UDC 622.23

M. V. Filatiev, Cand. Sc. (Tech.)

Donbas State Technical University, Lysychansk, Ukraine, e-mail: Mfilatev@gmail.com

DETERMINATION OF CROSS-CORRELATION DEPENDENCES BETWEEN THE PARAMETERS OF SWALLIES OF THE EARTH SURFACE AND THE MOVEMENT OF UNDERWORKED ROCKS

М.В. Філатьєв, канд. техн. наук

„Донбаський державний технічний університет“, м. Лисичанськ, Україна, e-mail: Mfilatev@gmail.com

ВИЗНАЧЕННЯ КОРЕЛЯЦІЙНИХ ЗАЛЕЖНОСТЕЙ МІЖ ПАРАМЕТРАМИ МУЛЬД ЗЕМНОЇ ПОВЕРХНІ ТА ЗРУШЕННЯМ ПІДРОБЛЕНИХ ПОРІД

Purpose. To set the correlation ratio between the parameters of underworked rocks and earth surface displacement.

Methodology. The techniques in use stipulate the selection of analytical relations to describe the curve of the ground depression. Characteristic stages of the ground depression and the corresponding parameters of displacement of underworked rocks are determined on the basis of these analytical relations. Using the results of known experimental observations linear and angular parameters are defined to characterize the ground depression and displacement of underworked rocks. Statistical analysis of the obtained data is carried out.

Findings. The crowd conditions of cross-correlation connections are set between the angular and linear parameters of settling of the earth surface and moving of the earned additionally breeds. By basic influence defining the coordinates of characteristic points of settling of the earth surface is a depth of conduct of stopping. Constancy of angular parameters is set for the considered depths in an interval of 106 ÷ 1195 m.

Originality. The formation of the upper boundary of rock displacement with a break of their continuity under the influence of the active phase of ground depression is established and confirmed by the results of statistical analysis for the first time.

Practical value. The obtained results allow predicting the stage of ground depression and the corresponding parameters of the displacement of underworked rocks.

Keywords: *ground depression, subsidence, underworked rocks, stages, linear and angular parameters*

Introduction. The most reliable consequences of the influence of working out coal seams on the earth's surface are determined on the basis of surveying measurements. To obtain experimental data, observational stations perform instrumental measurements. The spatial position of the frames of the profile line is established many times over several intervals. In parallel with observations on the earth's surface, the positions of the face are fixed. Comparison of the measurement results allows one to evaluate the displacement of the frames depending on the location of the extraction face. The excavation of coal seams, apart from the displacement of the earth's surface, causes a change in the state of the rocks. The experimental data obtained by the described method do not allow us to determine the parameters of the shift of the subsoil rocks directly. Reliable knowledge of such parameters is necessary for solving many mining problems associated with the manifestation of rock pressure. Their establishment by direct instrumental measurements in an underworked array is a laborious and financially high-cost operation. In addition, this approach does not allow predicting the parameters of rock displacement in advance when the dimensions of the excavation workings change. At present, the amount of accumulated experimental data for direct measurements in the mined rocks is not sufficient for their generalization and development of recommendations for the rational mining of coal seams in different mining and geological conditions. For this reason, analytical studies on the relationship between the parameters of the shifting of the rocks and the earth's surface are relevant.

The displacement the ground depression under its underworking of the sewage treatment works studied by the mathematical modelling of the process is considered to be a promising direction [1]. Such an approach to solving the engineers' tasks reduces the expenses on producing the immediate experimental investigations on the ground and in mine working [2]. The results of the earlier held observations by the moving of the by frame on the ground and by the development of the sewage treatment works in coal mines allow expanding the view of the process in the depth of the underworked rocks with the help of the mathematical models [3]. Such information is needed for the working of the activities on the rational underwork of the ground.

The investigations of the interdependence of the parameters of the ground moving and the moving of the

underworked rocks with the course of the mathematical models and experimental data have not taken place yet.

Analysis of the recent research. The theoretical part of the methods is based on the scheme of settling of the earth surface [4] according to the projection of the cleaning rocks (Fig. 1). In this scheme horizontally were made the distances (L) from the projection to the points of the observations. Point A corresponds to the beginning of the earth surface shifting, B – to the beginning of the active stage of the process. C – to the maximum stage of the speed of the settling, D – to the end of the active stage and F – the beginning of its considered scheme limits with point F. Its settling (η_0) is about 0.97–0.99 from the final (η_k) at finished process of the seal rocks [4].

The objectives of the article. The analyses included the results of the experimental observations of the earth settling depending on the development of the sewage treatment works, these results were obtained at mines "Belozerskaya" (bench Mark 132) [4], "Stepnaya" (3, 4, 5, 7, 8, 9, 11, 16, 23, 34, 37, 42, 43) [From works by Larchenko V. G. Impact of underground mining of coal seams on the state of the Earth's surface], "Gramoteinskaya" (40, 30, 28, 28) [5], Appalach coal pool (1, 2, 3, 4) [6] , "Yubileynaya" (24) [7], № 22, Komunarskaya (13) [8], Roorsk pool, layer Grimberg 2/3, lava 31 [From works by Gavrilenko Yu. N. Dynamics of subsidence Earth's surface at great depths and high development face advance rate], "Stashits", layer 352, lava 1002 [From works by Gavrilenko Yu. N. Dynamics of subsidence Earth's surface...], after A. F. Zasyadko (1), layer m^3, 13th west lava [From works Gavrilenko YU. N. Dynamics of subsidence Earth's surface...], after S. M. Kirov [From works by Avershin S. G. Displacement of rocks and the earth surface in the principal coal fields of the USSR]. The methods for the working out of the experimental data with the aim of the analytical description of the curve (2) of the settling of the points of the ground (Fig. 1) are shown in the work [9]. This curve for all objects is functionally described by the logistics, exponential or hyperbolic tangent of the dependence. In all cases the correlation relation was about 0.99.

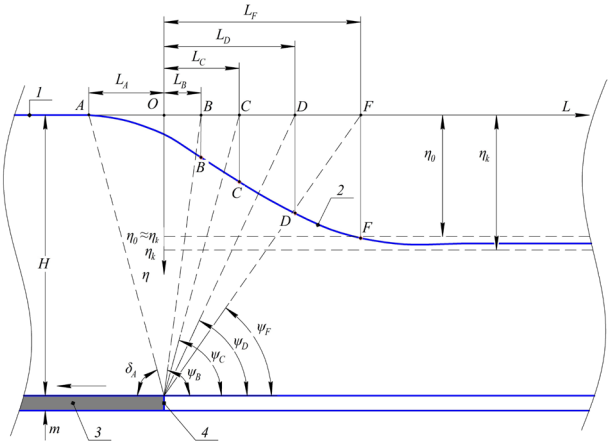

Fig. 1. The scheme of the settling of the earth surface according to the projection of the cleaning rocks:

1 – the earth surface; 2 the curve of the trajectory of the settling of the points of the earth; 3 – worked out layer; 4 – sewage treatment rock; m – the power of the worked out layer; H – the depth of the sewage treatment works; A, B, C, D, F are distinguished points of the curve of the ground depression; 0 – the point of the target with sewage treatment rock and the corresponding points A, B, C, D, F; dA – a boundary angle corresponding to the beginning of the earth shifting at point A; YA, YB, YC, YD, YF – the angle of the moving of the underworked rocks which determine the location of points B, C, D, F; η_0 – the depth of the flat bottom of the swales till the seal rocks; ← – the direction of the moving of the sewage treatment rock; C – maximum stage of the speed of the settling; D – the end of the active stage and the beginning of its considered scheme limits with point F. Its settling (η_0) is about 0.97–0.99 from the final (η_k) at finished process of the seal rocks; ← – the direction of the moving of the sewage treatment rock

Unsolved aspects of the problem. Using the principles of the identifying the stages of the process of the earth settling with the help of the derivatives [4], were counted for all three dependences of the distance between the projection of the sewage treatment breed and corresponding points (Fig. 1) of the curve of the ground depression L_A, L_B, L_C, L_D, L_F. Their meanings are counted according to these equations; they were closed to each other. In further calculations were used average meanings $\overline{L}_A$, $\overline{L}_B$, $\overline{L}_C$, $\overline{L}_D$, $\overline{L}_F$ (Table 1). The table provides the data on the power of the worked out layer (m), depth of the bedding (H) and H/m for each object of the observations. Using the meaning of the depth H and location of the certain points of the curve of the depression trajectory of the ground (*A, B, C, D, F*) other analysed parameters were determined.

Presentation of the main research. The boundary angles (dA) show the beginning of the moving of the ground and were identified from point A according to the projection of the sewage treatment rock (distances L_A). The angles of the moving of rocks (ψ_B, ψ_C, ψ_D, ψ_F) corresponding to different stages (points *B, C, D, F*) of the ground settling were determined according to the estimated scheme (Fig. 1). The site of the curve A–B corresponds to the primary period of the ground settling under the influence of the moving sewage treatment rock. The most active earth settling is on the site B–D, but at point C the maximum speed of the settling and curve bend is reached. Point D corresponds to the end of the active stage and transform to the attenuation of the process of the moving ground. At point F maximum settling is reached and further moving of sewage treatment rock practically does not influence the process of moving of the unworked rocks and ground.

The location of certain points of swallies on the ground (*B, C, D, F*) together with the angle Y_F gives a possibility to judge about the suggested height of expanding of moving of rocks with the gap of their continuity according to the sewage treatment rock (Fig. 2). If to come off the assumption about a possibility of the formation of zones of the underworked rocks with the gap of their continuity in the period of the active stage of moving of the ground, in general case the limit of its zones, the boundary, will be determined by the parameter H_D. The location of point D corresponds to the be-

Table 1

The information on the mining and geological conditions and average parameters for making the correlation analysis

The mine, the layer, literally source	m, m	H, m	H/m	The certain points of swallies of the earth surface (Fig.1)												
				A		*B*			*C*			*D*			*F*	
				$\bar{L}_A$, *m*	δ_A, degrees	$\bar{L}_B$, *m*	ψ_B, degrees	H_B, *m*	$\bar{L}_C$, мм	ψ_C degrees	H_C, *m*	$\bar{L}_D$, *m*	ψ_D degrees	H_D, *m*	$\bar{L}_F$, *m*	ψ_F degrees
"Belozerskaya", [4]	1.30	420	323	169	68	8	89	9	76	80	87	171	68	197	361	49
"Stepnaya", C_6 [From works by Larchenko V. G. Impact of underground mining...]	0.91	106	116	37	71	9	85	9	27	76	28	51	64	53	103	46
"Gramoteinskaya" [5]	4.50	220	49	57	75	43	79	40	82	70	76	137	58	128	237	43
Appalach coal pool, [6]	1.65	220	133	28	83	49	77	53	79	70	57	122	61	131	201	47
"Yubileynaya", C_6, [7]	1.00	150	150	34	77	24	81	27	46	73	51	77	63	86	135	48
No. 22 "Komunarskaya", K_3, [8]	1.47	652	444	178	75	91	82	101	200	73	222	337	63	374	595	48
A. F. Zasyadko, m_3, [From works by Gavrilenko Yu. N. Dynamics of subsidence Earth's surface...]	2.10	1195	569	292	76	129	84	154	356	73	424	547	65	652	1010	50
"Stashits", 352, [From works by Gavrilenko Yu. N. Dynamics of subsidence Earth's surface...]	2.10	480	229	126	75	8	89	14	60	87	108	128	83	231	263	61
Roorsk pool, layer Grimberg ⅔, [From works by Gavrilenko Yu. N. Dynamics of subsidence Earth's surface...]	2.20	920	418	253	75	36	88	51	151	81	272	308	72	440	636	55
After S. M. Kirov, [From works by Avershin S. G. Displacement of rocks and earth surface...]	1.70	205	121	30	82	8	88	19	23	84	54	44	78	104	86	67

ginning of the allocation of the ground settling. For this reason it is hard to believe that intensive moving of the unworked rocks under the side of the curve *D–F*. Depending on strength qualities of the contained rocks, the upper boundary of zones of underworked rocks may be situated in the range of H_B–H_D under the site *B–D* of the curve of the half-swallies. The counted values of the parameters H_B, H_C and H_D for the mines of different coal pools are given in Table 1. The given data allowed counting the coefficients for mutual correlation for sixteen parameters *m*, *H*, *H/m*, $\bar{L}_A$, $\bar{L}_B$, $\bar{L}_C$, $\bar{L}_D$, $\bar{L}_F$, δ_A, ψ_B, ψ_C, ψ_D, ψ_F, H_B, H_C, H_D (Table 2).

The absolute values of the coefficients of the correlation r allow rating the closeness of the concentration between analysed parameters. For a considered sample of the original data the influence of the power of layers on other parameters is not fixed ($r = 0.06 \div 0.26$).

The main factor affecting the values $\bar{L}_B$, $\bar{L}_C$, $\bar{L}_D$ and $\bar{L}_F$ is the depth (*H*) of the making sewage treatment works $r = 0.71 \div 0.97$. The element *H* has the functional influence on the parameters H_C and H_D, which are corresponded to $r = 0.98$ and 0.99. The influence of *H* on the parameter *HB* is a little bit smaller ($r = 0.78$). There is no connection between *H* and angle parameters (δ_A, ψ_B, ψ_C, ψ_D, ψ_F), as value r was in the rate of $0.07 \div 0.27$.

This indicates on some continuity of the angle parameters for considered depths in the internal of 106–1195 m. The influence of complex parameter (*H/m*) differed only a bit from the influence of *H*. The great scientific and practical interest relates to the continuity of the correlative connection between linear and angle parameters of the considered scheme (Figs. 1, 2).

For $\bar{L}_A$ the connection with all angle parameters ($r = 0.04 \div 0.38$) was absent, but it was significant with other linear elements $\bar{L}_B$, $\bar{L}_C$, $\bar{L}_D$, $\bar{L}_F$ ($r = 0.60 \div 0.94$). Practically the functional dependence was fixed with $\bar{L}_D$ and $\bar{L}_F$, for which the values of *r* were equal to 0.91 and 0.94. The powerful, strong connection of $\bar{L}_A$ occurred with H_C ($r = 0.92$) and with H_D ($r = 0.94$), but it was weaker with H_B ($r = 0.66$).

The same connection, in comparison with $\bar{L}_A$, was fixed for $\bar{L}_B$ with the angle ($r = 0.15 \div 0.55$) and linear ($\bar{L}_A$, $\bar{L}_B$, $\bar{L}_C$, $\bar{L}_D$) parameters ($r = 0.60 \div 0.93$). The element $\bar{L}_B$ functionally determines the possible boundaries of the rocks moving (H_B, H_C, H_D) with the gap of their continuity $r = 0.79 \div 0.99$.

The close correlative dependence $\bar{L}_C$, $\bar{L}_D$, $\bar{L}_F$ was fixed with all the rest linear parameters $\bar{L}_A$, $\bar{L}_B$, H_B, H_C, H_D. For them $r = 0.83 \div 0.99$. With angle parameters the correlation was absent $r = 0.02$–0.30. The boundary angle δ_A is not connected with moving angles ψ_B, ψ_C, ψ_D, ψ_F, ($r = 0.06 \div 0.43$), but the moving angles are closely connected with each other $r = 0.68 \div 0.97$. Among all fixed connections the most exponential is the depen-

Table 2

The results of identifying the coefficients of correlation between the parameters of swallies and ground moving and sewage treatment rocks moving

Parameters	The meaning of correlation coefficients															
	m	*H*	*H/m*	Point *A*		Point *B*			Point *C*			Point *D*			Point *F*	
				$\bar{L}_A$	δ_A	$\bar{L}_B$	ψ_B	H_B	$\bar{L}_C$	ψ_C	H_C	$\bar{L}_D$	ψ_D	H_D	$\bar{L}_F$	ψ_F
m	1.00	0.10	0.16	0.06	0.08	0.17	0.26	0.13	0.13	0.20	0.13	0.13	0.17	0.11	0.12	0.14
H	0.10	1.00	0.94	0.97	0.13	0.71	0.27	0.78	0.90	0.07	0.98	0.95	0.13	0.99	0.97	0.10
H/m	0.16	0.94	1.00	0.95	0.25	0.69	0.30	0.75	0.87	0.05	0.91	0.92	0.08	0.94	0.94	0.03
$\bar{L}_A$	0.06	0.97	0.95	1.00	0.35	0.60	0.38	0.66	0.83	0.13	0.92	0.91	0.14	0.94	0.94	0.04
δ_A	0.08	0.13	0.25	0.35	1.00	0.15	0.43	0.18	0.04	0.14	0.06	0.12	0.06	0.09	0.17	0.35
$\bar{L}_B$	0.17	0.71	0.69	0.60	0.15	1.00	0.39	0.99	0.93	0.55	0.82	0.88	0.42	0.79	0.83	0.32
ψ_B	0.26	0.27	0.30	0.38	0.43	0.39	1.00	0.30	0.08	0.91	0.13	0.02	0.82	0.18	0.10	0.68
H_B	0.13	0.78	0.75	0.66	0.18	0.99	0.30	1.00	0.96	0.46	0.87	0.91	0.32	0.85	0.87	0.22
$\bar{L}_C$	0.13	0.90	0.87	0.83	0.04	0.93	0.08	0.96	1.00	0.30	0.96	0.99	0.21	0.95	0.97	0.18
ψ_C	0.20	0.07	0.05	0.13	0.14	0.55	0.91	0.46	0.30	1.00	0.08	0.21	0.97	0.02	0.14	0.85
H_C	0.13	0.98	0.91	0.92	0.06	0.82	0.13	0.87	0.96	0.08	1.00	0.98	0.00	0.99	0.98	0.01
$\bar{L}_D$	0.13	0.95	0.92	0.91	0.12	0.88	0.02	0.91	0.99	0.21	0.98	1.00	0.14	0.98	0.99	0.14
ψ_D	0.17	0.13	0.08	0.14	0.06	0.42	0.82	0.32	0.21	0.97	0.00	0.14	1.00	0.06	0.08	0.92
H_D	0.11	0.99	0.94	0.94	0.09	0.79	0.18	0.85	0.95	0.02	0.99	0.98	0.06	1.00	0.99	0.04
$\bar{L}_F$	0.12	0.97	0.94	0.94	0.17	0.83	0.10	0.87	0.97	0.14	0.98	0.99	0.08	0.99	1.00	0.10
ψ_F	0.14	0.10	0.03	0.04	0.35	0.32	0.68	0.22	018	0.85	0.01	0.14	0.92	0.04	0,10	1.00

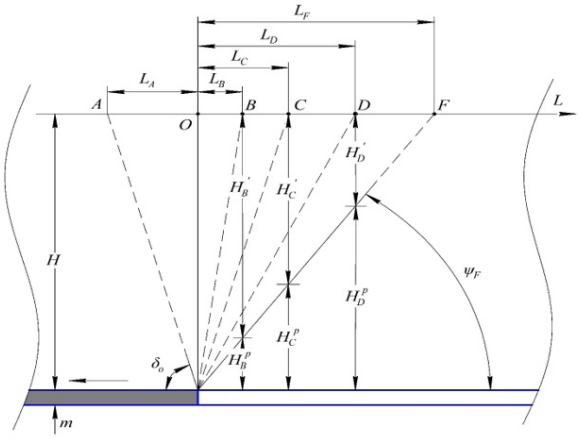

Fig. 2. The scheme to identifying the boundaries of the zones of the moving of underworked rocks with a gap of their continuity with the usage of the parameters of swallies of the ground (L_B, L_C, L_D, L_F) and the moving angle ψ_F:

H_B, H_C, H_D – the height of the possible expanding of the zone of the earned underworked rocks moving with the gap of the continuity according to the certain points B, C and D of the ground; H_B', H_C', H_D' – the power of rock layers without gap of their continuity; for the rest signs consult Fig. 1

dence of $\overline{L}_A$ on $\overline{L}_F$ (Fig. 3). The parameters characterize the beginning and the ending of the ground moving according to the projection of the sewage treatment rock. On average $\overline{L}_F$ is three times as big as the size $\overline{L}_A$.

The conclusion. On the basis of the results of the correlative analysis we can make the conclusion that contribute to the increasing of the quality of the mathematical modelling of the ground moving and underworked rocks:

- the main factor that determines linear parameters of $\overline{L}_A$, $\overline{L}_B$, $\overline{L}_C$, $\overline{L}_D$, $\overline{L}_F$ of the swallies of earth surface is the depth of the sewage treatment works;

- the power of the working layers in the rate of 0.91 ÷ 4.50 m and depth of rocks working in the interval

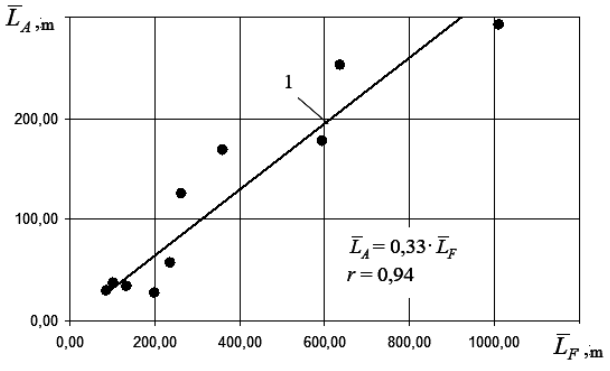

Fig. 3. Schedule of mutual dependence of linear parameters $\overline{L}_A$ and $\overline{L}_F$, that determined the beginning and the ending of the ground moving. The meaning of parameters which were obtained basically on experimental data, 1 – average direct; r – correlation coefficient

of 106 ÷ 1195 m hardly influenced all linear parameters $\overline{L}_A$, $\overline{L}_B$, $\overline{L}_C$, $\overline{L}_D$, $\overline{L}_F$, H_B, H_C, H_D;

- angle parameters δ_A, ψ_B, ψ_C, ψ_D и ψ_F do not depend on the depth of the working. For practical usage their average values $\overline{\delta}_A = 77^\circ$, $\overline{\psi}_B = 84^\circ$, $\overline{\psi}_C = 77^\circ$, $\overline{\psi}_D = 68^\circ$ и $\overline{\psi}_F = 53^\circ$ may be recommended that makes the identification of the location of the certain points of the ground easier;

- according to the element of the angle ψ_F and location of certain points *B, C* and *D* of swallies of earth surface the upper boundary of earned additionally rocks with the gap of their continuity may be approximately determined.

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Мета. Встановити значимість факторів, що впливають на зрушення земної поверхні при очисних роботах.

Методика. Підбір аналітичних залежностей для опису кривої осідання земної поверхні. Встановлення на їх основі характерних стадій осідання земної поверхні й відповідних ним параметрів зрушення підроблених порід. Використовуючи результати відомих експериментальних спостережень, визначили лінійні й кутові параметри, що характеризу-

ють осідання земної поверхні та зрушення підроблених порід. Виконана статистична обробка отриманих даних.

Результати. Встановлена тіснота кореляційних зв'язків між кутовими й лінійними параметрами осідання земної поверхні та зрушенням підроблених порід. Основним чинником, що впливає, який визначає координати характерних точок осідання земної поверхні, є глибина ведення очисних робіт. Встановлена постійність кутових параметрів для розглянутих глибин в інтервалі 106 ÷ 1195 м.

Наукова новизна. Уперше встановлені й підтверджені результатами статистичної обробки формування верхньої межі зони зрушення порід із розривом їх сплошності під впливом активної стадії осідання земної поверхні.

Практична значимість. Отримані результати дозволяють прогнозувати стадії осідання земної поверхні й відповідні ним параметри зрушення підроблених порід.

Ключові слова: *земна поверхня, осідання, підроблені породи, стадії, лінійні й кутові параметри*

Цель. Определить значимость факторов, влияющих на сдвижение земной поверхности при очистных работах.

Методика. Подбор аналитических зависимостей для описания кривой оседания земной поверхности. Установление на их основе характерных стадий оседания земной поверхности и соответствующих им параметров сдвижения подработанных пород. Используя результаты известных экспериментальных наблюдений, определили линейные и угловые параметры, характеризующие оседание земной поверхности и сдвижение подработанных пород. Произведена статистическая обработка полученных данных.

Результаты. Установлена теснота корреляционных связей между угловыми и линейными параметрами оседания земной поверхности и сдвижением подработанных пород. Основным влияющим фактором, определяющим координаты характерных точек оседания земной поверхности, является глубина ведения очистных работ. Установлено постоянство угловых параметров для рассмотренных глубин в интервале 106 ÷ 1195 м.

Научная новизна. Впервые установлено и подтверждено результатами статистической обработки формирование верхней границы зоны сдвижения пород с разрывом их сплошности под влиянием активной стадии оседания земной поверхности.

Практическая значимость. Полученные результаты позволяют прогнозировать стадии оседания земной поверхности и соответствующие им параметры сдвижения подработанных пород.

Ключевые слова: *земная поверхность, оседание, подработанные породы, стадии, линейные и угловые параметры*

Рекомендовано до публікації докт. техн. наук М. І. Антощенком. Дата надходження рукопису 22.01.16.