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DEFORMATION ANALYSIS OF PHYSICAL ROCK MASS MODELS

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Abstract: In the modelling laboratory of the Institute of Geotechnics some rock mining and geotechnical problems are solved using the physical rock mass models. The fundamental information for the interpretation of the model experiment are the geometric deformations of the model surface. An original surveying method was developed for measuring and mapping these deformations. This method makes use of modern automated devices and enables us to acquire the necessary information about the model deformations in a clear and comprehensive form: in the form of contour planes, coloured hypsometric planes and three-dimensional figures.

Key words: 2-D and 3-D physical rock mass models; measurement of deformations; digital model of deformations; Bernstein's-Bézier's patch, contour planes; coloured hypsometric planes; three-dimensional figures.

For over 30 years, physical rock models from the Institute of Geotechnics of the Czechoslovak Academy of Sciences have contributed to the solving of different rock mining and geotechnical problems. Successful experiments with these models have helped to explain some problems of stability: during the building of the Prague underground railway, in deep and open-cut coal mining methods, in designing optimal mining technology of some uranium deposits, and even in the investigation of the negative influence of open-cut brown coal mining on the local mineral springs in the Karlovy Vary area. These models are known as "equivalent models"; they are designed from equivalent materials with regard to the known geological structure of the rock mass itself. The equivalent materials used are prepared so that their mechanical and physical properties fulfil – on the selected model scale – the conditions of physical similarity with the organic properties of rock from which the rock mass has been created. Under these circumstances, it is possible to assume that the geometrical transformation of the equivalent model (caused by simulation of the problem under study) will be, on a given scale, qualitatively and quantitatively similar to the future deformations of the natural mass (Kohoutek, 1964; Kuznetsov *et al.*, 1959).

In this way, the equivalent models come to be a very effective means of predicting these deformations; in turn, the models contribute to the resolving of many rock problems of technogene character.

The analysis of the rock model deformations is the basis of all prognostic and interpretative reasonings (i.e. the continuous determination of deformations in the whole model area in an arbitrary phase of the model experiment). For this reason, an original surveying method was developed in the modelling laboratory of the Institute of Geotechnics which makes use of modern automated devices, and which enables us to acquire the necessary information about the model deformations in a clear and comprehensive form (Vencovský, 1989).

This method can be divided into two thematically different tasks:

(1) the measurement of the deformation stages of the model in the course of the experiment;

(2) the graphic representation of these measurements.

To deal with the first task, two special photogrammetric methods which made it possible to measure the deformation of both types of equivalent models (e.g., 2-D and 3-D models) were developed and fully automated in recent years.

As part of the second task an extensive software was elaborated, enabling the graphic interpretation of the deformation (or stress stage) of the rock model in the form of contour planes, coloured hypsometric planes and 3-D figures.

The 2-D model usually represents a vertical section view through the rock mass and the given problem is solved as a 2-D problem. The method of measuring the deformation of this model type is based on the stereoscopic comparison of the model photograph of a certain experiment phase with the photograph taken before the beginning of the experiment. This method involves the familiar stereoscopic observation of a stereopair on the time base that leads to the creation of the stereoscopic model surface. This surface represents the deformation trend of the rock model in the direction of the stereoscopic base. The simple qualitative analysis of the morphology of this surface usually provides very valuable information about the state of the model deformations in the given experimental phase. Nevertheless, the quantitative analysis of this surface is also necessary. The stereopair is then measured with a stereocomparator. In the stereoscopic model of the deformation surface, measurement points are selected which accurately represent its morphology. By using planar collinear transformation, it is possible to derive the coordinates of the measurement points and their positions in the model plane.

In this way two sets of coordinates $[X_0\ Y_0]$, $[X\ Y]$ for identical sets of measurement points are obtained. The coordinates are determined in one system, stationary relative to the rock model. It is further possible to derive two sets of motion components of points $[DX]$ and $[DY]$. These two sets and the set of coordinates of the measurement points from the initial experimental phase $[X_0\ Y_0]$, are used to define two empirical surfaces $[X_0\ Y_0\ DX]$, $[X_0\ Y_0\ DY]$ expressing the trend of the model deformations in both directions of the coordinate system axes. These surfaces are continuously defined by their digital models (DTM) which then become the basis of all automated modes of graphical representation for the deformation stages of rock models.

The 3-D model represents a 3-D object, and the photogrammetric method of measuring the deformations of this model type is different. The measurement points (e.g. targets) that serve to determine the spatial movements of the model material in selected phases of the model experiment must be shown on the model surface. The movements can be derived from the repeated stereophotogrammetric measurement of the model surface. For this reason the method used in our laboratory is based on direct transformation of the image coordinates of each measurement point into the spatial coordinate system XYZ. This system is defined in the neighbourhood of the model as a relatively stationary system. The necessary condition for the use of this method is the formation and measurement of the 3-D field, of the so-called control points in the neighbourhood of the model. The method of this concept is more precise than the well-known stereophotogrammetric method, and enables the use of ordinary photographic cameras. By means of the above-mentioned transformation, it is possible to determine the spatial position of all measurement points indicated on the model surface.

In this way, we obtain the sets of XYZ spatial coordinates of identical points that demonstrate the model deformation stages in the course of the experiment. If we denote the set for the initial phase $[X_0\ Y_0\ Z_0]$, we can derive, for each subsequent experimental phase, sets of coordinate transformations $[DX]$, $[DY]$, $[DZ]$ from which it is possible to form three sets of points $[X_0\ Y_0\ DX]$, $[X_0\ Y_0\ DY]$, $[X_0\ Y_0\ DZ]$. These sets discretely define three empirical surfaces represented in the given experimental phase and the trend of the model deformations in the direction of the coordinate system axes. As in the case of the 2-D model, the continuous determination of these surfaces is performed by means of their digital models which become the basis for their subsequent graphical representation.

These automated graphical outputs, as already mentioned, form the second part of the method the deformation measurements of the rock models. Creating these documents must be preceded by the design of the DTM deformation surfaces. This concerns the large-scale, topical problems that are the subject of research in different fields of science (above all in geodesy and geology). The solutions usually correspond to the character of the original surface and are not entirely universal.

The DTM design for the above purposes must enable the approximation of the

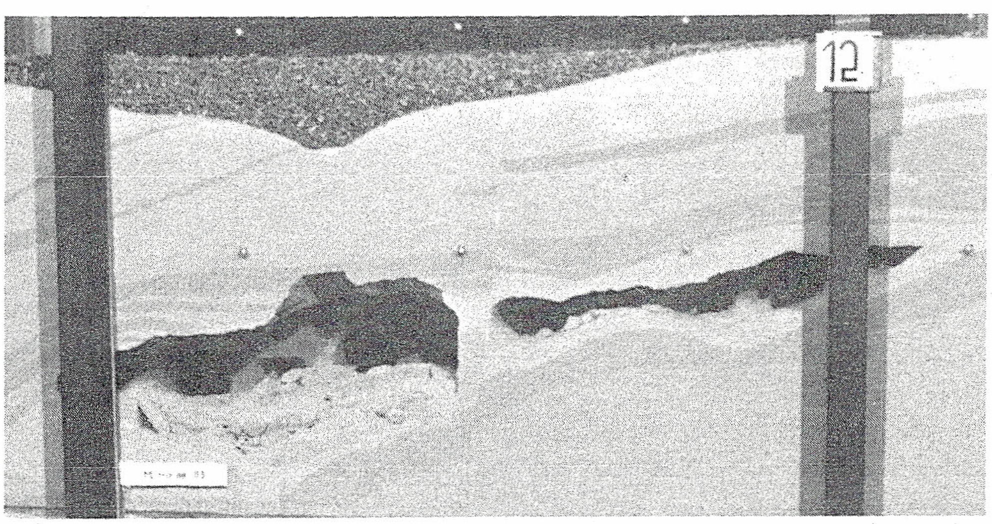

Fig. 1. Plane model in a certain phase after the extraction of the mineral raw material.

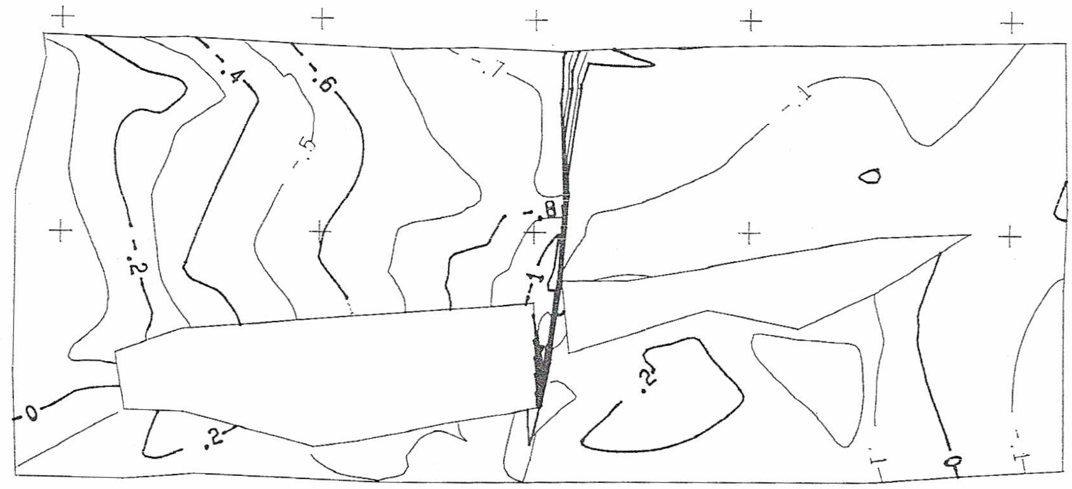

Fig. 2. Contour lines of the vertical component of the rock-model deformations.

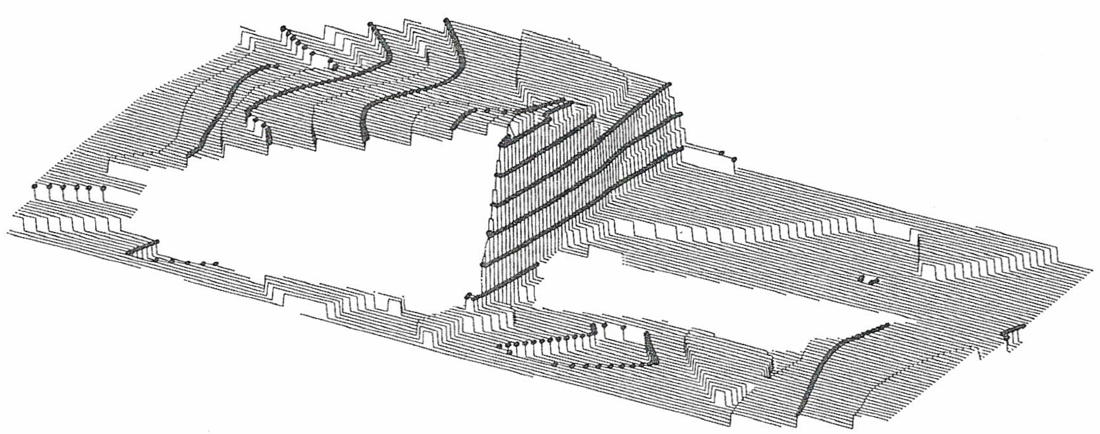

Fig. 3. 3-D view of the vertical component of the rock-model deformations.

smooth parts of the original surface and the parts with morphological singularities such as the fault and planar zones, because most deformation surfaces include these singular formations. Therefore, the design of our DTM is based on the generation of a net of triangles in the ground plane. The design enables us to determine and define (by using Bernstein's-Bézier's patch (Farin, 1980)) the surface element over each net triangle, which, in the case of the smooth zone of the original surface, smoothly and continuously passes into the neighbouring elements. If the net triangle is included in the linear morphological singularity, this will be replaced by a plane. The design enables the continuous passage of the smoothly curved elements into the planar ones and vice versa.

The graphic outputs can then be obtained either as the contour plans of the deformation surfaces or coloured hypsometric plans of these surfaces; finally, they can be obtained in the form of the 3-D figures on these surfaces. For this reason, these graphic documents are now very popular and frequently used. They can be obtained by means of software. In our laboratory these software facilities were not available in the past; therefore, it was necessary to develop our own appropriate software, which has also many uses in other fields of research: for example in connection with applying the FEM (Finite Element Method) in geodesy, topography, etc. This can be illustrated by the examples presented in Figs. 1–4.

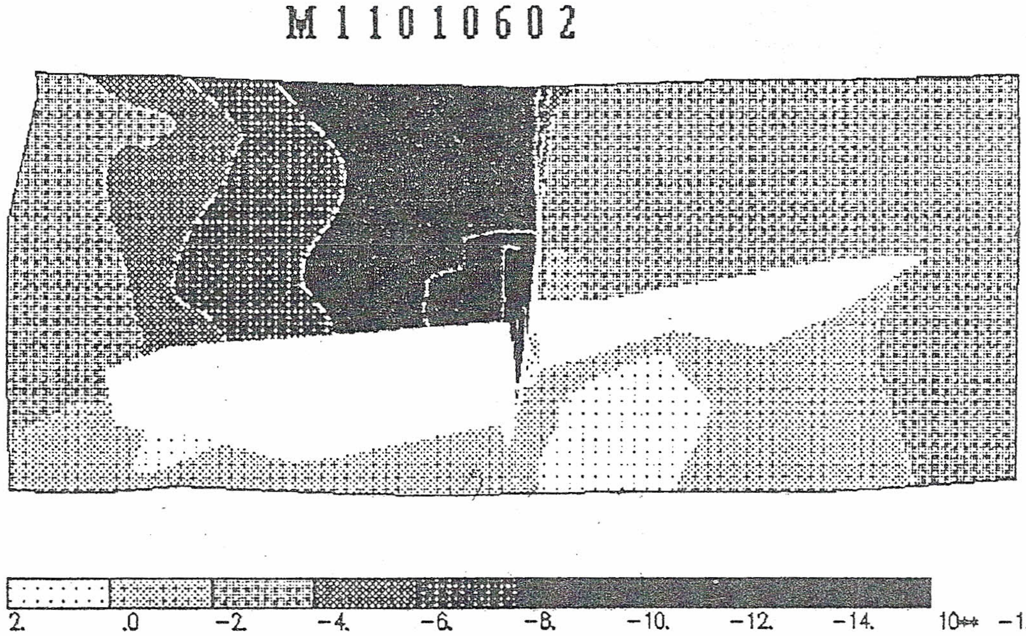

Fig. 4. Coloured hypsometric plan of the vertical component of the rock-model deformations.

REFERENCES

Farin, G. (1980). Bézier Polynomials over Triangle, TR/91, Dept. of Mathematics, Brunel University, Uxbridge, UK.

Kohoutek, J. (1964). The conditions of the physical similarity for the solution of the geomechanical problems, by use of models, *Lett. 4 of the Mining Institute of the Czechoslovak Academy of Sciences*, 10–28 (in Czech).

Kuznetsov, G.N., M.N. Bud'ko, A.A. Filippova, and M.F. Shklyarskiy (1959). *Study of rock pressure on models*, Ugletekhizdat, Moscow, 158 pp. (in Russian).

Vencovský, M. (1989). Methods of measurement and graphic representation of physical rock mass model deformation, *Dr.Sc. Thesis,* Institute of Geology and Geotechnics, Czechoslovak Academy of Sciences, Prague, 230 pp. (in Czech).

DEFORMAČNÍ ANALÝZA FYZIKÁLNÍCH MODELŮ HORNINOVÉHO MASÍVU

Miloš Vencovský

V laboratoři modelování ÚGt ČSAV se řeší některé geotechnické problémy pomocí fyzikálních modelů. Základní informací pro interpretaci výsledků modelového experimentu jsou geometrické deformace povrchu modelu. K určení a zobrazení těchto deformací byla zde vyvinuta automatizovaná měřická metoda, která umožňuje získat všechny nezbytné informace o zmíněných deformacích v jasné a přehledné formě: ve formě izočarových plánů, barevných hypsometrických plánů a ve formě tzv. 3-D pohledů.

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