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Forecast and assessment of the effects of the impact of mining tremors, induced by exploitation, on building objects with the use of GIS system

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Abstract. The article presents an analysis of the possibilities of using the GIS (Geographic Information System) class system to forecast and assess the impact of mining tremors on buildings located on the surface. The research was conducted with reference to the scope of activities which should be carried out by the mining entrepreneur, conducting exploitation in conditions of seismic hazard, specified in the Rules for the use of the GSIS-2017 mining seismic intensity scale. Due to the fact that the implementation of the mining tasks in a coal mine requires the processing of a huge number of information, deriving from different sources, it can be considered that it is a deliberate use of the GIS class systems. The article presents an analysis of the possibilities of using the GIS class systems based on a database developed in the ArcGIS system, containing observation material from the area of one of the coal mines, operating in the area of the Upper Silesian Coal Basin. The research has shown that the ArcGIS tooling system allows for the implementation of almost all tasks in the scope of the assessment of the mining tremors impact, including documenting damage to objects. In the case of tasks concerning forecasting the support programs are required.

1. Introduction

In accordance with the provisions of the Geological and Mining Law [1], the entrepreneur is obliged to conduct mining plant operations in a way ensuring, in particular, the safety of persons staying in the plant, the protection of environmental elements, the protection of the building objects and the prevention of damage of objects. In order to realize this task, it is important to have an appropriate scope of data, which can be specified in detail on the basis of implementing provisions to the Act. These data can be divided, from the point of view of the GIS system, into spatial and descriptive data. In the scope of spatial data, it is important that the Act imposes on enterprises the obligation to keep geological and surveyor documentation and its completion and updating, as mining works progress. Detailed regulations in the scope of surveyor - geological documentation are contained in the Regulation [2]. It allows the keeping of measurement, calculation and cartographic documents in an electronic form, and requires that spatial data can be presented in the state spatial reference system, specified in the Regulation [3]. Due to the fact that the implementation of mining tasks in each coal mine requires the processing of a huge number of information from different sources, it can be considered that it is deliberate to use the GIS class systems. The use of the GIS solutions to assess seismic risk as a result of induced seismicity in South Africa, is presented in the paper [4]. A proposal to use this type of a system in issues related to natural seismicity, among others in Romania, Spain and



Italy, are presented in the works [5,6,7]. Analyzing such solutions operating in coal mines in Poland, it can be stated that at the moment there is no one that can be considered as fully meeting the requirements for the GIS systems, in particular, regarding the possibilities of integration data from various sources and having spatial analysis functions. Therefore, in order to present the possibilities offered by the use of the GIS tools in this area, a database of this kind has been developed in the ArcGIS system ver. 10.1.

One of the most important problems related to the safe mining is the seismic hazard. In Poland, despite the limited mining, still the contribution of coal mining from the seams endangered by rock bursts, in total mining is over 50%. The research assumed that the database would be developed in the scope that enables the implementation of the mining enterprises tasks, concerning the influence of mining tremors on the building objects, in particular, also due to the provisions contained in the Regulation on plans of the mining plant motion [8]. The database was made for one of the coal mines, operating in the area of GZW, (the Upper Silesian Coal Basin). Spatial data obtained from the resource kept in the mine was used in a digital form. The scope of data necessary to be entered in order to implement the above mentioned tasks were specified, taking into account the provisions contained in the Principles of using the mining scale of seismic intensity GSIS-2017 [9]. The article briefly describes the stages of creating a database in the ArcGIS system, and the analysis of the possibilities of its use for forecasting and assessing of the impact of tremors induced by mining exploitation on the building objects were made.

2. Spatial and descriptive attributes of the basic objects

The GIS database has been developed for the area where damage occurred in the building objects as a result of mining tremors with seismic energy of 10^7 J and higher. These shocks were induced by mining works conducted in the 713/1-2 seam. In the research area there is a cubature development, including residential buildings, industrial buildings and facilities as well as public facilities. Taking into account the provisions contained in the Principles [9], the scope of spatial and descriptive attributes of the basic objects, i.e. building objects and tremors, has been specified. The attribute values were determined based on materials obtained from the mine, i.e. the buildings registration sheet, inspection reports containing data on damage to objects, data on mining tremors, a map of the area, a mining map of the seams 713/1-2 and 713/1-2 + 712/1-2, analogue materials containing data on damage to objects as a result of the above-mentioned tremors. The attributes are presented below:

- in terms of tremors: the coordinates of the tremor epicenter, the date of the tremor occurrence, the time of the tremor, the value of the seismic energy;
- in terms of building objects: the number of the registration sheet, coordinates of the centroid of the building, a type of a building, construction, address data, epicenter distance, technical condition of the object before the tremor, a category of static resistance, a category of mining area, a degree of vibration intensity according to the GSIS-2017 scale, caused of damage, damage according to GSIS-2017 scale, the values of the maximum resultant amplitudes, the horizontal components of acceleration and vibration velocity of the surface area in the place of location of the object, damage.

The values of the maximum amplitudes of vibration accelerations, as well as the maximum values of the resultant velocity amplitude of horizontal vibrations of the ground were calculated using the Vibration program by P. Bańki [10]. These values were used to determine the degree of seismic intensity at the site of the location, according to the GSIS-2017 scale. The analysis of the observational material allowed to state that as a result of 8 tremors that meet the energy condition, 240 building objects were damaged, including 36 public buildings, the remaining ones were residential buildings. The prepared database can be supplemented with other information specified in the Principles mentioned above.

3. Development of the GIS database

The values of the specified parameters, presented in the previous chapter, were prepared in Microsoft Excel, in files constituting batch files. As it was already mentioned, the database was developed in the ArcGIS ver. 10.1 according to the company ESRI. The ArcMap and ArcCatalog applications were used in the process of the database creation. Due to the fact that spatial data, acquired from the numerical map system in the mine, was obtained in the local SG-ROW system, the Fishnet plug was used to link together the grid of this system to the raster image of the surface map. After calibrating the raster image, using the batch method, the previously prepared files containing spatial and descriptive attributes of the objects were introduced. After loading the individual files, the shape and color of the point objects, i.e. the epicenter of tremors and centroids of the building objects, damaged as a result of tremors, were determined. The process of creating the database was presented in detail in work [11].

4. Analysis of the possibility to use the created database for the forecast and the assessment of the impact of mining tremors on building object

The scope of the tasks related to safe conducting of a mining plant operations includes, among others, the activities allowing to assess, forecast, monitor and evidence the impact of mining tremors on the building objects. Procedures for proceedings in the above mentioned scopes are given in the Principles [9].

The GIS system may support the implementation of a number of activities resulting from the provisions of the above mentioned document. It improves, among other things, the process of designating the building objects, located in the areas where the V degree of vibration intensity has been exceeded, in order to assess the effects of tremors occurrence and, as a consequence, to isolate the objects for which detailed expertise should be performed.

The impact of ground vibrations on the building objects depends to a large extent on the technical condition of the objects. Therefore, it is important to have such information about an object. This information can be obtained for a specific object (figure 1) or a group of objects in the ArcGIS system. It is also possible to obtain data on the number of objects with a specific technical condition, along with their selection in the map area (figure 2).

The above is of particular importance for the introduced regulations, in the present version of the mining intensity scale, concerning the dynamic resistance of the objects. Obtaining comprehensive information concerning the technical condition of an object, the construction of the given object and information about the category of continuous deformations of the mining area, with reference to determining the level of dynamic resistance of the object in the GIS system, would significantly improve the implementation of the above task.

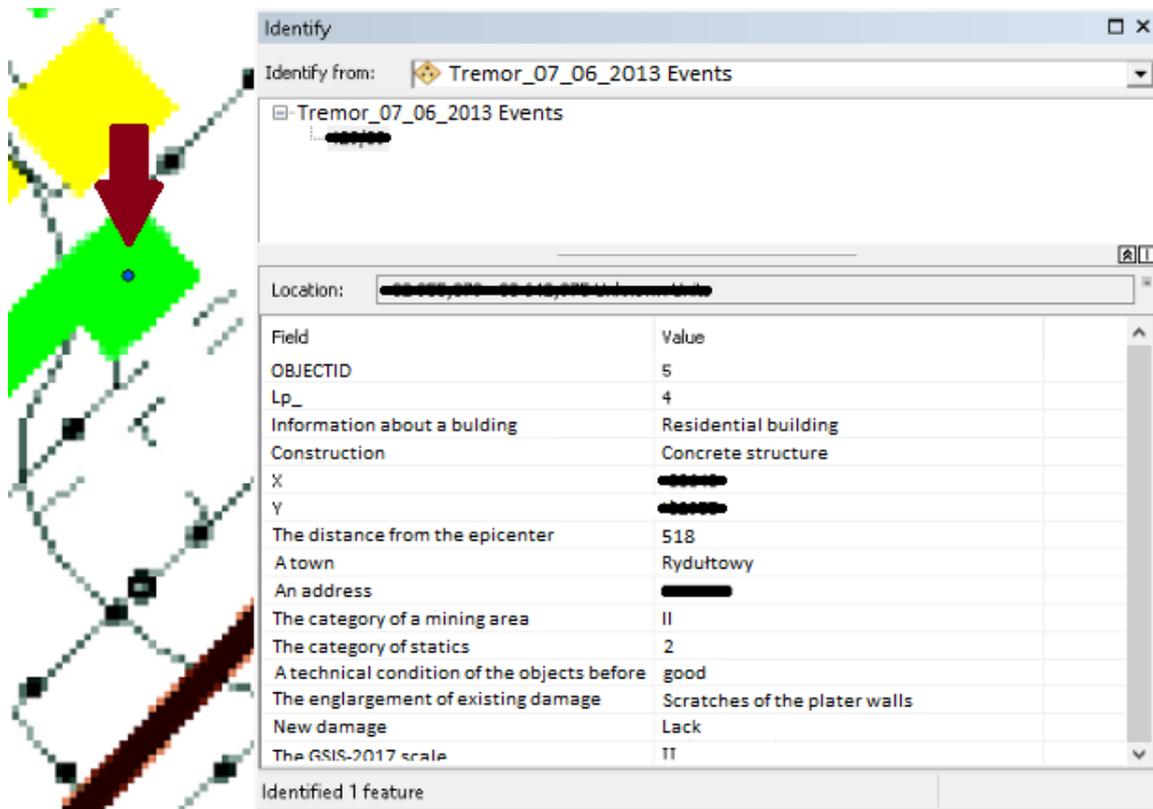


Figure 1. The values of the descriptive attributes of the object technical condition and other information concerning the indicated object.

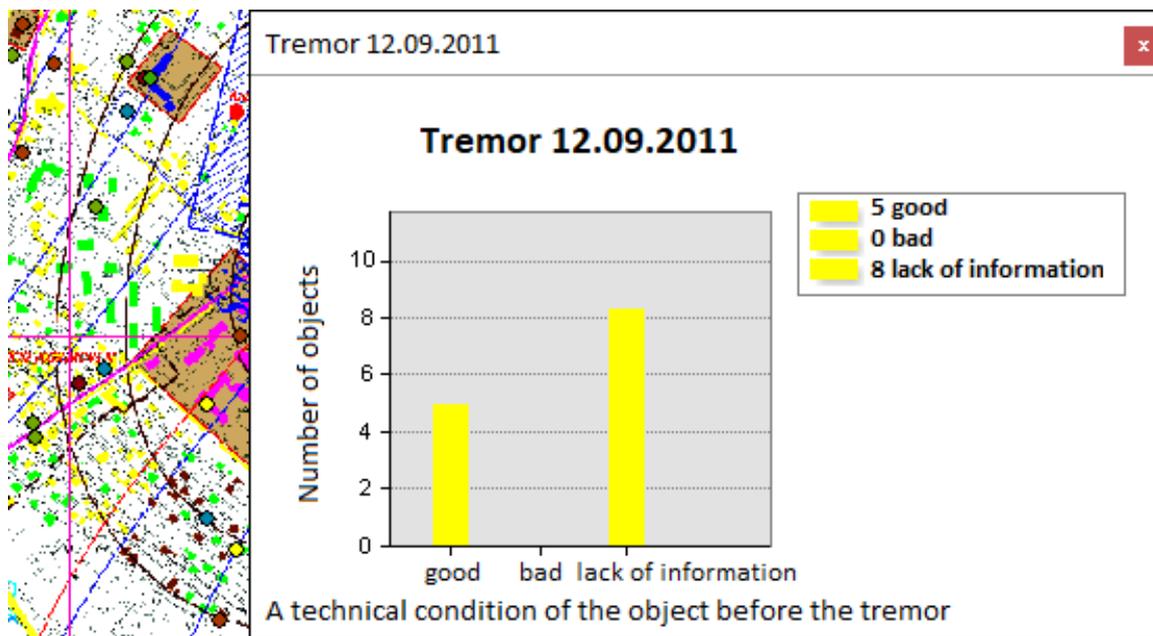


Figure 2. The distribution of the objects with a specific technical condition, bad - good technical condition.

As previous research [12] has shown, the ground vibrations caused by rock mass tremors have varied impact on the technical condition and safety of use of the objects. Determining the actual damage to objects due to ground vibration induced tremors is difficult because of overlapping of damage resulting from deformation of the ground and general structural factors.

For this reason, the principles of conducting and documenting the observation of the effects of ground vibration induced by tremors in the building objects have been specified in detail. The scope of inspections of the technical condition of the objects was mainly dependent on the degree of vibration intensity found after the tremor. The order in which inspections were performed was determined. First, inspections are carried out in the objects in which the effects of tremor impact that threaten the safety of use of the objects have been reported, and then in the objects where the effects were reported. It is also required to perform inspections in the objects with dynamic resistance lower than the stated intensity of vibrations and in the objects of special importance. According to work [2] such inspections should be started from objects located at the highest stated degree of vibration intensity. The appointment of such objects, based on the GIS database, takes place in a very simple way, using the spatial analysis function available in the software (figure 3).

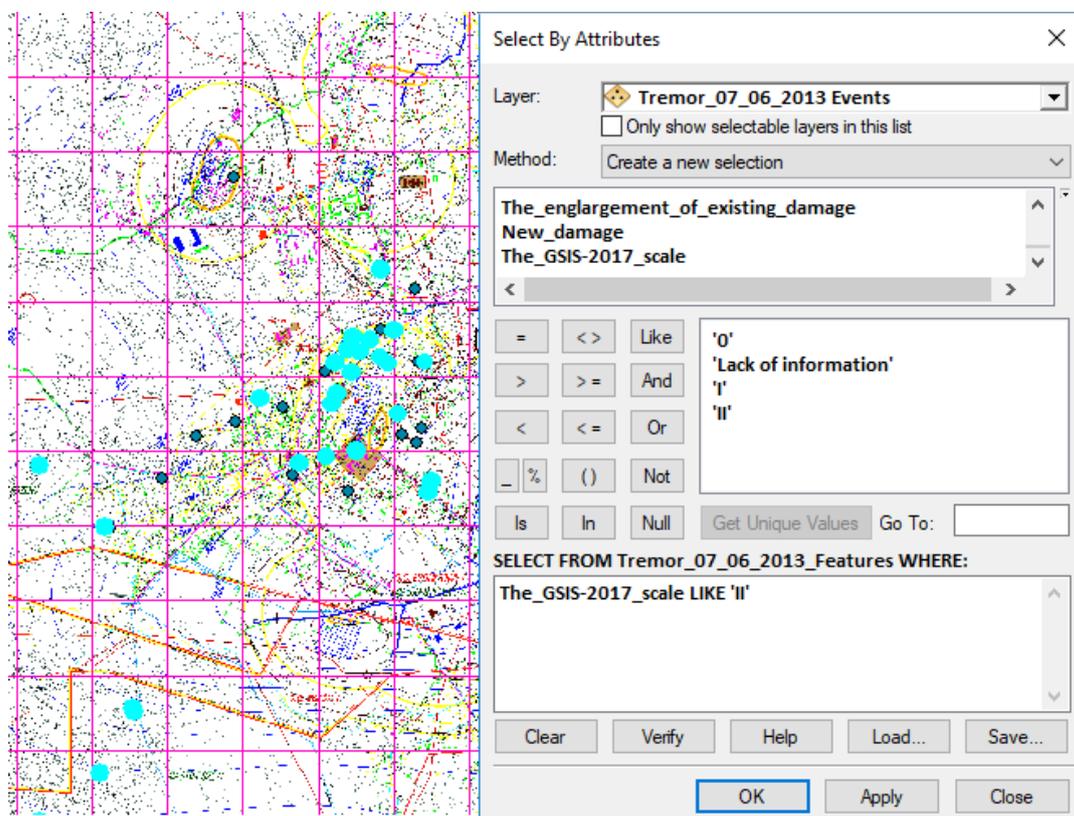


Figure 3. Buildings in the scope of the 2nd degree influences of vibration.

As a result of analyzes carried out on the developed database, discussed in Chapter 3, damage was found in more than 200 residential buildings. In total, inspections were carried out in 342 facilities, in 233 of them the effects of impact were reported. The analyzed tremors caused ground vibrations in the range of the 0, 1st and 2nd intensity levels in the GSIS-2017 scale. As a result of four tremors that occurred in 2011, 111 objects were damaged, 35 of which were located in the area within the impact of 1st degree intensity of vibration, 70 in the impact of vibration of 2nd degree, the remaining in the area of the impact of vibration of 0 degree. No damage was found in the objects located within the vibration range of 3rd degree and above. As a result of the tremors that took place in 2013, 119

objects were damaged, 17 of which in the area of the impact of 2nd intensity degree, 67 in the area of the impact of 1st degree intensity of vibrations, the remaining damaged objects were located in the area of 0 degree intensity vibration.

The correct implementation of the tasks contained in the analyzed Principles requires the collection of a wide range of data on buildings, tremors and data on the impact of exploitation that was carried out, including indicators of deformation of the mining area. In addition, the necessary scope of data was also specified, which should be collected during each inspection of the building object, i.e. data on the location of the object and its geometry, data on the existing construction and material solutions of the building, data on the current technical condition of the building, data on the impact of strong tremors of mining origin on the building, data on the impact of continuous deformation of the mining ground on the building.

The GIS system ensures the possession of complete information including the above mentioned data and the entire history of the object, which significantly streamlines the process of qualifying the damage. It also ensures that data obtained during inspections of the buildings exposed to ground vibration induced by mining tremors are archived in a way that allows quick and easy access to collected data.

Such a system also ensures appropriate documentation of the effects of ground vibration induced by tremors in the buildings, as recommended in the Principles. It is possible to generate a number of tables including, among others:

- information on damage report;
- information about buildings, i.e. location, geometry, construction, protection against mining influences, a technical condition of the object;
- information on building damage, i.e. characterizing parameters, damage to the building resulting from ground vibration induced by mining tremor, additional information (continuous deformations, dynamic impacts, resistance of the object, damage classification).

The program can generate tables containing data on damage to the building. Tables can be generated according to the recommendations included in the Principles [9]. Figure 4 shows a fragment of the input file containing the scope of this data.

Lp.	Information about a building		The coordinates of the centroid for individual buildings		Address data		Acceleration [mm/s ²]	Vibration velocity [mm/s]	The GIS-2017 scale	A technical condition of the object before the tremor	Caused damage		Damage according to the GIS-2017 scale
	The type and description	Construction	X	Y	A town	An address					The enlargement of the existing damage	New damage	
1	Residential and service building	Traditional construction	-228240	-222820	Rydułtowy	ul. Wolności 34	536,12	17,09	II	Good	Plasters cracks on a plinth, scratches of the plasters of the internal walls	Lack	They may cause slight enlargement of non-destructive damage existing in buildings such as lengthening scratches and cracks
2	Residential building	Traditional construction	-228220	-222200	Rydułtowy	ul. Wolności 62	446,15	14,31	II	Good	New scratches of the plaster facets	Lack	They may cause slight enlargement of non-destructive damage existing in buildings such as lengthening scratches and cracks
3	Residential building	Traditional construction	-228230	-222480	Rydułtowy	Kopcińskiego 15	470,65	14,39	II	Good	Scratches of the plaster of the walls and ceilings	Lack	They may cause slight enlargement of non-destructive damage existing in buildings such as lengthening scratches and cracks
4	Residential building	Concrete structure	-228285	-222885	Rydułtowy	ul. Wolności 226	477,77	14,95	II	Good	Scratches of the plaster of facets, wooden roof linings with a local paint chipping in two rooms	Lack	They may cause slight enlargement of non-destructive damage existing in buildings such as lengthening

Figure 4. Data on damage to buildings.

An important element of mine operations is also the forecast of seismic impacts of conducted or planned exploitation. The next stages include the analysis of the current level of seismic activity, registered in the vicinity of the conducted exploitation, the analysis of measurement data from the area for which we make the forecast, and determination of a function describing the distribution of ground vibrations on the surface, and analysis of the geological structure of the overburden, performing of a seismic activity forecast for conducted or planned operation.

Using the data, collected in the GIS system, on seismic energy and the number of recorded tremors, the first stage of the above mentioned forecast can be performed consisting in the development of the seismic activity distributions in time horizons, and the number of tremors distribution in individual energy classes. The above mentioned further stages are generally performed in specialized software. The final effects of calculations can be presented as isolines of the predicted degrees of vibration intensity of the ground, which can be loaded into the GIS system, and determine the predicted impact of ground vibrations on the surface objects. Detailed requirements, concerning the subjected predictions are presented in the work [9].

5. Conclusion

Mining exploitation conducted under certain conditions can induce the occurrence of tremors and rock bursts in excavations. The surface vibrations caused by tremors have a negative effect on building objects. The implementation of the basic task of a mining enterprise which is conducting the safe mining requires undertaking a number of activities, the scope of which is determined in Poland by the Act on Geological and Mining Law and executive regulations to the Act. In the case of coal mines, recommendations contained, among others, in the Principles of using the verified GSIS-2017 seismic intensity scale should be used. The results of the analysis of the possibilities of using the GIS class tool system to realize the tasks in the scope of forecasting are presented in the article.

Presented in the article the results of the analysis of the possibility of using the GIS class tooling system to perform tasks in the scope of forecasting and assessing the effects of the ground vibration induced by mining tremors impact, on building objects, showed that the ArcGIS tool system, which was used to develop the database on which the research was carried out, allows the majority of tasks in the scope of the assessment of the effects of the tremors impact, including documenting damage to objects. In case of tasks concerning forecasting, supporting programs are required. However, the results of the forecasts may contribute to the GIS base, thus expanding the scope of tasks realization in such a system, recommended in the above mentioned Principles.

Mining enterprises in Poland can significantly improve activities in this area, in particular due to the fact that data, especially concerning spatial attributes of objects, can be obtained from the existing numerical map systems. The systems currently used in enterprises that can be considered as the GIS class systems should be equipped with tools allowing to carry out tasks related to seismic hazard, in particular, as it has been demonstrated, in the scope of the assessment and documentation of the damage to objects as a result of the impact of tremors induced by mining exploitation.

The results presented in the article constitute a preliminary stage of research on the development of a decision support system concerning the impact of ground vibration induced by rock mass tremors, caused by the mining activities on building objects.

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