Interaction of deformation-strength characteristics of the support load-bearing elements in the preparatory workings

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Abstract. The objective of this work is to study the relationship of the deformation-strength characteristics of the fastening system with its displacement value. The tendencies of influence are divided into two groups. The multivariate computational experiments have been performed in the conditions of coal-face works. It is shown the influence of geomechanical conditions of the mine working maintenance on the fastening system operating mode change when choosing its rational deformation-strength characteristics. On the basis of the performed studies, it was concluded that it is necessary to adjust the fastening elements of each specific support setting scheme. This is necessary to provide recommendations for the maintenance schemes optimization of reusable extraction workings.

1 Introduction

The deformation-strength characteristics of the fastening system in the preparatory working is represented in the form of a function $q(u)$, which indicate the relationship between the bearing reaction q of support and its displacement value, and under the influence of the rock pressure manifestations during coal-face works. Therefore, the research was carried out from the point of view of the evaluation of the relationship between the deformation-strength characteristics of the preparatory working fastening system and the degree of its stability during the breakage face driving in the area from the bearing pressure zone in front of the longwall to the zone of the displacement processes stabilization in the coal-overlaying strata behind the longwall. At the same time, the relations of different forms of rock pressure manifestations were taken into account. For example, weakening of extensive rock volumes in the sides of mine working leads to a more intense lowering of the roof rock layers, and the same weakening of the side rocks and the formation of increased lateral rock pressure deforms the frame prop stays that leads to sudden drop of its load-bearing

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capacity. This, in turn, increases the loading on the reinforcement support prop stays with the probability of subsequent loss of their stability [1]. Thus, the revealed diversity of the rock pressure manifestation features requires consideration of the relationship between separate geomechanical processes in the following fields of study:

– interaction of rocks weakening in the sides of mine working and the processes of stratification and lowering of the roof rock layers;

– coupling of the bolting strengthening in the sides of mine working with that in its roof and setting the rational resistance modes of the formed armour-clad and rock structure as one of the fastening system elements;

– providing the operating modes synchronization of the fastening system constituent elements with each other and the search for its rational deformation-strength characteristics, depending on the geomechanical conditions for the extraction working maintenance in the zone of coal-face works influence.

The variety of mining and geological conditions for the maintenance of the preparatory workings and their fastening systems structures intensifies the need for a complex of multivariate computational experiments to reveal the regularities which are of interest to us [2, 3]. A wide range of trends in the influence of deformation-strength characteristics $q(u)$ of the fastening system elements on their state may be divided into two groups:

– patterns of the general function $q(u)$ relation for the fastening system as a whole and for its individual elements $q_i(u_i)$ with the main geomechanical factors of the mine working maintenance (mining depth, stress-strain properties of rocks in the adjacent coal-bearing strata, its structure and the structure of roof rocks in the mined-out area);

– patterns of mutual influence on each other of functions $q_i(u_i)$, making up the fastening systems of elements (i – element number).

Such a division, in our opinion, will enable a more systematic approach to assessing the effect of the fastening system operating mode on the extraction working stability and the prospects for its reuse.

2 The research problem setting

By now, a great deal of results of computational experiments have been accumulated which represent the trends of the geomechanical factors influence on the mine working support state [4, 5]. But our task involves consideration of patterns from a slightly different point of view, namely: the manner in which the geomechanical conditions of the mine working maintenance influence on the fastening system operating mode change in terms of determination of its rational deformation-strength characteristics [6]. Here it should be kept in mind the following. In normative documents [7, 8], the prediction of displacements does not consider the support reaction to restraint of displacements, and the loading value P upon the support is determined from the displacement coordinate $u = u_{max}$ with a certain margin in the direction of increasing. Any computational experiments using the finite element method (FEM) consider automatically the fastening system reaction to the mine working rock contour displacements. But, what is more, each calculation is carried out for a specific bearing reaction q at a specific yielding value u of each element of the fastening system. In such a way, we have not the entire picture of the loading P relationship with the deformation-strength characteristics $q(u)$. Hence, the problem of support operating mode optimization (even for mine working outside the zone of coal-face works influence) still requires its final solution. The complexity of solving the problem for the fastening system operating mode optimization in the zone of coal-face works influence is caused by two factors:

– firstly, the large volumes of coal-bearing massif with extensive areas of complete destruction, weakening and change of the original lithotypes structure are many times involved in the process of enclosing rocks displacement;

– secondly, the fastening system usually includes more elements and much more diverse; a safe-guard system with its structural features is added to it.

In view of the above mentioned factors, the complexity of the study and description of the geomechanical processes of the coal-overlaying strata displacement, the method of multivariate computational experiments performance is truly effective (in terms of adequacy). On the one hand, this method only gives a particular result in the calculation of the specific geomechanical model. But, on the other hand, having carried out a number of computational experiments with variation of any parameter, we can get a certain tendency of this parameter influence, and it can be expressed in the form of a certain rational interval or directly as a regression equation of the studied parameter relationship with other parameters in the geomechanical system.

In this respect, the results of both separate computational experiments and their purposeful series are of interest, which are stated, for example, in the works [9, 10 – 13]. Thus, in studies [9], the development of rock pressure manifestations (in the vicinity of preparatory workings) was studied in the process of breakage face advance: the tendencies were traced of the parameters change in the unloading zone and the bearing pressure zone, the growth of the loading on the elements of fastening system and safe-guard system of the drift. The logical result of research was the creation of calculation methods and methods for parameters choice of support setting means and extraction drift safe-guard with the purpose of their reuse.

Taken together, the two analysed works [9, 10] created the basis for the technical documentation development for reused extraction drifts maintenance in the Western Donbas mines. But, there is a common drawback: there are no criteria to optimize the deformation-strength characteristic for both the maintenance scheme individual elements, and the operating modes of the fastening and safe-guard system as a whole. That is, the issues of the function $q(u)$ relationship with geomechanical factors and the choice of the most effective operating mode of the maintenance scheme elements in specific mining and geological conditions, are not considered.

This setting is more complex and requires multiple expansion of the computational experiments variants. Therefore, attention is focused on separate fragments of the study of the relationship between the fastening system operating mode (and its elements) and the geomechanical parameters of the maintenance conditions for the extraction workings after the breakage face driving.

3 Mining depth influence on the fastening system state in the preparatory working

At the first stage, the fragments of influence of the mine working location depth H on the change of the load-bearing elements state for its maintenance under the angle of estimating the degree of rationality of these elements deformation-strength characteristics. Two variants of computational experiments with unchangeable structure and properties of the coal-bearing strata, the mine working dimensions and the design parameters of its maintenance scheme, have been carried out. The only difference is in mine working location depth: first calculation – $H = 300$ m, second calculation – $H = 450$ m; that is, the compared variants differ from each other by an increase in the mine working location depth by 50%.

The analysis of the state of mine working maintenance scheme elements has been started with consideration of the vertical stresses curves σ_{coal} (Fig. 1).

a *b*

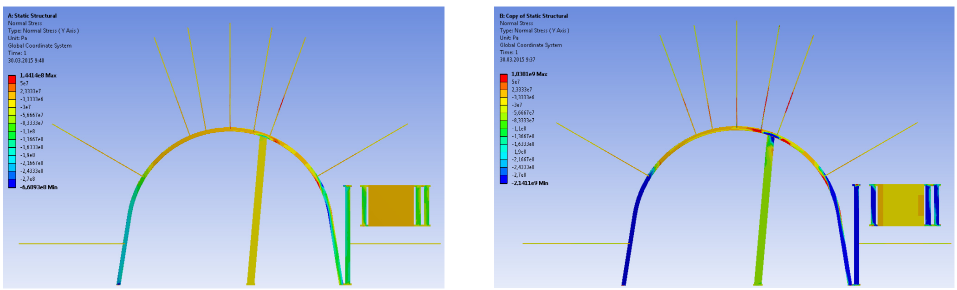

Fig. 1. Example of vertical stresses σ_{coal} distribution in fastening and safe-guard system of the preparatory working in dependence of the depth H of its location: a – $H = 300$ m; b – $H = 450$ m.

The component σ_{coal} distribution in the frame support (regardless of depth H) represents the specifics of load action in conditions of mine workings maintenance in the Western Donbas mines to the full extent: mainly unloaded state of the frame cap at high σ_{coal} in its prop stays. In the frame cap at $H = 300$ m (see. Fig. 1a) low σ_{coal} from 20MPa of tensile to 30MPa of compression are observed. The exception is the part of the cap length in the area of contact with the central wooden prop stay of the reinforcement support; here the compressive σ_{coal} increases up to 80 – 100 MPa, and tensile σ_{coal} increases up to 50 – 70 MPa. With an increase in the mine working location depth ($H = 450$ m) for the most part of its length, the frame cap is still unloaded with insignificant changes of σ_{coal}. But the part of the cap length, where there is an impact of the central prop stay of the reinforcement support, have expanded significantly; there the fluctuations in the absolute value σ_{coal} increased, especially in the compression area – to 250 – 300 MPa, and this causes the formation of creepage zones in the cap. In addition, the effect of alternating-signs of the bending moments is clearly manifested (4 maximums along the length to 1.1 m) with the greatest value along the length of a contact with the wooden prop stay. And this value causes plastic bending of a cap (see Fig. 1b).

The given results of the H parameter influence are consistent with the existing ideas about the geomechanical processes development in the vicinity of mine workings. But we focus on the above mentioned trends in terms of the rationality of the deformation-strength characteristics $q(u)$ of the frame cap. The mainly unloaded state of the cap can be explained by the action of a number of factors, two of which are predominant.

The first is strengthening of adjacent roof layers with bolting systems, as a result of which the formed load-bearing armour-clad and rock plate rests on the side rocks in the virgin massif, from one side, and on the safe-guard structure from the side of the worked out area. With the relative integrity of the armour-clad and rock plate, the deflection of the central part of its span is low and in joint deformation mode with a cap there are no significant vertical forces on the contact. It happens, specifically, because of the damping effect of the easily deformed weakened rocks in the fastened space and simply due to the gaps which appear between the frame cap and the rock contour. Consequently, the frame cap is always underloaded without tight contact with the armour-clad and rock plate.

The second is a cap, which due to the yielding joints actuation “leaves” from the rock pressure in the roof until the yield margin is used up, and its components are: construction yield of the frame support (for example, TSYS series), pressing-in of the frame prop stays into the soft bottom rocks, gaps between the cap and rock contour of the mine working, and others. The total value of vertical yield can reach 0.5 – 0.8 m (sometimes even more) and it is quite enough to compensate for any kind of armour-clad and rock plate deformations if it is in a stable state. The only alternative for the full loading of the frame cap is the formation of ultimate rock equilibrium from the destroyed incoherent rocks in the vast arch roof. These rocks with their weight, in case of collapse behaviour, form a vertical pressure which does not depend on the frame yield.

The scheme of this process is shown in qualitative terms in Fig. 2 and is as follows. In accordance with the classical ideas, the loading on the support is formed as a result of the interaction between the adjacent rock massif, which is weakened and increased in volume (lines $1f$ and $1d$), and the formation of an unstable volume of rocks within the dome of natural equilibrium (lines $2f$ and $2d$). The index “f” was assigned to a more “favourable” variant of mine working maintenance at the depth of $H = 300$ m; index “d” refers to more “difficult” conditions and corresponds to $H = 450$ m. The points A_f and A_d characterize the minimum possible loads P_f and P_d, respectively, in favourable and difficult mining and geological conditions.

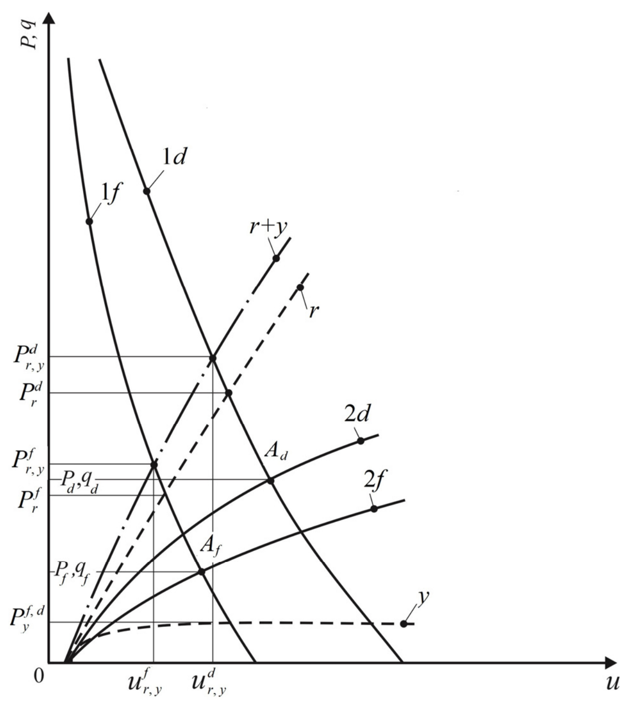

Fig. 2. The scheme of the loading, formed on the rigid (r) and yielding (y) components of the general fastening system in the mine working: $1f$ and $1d$ – deformation-strength characteristics of the weakening massif near the mine working contour in favourable (f) and difficult (d) mining and geological conditions; $2f$ and $2d$ – deformation-strength characteristics of natural equilibrium dome rocks; – – – deformation-strength characteristics of the rigid (r) and yielding (y) components of the fastening system; – · – general deformation-strength characteristics of the fastening system.

Dotted lines show the deformation-strength characteristics $q(u)$ for the rigid (index "r") and yielding (index "y") components of a single fastening system of the mine working, but chain-dotted line shows the general deformation-strength characteristics of the fastening system. As is obvious, the functions $q(u)$ for the rigid and yielding components are far from the optimal and do not pass through points A_f and A_d. It is expected that the rigid component takes over the bulk of the loading under any conditions, and their deterioration results in the loading growth ($P_r^d > P_r^f$) practically on a rigid component, whilst the yielding component is in approximately the same ($P_y^f \approx P_y^d$) conditions of load action.

The significant curve σ_{coal} changes in the frame cap happen in the area of setting the reinforcement support central prop stays: they abruptly increase the rigidity of a cap in the vertical direction and the component σ_{coal} is immediately amplified with an increase in H (see Fig. 1).

The very central prop stay is a rather rigid element, even with account of the crushing of wooden backings under the cap of the frame and under the footing of the prop stay. And if so, an increase of H by 50% (according to [5], a similar increase in the lowering of the roof rocks is predicted) should cause a sudden increase in stresses σ_{coal} in accordance with the developed scheme in Fig. 2.

When analyzing the curve σ_{coal} (see Fig. 1) in the central prop stays of the reinforcement support, it should be noted that at $H = 300$m $\sigma_{coal} \leq 30$ MPa; at $H = 450$ m $\sigma_{coal} \leq 83$ MPa. That is, there is an increase in stresses σ_{coal} by 2.7 – 2.8 times with an increase in H by 1.5 times. Therefore, there is a more intensive growth of σ_{coal} in the rigid element (in this case in a wooden prop stay), than an increase in the depth of mine working location. Although, for the sake of objectivity, it is necessary to consider that $\sigma_{coal} = 50 - 60$ MPa are already destructive for such wood, as redwood: most likely there is "fringing" of the wooden prop stay butt ends and its breakdown caused by bending.

A further fastening element in assessing of σ_{coal} at different H is the frame support prop stays. The common feature (regardless of H) is as follows:

– gradual growth of σ_{coal} happens in the frame prop stays, beginning with the yielding joint, and already at the end of the curvilinear part of the stress it reaches a maximum;

– in the prop stay from the side of virgin massif the maximum values of compressive σ_{coal} are distributed uniformly both along the length and in the cross section of SCP, and this indicates that there is no significant bending moment;

– in the prop stay from the side of mined-out area, the effect of a number of bending moments is clearly manifested (by its height): maximal one is in the curvilinear part of the prop stay and minimal one – in its footing area.

In quantitative terms: at $H = 300$ m maximal value of compressive σ_{coal} amounts to 190 – 210 MPa, at $H = 450$ m σ_{coal} increase to 270 – 300 MPa. That is, an increase from 40 to 45% is observed, which corresponds approximately to 50% increase in the depth of mine working location. These results will be analysed from the point of view of the frame prop stays operating mode. On the one hand, a loading is delivered on the prop stays, which is "collected" by the frame cap, and in this regard we can speak of a sufficient its independence from H, that is, of the yielding operating mode. But, on the other hand, the TSYS support construction is characterized by a certain inclination of the prop stays to the central axis of the drift; the vertical load acts on the width of this slope, and the prop stay, as such, does not already have a yielding node, because it is located higher – in the junction with the cap. Consequently, the frame prop stay operates in a rigid mode, but only in relation to the specified part of the loading on it. In general, the operating mode of the frame prop stay can be called "intermediate" by nature, as it is anywhere from rigid to yielding mode.

As a result, three operating modes of the fastening elements have been identified only by one SCP frame with the reinforcement support prop stay: rigid, yielding and intermediate. Obviously, the fastening elements, which operate in three different modes, are difficult to optimize from the point of view of achieving the conditions for forming a minimum loading on the drift fastening system.

In addition to the studied elements, there are two more elements in this fastening system – resin-grouted roof bolts and lateral prop stays of the reinforcement support, set on the border of the berm. These prop stays have a rigid working characteristic and the ratio σ_{coal} in favourable and difficult mining and geological conditions, which is similar to that for rigid structures.

A certain specificity of tensile σ_{coal} growth (in the range of $H = 300 - 450$ m) is observed in resin-grouted roof bolts, set in the mine working roof. The very tension area in the roof bolt gives evidence of its resistance to roof rocks stratification in the process of armour-clad and rock plate formation. When comparing the tension areas σ_{coal} length, their growth in all the roof bolts of the roof with an increase in the depth of the mine working location, is clearly manifested.

In conclusion of the tendencies analysis of the connection between the fastening system elements operating modes and mine working location depth, the stress intensity curves σ have been studied, since one curve σ_{coal} does not fully characterize the stress condition.

First of all, we can note that there are preserved all above mentioned tendencies of fastening system elements stress growth with an increase in H.

In the frame cap at $H = 450$ m an area of plastic deformations appears in the place of contact with the reinforcement support prop stay; here the cap bending is possible, though at $H = 300$ m this is not observed. The tension in the cap increases more significantly, in spite of its yielding mode of operation. Here, the horizontal stresses σ_x facilitate, since the cap with resistance to horizontal forces has a sufficiently rigid deformation-strength characteristic.

In the central reinforcement support prop stay there is an approximately threefold increase of σ with the growth of H by 50% due to the reason of the prop stay rigid mode of operation. A similar tendency is observed for a rigid lateral prop stay of the reinforcement support.

In the prop stays of the frame support, the increase in stress intensity approximately follows the patterns described for vertical stresses σ_{coal}.

The resin-grouted roof bolts, set in the roof, increase their resistance to stratification in such a way, that in the armature of one of them a plastic state occurs.

Based on the conducted studies results, it is necessary to draw such a basic conclusion: the deformation-strength characteristics $q(u)$ of a fastening element determines significantly the intensity of its loading growth with an increase in depth H of extraction working location; with that, some elements are overloaded, while loading of others is far from the ultimate loading. This different degree of "reaction" to the change in mining and geological conditions for mine working maintenance (shown in qualitative terms in the scheme Fig. 2) indicates the need to adjust the operating modes of the various elements, making up a particular fastening scheme.

4 Conclusions

Increased contact stresses in the areas of different fastening elements junction reduce their load-bearing capacity, since they cause the occurrence of the limiting and super-limiting state of the elements materials, while, in the rest areas of these elements there is a pre-limiting deformation. Thus, the bulk of the fastening elements materials remains underloaded and their load-bearing capacity is reduced. In some ways, we can speak of unequal strength of each fastening element by itself.

The increase in the level of strength uniformity of each of the conjugate fastening elements is intimately associated with the degree of their deformation-strength characteristics compatibility. And in this perspective this task is of primary importance. It is necessary to find a compromise between the two tendencies of impact of deformation-strength characteristics of separate fastening elements on their condition: on the one hand, – reduction of stress concentrations in dangerous areas of the structure; on the other hand, – attempt to minimize the loading on the fastening system as a whole and its separate elements.

Summing up the research results of coal-bearing massif interaction with the fastening system of preparatory workings in the zone of coal-face works influence, it should be noted that qualitative schemes for their operating modes optimization should be transformed into a set of quantitative patterns of interaction between geomechanical factors and the deformation-strength characteristics of fastening elements. And this set is the base to provide recommendations for the maintenance schemes optimization of reusable extraction workings.

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