ны рекомендации по изменению крепления с учетом использования „глубинного“ упрочнения пород. По отношению к расчетному пределу текучести стали основная длина стоек нагружена на уровне 85–94 % и находится в допредельном состоянии.

**Научная новизна.** Заключается в установлении особенностей изменения напряженного состояния горного массива и степени влияния зоны опорного давления впереди очистного забоя на нижерасположенную выработку.

**Практическая значимость.** Разработаны рекомендации по эффективному и надежному креплению восточного промежуточного штрека ш. „Степная“ ДТЭК ШУ „Первомайское“ с учетом особенностей поддержания надрабатываемых выработок.

**Ключевые слова:** *анкерная крепь, вычислительный эксперимент, напряженно-деформированное состояние, надрабатываемая выработка*

*Рекомендовано до публікації докт. техн. наук В. І. Бондаренком. Дата надходження рукопису 01.11.16.*

---

UDC 622.831.3

**O. M. Shashenko, Dr. Sc. (Tech.), Prof.,**
**N. V. Khoziaikina, Cand. Sc. (Tech.), Assoc. Prof.,**
**R. M. Tereshchuk, Cand. Sc. (Tech.), Assoc. Prof.**

National Mining University, Dnipro, Ukraine, e-mail: Shashenkoa@nmu.org.ua; nv.khozyaykina@gmail.com; Tereschuk.rm@ gmail.com

# DISTRIBUTION OF DISPLACEMENTS AROUND A SINGLE MINE WORKING DRIVEN IN STRATIFIED ROCK MASS

**О. М. Шашенко, д-р техн. наук, проф.,**
**Н. В. Хозяйкіна, канд. техн. наук, доц.,**
**Р. М. Терещук, канд. техн. наук, доц.**

Державний вищий навчальний заклад „Національний гірничий університет“, м. Дніпро, Україна, e-mail: Shashenkoa@nmu.org.ua; nv.khozyaykina@gmail.com; Tereschuk.rm@gmail.com

# РОЗПОДІЛ ПЕРЕМІЩЕНЬ НАВКОЛО ОДИНОЧНОЇ ВИРОБКИ, ЩО ПРОЙДЕНА В ШАРУВАТОМУ ПОРОДНОМУ МАСИВІ

**Purpose.** To estimate displacements in the neighborhood of a development working driven under mining and geological conditions of mines in Western Donbas and situated within the area of mining effect for further improvement of full-scale measurements being an important stage in the process of geomechanical model verification.

**Methodology.** A number of sequential operations of numerical modeling were involved making it possible to demonstrate deformational processes progressing in the neighborhood of “mine working-longwall” geotechnical system with a probability of 0.95 including those resulting in loss of elastoplastic resistance of marginal rock mass weakened either by mine working or by a network of underground cavities. Features of geomechanical processes taking place in the neighborhood of a mine working were analyzed with the help of complicated technical “mine working-pillar-rock mass” system being developed gradually within the rock mass.

**Findings.** The results of the numerical experiment helped determine rules of stratified rock mass formation around a mine working located within mining space effect in terms of difference levels of protective structure rigidness within longwall as well as estimate its effect on the integrity of entire geomechanical system.

**Originality.** For the first time the fact of both vertical and horizontal displacements of far point of deep benchmark station in the context of varying width of protective structure in longwall has been proved and their regularities have been determined.

**Practical value.** The determined regularities can be quite useful while estimating displacements of floor rocks and roof rocks in the process of full-scale measurements performed with the help of the leveling method.

**Keywords:** *stress-strain state, development working, protective structure, deep benchmark station, displacements of roof rocks, full-scale measurements, numerical modeling*

**Introduction.** Papers by E. Hoek [1], F. Tajdus, M. Cala, K. Tajdus [2], O. O. Sdvyzhkova [3, 4], S. M. Gapieiev [5], O. M. Shashenko [6, 7], Yu. M. Khalimendyk [8] and others concern the analysis of stress-strain state in the neighborhood of underground mine workings and open-cut workings. Above-mentioned researchers are representatives of schools of rock mechanics in Canada [1], Poland [2] and Ukraine [4–9]. Techniques being applied in this context vary from substantiation of empiric strength criterion [1] and analytical calculations [2–7] up to full-scale experiments [8]. As a result, the combination of different approaches helps obtain adequate geomechanical conditions. Objective of the research is in further correction of a technique verifying numerical models as they are advanced at the moment.

Features of geomechanical processes taking place in the neighborhood of complicated technical “mine working-pillar-rock mass” system developed in rock mass grad-

---

ually can only be seen within contour line of exposure in the form of displacement. One can only imagine what the nature of deformations inside the rock mass is while controlling partially the assumptions by the results of displacements of deep benchmarks. In this context a selection of immovable (zero) point in rock mass as a reference point remains disputable. In this connection both development and substantiation of numerical models helping estimate stress-strain state of nonhomogeneous rock mass in terms of neighborhood of a system of mine workings being operated within time and space is both topical scientific and technical problem and an objective of the research.

**The problem statement.** Long horizontal arched mine working of $2R_0$ width and $h$ height has been driven within stratified rock mass with layer density $\gamma_i$ at $H$ depth from the surface. Mine working (mine roadway) has been driven along the coal bed with underbreaking. Layers are horizontal; their thickness as well as physical and mechanical properties corresponding to the mining conditions of Construction Project Passport for “Shakhta Stepnaia” mine of “DTEK Pavlohradvuhillia” PJSC. Arched yielding metal support has been mounted in the mine working.

Taking into consideration the availability of wet slightly metamorphized rocks with a great amount of clay particles, stress distribution within undisturbed rock mass is considered as hydrostatic one, i.e. horizontal stress coefficient is $\lambda = 1$. Depth of the mine working is such that plastic range of stress (PRS) is formed around it. It is required to determine stress-strain state (SSS) parameters in the neighborhood of mine working: components of stress, displacement, and PRS dimensions.

**Presentation of the main research.** Taking into account the complexity of the stated problem (mine working geometry, structure of enclosing rock mass), its solution is only possible while applying a numerical technique. RS 2 software by Canadian company Rockscience was taken as a tool for the research. Hoek-Brown ratio is the point rock failure criterion [1].

Fig. 1 shows calculation scheme to solve the problem of plane deformation. Table represents physical and mechanical characteristics of the rock mass.

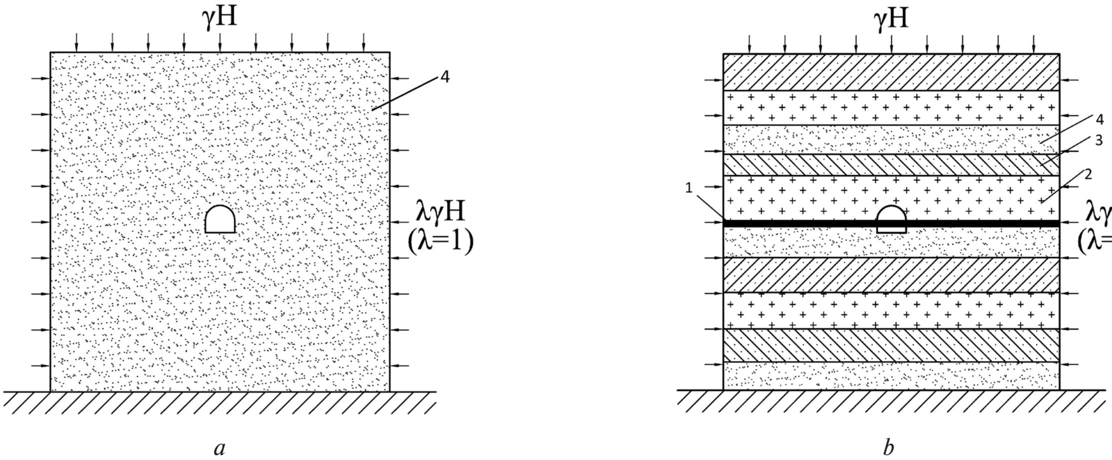
Fig. 2 explains distribution of radical stresses $\sigma_r$ and tangential stresses $\sigma_\Theta$ in the neighborhood of mine working located within homogeneous rock mass with averaged (average weighted) physical and mechanical properties

$$\overline{E},\overline{\mu},\overline{R_c}=\sum_i^n \frac{\left(E_i,\mu_i,R_{c_i}\right)h_i}{\sum h_i},$$

where $\overline{E}$, $\overline{\mu}$, $\overline{R_c}$ are average weighted values of elasticity module, Poison’s ratio, and ultimate one-axis compressive strength respectively, $h_i$ is thickness of $i^{th}$ rock layer, and $n$ is the number of layers.

The calculations involved the fact that the strength of rock mass $R_c^M$ differs from the strength of rock samples $R_c$ by the value of structural weakening coefficient $k_c$.

$$R_c^M = R_c k_c \,. \tag{1}$$



*a* *b*

*Fig. 1. Calculation scheme to solve elastoplastic problem concerning stress-strain state of rock mass within the neighborhood of long horizontal mine working:*
*a – homogeneous model; b – nonhomogeneous model; 1 – coal; 2 – argillite; 3 – sandstone; 4 – aleurolite*

*Table*

Physical and chemical characteristics of the rock mass under study

| Rock layer | Rock layer description | Young’s modulus E, MPa | Poison’s ratio, μ | Ultimate one-axis compressive strength, $R_c$, MPa |
|---|---|---|---|---|
| 1 | Coal | 13478.6 | 0.3 | 15 |
| 2 | Argillite | 3193 | 0.3 | 15 |
| 3 | Sandstone | 9000 | 0.3 | 30 |
| 4 | Aleurite | 2981.7 | 0.3 | 20 |

In terms of formula (2), the value of structural weakening coefficient is determined by formula [6]

$$k_c = 1 - \sqrt{0.5\eta}\exp\left(-0.25\eta\right),$$

where $\eta$ is a coefficient of rock mass strength variation determined by the formula

$$\eta = \sqrt{\frac{l_t + l_0}{l_t}\left(\eta_0^2 + 1\right) - 1},$$

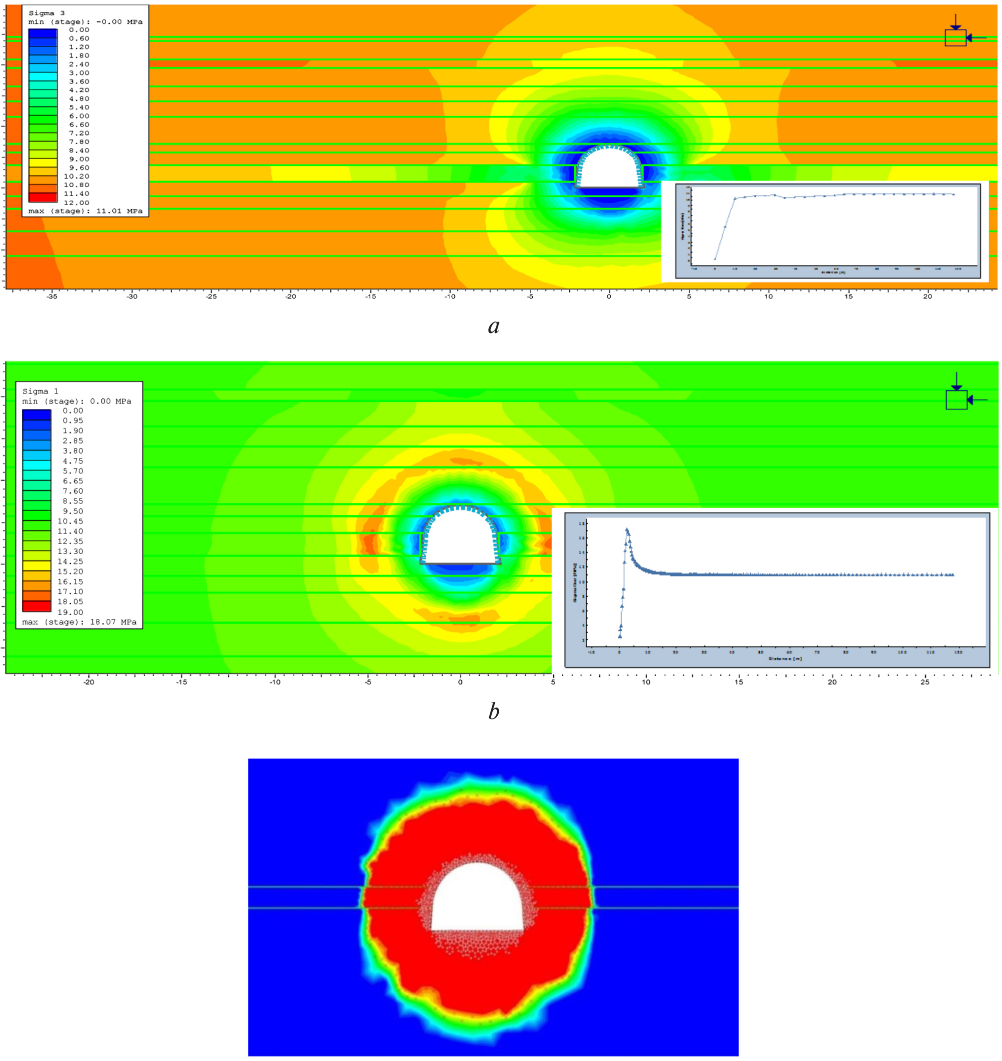
where $l_t$ is average distance between fissures; $l_0$ is typical dimension of standard rock sample; $\eta_0$ is coefficient of variation of rock sample testing results.

It follows from Fig. 2 that distribution of stresses in the neighborhood of mine working is almost similar to the solution of elastoplastic problem [6]. Divergence with accurate solution is 3–5 % depending upon the fact that the shape of the mine working is not round. A zone of nonelastic deformations of approximately round shape with $3R_0$ radius is formed around the mine working. Displacements within the mine working contour are 0.3–0.5 m. Such displacement value (U > 0.3 m) means that heaving of mine working floor is possible. Check of possible floor heaving according to the criterion by O. M. Shashenko [6].

The technique developed in papers by O. M. Shashenko [6] and S. M. Gapieiev [5] was applied for simulation of the mine working floor heaving by means of one-time rising of central point of a bottom (Fig. 4, *a*). In this context PRS shape from the side of mine working floor experienced substantial increase (6–8 times); floor displacements were 0.5–0.7 m (Fig. 4, *b*); and contour displacements within walls and roof remained at the level of 0.3 m. Such a feature of displacement evolution is typical for floor heaving process considered physically as a loss of elastoplastic resistance of a geomechanical system [3].

Comparison of the obtained parameters of geomechanical state of rock mass in the neighborhood of mine working corresponds up to 0.9 to the parameters measured in 161th boundary entry of the Construction Project Passport for "Shakhta Stepnaia" mine of "DTEK Pavlohradvuhillia" PJSC [7].

In terms of mining and geological conditions of the Construction Project Passport for "Shakhta Stepnaia" mine of "DTEK Pavlohradvuhillia" PJSC, displace-

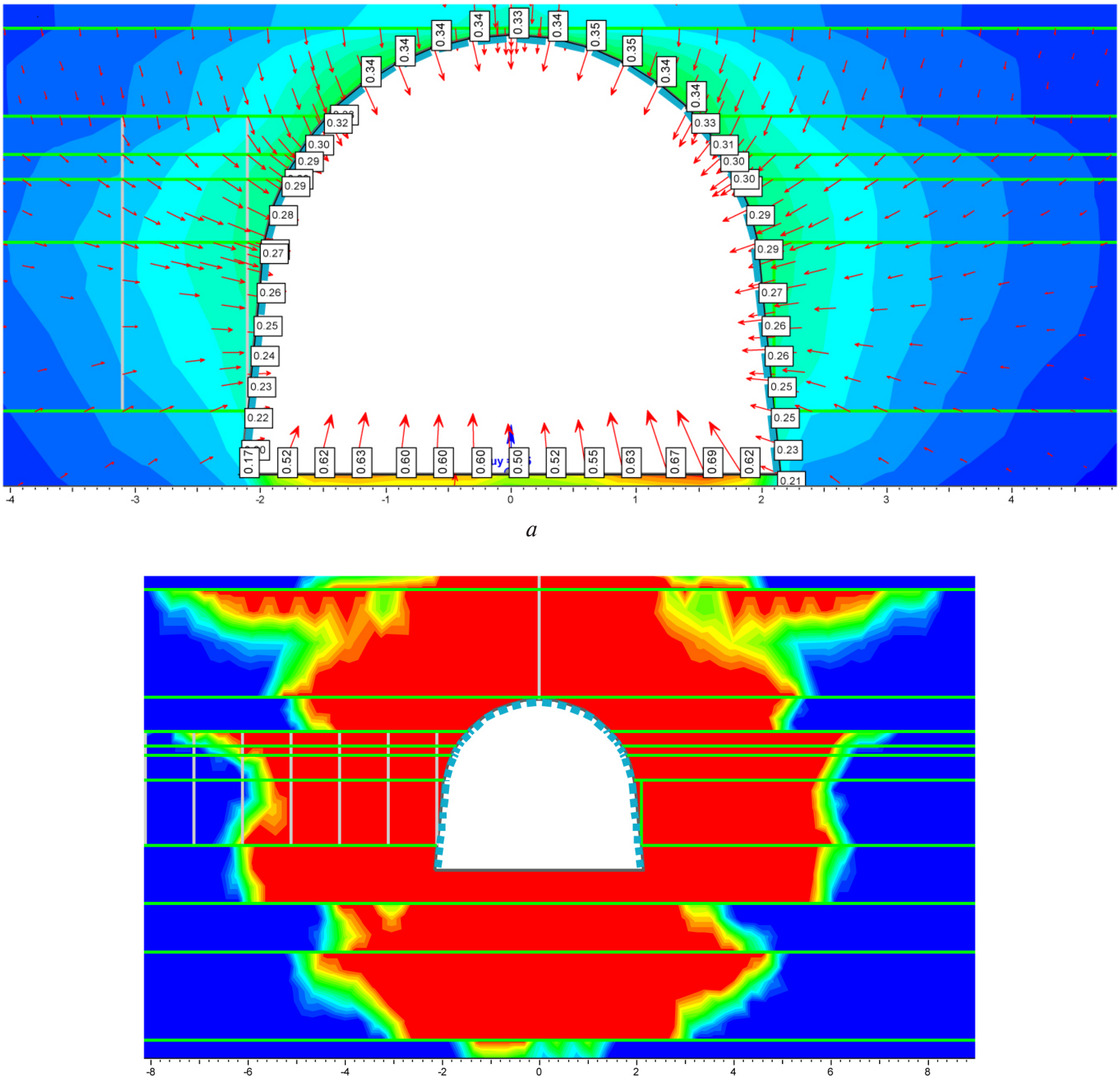


*a*

*b*

*c*

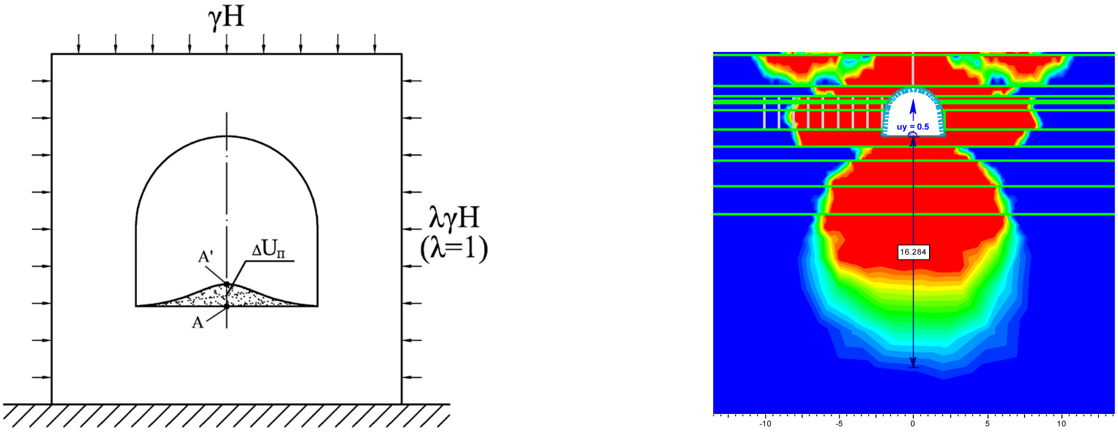
*Fig. 2. Distribution of radial (a) and tangential (b) stresses and shape of zones of nonelastic deformations (c)*



*a*

*b*

*Fig. 3. Displacement vectors (a) and PRS shape in the neighborhood of the mine working in the context of heterogeneous model (b)*



*a*

*b*

*Fig. 4. Simulation of floor rock heaving process in the mine working (a) and the result of numerical modeling (b):*
A is a point within the rock mass contour; A' is the position of A point after heaving process simulation; $\Delta U_n$ is the value of the mine working floor rising after heaving process simulation

ments in the neighborhood of the development mine working were measured in the context of varying width of protective structure of a longwall. Conditional width of the protective structure (pillar) varied from 1 to 8 m with one-meter spacing. Thickness of a seam to be mined was 0.95 m. In this context, both vertical and horizontal displacements within vertical axis in the mine working roof were estimated.

Figs. 5–7 shows the results of numerical calculations.

Fig. 5 explains nature of vertical displacements of 22 conditional points located regularly along vertical axis within the mine working roof at the depth of 0 to 6.0 m depending upon the varying width of protective structure (pillar).

Fig. 6 shows nature of horizontal displacements of 22 conditional points located regularly along vertical axis within the mine working roof depending upon the varying pillar width.

The abovementioned means that horizontal displacements in terms of height of the controlled line alternate in their signs transferring from compressive stresses to tensile ones.

Figs. 7 and 8 demonstrate separately vertical and horizontal displacements of control point within the mine

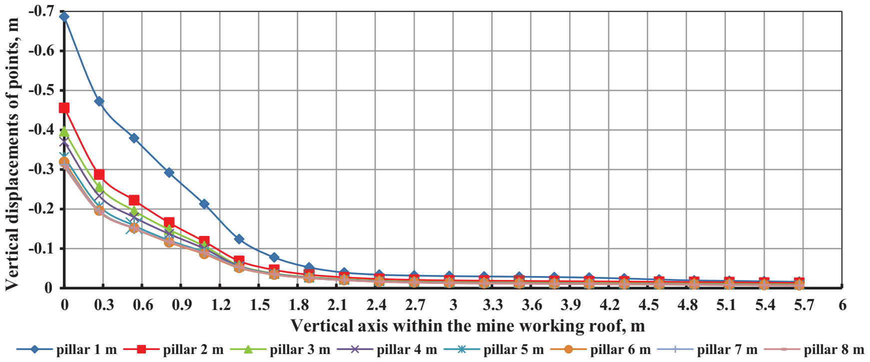


*Fig. 5. Dependence of vertical displacements of the conditional points along vertical axis within the mine working roof upon pillar width*

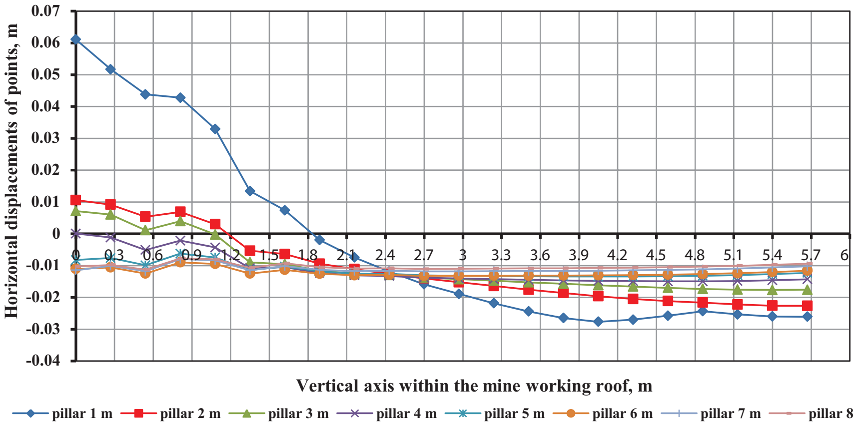


*Fig. 6. Dependence of horizontal displacements of the conditional points along vertical axis within the mine working roof*

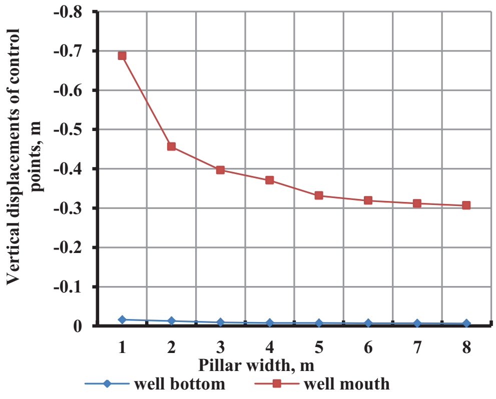


*Fig. 7. Vertical displacements of control points along vertical axis within the mine working roof is coal seam thickness is 0.95 m and pillar width varies*

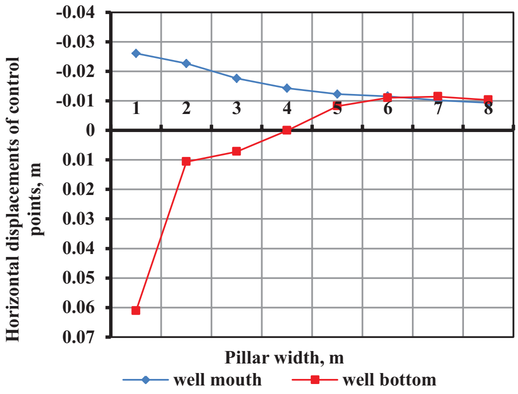


*Fig. 8. Horizontal displacements of control points along vertical axis within the mine working roof is coal seam thickness is 0.95 m and pillar width varies*

working contour as well as the most remoted one located at the distance of 6 m from the mine working contour.

It follows from Figs. 5–8 that the nature of displacements depends heavily on pillar geometry; moreover, in terms of its certain width horizontal displacements change their signs for opposite ones. The fact was already noted by Yu. M. Khalimendik in the process of full-scale measurement analysis [8].

The following stage of solving elastoplastic problem concerning stress-strain state of rock mass in the neighborhood of long horizontal mine working considers non-homogeneous rock mass (Fig. 1, *b*).

RS 2 software was applied to perform several stages of numerical modeling of SSS of the analyzed rock mass [3] weakened by single mine working. Fig. 9 demonstrates the calculation scheme.

Gradual modeling was to estimate horizontal displacements along vertical axis within the mine working roof as well as vertical displacements $U_{y_i}$ and $\sigma_{y_i}$ value along the line of protective structure whose width $a_{p_i}$ varied from 1 to 10 m, and coal seam thickness was 0.95 m.

Fig. 10 shows values of horizontal displacements of distant (well bottom) and close (well mouth) points along the vertical axis located in the mine working roof depending upon protective structure width.

The obtained results of horizontal displacements along the vertical axis in the mine working roof, vertical displacements $U_{y_i}$ and values $\sigma_{y_i}$ within the line of protective structure made it possible to calculate stiffness of protective structure in terms of varying pillar width using the formula

$$G_i = \frac{\sigma_{y_i} a_{p_i}}{U_{y_i}}.$$

According to the calculation results, $U_{x_i}\left(U_{y_i}\right) = f\left(G_i\right)$ function was considered and graph of the dependence of horizontal displacements of distant point of vertical line within the mine working roof on protective structure stiffness was built (Fig. 11). The graph is approximated by power dependence of the following type

$$U_{x_i} = 0.7G_i^{-0.3}.$$

**Conclusions and recommendations for further research.** Geomechanical model of a single in-seam mine working driven in stratified rock mass with the parameters corresponding to the mining and geological conditions of Construction Project Passport for "Shakhta Stepnaia" mine of "DTEK Pavlohradvuhillia" PJSC has been verified.

It was determined that value of horizontal and vertical displacements of a point located within a vertical well at the distance of 6 m from the mine working contour, may be 0.1–0.2 m depending upon the width of the protective structure (its stiffness).

While varying stiffness of the protective structure, it is possible to control displacements in the neighborhood of the development mine working and take them into consideration while selecting distant well point as zero one, i.e. reference point.

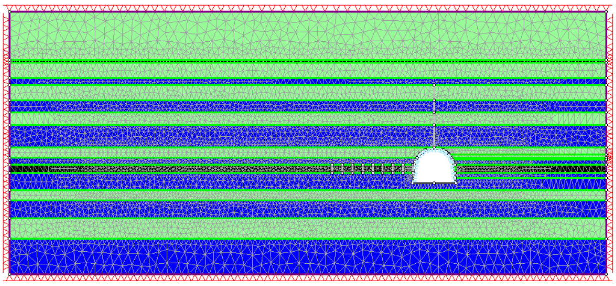


*Fig. 9. Calculation scheme to solve a problem of stress-strain state of stratified rock mass involving single mine working*

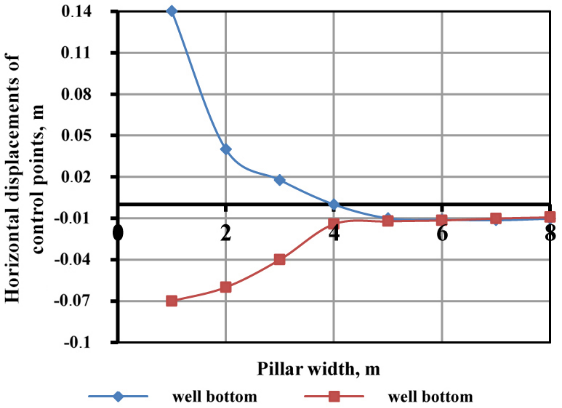


*Fig. 10. Dependence of values of horizontal displacements $U_{x_i}$ of distant (well bottom) and close (well mouth) points along the vertical axis located in the mine working roof on the width of protective structure $a_{p_i}$*

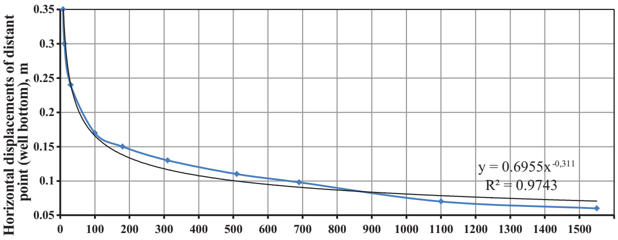


*Fig. 11. Dependence of horizontal displacements of distant point (well bottom) on the protective structure stiffness*

**References.**

**1.** Hoek, E., 2006. Rock mass classification. In: E. Hoek, 2006. *Practical Rock Engineering*. Ch. 11 [online]. Available at: <https://www.rocscience.com/documents/hoek/corner/Practical-Rock-Engineering-Full-Text.pdf> [Accessed 25 November 2016].

**2.** Tajdus, A., Cala, M. and Tajdus, K., 2012. *Geomechanika w budownictwie podziemnym projektowanie I budowa tuneli*. Krakow: Wydawnictwa AGH.

**3.** Sdvyzhkova, O. O., Babets, D. V., Kravchenko, K. V. and Smirnov, A. V., 2016. Determining the displacements of rock mass nearby the dismantling chamber under effect of plow longwall. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 2, pp. 34–42.

**4.** Babets, D. V., Sdvyzhkova, O. O., Larionov, M. H. and Tereshchuk, R. M., 2017. Estimation of rock mass stability based on probability approach and rating systems. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 2, pp. 58–64.

**5.** Gapieiev, S., Shashenko, A. and Solodyankin, A., 2010. Bifurcational model of rock bottom heaving in mine workings. In: *New Techniques and Technologies in Mining.* London: CRC Press / Balkema, pp. 71–76.

**6.** Shashenko, A. N., Pustovoitenko, V. P. and Sdvyzhkova, Ye. A., 2016. *Geomechanics*, Ukraine: Noviy druk.

**7.** Shashenko, O., Kovrov, O., Rakishev, B. and Mashanov, A., 2015. On the issue of analytical and empirical criteria application for rock failure assessment. In: *Theoretical and Practical Solutions of Mineral resources Mining*, Dnipro: Litograf, pp. 59–65.

**8.** Dmitrov, G. N., Khalimendik, Yu. M. and Baryshnikov, A. S., 2014. Improvement of the passport of maintaining first workings. *Ugol Ukrainy*, 4, pp. 3–6.

**9.** Solodyankin, O. V., Hryhoriev, O. Y., Dudka, I. V. and Mashurka, S. V., 2017. Criterion to select rational parameters of supports to reduce expenditures connected with construction and maintenance of development working. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 2, pp. 19–27.

**Мета.** Полягає в оцінці переміщень навколо підготовчої виробки, що пройдена в гірничо-геологічних умовах шахт Західного Донбасу і знаходиться в зоні впливу очисних робіт, для подальшого вдосконалення методики натурних вимірювань, є важливим етапом верифікації геомеханічної моделі.

**Методика.** Включає ряд послідовних операцій чисельного моделювання, виконання яких дозволяє з імовірністю 0,95 відобразити деформаційні процеси, що розвиваються навколо геотехнічної системи „виробка – лава“, які призводять до втрати пружно-пластичної стійкості приконтурного породного масиву, ослабленого виробками або комплексом підземних порожнин. Особливості геомеханічних процесів, що відбуваються навколо виробки, вивчались за допомогою складної технічної системи „виробка – цілик – масив“, яка поетапно створювалась у породному масиві.

**Результати.** Результати чисельного експерименту дозволили встановити закономірності деформування шаруватого породного масиву навколо виробки, що знаходиться в зоні впливу очисного простору, за різної жорсткості охоронної конструкції в лаві, оцінити її вплив на цілісність геомеханічної системи в цілому.

**Наукова новизна.** Полягає в тому, що вперше доведено факт і встановлені закономірності переміщень по вертикалі та горизонталі найвіддаленішої точки глибинної реперної станції при змінній ширині охоронної конструкції в лаві.

**Практична значимість.** Полягає в тому, що встановлені закономірності можуть бути корисними за оцінки зсувів порід підошви й покрівлі при виконанні натурних вимірювань методом нівелювання.

**Ключові слова**: *напружено-деформований стан, підготовча виробка, охоронна конструкція, глибинна реперна станція, переміщення порід покрівлі, натурні вимірювання, чисельне моделювання*

**Цель.** Состоит в оценке перемещений в окрестности подготовительной выработки, пройденной в горно-геологических условиях шахт Западного Донбасса и находящейся в зоне влияния очистных работ, для последующего совершенствования методики натурных измерений, являющихся важным этапом верификации геомеханической модели.

**Методика.** Включает ряд последовательных операций численного моделирования, выполнение которых позволяет с вероятностью 0,95 отобразить деформационные процессы, развивающиеся в окрестности геотехнической системы „выработка – лава“, которые приводят к потере упруго-пластической устойчивости приконтурного породного массива, ослабленного выработкой или комплексом подземных полостей. Особенности геомеханических процессов, происходящих в окрестности выработки, изучались при помощи сложной технической системы „выработка – целик – массив“, поэтапно создаваемой в породном массиве.

**Результаты.** Результаты численного эксперимента позволили установить закономерности деформирования слоистого породного массива вокруг выработки, находящейся в зоне влияния очистного пространства, при различной жесткости охранной конструкции в лаве, оценить ее влияние на целостность геомеханической системы в целом.

**Научная новизна.** Состоит в том, что впервые доказан факт и установлены закономерности перемещений по вертикали и горизонтали дальней точки глубинной реперной станции при изменяющейся ширине охранной конструкции в лаве.

**Практическая значимость.** Заключается в том, что установленные закономерности могут быть полезными при оценке смещений пород почвы и кровли при выполнении натурных измерений методом нивелирования.

**Ключевые слова:** *напряженно-деформированное состояние, подготовительная выработка, охранная конструкция, глубинная реперная станция, перемещения пород кровли, натурные измерения, численное моделирование*

*Рекомендовано до публікації докт. техн. наук С. М. Гапєєвим. Дата надходження рукопису 12.11.16.*