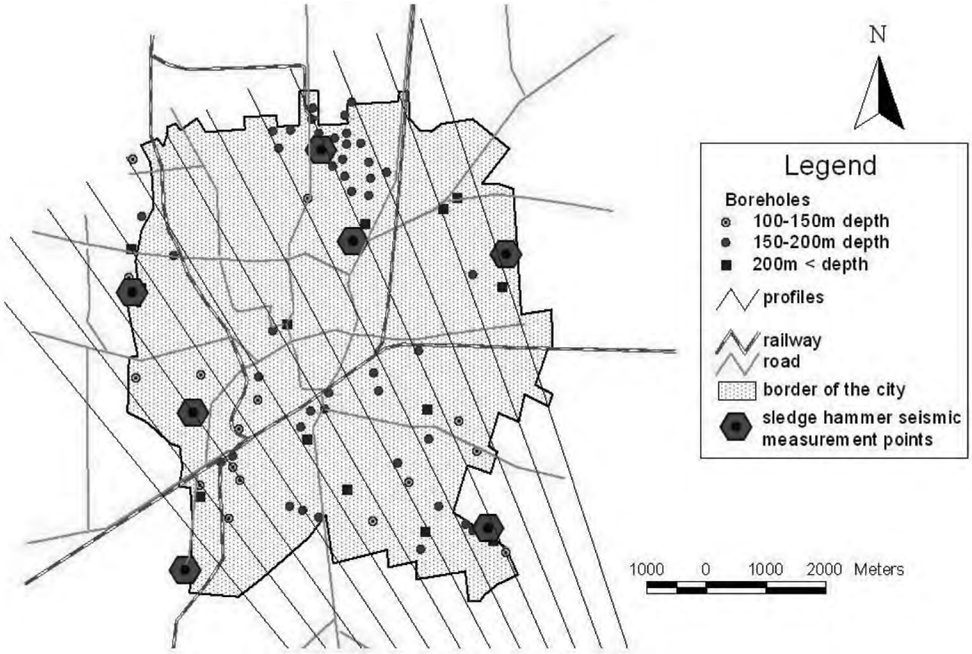

Fig. 2 Boreholes and 2D profiles inside the city of Debrecen (Figure 3 in Gribovszki and Panza, 2004).

In 2008, DSHA computations were performed by the hybrid technique along 4 different laterally heterogeneous profiles across the downtown of Budapest. Budapest, the capital city of Hungary, considering its population, cultural and economic values deserves accentuated attention from the point of view of natural hazards. The computations used the same seismic source (scenario No. 3) but different laterally heterogeneous profiles. The parameters of the seismic source were adopted from the parameters of the well-known 1956 Dunaharaszti earthquake. This Dunaharaszti earthquake was the strongest event (M5.6) that had ever occurred in the vicinity of Budapest, only 15 km far from the inner town of the capital (Figure 3).

Earlier than our computations, simpler bedrock based deterministic seismic hazard assessment computations were carried out with the use of modal summation for the whole territory of Hungary (Bus et al., 2000). In the case of the area of Budapest according to Bus et al. (2000) the designed ground acceleration values between 0.02*–0.04g can be expected for the bedrock. The same values were computed for Debrecen as well.

Szeidovitz et al. (2001) also computed the designed ground acceleration values for Budapest by modal summation method taking into account the thick loose sediments at the surface as well applying two different scenarios of the Dunaharaszti earthquake that occurred in 1956. They found 7° intensity on the MKS-64 scale (4.9 cm/sec horizontal component) for the southern Pest part of the inner town of the capital, when the epicentre was put into Dunaharaszti village.

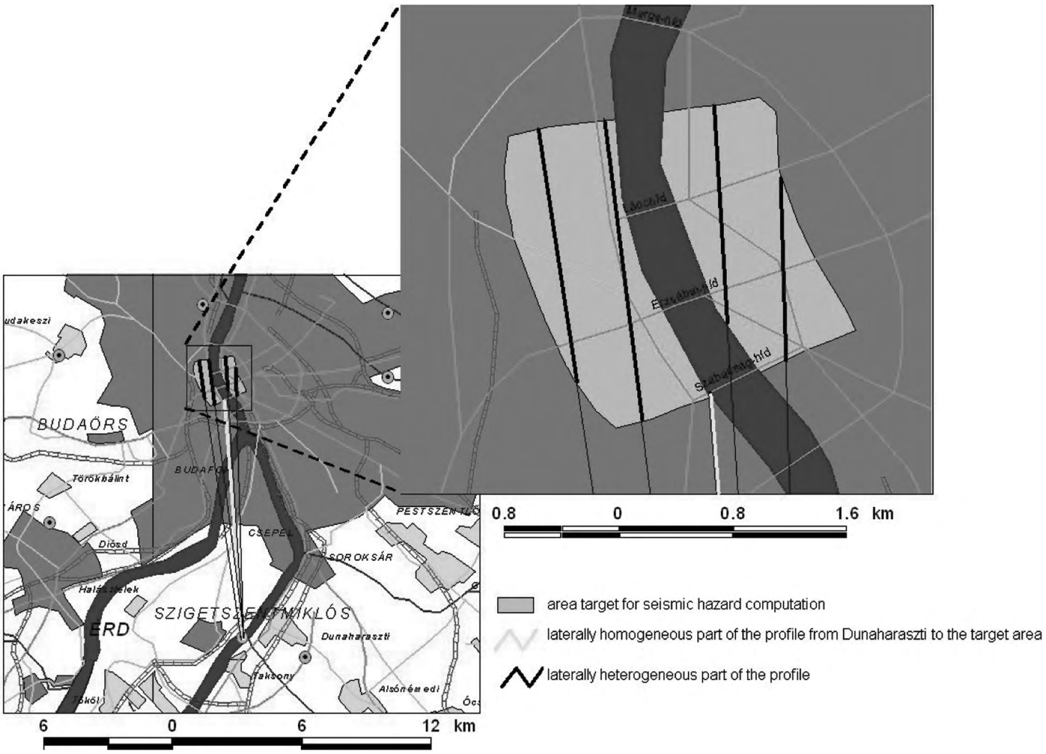

Fig. 3 Profiles between the downtown of Budapest, scenario No. 3 (Figure 2 in Gribovszki et al., 2010).

Panza et al. (2008) determined by the Neo-Deterministic Seismic Hazard Assessment (NDSHA) for Budapest 0.08–0.15g values, and for Debrecen 0.15–0.30g values.

This summary of our DSHA computations were preceded by the probabilistic seismic hazard assessment (PSHA) [Tóth et al., 2008, 2006]. According to Tóth et al. (2008, 2006) in the downtown of Budapest for a 50-year time-interval with 10% of no-exceedance the expected peak ground bedrock acceleration is 0.154g, and for Debrecen this value is between 0.1–0.105g.

According to results obtained by Bus et al. (2000) and Tóth et al. (2008, 2006) the bedrock related DSHA and PSHA earthquake hazard of Budapest and Debrecen in comparison with other cities of the world can be classable as medium.

The effects of local ground condition for the amplification of seismic waves was described by site response analysis in Hungary in Kegyes-Brassai (2017) as well. Earthquake hazard analysis and building vulnerability assessment has been done to determine the seismic risk of existing buildings in an urban area (city of Győr, Hungary) (Kegyes-Brassai 2015). Seismic microzonation in Budapest has been done as well by Győri et al. (2021) by joint analysis of active and passive surface wave methods.

2. Method

In the computations described in this paper synthetic seismograms are created by the hybrid method. A detailed modelling of the ground motion by hybrid method can take into account the local geophysical, geological, and geotechnical conditions at a site of interest (Panza et al., 2002). The hybrid method combines the modal summation method, valid for laterally homogeneous inelastic media (bedrock model) (Panza 1985; Panza & Suhadolc 1987; Florsch et al., 1991), with the finite difference method, which allows the modelling of the laterally inhomogeneous inelastic media (Fäh et al., 1990, 1994; Panza et al., 2000).

Wave propagation is treated by means of the modal summation technique from the source to the vicinity of the local heterogeneous inelastic structure that we want to model in detail. This laterally homogeneous inelastic structural model represents the principal crustal-properties of the propagation path from the focal source to the laterally heterogeneous area. This laterally homogeneous structure will hereafter be named "the bedrock model". It consists of several flat layers each of which is described by thickness and density values, P-wave and S-wave velocities and independent intrinsic attenuation values (Q).

The generated wavefield is then introduced into a grid that defines the heterogeneous area (2D profile) and it propagates according to the finite difference scheme. The laterally varying part of the applied hybrid model is constructed on the basis of the local geology.

Using this approach, the focal source, path and site effects are all taken into account and therefore it is possible to carry out a detailed study of the propagating wave field at even large distances from the epicentre.

3. Input Data

The target areas of DSHA computations are situated in a single profile (scenario No. 1), in the whole territory of Debrecen (scenario No. 2.) and in the downtown of Budapest. In case of Budapest the target area extends in N-S direction along the section of Danube from Batthyány square to Gellért square for a one km broad zone on both sides of the river (Figure 3).

The following initial data are requested for computation of synthetic seismograms:

- focal depths, focal mechanisms of the quakes, and the coordinates of epicentres;
- bedrock models between the hypocentres and the target areas of seismogram computations;
- 2D laterally heterogeneous models of near surface geological formations within the target areas.

3.1 Hypocentres and Focal Mechanisms of the Earthquakes

The main task was to define the scenarios corresponding to the earthquakes of the same size as the destructive events that occurred on 15th of October 1834 (in case of Debrecen), and the event occurred on 12th of January 1956 (in case of Budapest). For determining the parameters of the calculations of the Debrecen target area we relied on the work of Szeidovitz (2000) and for the calculations of the Budapest target area on the work of Szeidovitz (1986).

From the analysis of the felt intensity (up to IX) it has been possible to estimate a magnitude ranging from 5.5 to 7.1 (Szeidovitz, 2000) for scenarios No. 1 and 2. The supposed parameters of the source mechanism are dip: $\delta n = 70°$; rake: $\lambda = 0°$ (strike-slip); focal depth = 10 km; M = 6.0. Keeping fixed the dip and rake, we have considered two sources, one coinciding with the original epicenter of the earthquake of 1834 (Gálospetri, strike-receiver angle of 15°, scenario No. 1), the other close to Hosszúpályi village (strike-receiver angle of 165°, scenario No. 2). The parameters of the different scenarios' computations were summed up in Table 1.

The location of the epicentre at scenario No. 2 was justified by the fact that Hosszúpályi village is situated the closest to the city of Debrecen along the Mobile Zone fault system, so this could cause the highest seismic hazard for Debrecen. The explanation of this choice is the following. It can be possible to assume Hosszúpályi as the location for the earthquake's epicentre, since according to the generally accepted deterministic earthquake hazard principles, if an earthquake with a given magnitude has already occurred once at a given fault line, then another earthquake of the same magnitude can occur anywhere else along the same fault line.

When the epicenter is in Gálospetri (scenario No. 1), the length of the whole profile between the epicenter and the city of Debrecen is 46.8 km, of which the heterogeneous (local model) part is 2.3 km long. When the epicenter is in Hosszúpályi (scenario No. 2), the length of the whole profile between the epicenter and the city of Debrecen differs from 21 to 23 km long, of which the heterogeneous part is between 4.5–8.5 km long.

Only one earthquake scenario was used for the calculation of synthetic seismograms along the 4 different profiles in the case of the inner town of Budapest (scenario No. 3). The data of earthquake scenario No. 3 were the same as the data of the earthquake that occurred on 12th of January 1956 (Szeidovitz, 1986). The supposed parameters of the source mechanism are dip: $\delta = 90°$; rake: $\lambda = 0°$ (pure strike-slip left lateral); focal depth: h = 10 km; magnitude: M = 6.0; strike-receiver angle: $\varphi_0 = 40°$. The length of the wave path between the epicentre and the inner city of Budapest was 15 km; the length of the laterally heterogeneous paths (2D profiles) differs from 2.2 km to 3.4 km in the inner city. The location of the epicenter was in the centre of the triangle of Dunaharaszti, Szigetszentmiklós, Taksony villages. Figure 3 shows the 2D profiles on the surface. The detailed explanation of the focal mechanism can be found in Chapter 4/a-b of Varga et al. (2009) Final Report.

Table 3.1 Parameters of the different computations.

Parameters of the Computations	*Scenario No. 1*	*Scenario No. 2*	*Scenario No. 3*
Epicentre	Gálospetri	Hosszúpályi	Centre of the triangle of Dunaharaszti, Taksony, and Szigetszentmiklós
dip, δ	70°	70°	90°
rake, λ	0°	0°	0°
focal depth	10 km	10 km	10 km
magnitude, M	6.0	6.0	6.0
strike-receiver angle	15°	165°	40°
length of the whole profile	46.8 km	21–23 km	17.2–18.4 km
length of the laterally heterogeneous part of the profile	2.3 km	4.5–8.5 km	2.2–3.4 km

3.2 Bedrock Models

At the 1D part of the computation the seismic waves propagate along the laterally homogenous bedrock model (from the epicentre up to the beginning of the 2D part of the computation) for the model summation part of hybrid method synthetic seismogram computation.

In case of scenarios No. 1 and No. 2, P-wave velocity values measured at boreholes, and the results of some special research connection with the velocities, densities, and Q values of the upper 4000 m of the crust were taken into account in order to improve the previous parameters of the bedrock model. The PGT-1 seismic reflection section velocity parameters (Hegedűs and Takács, 1998) were used, whenever the layer depth has been larger than the well logging hole bottom data. The No. VI. structural unit of the Pannonian Basin model was used as a reference model (Bus et al., 2000) in the modal summation part of the computations at the deepest part of the bedrock model. In the above mentioned publication the Pannonian Basin has been divided into six regional structural units defined on the basis of geophysical and geological data. Parameters of the deepest layers have been adapted from the IASPE91 global model (Kennett and Engdahl, 1991) and from the velocity model of Mónus (1995) computed for the Pannonian Basin. In more details, see Gribovszki and Vaccari (2004) for scenario No. 1, and Gribovszki and Panza (2004) for scenario No. 2.

In case of scenario No. 3, the detailed data of the upper layer of this laterally homogeneous bedrock model can be found in Dövényi et al. (2008) Final report profile 5, V5-2 (XII. appendix). For the deeper part than 2000 m of the section, Bus et al. (2000) No. IV. model for the Pannonian basin was used as a reference model.

3.3 2D Laterally Heterogeneous Profiles

The destructive effects of seismic waves are strongly influenced by the physical parameters of the soil, within a few hundred metres from the topological surface. In order to characterize the laterally varying parts of the models, from the point of view of a heterogeneous inelastic structure, it was compiled on the basis of local geology, available geotechnical measurements, especially the knowledge of many shallow well loggings in Debrecen (Figure 2), in case of scenarios No. 1 and No. 2.

In case of scenario No. 3, the detailed data of the four 2D profiles can be found in “Geological structure of the inner town of Budapest and the geological-geophysical model of the northern part of Csepel island” Dövényi et al. (2008). Final Report, Appendix VII–XI. and XVI–XVIII.

3.4 Computation Parameters

The detailed explanation of computation parameters can be found in Gribovszki and Vaccari (2004) for scenario No. 1 (Gálospetri), in Gribovszki and Panza (2004) for scenario No. 2 (Hosszúpályi), and in Chapter 5 of Varga et al. (2009) Final Report for scenario No. 3 (Budapest).

4. Results

As the results of the computations P-SV (radial and vertical components) and SH (transversal component) synthetic displacement time series, velocity time series and accelerograms were computed along the local models,

- at 97 sites along the 1 laterally heterogeneous profile in Debrecen when the source was in Gálospetri (scenario No. 1);
- at about 100 sites at each 11 laterally heterogeneous profiles in Debrecen when the source was in Hosszúpályi (scenario No. 2);
- at about 90–95 sites in case of the all 4 laterally heterogeneous profiles at the inner town of Budapest (scenario No. 3).

All the computations two other kinds of figures were prepared too as results:

- Amplifications of peak ground accelerations along the profile (PGA(2D)/PGA(1D));
- Response spectra ratio along the profile (Sa(2D)/Sa(1D), RSR).

The 2nd and 3rd two figures were prepared in order to assess the site effects along the laterally varying part of the profiles. The response spectra ratio or spectral amplification represents the influence that local soil conditions introduce into the response spectra with respect to the bedrock model.

4.1 Results, Scenario No. 1

The influences in Debrecen of the Érmellék earthquake that occurred in 1834 were modelled by scenario No. 1. When the source is in Gálospetri (the original epicentre of the earthquake in fact occurred in 1834, at the Gálospetri graben, Érmellék seismo-active zone) the RSR (5% damping) along the profile are shown in Figure 4. The horizontal components of the ground acceleration caused the most significant damages, therefore we concentrate on the values of these components. The RSR maximum values (2.5) are seen in the horizontal components, at the second half of the profile and for frequencies below 1 Hz. This means that the multi-storey buildings at that part of Debrecen suffer a higher seismic hazard than the lower ones. Because of this, if an earthquake similar to the event of 1834 would occur, then it could cause much larger damage (larger macroseismic intensities) in a residential or industrial area with tall buildings than the damage was caused by the 1834 event, since in 1834 only single-storey buildings (and tall churches) existed in Debrecen.

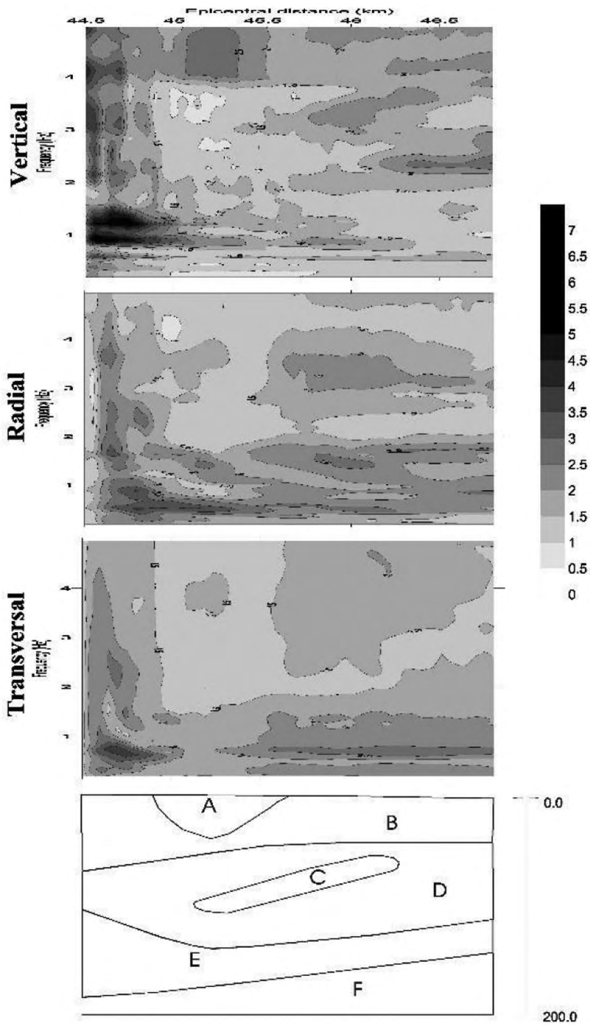

Fig. 4 Relative response spectra ratio with 5% damping versus frequency and versus the laterally varying profile in Debrecen, scenario No. 1 (Gálospetri epicentre).

The transversal component of PGA values, in case of the computations in scenario No. 1, can be converted into intensities and compared to the macroseismic intensity values estimated from the contemporary damage assessment reports in 1834. These PGA values extracted from synthetic signals are between 97–90 m/s^2 at the last 800 m of the profile (Figure 4). These values are approximately equal to 7° and 8° MSK-64 scale intensities (Bisztricsány, 1974).

In the majority of cases the application of the peak instrumental values (PGA, PGV, PGD) does not furnish sufficient information about the devastating effect of a given earthquake. Realizing this limitation, the Applied Technology Council (ATC, 1978) introduced the concept of the Effective Peak Acceleration (EPA). It is defined as the average spectral acceleration over the period range of 0.1–0.5 s divided by 2.5 (standard amplification factor for a 5% damping spectrum). EPA represents the acceleration which is most closely related to the damage potential of an earthquake (Newmark & Hall, 1982).

EPA values were calculated for three components in the case of scenario No. 1 (transversal component EPA values are shown in Figure 5). The curve shape of EPA values of transversal components is similar to the PGA curve but it represents significantly smaller values (50–57 m/s^2). By transforming EPA values into intensity values along the last 800 m part of the profile (where we have macroseismic intensities) 6° and 7° MSK-64 scale intensity values were obtained. The obtained results are in agreement with the observed macroseismic intensities due to the devastating 1834 earthquake, which occurred in the Érmellék seismo-active region (Figure 3 in Gribovszki & Vaccari, 2004).

These EPA and PGA values computed by the hybrid method (taking into account the effect of the subsoil) are an order of magnitude larger than the PGA values computed by Bus et al. (2000) for bedrock (0.020–0.040 g). Therefore, it can be concluded that the calculated values are in good agreement with each other, since in Debrecen loose, low velocity layered subsoil has been found below the surface (in the laterally 2D profile).

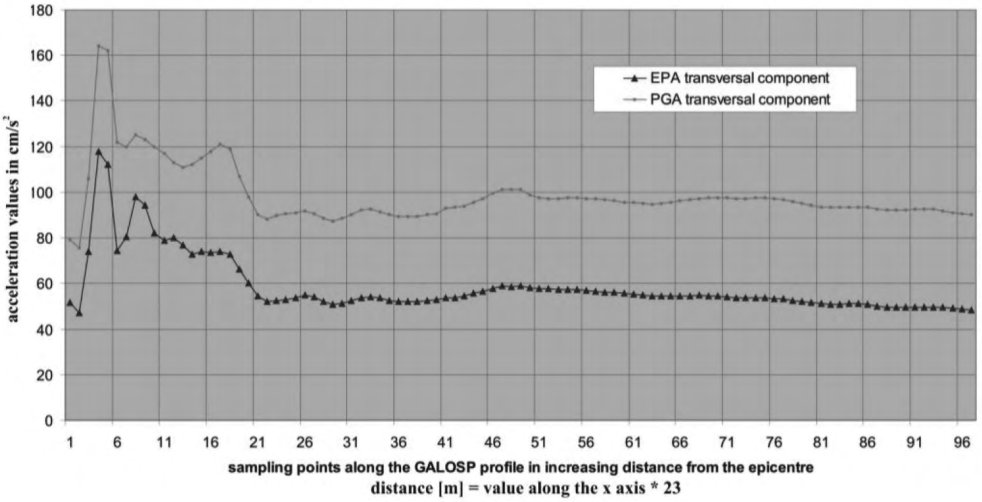

Fig. 5 Computed PGA and EPA values (transversal component) along the laterally varying profile in Debrecen, scenario No. 1 (Gálospetri epicentre).

4.3 Results, Scenario No. 2

The influences in Debrecen of an assumed earthquake occurred in the Mobile zone (epicentre was in Hosszúpályi village) were modelled by scenario No. 2. In the case of the Hosszúpályi epicentre computation (scenario No. 2), in the city centre of Debrecen, the trend of the RSR values is in good agreement with the observed decrease of the macroseismic intensities with increasing epicentral distance evaluated from the 1834 Érmellék earthquake.

Figure 6 (Figure 6 in Gribovszki and Panza, 2004) shows that the upper 200 m soil structure below Debrecen modifies the PGA values. The transversal components are six times larger than the vertical ones (and 10 times larger than the radial ones). The transversal PGA values drastically decrease from 0.38g to 0.15g, from the south-eastern part of the city to the north-western part. The maximal accelerations of the horizontal components are at the closest (southern) part of the city to Hosszúpályi village. The maximal acceleration values of the vertical component are at the centre of the city and its value is 0.05g. The maximal transversal acceleration values equal to about 8° intensity in MSK-64 scale (Bisztricsány, 1974).

Panza et al. (2008) computed for Debrecen by the Neo-Deterministic Seismic Hazard Assessment (NDSHA) 0.15–0.30 g values. These values are in good agreement with the values determined in this paper for the city centre of Debrecen by applying scenario No. 2.

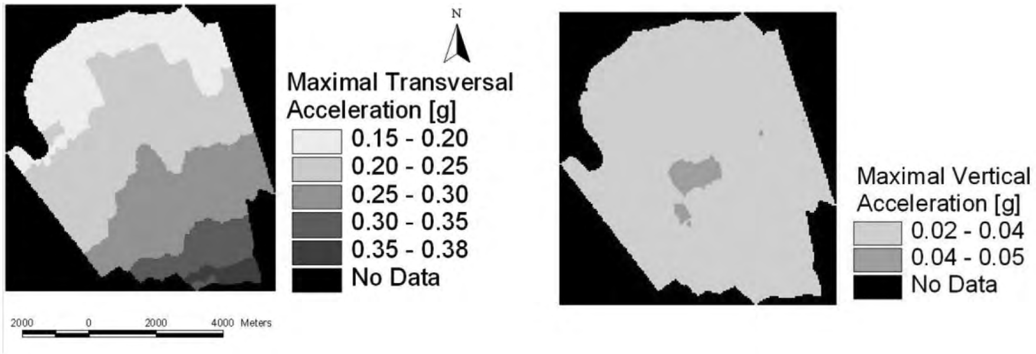

Fig. 6 Grid maps for the maximal acceleration values of the transversal and vertical components in Debrecen.

4.2 The Production Procedure of the Special Seismic Risk Map for the Territory of Debrecen

A special seismic risk map of the city of Debrecen, consistent with the 1834 Érmellék earthquake in terms of geometry (focal mechanism) but at a different place of hypocentre was produced.

It is known that the horizontal components of the waves cause the main damages of the buildings. In order to estimate the seismic risk at the city of Debrecen, the transversal component seismograms were used, since the maximal acceleration values were much higher for the transversal components than the radial ones.

The estimation of the seismic risk was based on the following, well known, formula:

$$\text{Seismic Risk} = (\text{Seismic Hazard}) \times (\text{Vulnerability}) \qquad ...(1)$$

The seismic hazard part of the multiplication was provided by the synthetic seismograms computed by the DSHA hybrid technique (Fäh, 1992; Fäh et al., 1994), and the vulnerability part was estimated by using the formula:

$$T = 0.1 \times n[\mathrm{s}] \qquad ...(2)$$

where, T is the eigenperiod of a given building and n is the number of floors of the given building (Csák et al., 1981). The reason why this formula was used is because an earthquake exerts the strongest destructive effect on a building, if the building eigenfrequency coincides with the frequency of the maximal amplitude of the response spectra.

The map of the distribution of the buildings with different number of floors in Debrecen was constructed by using aerial photos and a 1: 10 000 scale topographic map (Figure 7).

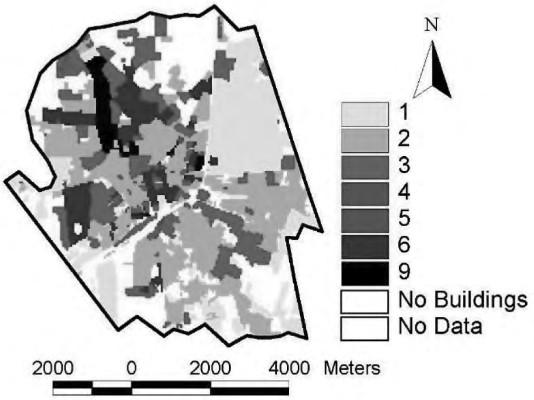

Fig. 7 Map showing the height (number of floors) of the buildings in Debrecen.

The procedure of the special seismic risk map's production summarized in one sentence is the following. If someone knows the number of floors at a given location, then by using Eq. (2), an acceleration value corresponding to the eigenperiod of the number of floors of a given building (at a given location) can be read off from the chart of spectral acceleration with 5% damping (SA 5%) computed by the hybrid technique. Details about the production procedure of the special seismic risk map can be read in Gribovszki and Panza (2004) and on Figure 12 in Gribovszki and Panza (2004) (the flow chart of the procedure of special seismic risk map s the production).

It can be seen from the seismic risk map of Debrecen city (Figure 8) that the most damageable part of the town is situated at about 1 km far south-eastward direction from the city centre. There are moderate damageable parts of the city not only on the southern part of the city, but at the city centre, and on the north too.

The estimation of the vulnerability of buildings by the eigenperiod of different storied buildings is the only one, and very simple way to characterize the vulnerability of the buildings.

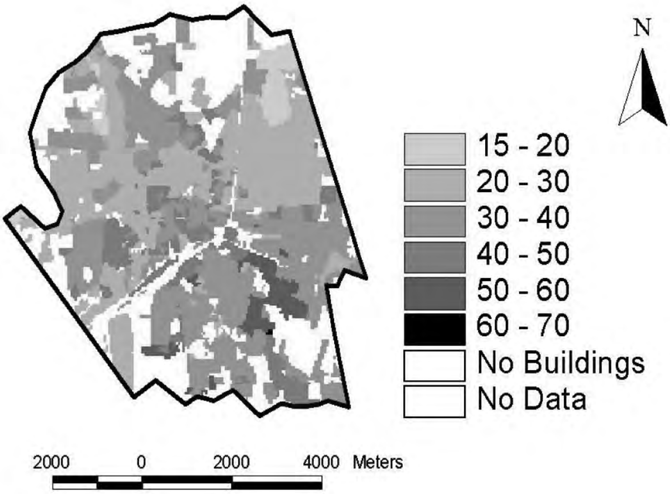

Fig. 8 Seismic risk map of Debrecen consistent with the 1834 Érmellék earthquake in terms of focal mechanism, but at a different location of the epicentre.

4.4 Results, Scenario No. 3

As the results of the computations, PGA (peak ground acceleration) grid maps of the downtown of Budapest for the three different components came into existence (Figure 9). Furthermore spectral acceleration (response spectra, SA) and RSR charts of the synthetic seismograms for the four different profiles were created as well.

The PGA grid maps (Figure 9) show that in case of all three wave components it is true that the loose, low velocity layered soil causes higher PGA values at the Pest part. The maximal PGA values manifest at the radial component at the Pest part of the downtown (100–200 cm/s^2), and these maximal PGA values are equal to 8° on MSK-64 scale (Bisztricsány, 1974). In case of the horizontal wave components the PGA results of hybrid method calculations were multiplied by the factors of 1.6 and 1.7 (compared to the 1D model PGA), where at the top of the soil, disadvantageous, loose layers (Holocene flood-plain sediments, debris covered surface) are situated. See, in more detail, in Varga et al. (2009) Final Report on pages 40–42.

Panza et al. (2008) computed for Budapest by the Neo-Deterministic Seismic Hazard Assessment (NDSHA) 0.15–0.30g values. These values are in good agreement with the highest values determined in this paper for the Pest part of the city centre in.

Szeidovitz et al. (2001) computed the designed ground acceleration values for Budapest by modal summation method taking into account the thick loose sediments at the surface as well, applying assumed scenarios of the Dunaharaszti earthquake that occurred in 1956. They found about 7° maximal intensity on the MKS-64 scale (B2 receiver: 4.9 cm/sec, radial component) for the southern Pest part of inner town of the capital, in case of the computation when the epicentre was put into Dunaharaszti village (S1 earthquake). This maximal intensity value is one degree smaller than our results. (The earthquake occurred in Dunaharaszti on 12th of January, 1956 caused 6.5° intensity in Mercalli-Cancani-Sieberg scale at Pest part of the inner town of Budapest, estimated by Szeidovitz (1986).

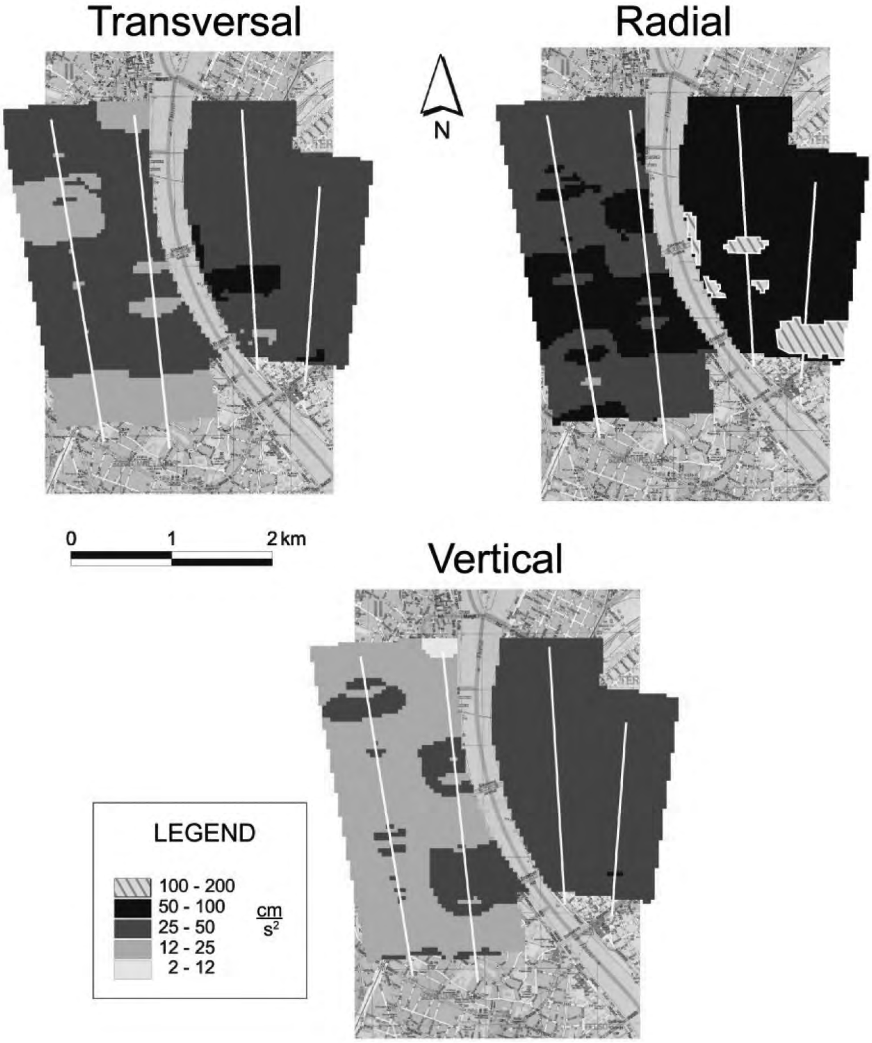

Fig. 9 Grid maps of peak ground acceleration values for the three wave components at the inner town of Budapest.

Figure 10 shows the Sa(2D) (response spectra of the synthetic accelerations taking into account the 2D laterally heterogeneous profile, as the local soil conditions) for profile 1 (Buda part in Budapest). The horizontal acceleration values differ from 10 cm/s^2 and 200 cm/s^2, and the maximal values magnify at higher than 2 Hz frequency domain. (This higher than 2 Hz resonance frequency coincides with the resonance frequencies of buildings with less than 5 or 6 floors.) At profile 1, the radial horizontal component maximal values can be found after the Gellért hill (right before 16 km), and at 16.9 and 17.7 km epicentral distance between 4–5 Hz frequency domain.

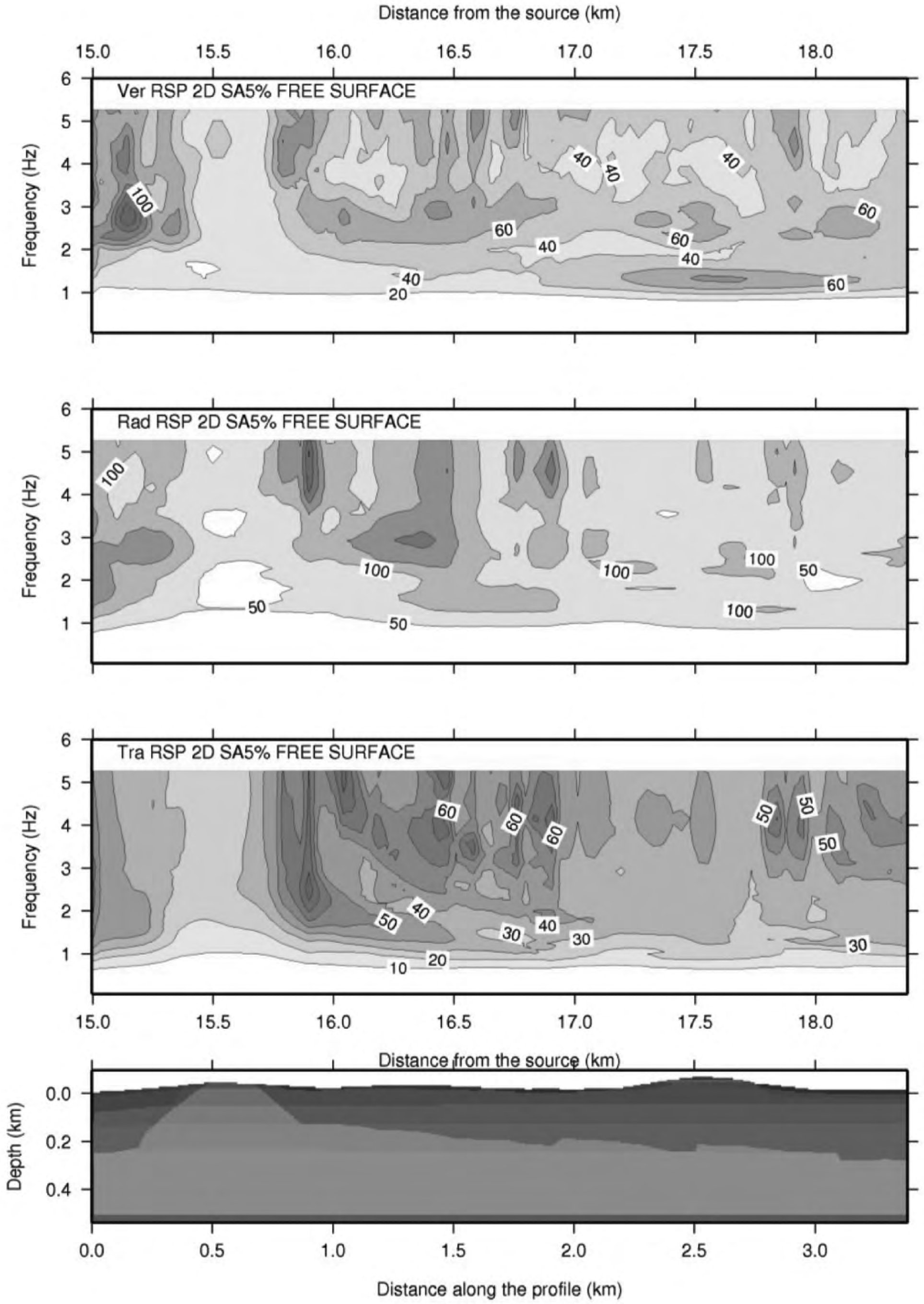

Fig. 10 Sa(2D)-Response spectra of the synthetic accelerations taking into account the 2D laterally heterogeneous profile (local soil conditions) for profile 1 (Buda part in Budapest).

For the downtown of Budapest, a special seismic risk map has been prepared (Figure 11). This special seismic risk map was created on the basis of the difference between the maximal amplitude frequencies of Sa(2D) of synthetic seismograms and the building's eigenfrequencies at every 0,1 km^2 of the downtown. The special seismic risk map shows that the buildings situated at the hilly western section of the downtown (Buda) have higher seismic risk than the ones at the flat middle and northeastern part (Pest). However, the buildings located at the southern part of Pest also have high seismic risk.

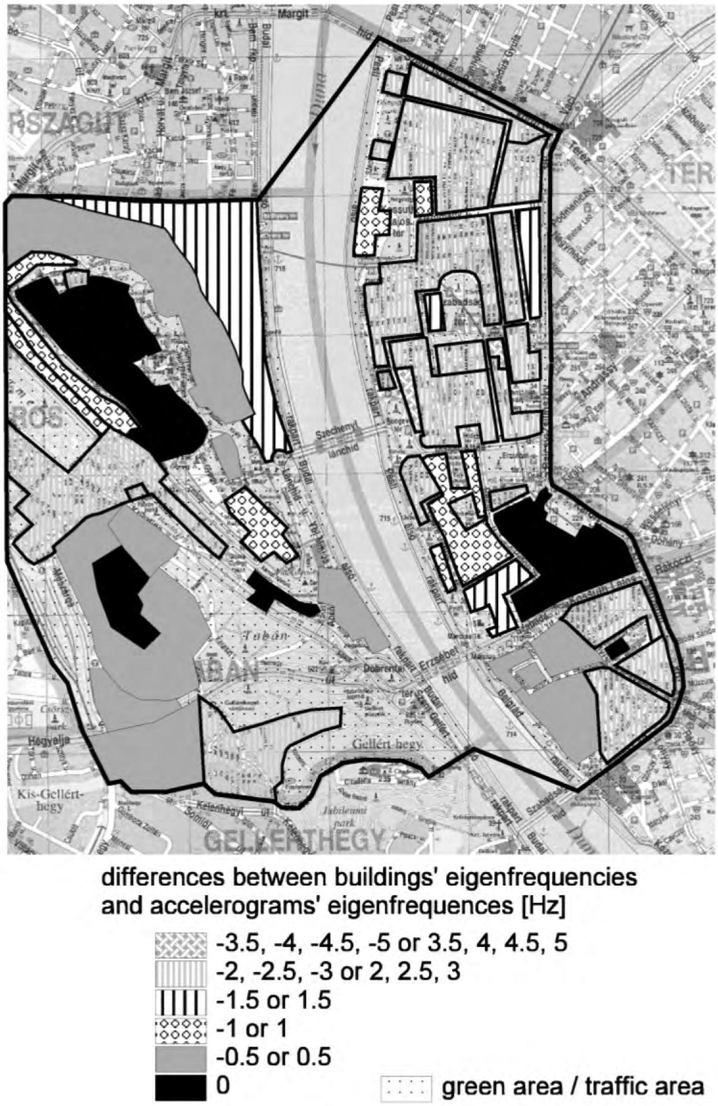

Fig. 11 Seismic risk map. Seismic Risk = frequency difference [Hz] = frequency of maximal acceleration of Response Spectra – eigenfrequency of building. The lower the difference the higher the seismic risk.

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In the late 1980s, together with Panza, we set up the Earth Science Commission of the Central European Initiative (CEI). The three working groups of the Commission (Geology, Geophysics and Geodesy) organised several technical seminars. In addition, the Commission organized five major conferences (Trieste, Sofia, Bratislava, Bucharest, and Ohrid), which mobilized specialists from across the region and played an important role in the reunification of the individual disciplines after 1989. In recognition of his activities, he was awarded the Medal of Honour by the President of the CEI in 2004.

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