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Results of the Ph.D. thesis

Studying the Geophysical and Geological Environment of Earthquakes and Deterministic Seismic Hazard of Debrecen (Hungary) Using Geographic Information System Tools

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A PRIORI INFORMATION

Among natural disasters earthquakes and other phenomena (landslides, tsunami) occurring as a consequence of earthquakes cause the biggest damages [Meskó 2002]. Determining the risks of earthquakes has become extremely important, even in Hungary, where medium earthquakes (M> 5.5) occur only rarely (once in every 40-50 years) [Tóth et al. 2002]. The reason for this is that a natural disaster happening nowadays would endanger the lives of more people than earlier as a result of the growing population. Another reason is that hazard assessments are more and more common to be required for building facilities that pose a risk to human life. As a consequence of all this we can understand why determining the hazard of earthquakes is so important.

In order to determine seismic hazard we have to be aware of the characteristics of the seismogene zones around the area we are investigating, thus we have to be aware of the size and frequency of possible earthquake. On the basis of the bulletin of historical earthquakes [Zsíros 2000] these parameters however cannot be determined with certainty. Knowing the mechanisms of processes that create earthquakes can help to make seismic risk estimation more accurate.

In the Carpathian Basin, and in Hungary the distribution of earthquake epicentres is incidental according to the observations and opinions of some authors [such as Bisztricsány 1977]. According to Horváth [1984] seismoactive zones in Hungary can be identified as former Neogene structural elements: most Hungarian earthquakes are related to the reactivation of these elements. There are however different cases, where seismoactive zones related to very young faults can be identified. According to Gerner et al. [1999] the spatial distribution of seismicity can be attributed to Miocene fault zones with some distortions related to incidental earthquake activity caused by the general weakness of the crust in the basin. The relationship between mapped faults and earthquake epicentres is difficult to define because the dip of the faults in not known in the depths where earthquakes occur. According to Szeidovitz et al. [2002] only a part of the earthquakes can be explained on the basis of the tectonic approach, this is why other approaches have occurred recently in connection to the generation of earthquakes in Hungary.

In order to make seismic risk approaches more accurate Jámbor & Szeidovitz [1995] compiled the *Quaternary kinematic map* of Hungary, where they showed all structures that on the basis of previous experience, geological and geophysical results might play a role in generating earthquakes.

The investigations of Lenkey et al. [2002] showed that in the areas of the Carpathian Basin where more seismic energy is released, thus seismic activity is stronger, heat flow values are lower, and vice versa, where heat flow is higher, seismic activity is weaker.

The investigations of Szabó & Páncsics [1999] show that lineaments based on the maximal horizontal gradient calculated from Bouguer anomaly maps very often correlate with the distribution of earthquake epicentres in Hungary.

According to Ádam [2002] in the zone of Transdanubian Conductivity Anomaly the three tectonic zones marked out by inductive vectors and magnetotellurics are in strict connection with the distribution of the earthquake epicentres.

Another antecedent of this thesis is the probability seismic hazard map compiled on the basis of calculations regarding the territory of entire Hungary [Tóth & Zsíros 2002], as well as peak ground acceleration values calculated with deterministic methods regarding smaller areas (Budapest, Paks) [Szeidovitz et al. 2001, Szeidovitz & Varga 1997]. Furthermore a deterministic seismic hazard map regarding the entire territory of Hungary without taking into consideration lateral changes in the subsoil was compiled in the framework of an international cooperation [Bus et al. 2000].

OBJECTIVES OF THE RESEARCH

On the basis of a priori information and perspective research directions the objectives of the candidate's investigation are the following:

1. Collecting and archiving geological and geophysical data in connection to earthquake epicentres and earthquake generation in geographic information system (GIS).
2. Refining and supplementing the *Map of Kinematic and Earthquake Epicenters* [Jámbor et al. 1999].
3. Investigating the relationship between specific geological and geophysical structures and the distribution of earthquake epicentres through geographic information system (GIS) analysis.
4. Determining seismic hazard in Debrecen (Eastern Hungary) through deterministic seismic hazard calculations using a hybrid method taking into consideration the characteristics of the local subsoil besides the parameters of the bedrock.
5. Compiling a risk map taking into consideration the results of deterministic seismic hazard calculations and the characteristics of buildings in Debrecen.

APPLIED METHODS

During the compilation of the geographic information system in order to investigate the geological and geophysical environment of earthquakes the following methods were used by the candidate. The candidate digitized and oriented the different maps creating the layers of the system. She obtained maps from different institutions and refined the orientation parameters of these maps. The candidate created point, line and polygon themes in the geographic information system on the basis of the elements of the maps and coordinate values. Using the digital surface modelling (DSM) processes of the applied softwares the candidate compiled TIN (*Triangulated Irregular Network*) models and grid surface models on the basis of the points representing surfaces of different geological layers. Using these digital surface models the candidate compiled cross sections. Using the appropriate functions of the applied programs the candidate compiled a slope category map from the surface levels.

In order to investigate the relationship between the different layers the candidate used the following analysis tools in the geographic information system: selection (by theme / by geographical location / by property), creating intersections and union, establishing buffer-zones (of vector type data), summation, multiplication and reclassification (of grid type data).

Candidate relocated hypocentres by applying HYPOINVERSE-2000 software taking into account the special velocity structure of deep sedimentary basins. Using relocations she refined the 'critical' hypocentres listed in the Hungarian Earthquake Bulletins.

In order to determine seismic hazard in Debrecen the candidate calculated synthetic seismograms, which were created using a hybrid method based on the joint application of modal summation and finite differences methods developed at the Department of Earth

Sciences of the University of Trieste [Panza et al. 2000]. With the above method not only the characteristics of the bedrock and the attenuation but also the parameters of the local subsoil can be taken into consideration. After the calculations the candidate rescaled the accelerograms according to the magnitudes of the earthquakes using Gusev's [1983] method.

UTILIZED DATA

The geographic information system created to investigate the geological and geophysical environment of earthquakes includes the following map layers:

- Macroseismic epicentres map: Epicentres of the highest intensity earthquakes observed by the population in a given town, supplementing the *Map of Kinematic and Earthquake Epicenters* [Jámbor et al. 1999];
- Microseismic epicentres map: Termors recorded by densely installed monitoring network (Hungarian Earthquake Bulletins (HEB) 1995-2003 [Tóth et al. 1996-2004]);
- Quaternary kinematic map of Hungary [Jámbor & Szeidovitz 1995];
- Map of Quaternary crust movements by the application of Rónai [1977]' s method;
- Pleistocene faults and depressions [Schweitzer 1993];
- Thickness of the Quaternary formations in Hungary [Franyó 1992], at the area of Nyírség this map was refined by the map: The thickness of Quaternary formations at the Southern part of Nyírség [Jámbor 2000];
- Geomorphological map [Pécsi et al. 2000], using only recent tectonic elements of this map;
- Fracture system map of Hungary of formations older then Pannonian [Rumpler & Szabó 1985]
- Neogene tectonic map of the Pannonian Basin and the Surrounding Alpine-Carpathian-Dinaric Mountains [Horváth 1993];
- Stripped gravity map [Bielik 1991];
- Bouguer anomaly map of Carpathian-Pannonian region [Szafián et al. 1997];
- Heat flow map corrected for the cooling effect of Neogene sediments [Lenkey 1999];
- Telluric conductivity maps:
    - Telluric conductivity map of Eastern Hungary [Madarasi 2001];
    - Telluric conductivity map of Transdanubia [Nemesi & Madarasi 1999]]
- Digital surface models of different geological layers:
    - Upper Pannonian surface [Csiky et al. 1987];
    - Lower Pannonian surface [Csiky et al. 1987a];
    - Pre-Tertiary basement [Kilényi & Šefara 1989];
    - Depth of Mohorovičić-discontinuity [Posgay et al. 1991, Lenkey 1999];
- Digital Elevation Model (DTM-500);
- Recent waterstreams, settlements and so on [layers of Digital Topographic Database-200];
- Minimum and maximum ground-waterlevel with the contours of piedmonts [Pécsi et al. 1989]

All layers of this GIS are saved in EOV system (Uniform National Projection System) [Bácsatyai 1993].

The candidate used the following data during earthquake hazard calculations:

- To create the bedrock model:

- ❖ P wave velocity values measured in boreholes [Hungarian oil and gas company (MOL) database];
- ❖ Velocity and density values regarding the Carpathian Basin according to different local geological eras and different rock types [Szabó & Páncsics 1994];
- ❖ In case of layers deeper than the bottom of boreholes the candidate used the velocity data of the deep seismic reflection profile PGT-1 for the bedrock model [Hegedűs 1998];
- ❖ At more than 15 km depths of the bedrock model the structural element No. VI. of the Carpathian Basin [Bus et al. 2000] was used as a reference model;

- o The candidate used the stratigraphical data of water drillings in Debrecen and P wave velocity values of sledge hammer seismic measurements to create subsoil models;
- o At both the subsoil model and the bedrock model the candidate used the depth-Vp/Vs profile regarding the Great Hungarian Plane calculated by Mészáros & Zilahy-Sebess [2001] and Q values by Mammo et al. [1995], which were determined for deep sedimentary basins.
- o When compiling the seismic risk map of Debrecen the candidate used 1 m resolution aerial photographs of the town and 1:10 000 topographic maps in order to determine vulnerability.

SUMMARY OF NEW SCIENTIFIC RESULTS

I. **The candidate created a geographic information system in order to investigate the geological and geophysical environment of earthquake epicentres with the help of ArcView 3.2 software.**

She collected geological, geophysical mapping data related to earthquakes and integrated them into a geographic information system. Maps in analogue format were digitalized and oriented. The parameters of digital maps were made more accurate. The system comprises 23 different digital maps, which are represented by 2 point type, 6 line type, 3 poligon type and 15 digital surface model type (TIN or grid format) layers. Using the above system analysis can be carried out among the epicentres of earthquakes and the elements of different maps, which can help to identify relationships between the location of epicentres and geological and geophysical elements.

The candidate refined and supplemented the *Map of Kinematic and Earthquake Epicenters* [Jámbor et al. 1999] and filtered the hypocenters of HEBs in order to produce the *Macro- and Microseismic epicentre maps*. The *Map of Kinematic and Earthquake Epicenters* originally contained 213 events. At this map not only one epicentre but all the settlements affected the most were related to each event. In case of an event related to more highly affected settlements the candidate studied descriptions related to the earthquake, earthquake questionnaires, data of macro and micro-seismic bulletins and defined the probable location of the epicentre. The surface projection of hypocentres found in Hungarian Earthquake Bulletins [Tóth et al. 1996-2004] were integrated into the geographic information system and were filtered on the basis of localization error values.

I.a Accomplished relocalization of some ’critical’ earthquake occurred between 1996 and 2002 based on arrival time data using the HYPOINVERSE-2000 software. In the case of these events the macro- and microseismic epicentres were situated more than 10-15 km far from each other. Taking into account the velocity structure of deep sedimentary basins the distance between the different kind of epicentres decreased significantly.

II. **The candidate established the following relations between the layers of the geographic information system and epicentres:**

II.a The map of *Pleistocene faults and depressions* [Schweitzer 1993] and the recent tectonic elements of *Geomorphological map* [Pécsi et al. 2000] show significant relationship with the distribution of macro and microseismic epicentres, and the 5 km wide buffer zones of the elements of these maps contain 71 % of the macroseismic epicentres, and 76 % of the microseismic epicentres.

The elements of *Quaternary kinematic map of Hungary* [Jámbor & Szeidovitz 1995] do not show significant relationship with the distribution none of different kind of epicentres.

The elements of *Neogene tectonic map of the Pannonian Basin and the Surrounding Alpine-Carpathian-Dinaric Mountains* [Horváth 1993] show significant relationship with the distribution of the microseismic epicentres with a horizontal localization error greater than 5 km. In the other cases one cannot be found relationship. The 5 km wide buffer zones of the faults of the map situated at the territory of Hungary contain 54 % of macroseismic and 58 % of microseismic epicentres.

The location of volcanic cones and veins represented on the *Geomorphological map* of Hungary [Pécsi 2000] show significant relationship with the macroseismic epicentres with a horizontal localization error between 5 and 10 km. Furthermore the macroseismic epicentres show multiple of average density of epicentres at the surrounding of volcanic cones and veins.

The beforementioned results show that although it was possible to find relation between the location of fault-zones and the distribution of epicentres it also became clear that all of the Hungarian earthquakes cannot be explained with the help of movements along known tectonic elements.

II.b Candidate established that the density of epicentres are higher than the average value at the 5 or 10 km wide buffer zones of 20-40 degree slope of pre-tertiary basement. However in these areas active faults can be found too, so it cannot be stated unequivocally that these events are caused by the slipping of the sediment on the basement.

II.c The candidate found traces of recent movements with the help of the multiplication map of the *Thickness of Quaternary formations* in Hungary [Franyó 1992] map and the *Digital Elevation Model*. On the multiplication map the seismically active area around Kecskemét can be seen — the thickening of the Quaternary sediment is followed by the rising of recent surface — and the same is true for the surroundings of Hoportyó (Nyírség area). The multiplication map does not reflect however the other active areas of the Hungarian Plane (Szeged, Jászberény, Békés, etc.).

III. **She assessed that the maximum response spectra ratio values of horizontal components created from synthetic seismograms calculated for the inner area of Debrecen are found below 1 Hz.**

Two independent computations have been performed using two different seismic sources and profiles. In both computations the seismic sources have been located in the so called „Mobile Zone". The epicentre of one of the hypothetic earthquakes was in Gálospetri, the other one was in Hosszúpályi.

It is known that buildings are most vulnerable to the components of horizontal acceleration. At the same time in case of calculations for the inner area of Debrecen the biggest acceleration values were found for the transversal components. The fact that the maximum values of horizontal response spectra ratio are found below 1 Hz means that buildings higher than ten-storeys can be more damaged than buildings with one or a few storeys. Consequently, if an earthquake with similar parameters to that in Érmellék in 1834 was generated nowadays, it would cause bigger damage than the historical earthquake in Debrecen. As in 1834 there were mostly one-storey buildings in the town, nowadays there are residential buildings with many storeys and industrial buildings as well that could be more damaged than low-rise buildings, according to the results of the response spectra ratio.

IV. **The candidate compiled three different grid maps representing the three different wave components for peak ground acceleration values covering the entire area of Debrecen using the calculations made along 11 different profiles in the town.**

The hypothesis of the calculations was that an earthquake with a magnitude of M = 6, would be generated in Hosszúpályi, the settlement closest to the town within the Mobil zone, the area posing the greatest seismic hazard for Debrecen.

The ratio of transversal and radial wave components compared to each other in different areas of the town was about double in the South-Eastern part near Hosszúpályi and ten-fold in North-Western areas. The change characterizing the acceleration is the following:

- at the transversal component: from the maximum of 380 cm/s^2 in South-East acceleration decreases to the minimum of 150 cm/s^2 in the North-West.
- At the radial component: from the maximum of 160 cm/s^2 in South-East acceleration decreases to the minimum of 15 cm/s^2 in the North-West.

The candidate obtained the maximum values of vertical wave components in downtown but it is not higher than 43 cm/s^2. Maximum values can be found at transversal components.

V. **On the basis of hazard calculations and the parameters of buildings in Debrecen the candidate compiled a special seismic risk map covering the city.**

Seismic risk can be defined as the multiplication of earthquake hazard and vulnerability of the area. Hazard values were provided by spectral characteristics of synthetic seismograms, while the vulnerability of the area was one of the characteristics of buildings in Debrecen, the number of storeys. The following relationship can be found between the number of storeys and the eigenfrequency of buildings (which is related to the vulnerability of the building) [Csák et al. 1981]:

$$T = 0.1 \times n,$$

where **T** is the eigenperiod of the building in seconds,
n is the number of storeys.

Consequently, in order to be able to compare spectral characteristics of synthetic seismograms in a certain point of the town to the number of buildings that can be found there a new map has to be compiled, which shows the number of storeys of buildings in the town. In order to compile this map the candidate oriented and interpreted aerial photos of Debrecen as well as used the indications of storeys in different 1:10 000 topographic maps.

In order to compile the different maps and to carry out investigations about them the candidate used geographic information system tools. As a result of the investigation a special earthquake risk map covering Debrecen was created, which shows the grade of relative damages can be expected in different areas of the town in case of an earthquake with the given parameters generated in Hosszúpályi.

According to the earthquake risk map the most affected area of the town would be the area 1.5 km away from the historic centre, but the Southern part of the Town close to Hosszúpályi, as well as the downtown and some Northern areas would be damaged significantly.

UTILIZING THE OUTCOMES OF THE THESIS

The geographic information system created to investigate the geological and geophysical environment of earthquake epicentres can be a good basis for further analysis, and for adding further data. The investigation of the layers of the geographic information system with the help of data mining methods has already started.

The seismic hazard map covering Debrecen answers the question about where serious damage would be created and where a reinforcement of the buildings is required. With the help of the grid maps of the response spectra used at the compilation of the map it can be designed in which areas buildings with a specific eigenfrequency should not be built. Of course the method of seismic risk map compilation can be adapted to the case of other cities.

PERSONAL PUBLICATIONS RELATED TO THE PH.D. WORK

Publication in foreign journals:

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Extended abstracts published for international conferences:

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