GEODESIC SUPERVISION OF CONSTRUCTION FACILITIES IN THE AREAS OF MINES USING WASTE IN UNDERGROUND HEADINGS REMOVAL

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1. INTRODUCTION

Infringing balance structures in engineering facilities foundation by widely understood activities in geoengineering and mining results in occurrence of hazards to engineering facilities on the surface. Consequently, one should aim at securing them and the basis for such security are detailed forecasts and cyclic geodesic observations. Forecasts and experts' reports on engineering facilities deformation should be prepared with the use of methods adequate to possibilities – widely available nowadays – of applying numerical methods, specialized programming and modern supercomputers. The Finite Element Method that has been used by the author for many years in research on deformations offers wide possibilities of evaluating the condition of the tested facility; however, it should be applied with caution, which requires huge experience in using specialized software. FEM model research, verified by geodesic measurements, are merely the whole of valuable materials that allows for evaluating the conditions of tested facilities. On the basis of such research and experts' reports, one can design preventive activities, so that constructions endangered with deformations were safe. Securing underground headings being the cause of deformation on the surface, that is removing post-mining voids by filling them so that construction facilities were safe is a concept of comprehensive research and monitoring the status of hazards presented in the paper.

2. HAZARDS TO ENGINEERING FACILITIES IN MINING AREAS

Mining activities often result in damage to the balance in a rock mass, which – in consequence – causes the occurrence of hazards to the facilities existing on the surface. Their safe operation depends, accordingly, on monitoring the deformation of the surface and construction facilities in the whole zone influenced by mining. Filling mining headings, also with waste materials, should have favorable influence on surface facilities as far as mining damage minimization is concerned. This problem, due to a most complicated center and the significance of construction experts' reports in mining areas, requires particular caution in selecting measurement methods, as well as analyzing and interpreting the results.

The paper presents a concept of applying model analyses of Finite Element Method in research on the engineering facilities' deformation, deformed as result of mining activities and an attempt to evaluate the scale of reducing mining damages by using waste in underground headings removal. Mining technologies using waste materials as filling material should be monitored with geodesic methods, both in the sense of stored waste material and their influence upon the surface and engineering facilities on the surface. Using model methods in research on surface infrastructure deformation shall be presented upon the example of buildings located in the mining areas of mines using

waste in headings removal. Accordingly, degree of hazards to construction facilities should depend on the method of filling the post-mining voids, that is removing the cause, and geodesic monitoring, designed on the basis of FEM shall allow for detailed supervision and location of possible hazards. Ongoing supervision shall allow also for such control of mining operations in order to minimize its effects on the surface.

Research of construction facilities deformation on the surface is done with the use of geodesic methods and their results and interpretation have very large significance due to the safety of the facilities on the surface. In many cases, measurement methods are used in selected observation points and do not reflect the occurring changes fully. Considerably more information on the changes occurring to the geometry of the examined engineering objects on the surface can be obtained as result of a model interpretation of the results with methods taking advantage of modern computing techniques and potential of new generation computing machines as well as specialized software for examining deformation. In mining operations, one should analyze in detail the effects on the surface, because they have significant impact upon the economical outcome of mining operations as well as, the safety of facilities on the surface. Accordingly, experts' opinions are being prepared and geodesic measurements are often a basis in evaluating the condition and safety of construction facilities. Accordingly, one should apply modern measurement methods and process them in a modern way, so that one could evaluate precisely the condition of engineering facilities and possible hazards to them. A measurement, made in accordance with the needs, and calculations aiming at providing full information on deformation of facilities in mining areas, are basic assumptions for geodesic and computing works, the execution of which is possible due to cooperation and active participation of geodesists in industrial teams. Computing should be performed by specialists knowing the reality and measurement technologies as well as equipment used in geodesic measurements. Voids in the rock mass, being a result of mining, are removed in accordance with mining technology principles and the method of removing them has a considerable significance for facilities located on the surface. In removing headings, filling materials have large significance, in particular their amount and parameters, which results, if possible, in reestablishing the balance condition in the rock mass and minimizing the mining damage on the surface.

Geodesic monitoring of engineering facilities deformation in mining areas should be treated comprehensively in several aspects, including the problems of evaluation and analysis of the causes that should be controlled in order to minimize the effects. Accordingly, the problem includes:

- **Defining the influence range of mining geoengineering by determining zones where observations should be conducted,**
- **Determining geometric shapes of voids occurring in the rock mass, their location and the evaluation of amounts characterizing the scale of changes occurring in the rock mass,**
- **Examining the deformation of engineering facilities on the surface in the mining activities influence zone.**

For the problem defined as above, the Finite Element Method is particularly important, because all these problems may be analyzed in detail within one algorithm and with professional software.

3. APPLICATION OF ABAQUS SOFTWARE, FINITE ELEMENT METHOD

ABAQUS software is a very good tool offering wide possibilities of analyses within deformation research, both for the rock mass, where the cause lies, and for engineering

facilities on the surface where the effects are observed. In deformation research, the segments of ABAQUS software were applied, installed in the Academic Computer Center CYFRONET AGH in Krakow. Large capacity computers (128 processors) were used during calculations. ABAQUS/PRE and ABAQUS/solver software was used, as well as a special library for geotechnical analyses calculations. Special infinite elements were used in the calculations, minimizing the influence of boundary conditions of the model and division of calculations into stages in supermodels as the rock mass and submodels as engineering facilities on the surface. Calculations made once in a supermodel for the rock mass are transferred through the foundation into engineering facilities as submodels at further stages of the calculations. Such comprehensive approach to the issue of deformation research gives very wide opportunities at the stage of forecasting deformation, observation design, results analysis and providing experts' opinions for engineering facilities on the surface. As proven by many years' experience in the conducted experiments, one should be very careful in forming model assumptions and conclusions made, which requires huge experience in the applications of FEM and calculation software.

4. DETERMINING THE INFLUENCE ZONE WHERE OBSERVATIONS OF ENGINEERING FACILITIES SHOULD BE CONDUCTED

An attempt was made to apply FEM in the research on the range of influence for voids occurring in the rock mass, i.e. determining the zone where geodesic observations should be made. In a flat rock mass model, the zone of occurring lowerings was analyzed, and then using MATLAB software, two equations were determined, describing analytically the influence zone in a rock mass, i.e. the scope of influence on the surface. Drucker-Prager model, well-suited to a rock mass, was used in calculations. Fig. 1 presents the results of vertical dislocations in a rock mass as a supermodel, performed with Finite Element Method, with the use of ABAQUS software.

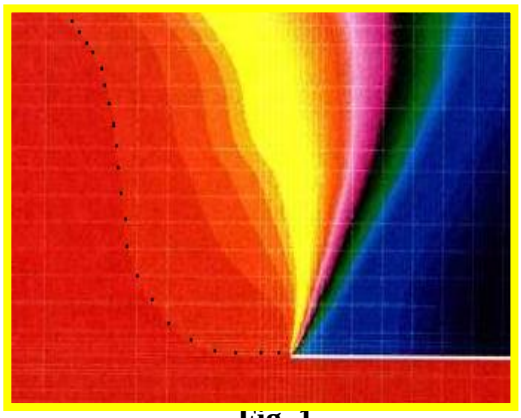

Fig. 1.

Three curves have been shown in diagram in Fig. 2. The influence range curve, obtained from FEM calculations and two equations describing analytically the diagram obtained by way of model research in a FEM flat model system.

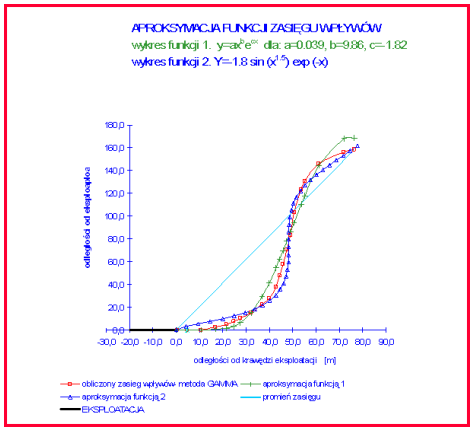

Fig. 2.

Thus obtained range zone is the function of:

- **A system of geological layers in a rock mass,**
- **Geomechanical properties in the rock mass layers and the assumed constitutive model,**
- **Post-mining voids location,**
- **Methods of removing them – e.g. by fall of roof or using waste materials as filling,**
- **Horizontal distance from the void edge and the depth in the rock mass.**

These are numerous factors that should be analyzed carefully at the initial stage and due to their diversity it is advisable to verify them successively on the basis of geodesic measurements on the surface, i.e. to use the reverse analysis method in consecutive model calculations.

5. DETERMINING GEOMETRICAL SHAPES OF POST-MINING VOIDS, THEIR LOCATION AND THE EVALUATION OF SIZES CHARACTERIZING THE SCALE OF THE CHANGES OCCURRING IN THE ROCK MASS

Examining hazards to engineering facilities in mining areas should be started from the location and the cause scale, i.e. from recognizing the mining situation. Recognizing the cause will allow for proper designing methods and precision of geodesic observations. The whole algorithm is based on the geometry in FEM, so this stage should be treated as an important factor in model research. Preparing a model for calculations, i.e. preprocessing, where one should define the geometrical shape of voids in the rock mass and their location may be used in analysis and graphical presentation of the results of geodesic measurements with the application of FEM. A very good tool is ABAQUS/PRE software that was used to prepare a model of salt rock mass where the mining was done by way of leaching in Bochnia-Łężkowice. The caverns existing in the rock mass were measured by means of a sonic sounder and then filled with blast furnace slag, filling the rock mass so that to minimize the deformations on the surface. An FEM spatial model was made for one zone in the mining area, which was presented in Fig. 3.

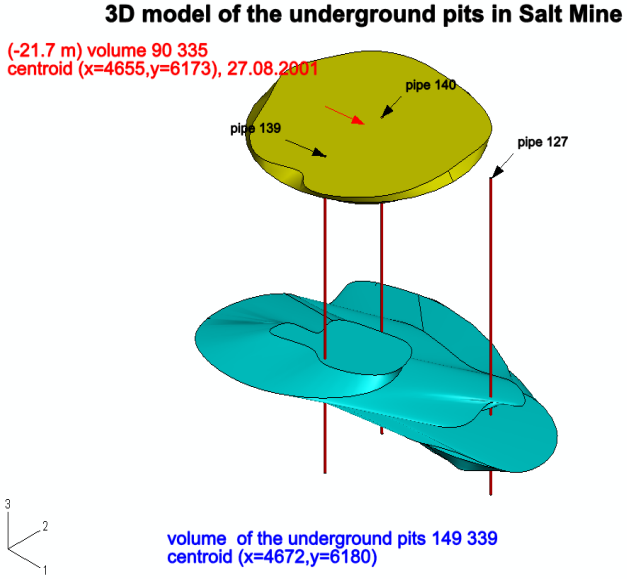

Fig. 3.

The picture presents underground caverns and a collapse sink that appeared on the surface. Despite filling underground voids with waste material, this activity did not result in sufficient protection of the surface and the following conclusions may be drawn:

- **The voids were not filled to an appropriate degree to secure them (voids volume – 149 339 m^3, collapse sink volume – 90 335 m^3), or**
- **Not all post-mining voids existing in the rock mass were included into measurement.**

ABAQUS/PRE software can calculate volumes and transfers of geometrical shapes, which was presented in the diagram. FEM model research allows for presenting geometry of changes to the rock mass and the calculations provide for a detailed description of changes, i.e. deformation.

6. EXAMINING THE DEFORMATION OF ENGINEERING FACILITIES ON THE SURFACE - IN THE MINING ACTIVITIES INFLUENCE ZONE

Engineering facilities on the surface are deformed as result of deformation and stress occurring in the foundation. Location of facilities particularly endangered with deformation, their deformation forecasts and measurement methods may be evaluated using FEM model research. The paper's author suggests stage research with the application of supermodels and submodels, which is a good solution from the point of view of research economics and organization. Following an example of Bochnia-Łężkowice Salt Mine, a FEM model was prepared with the application of ABAQUS software, Fig. 4. A spatial model of the zone being mined consists of over 1 300 000 elements (a supermodel) and it has been calculated by ACK CYFRONET. The figure being a result of FEM model research includes forecast of settling on the surface. Accordingly, all engineering facilities located in the resultant settlement basin should be included in geodesic measurement and their methods and precision should be adjusted to forecasts resulting from an initial analysis of specific facilities (submodels).

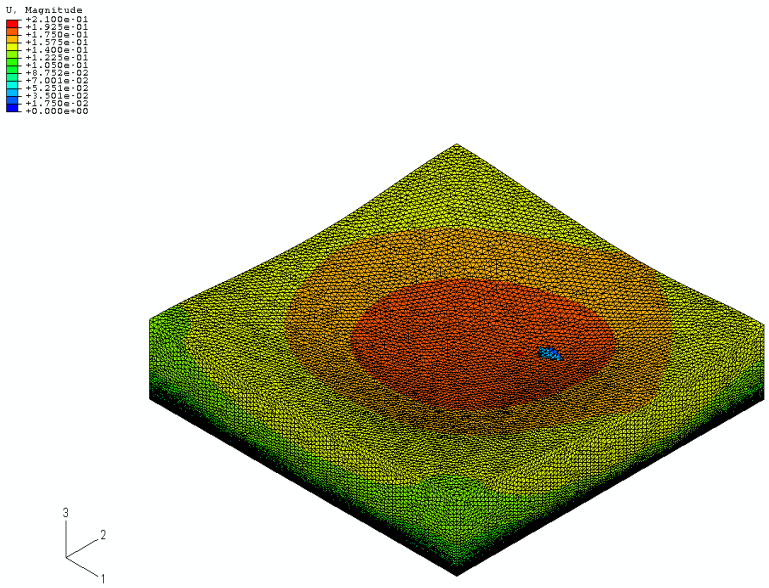

Fig. 4.

At the stage of forecasting the deformation of engineering facilities on the surface, lowering in the base zone (a supermodel) are transferred to the model of an examined

facility on the surface (a submodel). At the measurement stage, there is a verification of forecasts and model assumptions as well as a detailed description of the deformation with the application of the earlier presented models of examined facilities' models. Options for applying FEM in examining engineering facilities on the surface have been presented on the example of a multi-story building with a framework structure, placed on a foundation. Fig. 5 presents a spatial model of the examined building as result of model research in deformation, with the application of FEM and ABAQUS software. Such approach to the problem of research in deformation allows for a detailed analysis of the facility, at the same time introducing preventive measures and locating places particularly endangered with hazards to examined facilities.

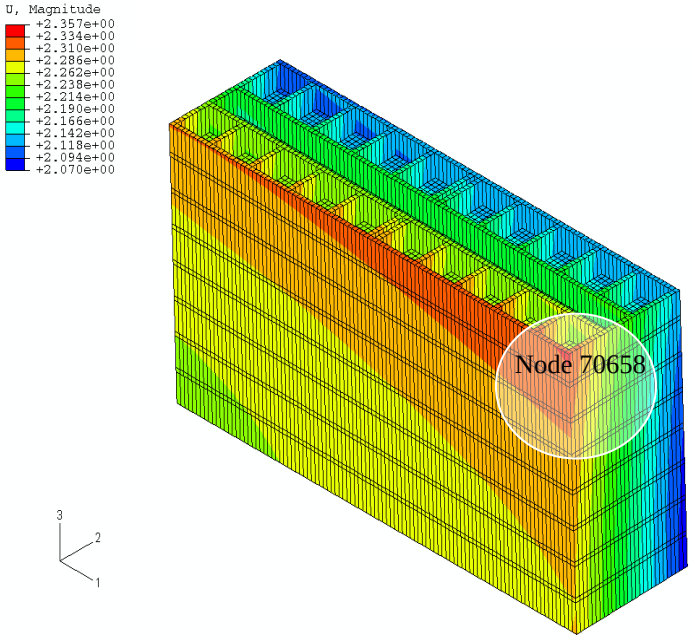

Fig. 5.

Any values characterizing deformations in the model may be printed by indicating locations in the screen of ABAQUS/PRE, which was presented in an example printout below.

Probe Values Report, written on Thu Mar 22 16:34:46 2007
ODB: C:/ABAQUS/OBLICZENIA/Job-obn-wych.odb
Step: Step-1, Frame: Increment 1: Step Time = 2.2200E-16
Probe values reported at nodes

Part Instance	Node ID	Orig. Coords X	Y	Z
PART-1-1	70558	0.	0.	32.
PART-1-1	67703	0.	14.	32.
PART-1-1	67904	50.5	14	32.
PART-1-1	70658	50.5	0	32.

Part Instance	Node ID	Elements	U: Magnitude
PART-1-1	70558	Elem-1	2.322
PART-1-1	67703	Elem-1	2.111
PART-1-1	67904	Elem-1	2.134
PART-1-1	70658	Elem-1	2.357
Minimum		Elem-1	2.111 at Node 67703
Maximum		Elem-1	2.357 at Node 70658

7. CONCLUSIONS

The presented example of using FEM in deformation research is a tool allowing for conducting detailed analyses made in view of:

- **Locating post-mining voids and the method of securing them**
- **Forecasting changes on the surface**
- **Designing geodesic research of deformations**
- **Global description of deformation in the rock mass and in facilities on the surface in the geodesic measurement interpretation**
- **Model experts' opinions on the hazards to engineering facilities on the surface.**

The paper presents several significant aspects related with research made with the application of FEM and ABAQUS software. A comprehensive approach to the problem, taking into account both the causes and the effects in a single algorithm is, in the author's opinion, a significant advantage of FEM model research. The research was presented following an example of the analysis of the influence of applying various waste materials in mining technologies that aim at securing post-mining voids in order to minimize mining damages and hazards to engineering facilities on the surface. Forecasting is difficult and it is often conducted in the aspect of safety supervision, so one should use methods offering wide possibilities of describing the changes in the rock mass and in the facilities located on the surface. In the author's opinion, one should apply modern IT resources based on known theories of model research so that the results could approach the problem comprehensively and be communicative in wide circles of specialist in various areas related with mining, geoengineering and construction activities. As proven by the author's experience, when applying FEM model research, one should be very careful when drawing conclusions as to hazards to engineering facilities and one should be aware of the fact that these are methods and algorithms approximating the conditions of examined facilities and the tools being professional programs provide numerous analysis possibilities, however, they require introducing model assumptions. Verification of such assumptions on the basis of geodesic measurements conducted cyclicy should be conducted on ongoing basis and only verified results are valuable material in analyses and experts' opinions regarding hazards to engineering facilities on the surface.

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