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DISPLACEMENT OF UNDERMINING ROCK MASS ABOVE THE MOVING LONGWALL

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ЗРУШЕННЯ ПІДРОБЛЮВАНОГО МАСИВУ НАД РУХОМИМ ОЧИСНИМ ВИБОЄМ

Purpose. Establishment of laws of change and distribution of the rock mass displacements and deformations on the basis of surveying instrumental observations at undermining the main roadway in the conditions of flat coal seams development in Western Donbas.

Methodology. The underground observation station is laid to establish the nature of the spatial displacement of rock mass points in the 2nd West Main haulage drift of c_5 layer at "Heroiv Kosmosu" Mine, Industrial Structure Unit. The drift was undermined by clearing works at lava 128 of c1 layer with a thickness of 1.2 m. Processing depth was 80 m. The observations were made using the electronic tachymeter "TOPCON 235N" at 13 metering sections, laid at a distance of about 20 m from each other. Each section at the support is fixed with four survey points: in the walls of mine working, in its roof and the soil. The total length of the observation station was 280 m. The last observation was carried out at a distance of 165 m from lava 128 coal face. To fix mutual displacement of the mine working support and the rock mass, three additional auxiliary metering sections, which consisted of a pair wall ranging marks, were laid. In total there were 4 series of observations at different distances from the face of lava 128. The diagonal arrangement of the main haulage drift with respect to the face line allowed the capture spatial displacement of the rock mass at different distances from the working face. The spatial coordinates of the survey points were determined for each series of the observations.

Findings. According to the results of instrumental studies, the spatial coordinates of the survey points are established for each section. To eliminate the impact of convergence on results, the analysis of observations was carried out not according to the survey points, but regarding the center of gravity of the survey section. Uplift of survey points was recorded during the second observation. Thus, the uplift was recorded both in the soil and in the top of the mine working. The maximum value of lifting of the section gravity center was 30 mm. According to the results of studies it is found that rock mass has shifted to the horizontal plane in the direction of movement of the working face after the passage of lava. The maximum value of horizontal displacement of the section gravity center is fixed above the center of the lava and is 240 mm, which coincides with the results of instrumental observations on the Earth surface. The sizes of the propagation zone of rock mass displacement and deformation above the boundary part of the lava were established.

Originality. For the first time the regularities of spatial displacement of undermining rock mass above the current lava in conditions of the flat coal seams development are established.

Practical value. The research results in their subsequent accumulation provide an opportunity to develop a method for predicting displacement of rock mass above the excavation mine workings of coal mines.

Keywords: *instrumental observations, bench mark, undermining, the coal seam, subsidence and deformation, rock mass*

Introduction. Underground mining of coal seams violates the equilibrium state of the rocks, leading to their displacement and deformation as a result of redistribution of stresses in the undermining rock mass. These geomechanical processes negatively affect the conditions of maintaining mine workings and they are the cause of the dangerous manifestations of rock pressure. Significant financial resources are spent on the maintenance of the main and development workings. The adoption of reasonable and effective technical solutions to ensure the safety of workings in the area of influence of clearing works is not possible without the availability of reliable information about the patterns of displacement and deformation of undermined rock mass.

Analysis of the recent research and publications. In studying the process of displacement of rock mass, the research is usually conducted separately for the conditions of the Earth surface and rock mass. Regarding the Western Donbas displacements of undermined rock mass remain insufficiently studied with insufficient knowledge of the process of the Earth surface subsidence. This also applies to other mining regions.

The methods for calculation of horizontal and vertical deformation of the rock mass are theoretical and mainly applicable to the zone of high rock pressure. These methods have not found further application due to lack of confirmation of their reliability by experimental data. The results of calculation of the vertical deformation at high rock pressure zone under existing methods (Savost'janov A. V.) are not consistent with the results of full-scale instrumental observations. Observations of the earth surface subsidence in the Western Donbas are few and limited by two observation wells with depth bench marks and two observation stations in undermined mine workings. On the basis of these observations, the scheme of displacement of rock mass under moving production face is proposed. Thus, research studies were performed to determine the parameters of vertical movement and rock deformation. The horizontal displacement and deformation of the rock mass are not studied in the Western Donbas.

The experimental results at existing rates and coal mining technology [1] indicate that the current schemes of displacement process are no longer relevant. This also applies to the methods for predicting displacement and deformation of the earth surface and rock mass.

Therefore, carrying out scientific research to determine patterns of horizontal deformation of the rock mass in the development of flat coal seams is an actual scientific and technical problem.

Objectives of the article. Insufficient study of issues of displacement of rock mass is associated with a small number of instrumental observations of the behavior of undermined rock mass. The objective of experimental studies is to establish numerical characteristics of displacement of undermined rock mass above the clearing mine workings of mines of the Western Donbas.

Presentation of the main research. Underground observation station was laid in the 2nd West Main haulage drift (2ZMOSH) of c_5 layer, at "Mine Blagodatnaya" Industrial Structure Unit to establish the nature of the spatial displacement of the points of the rock mass. 2ZMOSH was undermined by clearing works of lava 128 of c1layer with a thickness of 1.2 m (Fig. 1). The depth of drift undermining was 80 m, and a depth to the c_1 layer in the zone of laying observation station – 330 m.

The observations were made at 13 metering sections (type 1, Fig. 2), laid at a distance of about 20 m from each other. Fig. 2 shows the location scheme of survey points in the metering sections. Additionally, there were inherent 3 metering sections (type 2), which were consisting of the wall benchmarks. For the convenience of finding the metering sections, the surveyed points were marked with paint.

The reference points were laid outside the influence of lava 128 at a distance of over 190 m from its border. The observations included the measurement of the spatial coordinates of survey points with the electronic tachymeter "TOPCON 235N". The measurements were

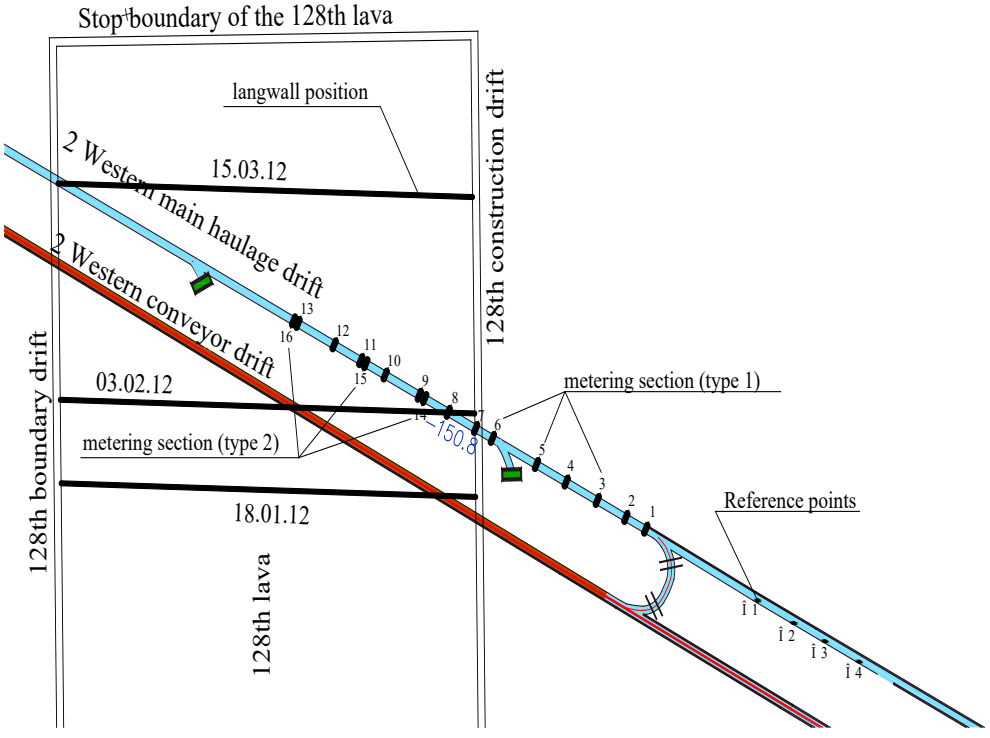

Fig. 1. Plan for underground observation station

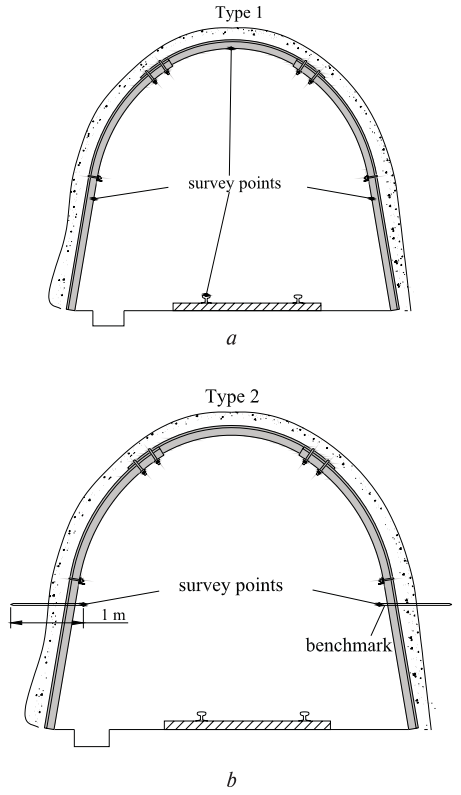

Fig. 2. Scheme of survey points in the measuring section

carried out at two positions of the horizontal circle of the tachymeter with three-time measurement of the distance to the point. Measurement accuracy of horizontal distance was 2 mm.

Laying of observation station and production of the first observations were made at the time when the face of lava 128 was at a distance of 100 m from the measuring section No. 1. In total, there were 4 sets of observations with the position of the face of 100, –17, –56 and –165 m ("–" sign indicates the removal of the face from the observation station). The diagonal arrangement of the main haulage drift with respect to the mining face line has allowed fixing spatial displacement of survey points at different distances from the mining face.

Under the influence of rock pressure, which was formed in front of a moving mining face in the undermining mine working, there occurs vertical and horizontal convergence, which reduced the "purity" of the experiment. Displacement of the survey points in the high-pressure zone of the rock pressure can be decomposed into two components: the shift caused by the movement of the rock mass and the displacement due to the convergence of mine working. To eliminate the effect of the convergence, the analysis of the results of observations is carried out not from survey points but from the center of gravity of the measuring section O. The coordinates of the center of gravity were determined by the formula

$$X_O = \frac{\sum X_i}{n}; \quad Y_O = \frac{\sum Y_i}{n}; \quad Z_O = \frac{\sum Z_i}{n},$$

where X_0, Y_0, Z_0 are the coordinates of the center of gravity; X_i, Y_i, Z_i are the coordinates of the survey points of measuring section; n is the number of the survey points in the metering section ($n = 4$).

During the second observation in the interval between sections No. 6–8 the lifting of the survey points were observed. At the same time the lifting was fixed in the soil and in the top of the development. The maximum value of lifting of the gravity center of the section was 30 mm (measuring-section No. 6), which may be caused by bending of lithological layers above the moving mining face. This phenomenon was recorded on the Earth surface at various geological characteristics of coal deposits development and significant advance rates of the working face movement [1]. Further away from the metering sections of the working face, the lifting changed by slightly lowering, whose value reached 25 mm. This demonstrates the wave nature of the load redistribution process ahead of the moving working face. Speed of the working face movement during the observation was 4–5 m/day.

According to the results of the third observation, the lifting of survey points is not fixed. This can be explained by the decrease in moving speed of the working face up to 60–70 m/month (2–2.5 m/day) and its short duration stops. Manifestation of rock pressure in the form of soil heaving and frames lowering was recorded at a distance of about 60 m. The difference in lowering the benchmarks and the survey points on frames constituted 20–30 mm. Maximum subsidence was recorded on the 9th measuring section at a distance of 5 m from the face of lava 128 (150 mm).

Fig. 3–5 show graphs of the vertical and horizontal displacements of the survey points at different distances L from the boundary developed space (of 128th construction drift). Fig. 4 shows the displacement of the center of gravity of survey sections.

The first signs of rock pressure recorded in the edge part at a distance $L = 90–100$ m from the planned projection of the contour of developed space. During the 4th observation the deformation of 2 ZMOSH at the section of emplacement of observation station ended. It was unable to perform a full range of measurements over the entire length of the profile line due to the ripping of soil of mine working between sections No. 9–13. Maximum soil lifting accounted 345 mm (6 in section), the lowering of the mine working walls – 679 mm. Vertical displacements of the of survey points at arch support racks and benchmarks at underworking of 2ZMOSH have similar values. This indicates to small quantities of convergence due to pressing racks into the soil (Fig. 3). Maximum convergence of mine working at the studied area was 1 m.

Horizontal movement $\xi^{\perp}$ in a direction perpendicular to movement of the longwall, occur in the range of –55...65 m. Their maximum value (85 mm) is fixed at a distance of 8 m from the boundary of lava 128 towards the pristine rock mass. The magnitude of the horizontal displacement of the survey points and the benchmarks are practically identical as in the case of vertical displacements. This indicates to the joint deformation of mine working support and marginal rock mass. Maximum value of $\xi^{\perp}$ is 25 % of the maximum horizontal

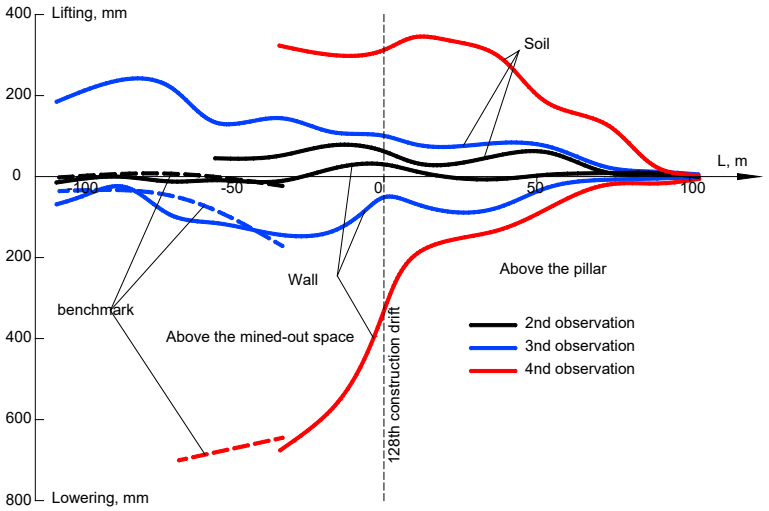

Fig. 3. Vertical displacement of survey points

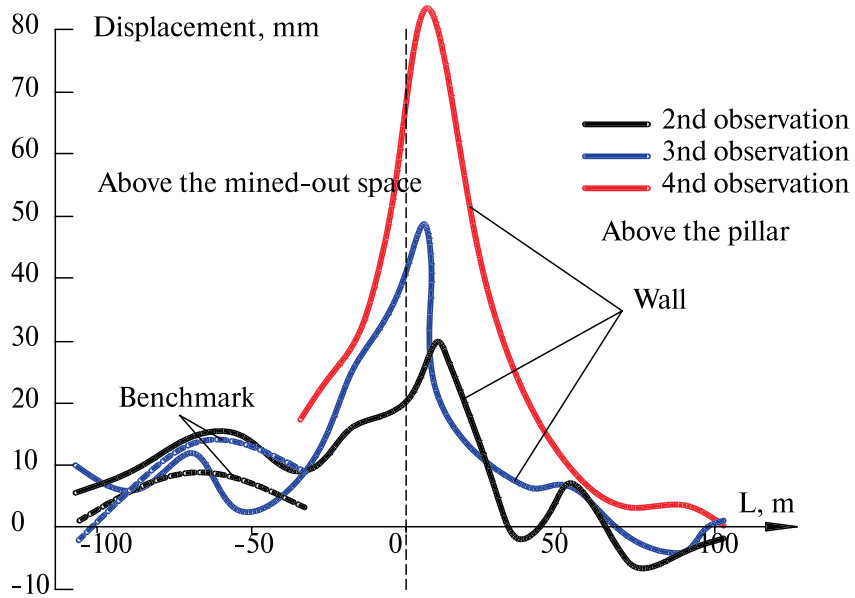

Fig. 4. The horizontal displacement of survey points in a direction perpendicular to the working face movement

displacement at the surface (320 mm) [2]. The ratio of the depth of undermining the drift and the Earth surface is 27 %. Consequently, the horizontal displacement is uniformly distributed within the underworked rock mass, linearly increasing to the earth surface.

It should be noted that the range of the spread of horizontal displacement in the direction of untouched rock mass is smaller than the vertical one. This indicates the different reasons for their formation.

Under the influence of rock pressure the walls of mine working approach each other with occurrence of the horizontal convergence. Therefore, horizontal displacement quantity $\xi_{||}$ of points in a direction parallel to the movement of the longwall (Fig. 5) are formed by two factors: by the action of the rock pressure and consequently the horizontal displacement of rock mass. It is appropriate to assume that the displacement of points of the left and right walls of mine working under the influence of rock pressure have the same values which are opposite in sign. According to this, the horizontal movement of the points caused by the movement of undermined rock mass can be defined as arithmetic average of the actually measured horizontal displacement of the left and right walls.

At the time of the second observation the survey point had the horizontal displacement in the direction of the approaching longwall (in Fig. 5 they are marked with the symbol "–"). Their maximum value was 26 mm. After passing lava 128, horizontal displacement values change their sign for the opposite one under the drift. Maximum values $\xi_{||}$ (360 mm) are fixed on the right side of mine working above the mined-out space. Further away from the borders of lava 128 their values gradually decrease and at a distance of 65–70 m from the 128th prefabricated drift the value $\xi_{||}$ equals to zero. At this point displacement of points of the left

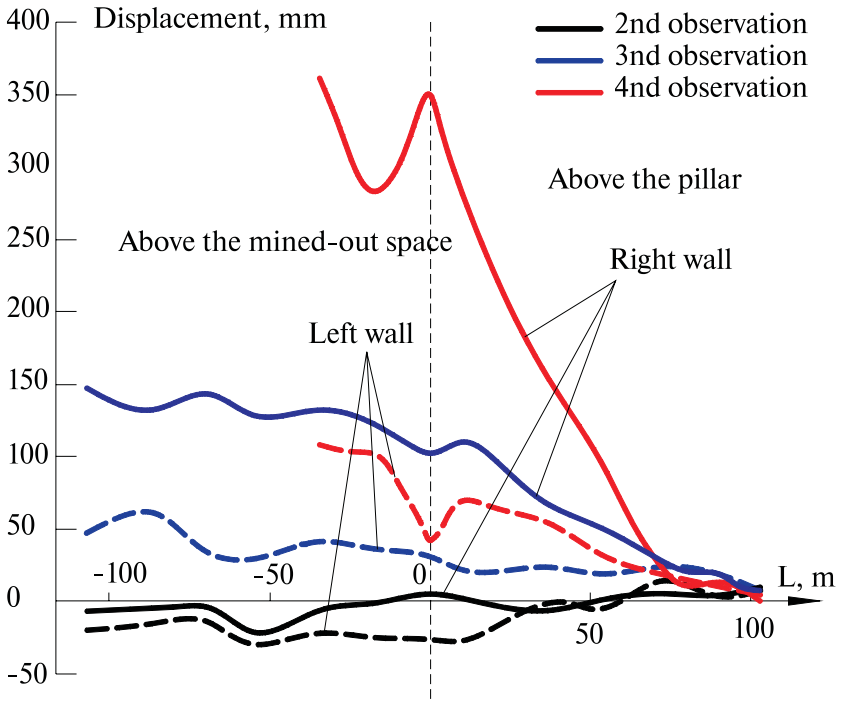

Fig. 5. The horizontal displacement of survey points in a direction parallel to movement ofthe working face

side also have positive values, but smaller in value ($\xi_{||}$ = = 120 mm). Thus, the horizontal movement of points caused by the motion of undermined rock mass was $\xi_{||}$ = 360–120 = 240 mm. The same value of the horizontal displacement was fixed on the earth surface after the passing longwalls in other mining and geological conditions at mining of coal seams in the Western Donbas. This indicates that the horizontal displacements at a distance of 80–330 m into the mined seam roof are constant.

Conclusions and recommendations for further research. The results of the analysis of the instrumental observations of the displacement of undermined rock mass allowed establishing the following regularities:

- in front of moving mining face above the center of the longwall there is the lifting of rock mass observed due to the bending of lithological layers, which is consistent with observations on the earth surface in the same geological conditions of undermining;
- after the effect of longwall on undermined rock mass, horizontal displacements are fixed at the survey points in the direction of the lava mining. The value of displacement is 240 mm, which corresponds to similar displacements on the earth surface;
- the nature of the distribution of the horizontal displacements of the survey points in the direction perpendicular to the motion of longwall is described by the symmetrical curve. Position of the point with the maximum displacement in this direction shifted toward untouched rock mass.

To develop prediction methodology of vertical and horizontal displacements of the rock mass above the mining longwall it is necessary to conduct additional instrumentals observations to determine the spatial displacement of the survey points.

References/Список літератури

1. Kolchik, E. I., Revva, V. N., Kolchik, A. E., Sofiiskii, K. K. and Kolchik, I. E., 2009. Displacement of the Earth surface at high speeds of coal seams mining. Fiziko-tekhnicheskie problemy gornogo proizvodstva: Zb. nauk. pr., Is. 12, pp. 47–54.

Сдвижения земной поверхности при больших скоростях отработки угольных пластов / Е. И. Кольчик, В. Н. Ревва, А. Е. Кольчик [и др.]; Физико-технические проблемы горного производства: Сб. научн. трудов. – 2009. – Вип. 12. – С. 47–54.

2. Kuchin, A. S., 2011. The spatial displacement of the points at undermining. *Razrabotka rudnykh mestorozhdenii*, Vol. 94, pp. 128–134.

Кучин А. С. Пространственное смещение точек при подработке / А. С. Кучин; Разработка рудных месторождений. – 2011. – Вып. 94. – С. 128–134.

Мета. Встановлення закономірностей зміни й розподілу зрушень і деформацій гірського масиву на підставі проведення маркшейдерських інструментальних спостережень при підробці магістрального штреку в умовах розробки пологих вугільних пластів у Західному Донбасі.

Методика. Для встановлення характеру просторового зміщення точок масиву гірських порід у 2-му західному магістральному відкотному штреку пласта c_5 ПСП „ШУ „Героїв Космосу“ закладена підземна спостережна станція. Штрек підроблявся очисними роботами 128-ої лави пласта c_1 потужністю 1,2 м. Глибина підробки склала 80 м. Спостереження проводилися за допомогою електронного тахеометру „TOPCON 235N“ на 13-ти перетинах, закладених на відстані близько 20 м один від одного. У кожному перетині на кріпленні закріплені чо-

тири знімальні точки: у бортах виробки, у її покрівлі та підошві. Загальна довжина спостережної станції склала 280 м. Останнє спостереження виконане при віддаленні вибою 128-ої лави на відстань 165 м. Для фіксування взаємного зміщення кріплення виробки та гірського масиву додатково закладені 3 допоміжних замірних перетини, що складалися з парних бокових реперів. Усього виконано 4 серії спостережень за різних відстаней від вибою 128-ої лави. Діагональне розташування магістрального відкаточного штреку по відношенню до лінії забою дозволило фіксувати просторове зміщення гірського масиву на різному віддаленні від очисного вибою. Для кожної серії спостережень визначалися просторові координати знімальних точок.

Результати. За результатами інструментальних досліджень встановлені просторові координати знімальних точок для кожного перетину. Для виключення впливу конвергенції на результати, аналіз спостережень виконано не по знімальних точках, а по центру тяжіння знімального перетину. На момент другого спостереження зафіксовані піднятя знімальних точок. При цьому підняття зафіксовані як у підошві, так і в покрівлі виробки. Максимальна величина підняття центру тяжіння перетину склала 30 мм. За результатами досліджень встановлено, що після проходу лави масив гірських порід змістився в горизонтальній площині у напрямку руху очисного вибою. Максимальна величина горизонтальних зміщень центру тяжіння перетину зафіксована над центром лави та склала 240 мм, що збігається з результатами інструментальних спостережень на земній поверхні. Встановлені розміри зони розповсюдження зрушень і деформацій масиву над крайовою частиною лави.

Наукова новизна. Уперше встановлені закономірності просторового переміщення гірського масиву, що підробляється над діючою лавою в умовах розробки пологих вугільних пластів.

Практична значимість. Результати досліджень за їх подальшого накопичування надають можливість розробити методику прогнозування зрушень масиву гірських порід над очисними виробками вугільних шахт.

Ключові слова: *репер, підробка, вугільний пласт, зрушення та деформації, масив гірських порід*

Цель. Установление закономерностей изменения и распределения сдвижений и деформаций горного массива на основе проведения маркшейдерских инструментальных наблюдений при подработке магистрального штрека в условиях разработки пологих угольных пластов в Западном Донбассе.

Методика. Для установления характера пространственного смещения точек массива горных пород во 2-ом западном магистральном откаточном штреке пласта c_5 ПСП „ШУ „Героев Космоса“ заложена подземная наблюдательная станция. Штрек подрабатывался очистными работами 128-й лавы пласта c_1 мощностью 1,2 м. Глубина подработки составила 80 м. Наблюдения проводились с помощью электронного тахеометра „TOPCON 235N“ на 13-ти замерных сечениях, заложенных на расстоянии около 20 м один от другого. В каждом сечении на крепи закреплены по четыре съемочных точки: в бортах выработки, в ее кровле и почве. Общая длина наблюдательной станции составила 280 м. Последнее наблюдение выполнено при отдалении забоя 128-й лавы на расстояние 165 м. Для фиксирования взаимного смещения крепи выработки и горного массива дополнительно заложено 3 вспомогательных замерных сечения, которые состояли из парных боковых реперов. Всего выполнено 4 серии наблюдений при разном удалении от забоя 128-й лавы. Диагональное расположение магистрального откаточного штрека по отношению к линии забоя позволило фиксировать пространственное смещение горного массива на разном удалении от очистного забоя. Для каждой серии наблюдений определялись пространственные координаты съемочных точек.

Результаты. По результатам инструментальных исследований установлены пространственные координаты съемочных точек для каждого сечения. Для исключения влияния конвергенции на результаты, анализ наблюдений выполнен не по съемочным точкам, а по центру тяжести съемочного сечения. На момент второго наблюдения зафиксированы поднятия съемочных точек. При этом поднятие зафиксировано как в почве, так и в кровле выработки. Максимальная величина поднятия центра тяжести сечения составила 30 мм. По результатам исследований установлено, что после прохода лавы массив горных пород сместился в горизонтальной плоскости в направлении движения очистного забоя. Максимальная величина горизонтальных смещений центра тяжести сечения зафиксирована над центром лавы и составила 240 мм, что совпадает с результатами инструментальных наблюдений на земной поверхности. Установлены размеры зоны распространения сдвижений и деформаций массива над краевой частью лавы.

Научная новизна. Впервые установлены закономерности пространственного перемещения подрабатываемого горного массива над действующей лавой в условиях разработки пологих угольных пластов.

Практическая значимость. Результаты исследований при их последующем накоплении предоставляют возможность разработать методику прогнозирования сдвижений массива горных пород над очистными выработками угольных шахт.

Ключевые слова: *репер, подработка, угольный пласт, сдвижения и деформации, массив горных пород*

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