GIS-technologies in geophysical information databases processing

V B Zaalishvili*, A S Kanukov, M I Fidarova
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences, 93a, Markova str., Vladikavkaz, 362002, Russia

E-mail: vzaal@mail.ru

Abstract. There are vast opportunities for obtaining a huge amount of information about various objects in modern world. This information can often be processed only using modern computer technologies. The development and implementation of the new methods for modeling the geological objects, moving or spreading a particular geophysical process, represent an important task of establishing interconnections and spatial distributions’ correlation in various physical fields. The seismic events recorded by 20 seismic stations installed in the areas with different soil conditions have been analyzed. To exclude the influence of the seismic vibrations source type, the seismic records were selected for each station, the epicenters of which were in the same area 20x20 km in size. The diagrams depicting the vibrations real spectrum acceleration area were prepared. For most of the obtained dependences, it was found that the real spectrum area of vibrations and acceleration are related in a nonlinear manner. In this case, the nonlinear dependence begins to develop, as a rule, at the acceleration values above 0.1g. From this we can conclude that the use in the construction calculations of the expected earthquake manifested intensity values is not sufficient for a reliable assessment of the possible seismic impact level, since the dependence of the incoming energy on the intensity magnitude is not linear. This implies the need to build the seismic hazard maps of the territory in the acceleration units.

1. Introduction
Due to the fact that the elements of the geo-technological complex have a spatial characteristic, it is necessary to develop not just information, but geoinformation support [1]. The development and implementation of the new methods for modeling the geological objects, moving or spreading a particular geophysical process, represent an important task of establishing interconnections and correlation of various physical fields’ spatial distributions [2-7]. For example, one of such tasks solved with the help of GIS-systems is the task of forecasting the earthquakes’ possible consequences, which is based on the method of taking into account numerous objective and subjective factors that form the seismic risk level in urban areas [8-9].

As the basis for the geographic information system functioning for modeling hazardous natural and technogenic processes, the use of the principles implied for supporting the Urban Development Information Systems (UDIS) is presented [10]. According to the urban planning code of the Russian Federation, UDIS are a systematic set of documented information about the territories’ development, their development, land plots, capital construction objects and other information necessary for urban development (Town Planning Code of the Russian Federation).
Seismological studies for various purposes, including the construction industry tasks have been carried out in our country for over a century [11-13]. One of such studies’ results is the territory seismic hazard assessment, which traditionally comes down to calculating the maximum possible seismic influences that should be taken into account during construction in seismic areas. Seismic hazard is specifically displayed on the so-called seismic-risk zoning maps of a particular territory. In Russia, depending on the tasks and the necessary seismic hazard mapping details, three levels of seismic zoning are implemented:

1. general seismic-risk zoning (GSZ) - for the entire territory of the country;
2. detailed seismic-risk zoning (DSZ) - for limited areas and individual regions;
3. seismic micro-zoning (SMZ) - for cities, towns and large construction sites.

As a result of a number of studies on seismic hazard assessment conducted by employees of the Geophysical Institute in 2006-2013, original probabilistic maps of detailed seismic zoning (DSZ) of the Republic of North Ossetia-Alania [14-15], maps of seismic microzoning of territories (SMZ) of populated areas were created points - administrative centers of North Ossetia-Alania [16-22]. It should be noted that cartographic materials should comply with the world level currently presented to spatial data and have, first of all, the ability to directly integrate into any modern information systems.

In the process of conducting the research, the existing automated systems for providing the urban planning activities, the cadastral system, as well as other information resources that could possibly be used as the basis for the system functioning to access the seismic hazard maps were considered. As a result of our studies, we developed a structural-functional model of UDIS [10], which makes it possible to create an information system for the user needs, while maintaining compatibility with other products built according to this model, as well as a number of the existing systems. This model formed the basis of the developed modeling geographic information system.

In recent decades, there has been a rapid increase in information technology. The use of digital stations once created the ability to automate the earthquake records processing and the creation of powerful databases [23]. Currently, information storage volumes and computing speeds are growing exponentially. At the same time, in many regions of the world the number of registration stations for strong movements is increasing. Moreover, to solve the problems of engineering seismology, the stations’ locations are selected in such a way as to cover all the possible soil conditions of the territory. Data on engineering and geological conditions are an integral part of modern seismological databases. A similar database was created at the Geophysical Institute of the VSC RAS and includes the data from K-NET networks (Japan) and a number of other networks from around the world [24-25].

The use of seismological databases (DB) for the construction and installation works has certain features. First of all, in the database, in addition to the earthquake characteristics, the ground conditions for the seismic stations’ location and the intensity of the expected seismic impact, i.e. the corresponding seismic effect should be included [25]. The availability of data on soil conditions makes it possible to search for a model of the soil thickness that is most appropriate for the studied area, including taking into account the groundwater level in these areas [26]. In addition, the databases may contain additional information, for example, environmental information characterizing the areas included in the database [27]. The creation of geological models involves the soil densities relationship use with the velocities of transverse seismic waves in them and the corresponding set of soil characteristics [28]. The models include the thickness of the soil layers composing the soil stratum and the propagation velocity of the transverse seismic waves in it. Next, a selection of earthquake records for certain parameters is made. Such parameters are the earthquake magnitude, the epicentral distance and the source depth, which are determined by the active faults map in this region. Since the number of earthquake records exactly matching the conditions is small, the earthquakes search that satisfies the certain intervals of these parameters’ values is performed. For this reason, the maximum oscillation amplitudes are recalculated at a given epicentral distance. For the database under consideration, the following attenuation law was adopted:

$$A = A_0 e^{-ax}, \quad (1)$$

where $A$ – is the vibration amplitude;
\( \alpha \) – is the attenuation coefficient;
\( x \) – determines distance.

In a first approximation, the absorption coefficient \( \alpha \), can be considered permanent. In general, it is an oscillation frequency function.

The absorption coefficient \( \alpha \) can be calculated using the attenuation model for a given region. Thus, a data bank is formed, which, in addition to the earthquake records and the data on the ground conditions of station locations, also contains the empirical formulas for various records’ classes.

The Geophysical Institute, in addition to developing seismic hazard maps in MSK-64 points, developed seismic hazard maps of the territory of the Republic of North Ossetia-Alania in acceleration units. According to Building Codes and Regulations II-7-81*, Design seismicity is the value of the design seismic impact for a given repeatability period, expressed in terms of the macro seismic scale or in the kinematic parameters of soil motion (acceleration, speed, displacement). At the same time, for civil engineers the most convenient is the use of seismic hazard maps in accelerations. At the same time, the intensity conversion into acceleration is carried out according to the formula described in the MSK-64 scale:

\[
\lg(PGA) = -0.1 + 0.3 I
\]  

Since it is not possible to directly obtain the intensity value from a seismic record, we investigated the acceleration dependences of the soil vibrations’ real spectrum area. To do this, we used the database of strong movements K-NET (Japan). The territory of Japan was divided into cells measuring 20 by 20 km and each record was assigned the cell number value in which the epicenter of this record was located.

The task of constructing such a grid in the form of a shape-file often arises in ArcGIS. Such a grid, for example, can be used as a coordinate grid. The easiest way to solve this problem is realized by using the Create Fishnet utility from the Feature Class toolbox. This utility is located in the ArcToolbox section, the following fields are filled for its use:

The name of the output mesh shape-file is set in the Output Feature Class window. To make it easier to define the extreme points, it is possible to load the name of the layer for which the grid is being performed. In the Cell Size field, the width and height of the grid (in our case, 500 m) are specified and in the Number of Rows / Columns field the number of grid cells is specified. The result of using the utility is a shape-file in which each cell has the type of a polygon kind. By adding an additional field to each polygon, using the additional tools in ArcGIS, it is possible to calculate the parameters of interest.

The task of assigning a cell number to a record is solved using the Spatial Join utility from the Analysis Tools toolkit, Overlay section.

Thus, we get the opportunity to study various kinds of dependencies for the records recorded by a particular station and coming from one source in addition to using ArcGis. This problem is also successfully solved using a modeling geographic information system, using PostGis database management system, the capabilities of which include the operations with objects that have a spatial reference.

Records of 20 stations installed in the areas with different soil conditions were selected. The worst values of longitudinal and transverse speeds for all stations under consideration are presented for the station “TTR005”, where the transverse wave value is: \( V_s = 110 \text{ m/s} \).
Figure 1. The real spectrum area dependence of soil vibrations on acceleration, expressed in fractions $g$.

Figure 1a shows the dependence of the soil vibrations real spectrum area on all the acceleration values, expressed in g fractions. Figure 1b shows the same dependence limited by the acceleration range from 0 to 0.2g. As it can be seen from the graphs, this dependence is non-linear. The graph has a linear form only in the region not exceeding 0.1g. Figure 2 shows the soil conditions for the IBR003 station, which has higher speeds compared to the TTR005 station.
Figure 2. Station ground conditions TTR005

Figure 3. Dependence of the real spectrum area of soil vibrations on acceleration, expressed in fractions g.

y = 1322.8x + 4.9092
R² = 0.8117

y = 1350.3x + 3.975
R² = 0.8032
As it can be seen from the graphs in Figure 3, the dependence is also non-linear. In this case, the graph has a linear shape only in the region not exceeding 0.2g. Moreover, in the region of 0.4g, the character of the dependence changes again.

For most of the obtained dependences, it was found that the real spectrum area of vibrations and acceleration are related non-linearly. In this case, a non-linear dependence starts developing, as a rule, at the acceleration values above 0.1g. From this we can conclude that the use of the expected earthquake manifested intensity values in the construction calculations is not sufficient for a reliable assessment of the possible seismic impact level, since the incoming energy dependence on the intensity magnitude is not linear. This implies the need to build the seismic hazard maps of the territory in acceleration units.

Summary
The development and implementation of new methods for modeling the geological objects, moving or spreading a particular geophysical process, represent an important task of establishing interconnections and correlation of various physical fields’ spatial distributions.

As the basis for the functioning of the geographic information system for modeling hazardous natural and technogenic processes, the use of the principles used in Urban Development Information Systems (UDIS) is presented.

As a result of a number of seismic hazard assessment studies, original probabilistic maps of detailed seismic zoning (DSZ) of the Republic of North Ossetia-Alania and the maps of seismic microzoning of territories (SMR) and settlements - administrative centers of the republic have been created.

The use of strong movements databases for the construction and installation works’ purposes has certain features. In the database, it is necessary to include the ground conditions of seismic stations and the seismic impact manifestation intensity under consideration, i.e. corresponding seismic effect.

By special criteria, records of the stations located in various soil conditions were selected. For most of the obtained dependences, it was found that the real spectrum area of vibrations and acceleration are related non-linearly. In this case, a non-linear dependence starts developing, as a rule, at the acceleration values above 0.1g. From this we can conclude that the use of the values of the expected earthquake manifested intensity in the construction calculations is not sufficient for a reliable assessment of the possible seismic impact level, since the incoming energy dependence on the intensity magnitude is not linear. This implies the need to design the seismic hazard maps of the territory in acceleration units.

Acknowledgments
The reported study was funded by RFBR, project number 19-35-90127

References
[1] Dzeranov B, Gogichev R and N Dzhusoeeva 2017 Geology and Geophysics of the South of Russia 3 40–56.
[2] Zaalishvili V, Melkov D, Kanukov A, Dzeranov B, Shepelev V 2016 International Journal of GEOMATE 10 (1) 1670-1674.
[3] Zaalishvili V, Melkov D, Dzeranov B, Morozov F, Tuaev G 2018 International Journal of GEOMATE 15 (47) 158-163.
[4] Zaalishvili V 2016 Measurement Techniques 58 (12) 1297-1303.
[5] Zaalishvili V, Nevskaya N, Melkov D 2014 Izvestiya. Physics of the Solid Earth 50 (2) 263-272.
[6] Zaalishvili V, Melkov D, Kanukov A 2019 Akustika 32 279-283.
[7] Zaalishvili V, Nevskaya N, Nevskii L, Shempelev A 2015 Journal of Volcanology and Seismology 9 (5) 333-338.
[8] Zaalishvili V, Melkov D 2014 Izvestiya. Physics of the Solid Earth 50 (5) 707-718.
[9] Milyukov V, Yuskin V, Kopaev A, Mironov A, Dem’yanov G, Semyagin R, Basmanov A, Popad’Ev V, Nasretdinov I, Zaalishvili V, Kanukov A, Dzeranov B 2014 Measurement Techniques 56 (10) 1105-1110.
[10] Zaalishvili V, Kanukov A, Melkov D, Makiev V, Dzobelova L 2018 *International Journal of GEOMATE* 15 (51) 160-166.

[11] Gorbatikov A, Rogozhin E, Stepanova M, Kharazova Y, Andreeva N, Perederin F, Dzeboev B, Zaalishvili V, Melkov D, Dzeranov B, Gabaraev 2015 Evestiya. *Physics of the Solid Earth* 51 (1) 26-37.

[12] Shempelev A, Zaalishvili V, Kukhmazov S 2017 *Geotectonics* 51 (5) 479-488.

[13] Zaalishvili V, Nevskaya N, Nevskii L, Shempelev A 2015 *Journal of Volcanology and Seismology* 9 (5) 333-338.

[14] Zaalishvili V, Melkov D, Gabaraev A, Dzeboev B, Dzeranov B, Kanukov A and Shepelev V 2011 *Materials of the All-Russian Scientific and Practical Conference dedicated to the 10th anniversary of the founding of the KNII RAS "Science and Education in the Chechen Republic: State and Development Prospects"* 335–342.

[15] Zaalishvili V, Melkov D, Dzeranov B and Kanukov A 2010 Proceedings of the international scientific-practical conference "Young scientists in solving urgent problems of science", Vladikavkaz 348–351.

[16] Zaalishvili V, Melkov D, Gabaraev A, Dzeboev B, Dzeranov B, Kanukov A and Shepelev V 2011 *Proceedings of the IV Caucasian International School-Seminar for Young Scientists "Seismic Hazard and Seismic Risk Management in the Caucasus"* 02–106.

[17] Zaalishvili V and Rogozhin E 2011 *Earthquake-resistant construction. Building Safety* 3 31–43.

[18] Zaalishvili V and Dzhgamadze A 2011 *Proceedings of the IV Caucasian International School-Seminar for Young Scientists "Seismic Hazard and Seismic Risk Management in the Caucasus"* 155–167.

[19] Zaalishvili V, Dzeranov B and Gabaraev A 2011 Proceedings of the IV Caucasian International School-Seminar for Young Scientists "Seismic Hazard and Seismic Risk Management in the Caucasus" 155–167.

[20] Zaalishvili V, Dzeranov B and Gabaraev A 2011 *Geology and Geophysics of the South of Russia* 1 48–58.

[21] Zaalishvili V and Dzhgamadze A 2012 *Materials of the II All-Russian scientific and technical conference “Modern problems of geology, geophysics and geoecology of the North Caucasus”* 442–446.

[22] Zaalishvili V 2013 *Materials of the International Symposium "Sustainable Development: Problems, Concepts, Models" dedicated to the 20th anniversary of the KBSC RAS, FSBSJ KBSC RAS II* 106–110.

[23] Zaalishvili V, Melkov D, Kanukov A, Dzeranov B 2016 *International Journal of GEOMATE* 10 (1) 1656-1661.

[24] Zaalishvili V, Kharebov K and Kharebov A 2013 *Geology and Geophysics of the South of Russia* 3 39-44.

[25] Zaalishvili V 2014 Geology and geophysics of the South of Russia 3 3-39

[26] Zaalishvili V, Dzhgamadze A, Gogichev R, Dzeranov B, Burdzieva O 2018 *International Journal of GEOMATE* 15 (51) 22-30.

[27] Burdzieva O, Zaalishvili V, Beriev O, Kanukov A, Maisuradze M 2016 *International Journal of GEOMATE* 10 (1) 1693-1697.

[28] Zaalishvili V 2014 Geology and geophysics of the South of Russia 4 (2) 15-44.