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Earth Pressure near a Longwall Working Place

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Abstract

The earth pressure around a longwall working place has been studied, taking into account several factors such as the balance of force, the supporting capacity of the overlying layers, and the retardation of the surface subsidence. As the results, the authors have derived a theory on the transition of stress conditions in the ground above a mined area; that the earth pressure distribution in a goaf is at first very irregular but it becomes more and more uniform as time passes, as illustrated in Fig. 7, and that less irregularity is seen on the plane farther from the coal seam as shown in Fig. 6. This theory has proved serviceable to explain various facts that had otherwise never been understood.

1. Introduction

Many researches have been eagerly carried out on the earth pressure near a longwall working place by many investigators, but their opinions do not always agree with each other. Consequently, it is supposed that room is still left for further study. The authors have, therefore, attempted to study this problem to make a link in the chain of the studies on the underground earth pressure.[1]

Brief comments shall be made on some of the main opinions hitherto published. For a long time, it has been a widely accepted conception that over a longwall working place, as over a drift, a pressure dome is formed spanning between the coal face and the part of the goaf where the packing material has already been fully compressed, and that only the weight of rock inside the dome is supported by the props and also by either the packing material or the caved rock which is partly compressed.

According to this theory, it is easily understood that the face supports are slightly loaded compared with the weight of superincumbent layers, that there appears a pressure which is greater than the initial pressure on the edge of the coal seam. However, the mechanism by which the pressure dome is formed is not explained by this theory. Interpreting the pressure dome literally, the rock mass outside the dome

is considered to be free from the inner rock mass. If so, it is unreasonable that the rock mass outside the dome can stand over such a long span from the coal face to the fully compressed packing.

A more simple theory is that the earth pressure near a face can be treated by means of the statics considering the roof to be a beam or a flat plate. This theory is, indeed, serviceable for calculating the loads on face supports, but all other phenomena around a working place caused by the earth pressure can not be elucidated from the theory.

Starting from a quite different standpoint, such a theory has recently been presented that the ground can be treated as a mass of loose material because fissures have already developed in the ground.[2] It is justifiable not to look upon the ground as a continuous elastic body, but, as the ground is neither homogeneous nor isotropic and is composed of innumerable irregular rock pieces gearing with each other, the results obtained by this theory are of doubtful value.

2. Special Features of Earth Pressure Phenomena around a Working Place

As a very wide opening is produced, compared with its height, in a longwall working place, the earth pressure phenomena around a face take different appearances from those around a drift. Let us assume that a longwall face of a flat or nearly flat coal seam is situated at a considerable depth and assume that the coal face is sufficiently long, then we can treat the earth pressure as a two-dimensional problem, except at the both ends of the face.

When a working place is first prepared in a virgin field, a stress state somewhat similar to that which occurs around a drift in an elastic ground is expected to appear. However, the elastic theory is not strictly applicable for the reason that the ground is composed of stratified rocks which probably have initial fissures of some geological origin. Under the assumption that the ground is isotropic and homogeneous, the stress conditions around an elongated rectangular opening lying horizontally were

investigated by means of photo-elastic experiments. The models, 15 cm square and 6 mm thick were prepared of phenolite plate, having a rectangular hole, 8 mm × 40 mm, at the center of each model. These models were compressed in a photo-elastic apparatus and observed. Fig. 1 shows the stress pattern photographed under circular polarized light. Depending upon the photograph as well

Fig. 1

as the isoclinic lines observed under plane polarized light, we obtained a chart illustrating the directions of principal stresses, which is shown in Fig. 2. The stress distributions along a few lines were analysed and illustrated in Fig. 3. In this figure, z-axis is taken vertically downward, while x-axis horizontally. σ_x and σ_z represent the normal stresses in x- and z-directions respectively, while τ_{zx} represents the shearing stress in z-direction on x-plane and σ_S, the tangential stress on the inner surface of the opening. Each stress represented by the ratio of the stress to the unit load applied to the model
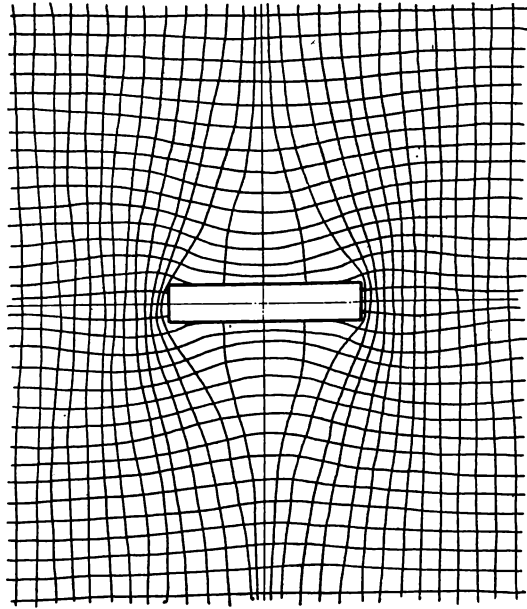

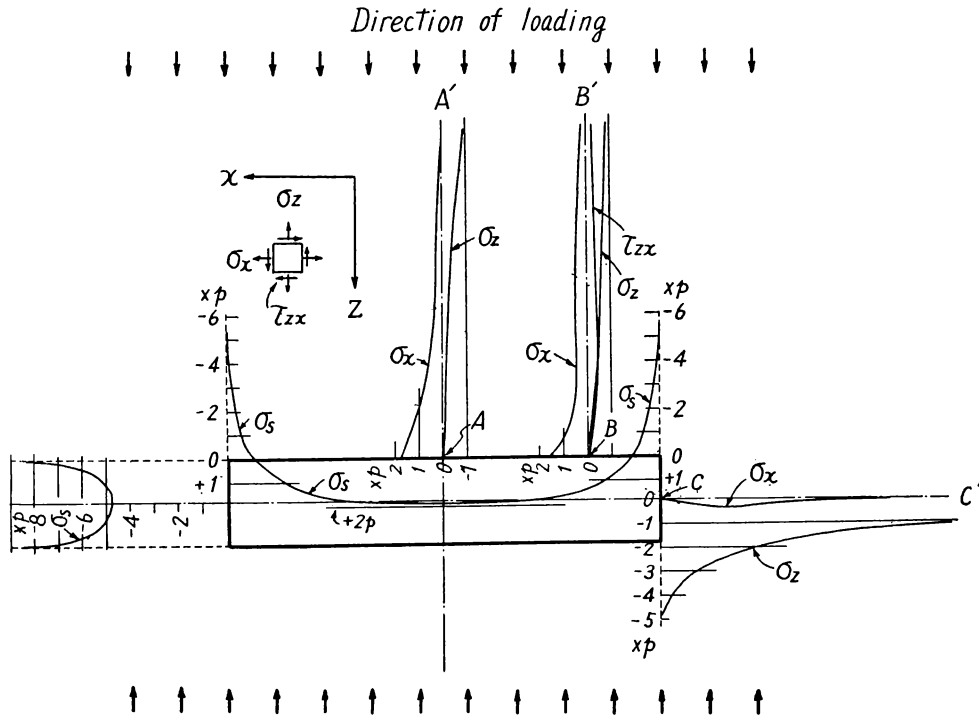Fig. 2   The direction of the principal stress.

Fig. 3   The stress distribution around a rectangular hole.

is plotted against the distance. According to the custom, a possitive stress denotes a tensile stress and a negative stress, a compressive stress. From Fig. 3, it is seen that tensile stresses appear on the roof and floor, high compressive stresses on the side walls, and high shearing stresses in the ground diagonally outward from the corners of the opening. It is a matter of course that these stresses grow in magnitude with the progress of the face. Along AA' and CC', there appears no shearing stress. Failures will soon occur at points or along planes where high stresses appear as the strengths of rocks are comparatively low especially along bedding planes.

Considering that the initial stress in the ground is $-\gamma z_1$, where γ is the specific weight of the ground, z_1 the depth of the coal seam, that the tensile strength of any sedimentary rock is about some tens of kg/cm^2, and that the compressive strength is some hundreds kg/cm^2 while the tensile or shearing strength along any bedding plane is less than a few kg/cm^2, it is easily expected, from the details above described, that the strata will separate from each other due to shearing along the planes of stratification, that the lower roofs will break due to tension, and that the upper ground will break due to shearing in the direction of maximum shearing stress. Once the nether roof caves, the upper roofs come to fail and subside successively, until the whole ground above the working place subsides and arrives at a new equilibrium.

In the fields where one or more seams have already been extracted, it is a matter of course that we cannot, from the first, treat the earth pressure problem around a working face in the light of the theory of elasticity.

3. Stress before and behind the Coal Face

The stress in z-direction, σ_z, before the coal seam is worked is $-\gamma z_1$, as described already. Once an opening is made for mining, each pair of stresses, which has been appearing on the surface to be exposed by excavation, disappears because when one of the stresses is lost, the other cannot exist. Consequently, the state of stress varies. As the total weight of ground above the coal seam remains constant even after the coal seam is worked, we obtain the following equation:

$$\int^F \sigma_z dF = -\gamma z_1 F , \qquad (1)$$

where F is an area on z_1-plane, outside of which no influence on the stress is found. In the open space produced by mining, however, the vertical stress disappears and, for that reason it is supposed that stresses greater than the initial stress $-\gamma z_1$ will occur both before and behind the coal face. But the stress distribution cannot be strictly analysed for the ground is not homogeneous and isotropic. At the present stage, therefore, we cannot but infer it depending upon the experiences and the common sense on statics.

In the first place, we will show, for reference, the stress distribution curves presented by various authors, Haack,[3] Fritzsche,[4] Patteisky[5] and Spruth,[6] in Fig. 4. It seems at a glance that the curves in this figure somewhat differ from those in the original papers, but it is due to the fact that they are rewritten by us in order to coordinate the dimension and the unit of stress. Curve *e* in the figure shows the authors' opinion as will be described later. Now, let us discuss on these curves :

(1)　Considering Eq. (1), it is expected that the area between a stress distribution curve and a base line is nearly equal to the area between the γz_1 line and the base line in regard to the same working place, except the neighbourhoods of both sides of the working place. Curve *a* and *c* in Fig. 4, however, seem to deviate too much from this relation.

(2)　The maximum vertical stress before the coal face ranges from several times of $-\gamma z_1$, (Curve *a* and *c*), to less than twice of it (Curve *d*). In the authors' opinion, this stress grows until the coal seam fails, and it decreases after the coal seam fails. The maximum stress, therefore, amounts to various magnitudes, depending on the strength of the coal seam, the initial stress $-\gamma z_1$ and other conditions. If the stress in a coal seam decreases near the coal face, the maximum stress removes to a farther point.
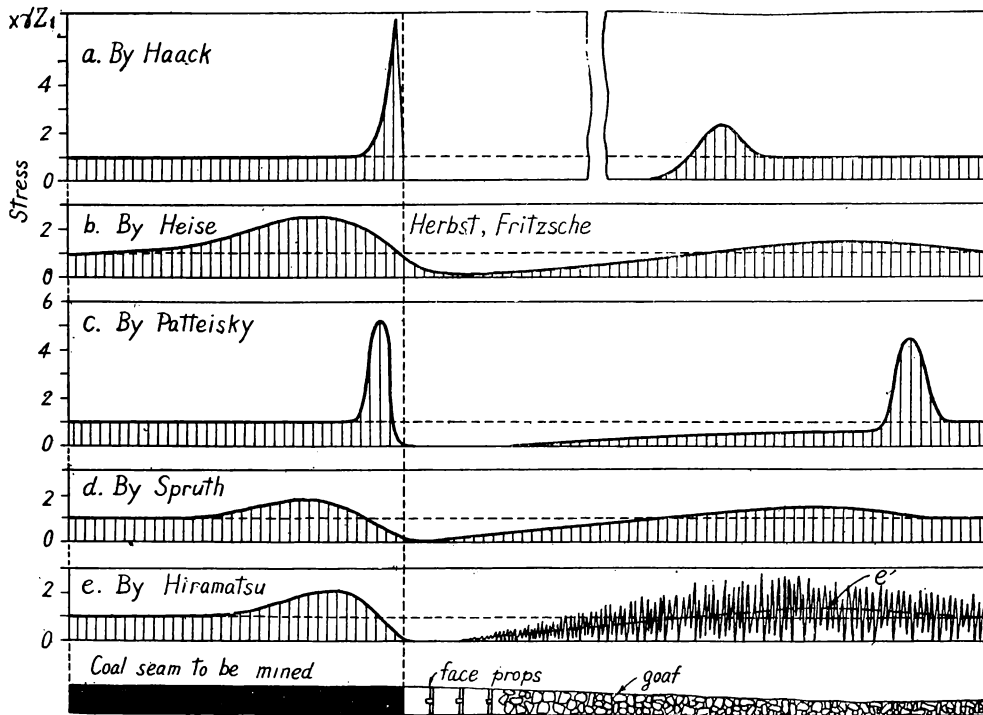

Fig. 4　The stress distribution along a coal seam by several authors.

For example, if a coal seam, 500 m deep, has a compressive strength of 200 kg/cm², the initial stress is about −125 kg/cm², so that the maximum stress before the coal face will be about 1.6 times the initial stress.

(3)   All the authors are of the opinion that the maximum stress on the packing is somewhat lower than that on the coal seam and this is reasonable because the compressibility of the packing is greater than that of the coal seam.

(4)   The distance between the two peaks of stress, before and behind the working place, ranges from 30 m to 150 m according to several authors.   Between the two points where these two peaks of stress appear, the vertical pressure is low.   Assuming that the packing in the goaf is capable of supporting only the total weight of overlying ground only when it is fully compressed, the maximum vertical stress in the packing should be found at a long distance behind the coal face, say at hundreds of meters. If so, the roof strata must stand without support over a long span.   But the strata are not strong enough to span over such a long distance.   Considering the strength of strata, the peak of stress in the goaf would appear at a comparatively short distance from the coal face.   Such being the circumstance, the problem is not yet be cleared.

P. Kühn says that a time factor must be taken into account.[7]   But the problem is not solved by simply considering a time factor because force is always in balance and any elastic body cannot be subjected to a stress greater than its strength even for a short period.

The authors have studied on this problem and have come to the following conclusion :

In the goaf, the pressure from the roof is transmitted to the floor through the contact points of numerous pieces of packing material.   Thus the pressure in the goaf does not distribute smoothly as in the coal seam, but it distribute itself extremely irregularly concentrating at contact points, as shown by Curve e in Fig. 4.   Averaging this pressure distribution curve, we obtain Curve e′, shown with a dotted line.   The area between Curve e and the abscissa is equal to the area between Curve e′ and the abscissa.   The peak of the pressure Curve e′ lies at rather a short distance, say about 30 m from the coal face.   Seeing in this light, it is not unreasonable to consider that a heavy load acts on the loose packing at such a short distance from the coal face.

The pressures appearing at contact points are, therefore, exceedingly high, and the smaller the contact surface is, the higher is the unit pressure.   It may be doubted whether or not the rock pieces packing the goaf, having comparatively low strengths, can hold out itself against so high pressures.   It would be impossible if no breaking of rock is allowed.   But it is no matter that rock pieces crush.   When too heavy pressure appears at a contact point, the contact surface will become wider and as the result the unit pressure will decrease down to a limit to hold the rock pieces.   Thus it may be approved to admit the existence of a high pressure near a coal face.

4. Stress Distribution above and below a Coal Seam

Working one coal seam has influences upon the states of stress around a gallery driven near the coal seam or upon the earth pressure appearing in another working place following the former. In order to discuss these influences, it is necessary first to clarify the earth pressure above and below a working face.

The strict analysis of this problem, however, is as difficult as the study of the stress before and behind a coal face; hence, we attempt to investigate it qualitatively by drawing special curves, illustrating the distribution of σ_z. These curves are drawn in such a manner that the density in the horizontal direction is proportional to σ_z. Let us call these curves σ_z-lines in this paper. As σ_z increase with depth, the number of σ_z lines increases with depth as well. But, so far as the vicinity of a deep coal face is concerned, the variation in σ_z with depth is so little that the variation in the number of σ_z-lines can be neglected.

For example, the σ_z-lines a- round a rectangular opening, which has the ratio of its width to its height of 5:1, are shown in Fig. 5. The curves representing the directions of the principal stress are as illustrated in Fig. 2. They are drawn at regular intervals where no influence of the opening is seen. These two kinds of curves are similar to each other, but it is to be noticed that the σ_z-lines are never cut by openings and are kept constant in number if the increase

Fig. 5 σ_z-lines.

with depth is neglected, while the principal stress curves are cut by the surface line of the opening and vary in number. This fact is understood easily by considering the fact that σ_z satisfies Eq. (1) and, on the other hand, the principal stress curves are always perpendicular to the wall surface of openings.

If we can draw such σ_z-lines in a ground where a coal seam is being worked, we can readily obtain the distribution of σ_z at any level. As the exact σ_z-lines cannot be drawn, we shall assume them referring to the principal stress curves.

Since action always brings about reaction, the stress distribution above and below a coal seam must be alike. The stress in the floor strata of a goaf, therefore, must
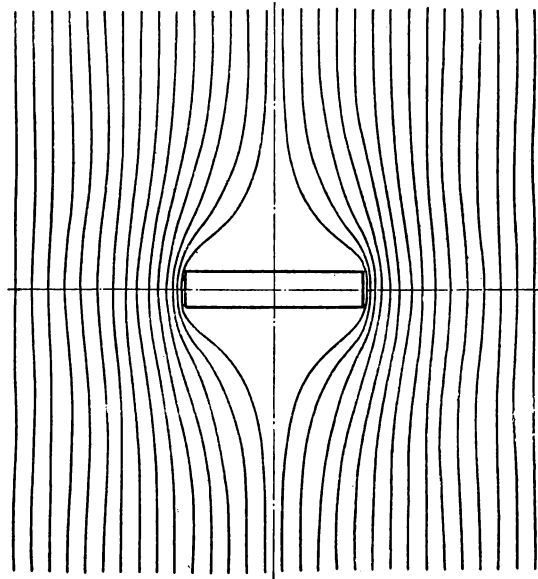
distribute very irregularly as in the roof strata.

Another point to be noticed is that the stress distribution on a horizontal level is less irregular as the distance from the coal seam becomes farther, because a concentrated pressure is transmitted in an elastic body while it is spreading. At the same time the two peaks of stress become lower and approach each other.

Taking into account of all that is mentioned above, we obtain the distribution curves above and below a coal seam, which is being worked, as shown in Fig. 6.
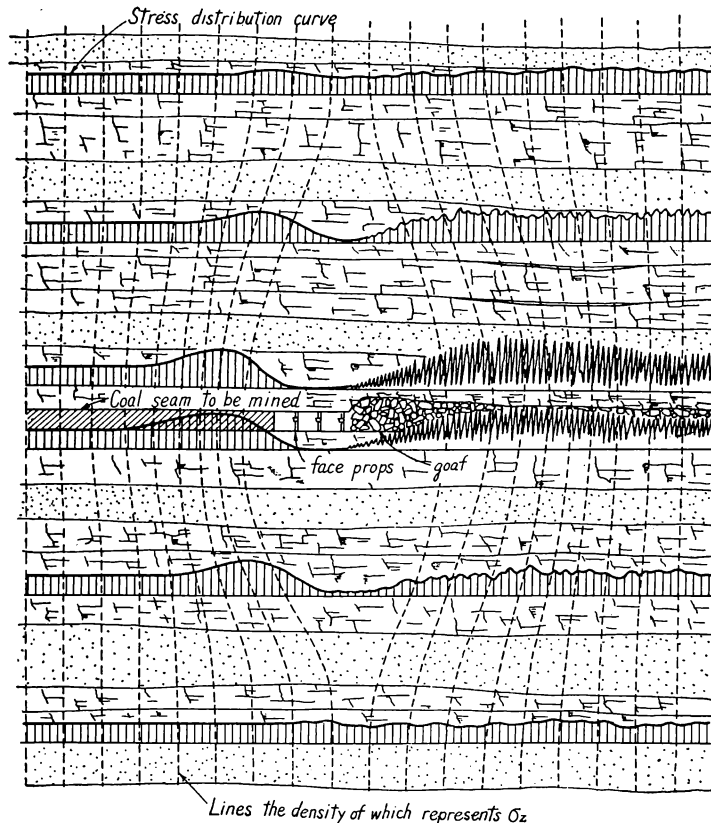

Fig. 6   The stress distribution above and below a coal seam.

According to an arch theory, it is supposed that a gallery driven above or below a coal seam which is being mined will be subjected to only a small pressure for a long period of time until the subsidence is settled. Consequently, the maintenance of such a gallery will be easy. The practical experiences, however, are contrary. According to the authors' theory, the gallery stands under a very bad condition except for a short period when a working face is being progressed just above or below the gallery. Therefore, the frequent damages of such a gallery are well explained by the theory.

Experiences show that when two coal seams lying close together are so worked that one face follows another with a distance of several tens of meters, the pressure acting on the rear face is almost similar in strength to that acting on the preceeding face. This fact is also well explained by the theory.

5. Variation in Stress with Time

Curve *e* in Fig. 4, showing the stress distribution near a working face, advances with the progress of the face with the peaks of stress before and behind a coal face always accompanying the face. The irregular stress distribution in a goaf gradually becomes smoother with time as described before. However, the average stress does not vary much.

The crushing of broken rocks in a goaf and the filling of opening left among them followed by the subsidence of the lower roof, cause new openings in the roof strata, which in course of time are also filled with broken rocks or with subsiding roofs. These phenomena spread upward and continue until no more breaking and filling takes place at which time the surface subsidence ceases. The surface subsidence does not appear at a point on the surface directly above the coal face for a considerable period, yet the balance of force is always maintained.

Fig. 7 illustrates the authors' conception on the variation in the stress with time along a coal seam which is being mined. The stress distribution above a coal seam which is being mined is somewhat equal to that below the seam. But, it is supposed that the stress distribution in the floor strata will be more smooth than in the roof
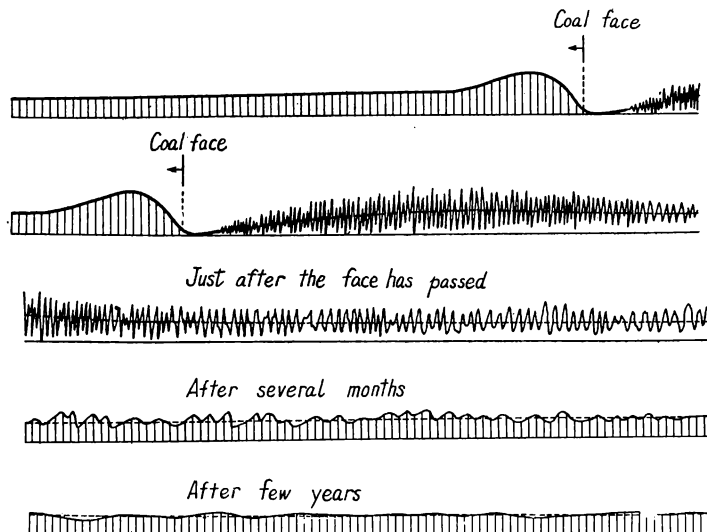

Fig. 7 The variation in stress distribution with time.

strata, and the stress becomes smooth more rapidly in the floor strata, because roof strata are subjected to rearrangement until the stress distributes itself almost uniformly while the floor strata are not. In short, the state of stress is supposed to be a little better in the floor strata, but the verification of this fact by actual examples would not be easy owing to the diversity in the nature of strata.

Strong strata behave similarly as weak strata, but the former breaks into larger pieces. Consequently, in stronger strata, the stress distribution is more irregular, more time is required to average the stress, the surface subsidence appears later and lasts longer, and its final amount is less. Comparing the coal mines in Chikuho District, Kyushu, Japan, where the ground is composed of moderately hard rocks, with Miike Coal Mine, Oomuta, Fukuoka Prefecture, and with Oomine Anthracite Mine, Yamaguchi Prefecture, which have hard grounds, it is noticed that the above is true.

When a working face stops or comes to an end point of a pannel to be mined, the circumstances become somewhat different. The peaks of stress do not progress any further, but in course of time the averaging of stress takes place in the ground influenced by mining. The σ_z-lines once disturbed, therefore, returns gradually to the original state. The stress distribution becomes more and more smooth and the space produced for mining is filled of itself with broken roof rocks. The breaking of the roof occurs not only above the open space but also in the unmined area before the face, because there appears high shearing stress in the direction of the so-called "break angle". Thus, the surface subsidence can be seen beyond the limit line of mining. These circumstances also exist for the ground behind the start line of the face.

6. Conclusion

Considering the balance of force, the strength of strata, the compression of packing in a goaf and the subsidence of ground, the earth pressure phenomena near a longwall working face has been discussed and a theory on the stress distribution has been obtained. Its outline is as follows.

The earth pressure keeps away from the open working place and acts on both sides of it, but a concrete pressure arch cannot be defined. In a goaf, the stress distribution at first is very irregular. Averaging it, we find a heavy pressure not so far apart from the coal face, where the packing material has not yet been fully compressed. The stress states above a coal seam which is being worked are some-what similar to those below the coal seam. The irregularity becomes less with the distance from the coal seam. In course of time, breaking of strata, filling of the opening caused by mining and subsidence progress, and the stress distribution becomes more and more smooth, but the balance of force is always maintained. At last an equilibrium is again obtained when no more subsidence and other phenomena are seen.

The authors have succeeded by this theory in the explanation of various facts which are frequently experienced in practice.

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