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THE NEW METHOD OF FORECASTING OF INFLUENCES OF THE TUNNELING UPON THE SURFACE

Summary. Calculation methodology for the determination of subsidence hollow discussed in this contribution represents a new approach to the solution of the influence of the underground workings upon the surface,which is a certain compromis solution between the analytical,empiric and engineering methods on the one hand and the method of finite elements on the other hand.

NOWA METODA PROGNOZOWANIA WPŁYWÓW ROBÓT GÓRNICZYCH NA POWIERZCHNIĘ

Streszczenie. Przedstawiona w tej pracy metodyka obliczania obniżeń terenu jest nowym podejściem do rozwiązywania zagadnień wpływu wyrobisk podziemnych na powierzchnię. Podejście to stanowi pewien kompromis pomiędzy metodą analityczną, empiryczną i inżynierską z jednej strony i metodą elementów skończonych z drugiej strony.

НОВЫЙ МЕТОД ПРОГНОЗИРОВАНИЯ ВЛИЯНИЯ ГОРНЫХ РАБОТ НА СОСТОЯНИЕ ПОВЕРХНОСТИ

Резюме. Представленная в настоящей работе методика расчета оседаний територии - это новый подход к решению проблемы bлияния подземных горных выработок на состояние поверхности. Этот метод является в некоторой степени компромиссом между аналитическим, импирическим и инженерным методами с одной стороны и методом конечных элементов с другой стороны.

The present developed forecasting methods of subsidence phenomena above the subsurface underground workings can be subdivided into two main groups from the view-point of the assumptions of the solution:

(a) Analytico-numerical methods,

(b) Empiric engineering methods.

Creation of such a model of a geotechnical situation is the basis of the solution by means of analytico-numerical methods, which we can solve either in an analytical way or in a numerical way,or on which other physico-mathematical procedures of the solution can be applied (JEFFERY, SAGASETA, FEM, etc.).

The empiric engineering methods do represent a quite another procedure. In accordance with gained real information in the field of subsurface underground workings, the spectrum and number of which have been increasing, the probable dependences between in objective manner given parameters and searched ones (PECK) are assessed.

The evaluation of surface subsidence above the shallow situated workings includes two basic problems, which do differ in the field of their character.

1. During the underground working realization, ground loss (V0) can occur. The right reasons of this occurrence are given by technologic circumstances following from both the driving method and underground working supporting as well, e.g. in case of shield tunnelling, this ground loss is given by the main difference between the dimensions of a shield and actual section ensured by means of a support. Professional skills in the field of technology of a working realization do play the most important role in this field. The second reason of this ground loss is connected with changing surroundings in the vicinity of an underground working. The size of this ground loss is given by the deformation range of an environment which exceeds the limit of a gross section of underground workings.

2. In a rock environment in the vicinity of an underground working,in particular points,the individual displacement can occur, and the greatest attention has been paid to both size and direction of displacement of points being situated on the surface, which do determine the form of a subsidence hollow.

Forecasting of a volume of a ground loss is too difficult as it is determined by means of many factors, to which these below-mentioned factors belong:- non-linear behaviour of a rock environment, deformation delay, shape of a working, technology of a realization, type of a support, three dimensional character of the whole problem, etc., the mathematical expression of which seems to be too complicated. Nevertheless, one can state the important fact that theoretical analytical methods are not too reliable at all. Working experience only (measurements) gained in accordance with the observed actual cases, is the basis for actual forecasting of influences of shallow tunnelling upon the surface. Both magnitudes and courses of particular displacements inside the rock mass and on its surface as well are influenced by properties and behaviour of this rock mass. The influences of a structural character of a working (e.g. its shape, size, type of a support, etc.) are not too important in most cases.

Analytical, numerical, engineering and empiric (i & e) procedures, assessing the values of maximum subsidences and ranges of subsidence hollows, include all the most important factors in their whole (not individually), which do play an important role in the field of the occurrence and origin of subsidence phenomena.

The analytical methods are derived under the assumption, main simplifications has to be accepted. As far as the shape of a working, it is of a circular section, the environment is of a consistent type having the idealized strain properties (the condition of elastic strain), and an idealized stress state (hydrostatic field of stress) as well.

Numerical methods, first of all the FEM method, get over many lacks of the analytical methods. They are independent upon the shape of a working, various environment can be simulated by means of these methods. In spite of this fact, their reliability depends upon the assessement of representative values of strain properties of the environment. In case of the FEM-method, there is one specific problem being connected with constitution of a calculation model with definition of extreme geometric conditions, i.e. with the attachement of the model floor, which does influence the magnitude of the subsidence.

The advantage of the i & e methods in comparison with above-mentioned methods is that fact that there comes to transformation of one of key issues, i.e. the assessement of strain properties of the environment, the right classification of this environment, and its introduction within the particular empiric statistic(al) dependence. Results gained by means of these i & e methods are satisfactory enough under such a condition if working overburden consists of the only type of the environment. Reliability extent of forecasting, carried-out by means of the above-mentioned methods, is determined by the range of necessary generalization (simplification, idealization) of a particular geotechnic situation. Generalization relates to these below- mentioned facts first of all:

(a) Rock environment in the vicinity of a working incl. overburden consists of one rock type (homogenity of the environment),

(b) Assumption of elastic strain of rock environment,

(c) Effects of hydrostatic field of original stress within rock mass,

(d) Circular shape of underground working.

From these facts follows that the trends towards further precision of forecasts and their increased reliability lead to the development and searching for new methods, which will enable to include such influences, which the present methods are not able to include. These below-mentioned influences belong to these factors:

(a) Influence of rock systems consisting of more strata,

(b) Non-homogenity of tunnel's overburden,

(c) Influence of a different coefficient of lateral pressure in a undisturbed rock mass and the influence of surface surcharge,

(d) Influence of a working shape,

(e) Influence of a working support,

(f) Possibilities of expression of various strain forms in the tunnel's vicinity (measurements, calculations, influences of stowing compressibility, etc.),

(g) Anisotropy of rock environment,

(h) Influences of faults (structural elements) upon both rock stiffness and strain in the tunnel's vicinity,

(i) Possibility to carry-out the inversion analysis of the environment.

The mentioned new methodology of forecasting do try to include some of these mentioned factors into the calculation of its own.

The solution of the assesment of a subsidence hollowin the generally inhomogeneous environment can be subdivided into two main parts:

1. Assessment of a subsidence hollow on a boundary of two inhomogeneous strata due to the changes during driving.
2. .Assessment of a subsidence hollow in the surface territory, which corresponds to set subsidence curve on a boundary of inhomogeneous strata.

Solution of the first part of this task can be subdivided into these three main parts:

(a) Stress assessment and displacement determination in **elastic heavy half-plane**, i.e. half-plane being loaded with its own weight g, under the influence of non-supported underground working of a circular form, the centre of which is situated in the distance d from the contact line of a half-plane. This heavy half-plane is characterized by means of an initial stress state (stress state in an undisturbed rock environment):

$$\sigma_y^{\theta} = \gamma(y - d)$$

$$\sigma_x^{\theta} = \frac{\nu}{(1-\nu)} \quad \gamma(y - d$$

$$\tau_{xy}^{\theta} =$$

ν .... Poissons ratio of a rock

(b) Determination of stress strain relations corresponding to uniform inside loading p of an outline of underground working (i.e. the influence of a support of underground working is modelled in this way).

(c) Determination of stress strain relations corresponding to continuous outside surcharge of a contact line of a heavy half- plane (i.e. the influence of a weight of an overburden stratum within two-strata calculation system is modelled).

Submitted method is based on the assumption that the rock environment can be modelled by means of an elastic half plane with a circular opening, the centre of which is situated in a certain distance from the boundary of a considered half plane. Stress strain state of this elastic half plane in the course of loading processes is described and defined by means of basic differencial equations of elasticity (differencial equation of equilibrium, the equation of continuity of deformations/strains). The main result of the solution of a given system of these differencial equations with corresponding extreme conditions on the boundary of a half plane, and on the outline of an underground working are the relations for the calculation of stress and strain in any point of the elastic half plane, i.e. in the surface point as well. Proposed calculation method enables to include three types of loading into this calculation:- the own weight/load of a rock, - support reaction, and surface surcharge of a half plane (surcharge means surcharge on the whole area of this half plane, not a local surcharge only, e.g. by means of buildings). The influences of considered types of loading are superimposed. Within the very solution of a given task for the own weight/load of a rock, there is the assumption that a "heavy half plane" (half plane being loaded with the own weight of a rock) is in equilibrium state before underground working is driven, and this equilibrium state is characterized with a certain initial state of stress. During opening driving, this initial equilibrium state is disturbed, and the stress strain state inside the rock mass is changed, and there are additional stresses and strains there, which do correspond to these changes. These additional stresses and strains do depend upon the magnitude of the initial stresses in an undisturbed rock mass, upon the material characteristics of the rock environment, upon the shape of transversal cross section of underground working, upon its size and the depth of the centre position of this underground working under the surface, and upon technology of drivage of this given underground working as well. The total stress within rock mass being disturbed by means of the unsupported underground working is then given by the sum of both the initial and final stresses.

Relations for the assessment of the initial stress and strain are well known, the whole issue is reduced to the determination of the additional stresses and to them corr esponding additional displacements within the rock environment. Further steps do apply the theory of the functions of a complex variable and the theory of complex potentials. These complex potentials, corresponding to set Airy's function, define then searched components of the total stress by means of Muschelisvili's equations:

$$\sigma_r + \sigma = 2\left(\varphi_1'(z) + \overline{\varphi_1'(z)} \right)$$

$$\sigma - \sigma_r + 2i\,\tau_{r\theta} = 2\left(\bar{z}\,\varphi_1''(z) + \psi_1'(z) \right) e^{2i\theta}$$

$z = r\,e^{2i\theta}$, r,θ ... Polar coordinates

$\varphi_1(z), \psi_1(z)$ ...... complex potencials

Relations for the additional displacements in any point of the rock environment, i.e. for points on the surface as well, have been gained by means of the integration of the additional stress components. The support influences is modelled by introduced inside constant loading. Surcharge of a boundary (of surface) of a half plane is included into the calculation by means of a coefficient, which is a proportion of displacements in the roof, and there are both the own weight of rock and considered surcharge, and displacements due to the own weight of a rock only. Calculation method is based on such an assumption that a proportion of corresponding displacements on the boundary of a half plane will be identical with the proportion of the above-considered displacements on the outline of a working. Kirsch's method of solution has been used for the assessment of the surcharge influence of the boundary of the half plane.

The above-mentioned stress strain states, having the validity for circular underground working, will be then modified by means of a shape coefficient being given by displacements proportion in a certain point for both arched and circular underground working at a given depth of the working position under the surface. Shape coefficient has been gained by means of the evaluation of parametric calculations by means of the finite elements method. By means of regressive analysis, a corresponding shape coefficient as well as the function of the depth of working position under the surface have been set in accordance with gained discrete values (with regard to working position under the surface).

Submitted calculation method takes into consideration technologic view-point of working driving and supporting, i.e. by means of technologic coefficient, which is given by proportion of the sum of both technologic and actually measured displacements and calculated displacements in the roof of underground working.

If within a calculation a two-strata system is considered, a subsidence curve on a free boundary of the surface can be set according to such a determined (assessed) subsidence hollow. Such methods have been used, which do determine the functional dependences of a subsidence of a free surface upon the magnitude of non-dipped extracted area and upon the depth of its position under the free surface. Extracted area is characterized by means of a constant thickness.Aversin's , Martos's and Knothe's methods do belong to the group of calculation methods, which have been used for further determination of a subsidence curve on a free surface in accordance with knowledge of a subsidence curve on a contact boundary. Transversal cross section of the area, which is set by means of a contact boundary and a set

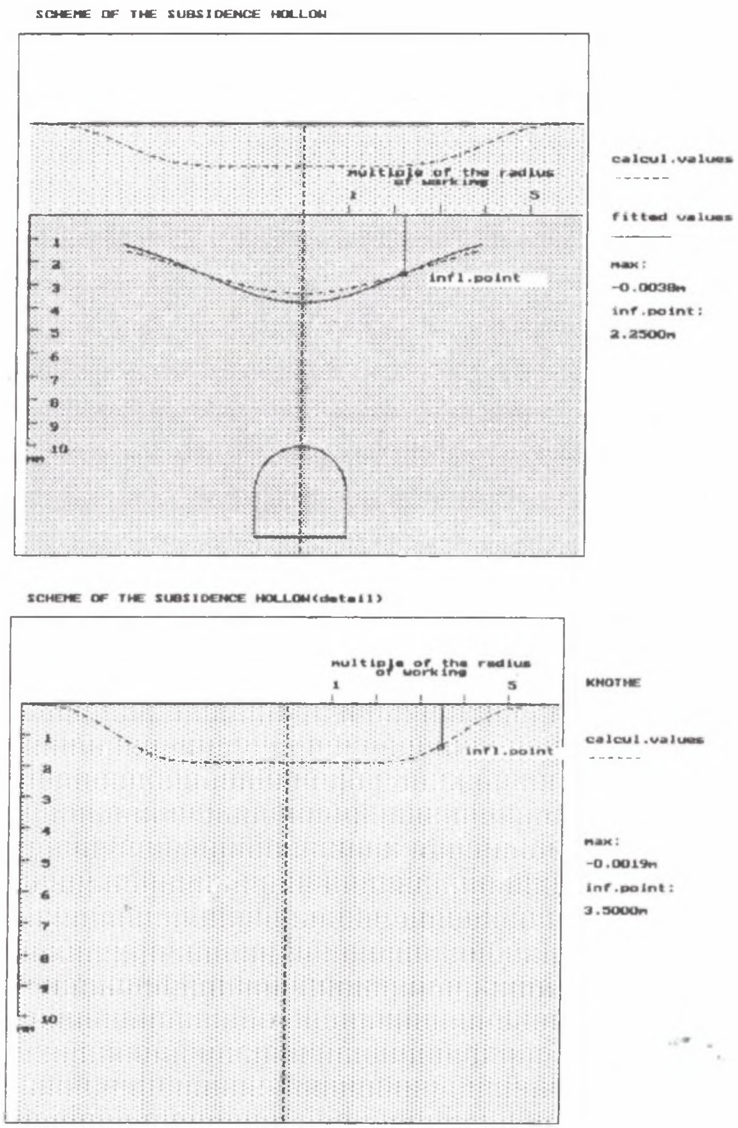

Fig.1.Scheme of the subsidence hollow

Rys.1. Schemat niecki obniżeń

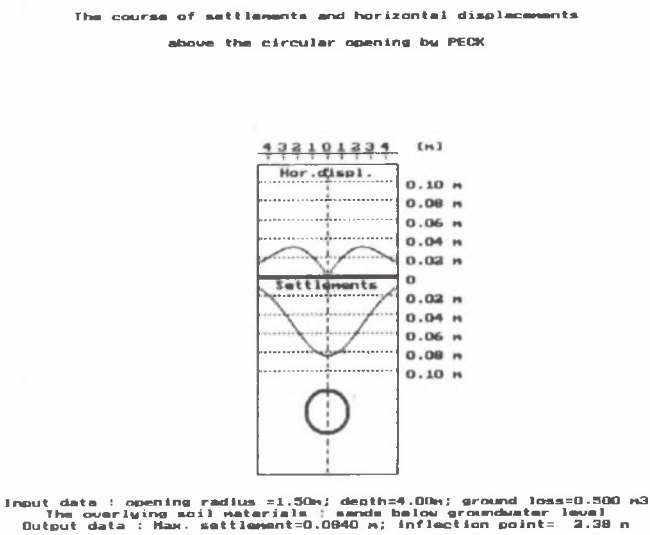

Fig. 2.The course of settlements and horizontal displacement above the circular opening

Rys.2.Wykres osiadań i przemieszczeń poziomych ponad wyrobiskiem o przekroju kołowym

subsidence curve, will be divided into a certain number of zones, which are characterized with both their width and their thickness, and the influence of these zones, which do model the individual partial mined areas, will be then superimposed each other.

References

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