BASIC MECHANISM OF STRATA FRACTURES FORMATION
AND EXPANSION AROUND MINE WORKING

By

C. Jeger

ex-head of research in strata control then heatings and gas drainage

ABSTRACT

Underground measurements, observations and computed simulations, started a long time ago were concerning the study of:
- occurrence of typical rockburst,
- inducing, stretching of main fractures in the roof of caved longwalls.

They made obvious that a foundational phenomenon of inducing of strata fractures involving contact between two layers quite different in their elastic characteristics: coal seam and rock layer.

The start of primary cracks in maximum abutment zone takes place in the rock near the contact surface. It is opening of crevasses induced by tension stress component resulting of difference of rigidity of both materials and no sliding on interface.

Occurrence and stretching of these crevasses are a rheological phenomenon so that the rate of advance and stop of the face influence the distance between the crevasses and the stretching of these ones.

The characteristics of these cracks in space and time affect mining conditions.

So it is for fractures proximity and expansion inducing eventual blocks formation in longwall roofs in front of faces, for depth and delay of roadways ribsides fracturing, inducing some rockbursts.

In longwalls roofs, cracks initiated in front of a face can be either quite close or quite distant each from the other one, according to the depth of crushed coal in front of the face, which affects also extension of the cracks.

If first roof bed is thick, cracks can expand:
- either so much that often heavy blocks are created before the roof being uncovered; it occurs when cracks stay long enough in front of face (deep crushed coal face),
- or not enough to creating blocks so that uncovered roof is quite a self supporting cantilever; it occurs when face is advancing fast.

If first bed is thin, blocks are always created but their width depends on the depth of crushed coal.

According to the thickness of the first roof stratum, wide spacing of the cracks but long stretching of them or the reverse can make easier mining.

Often characteristics depend on some peculiarities of the mining, particularly on the orientation of roadways and faces with regard with strata slope and to seam cleats direction.

As some typical rockbursts are concerned, basic rupture initiation mechanism is the same but the phenomenon result in sudden cracking. In addition to or even instead of well known methods destressing faces or reinforce locally a proper orientation of the mining working can be used for prevention of rockbursts.

INTRODUCTION:

When studying rockbursts in a South coalfield and, later, roof fallation in caved longwalls of a North West French coalfield, some observations suggested a basic mechanism inducing fractures from the contact surface between coal seam and a quite rigid rocklayer (caved roof or in-seam rocklayer). A crack was initiated at first in the rocklayer near this surface, in a part where both layers did not yet crush nor yield (in this part materials are nearly elastic solids).
The hypothesis of this basic phenomenon was suggested at first by peculiar observations and results of measurements. It is confirmed by computed simulation.

Then factors influencing proximity of these ones were discerned between these cracks and in some conditions stretching can create blocks in front of longwall faces or roadways ribside or, in sudden, rockbursts.

Ways to modify characteristics of these cracks for improving mining conditions are finally deduced.

I - THE BASIC PHENOMENON

1.1 MAIN OBSERVATIONS

In case of some rockbursts:

First observations, which suggested the basic phenomenon, concerned rockbursts in roadways ribside in front of a longwall face.

Plots of some disturbed zone were made by surveyors (Fig. 1.1.a and 1.1.b).

These sketches show that first main rupture took place at a few meters depth and that a big block of a strong in seam rocklayer and of surrounding coalfaces was projected into the roadway.

Only in the zone of main fractures, there is crushed coal and a big void above it.

This can be understood, if at that place, first rupture took place in rocklayer tensed by coalfaces. The later, initially restrained by rocklayers could destrain suddenly after rock rupture and ejeective blocks of rock and coalfaces.

This phenomenon is also suggested by measurement results. In the main layers of the roadway ribside (intermediate limestone-layer and upper and lower coallayer), we measured expansion between anchorheads fixed at 1.30 and 4 m depth in boreholes perpendicular to the roadway walls (Fig. 1.1.a).
Observations in case of longwall roof:

In the studied longwall, first roof bed was a very thick sandstone layer (5m).

In the front of the mining wall as well as above the first part of the working zone, fissures were visible at the bottom of this roof (we could locate them in front of the face by endoscopy, then, in working zone, record them by drawing, plotted later on Fig. 2.1.1.a). For a big part of studying time, this first thick roof rock layer was in continuity with the roofbed quite far away in front of the facewall (there was almost no pressure on the supports, no block movements above the first part of the working zone (Fig. 1.1.e).

Fig. 1.1.e

This suggested that fissures at the bottom of the roof were probably only cracks (like narrow crevasses) created by tensile stress components in rock at the coal-rock interface.

1.2 EXPLANATION OF THE BASIC MECHANISM

The below described mechanism occurs if coal and rock layer are together cut by a mining wall and perpendicularly overstressed by abutment stresses (like near a face of caved longwall or in some roadways rib sides) and if friction along contact surface is high enough to avoid sliding.

Crack inducing can be understood as following: because elasticity moduli of solid coal and rock are different, if free sliding on their contact surface, overstressed coal and rock layers should laterally expand differently (Fig. 1.2.a). But, if enough friction, coal is restrained by rock which is tensed.
by coal near interface (Fig. 1.2.b).

![Diagram](image)

Fig.1.2 Lateral expansion of compressed adjacent coal and rock-layer.

Now, for any rock, tensile strength is small. So, tensile component of stresses induced by coal can open a crack K in roofrock from interface OA before failing of coal. But opening of this crack distresses the coal which immediately later breaks easily, more or less progressively according to the previous state of stress or to the coal rigidity.

Distance of the last crack to the wall or to the previous crack as well as the speed of its expansion will be examined later. But first occurrence of such initial crack in the rock must be verified.

1.3 SIMULATION

To be sure of the hypothesis presented above and to test influence of some parameters, we simulated, by computed calculations, the evolution of a modelled two layer elastic body compressed up to occurrence of the first rupture point.

Two models are used:
- the first simulates an in-seam rock-layer (rigid limestone) between coal-layers, with an overstraining uniform all over the massive (like in pillar or in roadway rib-styles of South coalfield, because of very thick and rigid roof; Fig. 1.3.a)
- the second simulates a seam under a quick thick roofbed (sandstone) with a progressive flexural like measured in front of a face in North West coal-field (Fig. 1.3.b); (measurements methods and results are explained in next chapters).

The model is limited on lines of real symmetries and on in mobile limits, i.e. lines on which perpendicular displacements take place.

![Diagram](image)

Fig.1.3 Models used for computing.

Strengths and elastic moduli are similar to those measured on samples from coal-seams and rock-layers involved in our studies in situ (Table 1).

Both bodies are assumed remain linearly elastic up to the first rupture point. If a small volume of coal would be preplastified in maximum stress zone, its deformation moduli would be higher than elastic ones, and involved phenomenon would be more probable. We used intrinsic curve as failure criterion and the distance called "CRUP" Mohr circle to this curve as failure proximity criterium. Intrinsic curve was established with strength limits given in table 1.
Table 1

Discretisation method was "lumped parameters" method and numerical analysis and computation were made with Gauss-Seidel method.

Results of computation show that in case first failed point lies in the rocklayer and not in the coal seam.

A. Concerning in seam rocklayer, some results are shown on Fig. 1.3.c.

We made varying 2 main parameters:

- ratio \( \frac{L}{H} \) which,
  
  - for a pillar is related to the width of this pillar (compared to the thickness of the seam)
  
  - for a ribside under a rigid and thick roof is related to the depth of the crushed zones on both sides of a not expanded overstressed zone,

  and ratio \( \frac{HC}{HR} \)

  = coal layer thickness

  rock layer thickness

  Greater is \( \frac{L}{H} \), deeper can the first crack take place.

  Greater is \( \frac{HC}{HR} \), deeper also can be this crack.

Given in Fig. 1.3.c

In a little "softer" rock "B", first crack takes place for a smaller overstrain "e" and can be a little deeper than in a stronger rock A.

Calculated friction coefficient "f" necessary to avoid sliding on interface, is low, except if there is very soft material on interface, sliding between rock and coal is improbable.

B. As best caving thick roofbed is concerned, some results are shown on Fig. 1.3.d.

First crack occurs also in the rocklayer near interface. If there is easy sliding between the top of this roofbed and overlying strata, first crack can be deeper than if this top is restrained by the later.

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2 - INDUCING AND EXPANSION OF FRACTURES IN ROOF OF CAVED LONGWALLS

A quite detailed study was made in longwalls in North coalfields.

2.1 - Inducing of roof fractures above the seam in front of caved longwalls.

2.1.1 - Observations and measurements:

They are described on Table 2.

<table>
<thead>
<tr>
<th>measurement of</th>
<th>method</th>
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<tbody>
<tr>
<td>roof cracks location</td>
<td>above the seam + extensometry.</td>
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<tr>
<td></td>
<td>above the working zone = drawing</td>
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</tbody>
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Table 2

As pointed out in § 1.1, initially main roof fractures were "primary" cracks opened at the interface rock-coal. These cracks were located by extensometry and endoscopy, then their traces were drawn when they became visible in working zone. (Fig. 2.1.a)

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Their main direction was parallel to the face. There were arborescences, some of which connecting 2 successive cracks. Always the most recent crack took place near a position where the maximum abutment overstress stood for a certain time. Coalseam was crushing (expansion increasing) between this position and the face wall.

2.1.2 - Distance between primary fissures:

During the measurements time, there were 2 typical periods:
- in a period called A, as related in § 1.1., fractures were still crevasses when uncovered by shearing, and remained so above a part of the working zone. In this period, maximum abutment position was always very close from the face wall (1m to 3m). Abutment maximum stress, as shown by cells pressures, tightly pressed in coal, was very high (cells pressures do not indicate value of maximum stress but higher is the variation of average stress, higher is the variation of cell pressure. Even as shown by Jeger (1969), a big part of crushed coal is like a plastic medium; in such a part these variations can be proportional).

Mean distance between cracks was around shearing pass. All this is shown on Fig. 2.1.b.

In the other period called B, broken part of coalseam was much deeper (4 to 7m). (We shall see later why). Maximum abutment stress was much lower than in period A. Distances between primary cracks were much greater, corresponding to face advance on a shift or on a day, (Fig. 2.1.c).

Fig. 2.1.b Mean distance between cracks when high abutment peak (Period A).


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higher is the final maximum value \( S'1 \). Higher \( S'1 \), higher the tensile component in the rock on the interface.

When and where a crack will occur in the roof? Here we have to take into account the rheology of fissuration: a stress deviator can open a crack only if its intensity is high enough and if it stays long enough on the same position (even if crack is open by tensile component).

It was like \( S1 \) as example. But it did not stay long and strong enough at that place, to open a crack in the roof because preplastically part of such a coal yields and fails quickly at low depth. Limit of cleft failed part becomes deeper and maximum vertical (and horizontal) stresses components on interface become lower, like \( S'1 \) as example and so on up to \( S'1 \) which stays enough long and is enough strong to induce a crack \( K \) in the roof \( (K \) is not always exactly below the peak of \( S'1 \); heterogeneous strength of roof rock creates a dispersion of positions of \( K \).

a) If coal seam cannot break deeply, value of \( S'1 \) is quite high and a crack (crevasse) is open a short time after a shearing pass. After the next shearing pass, another crack will be opened and distance between successive cracks will be around depth of shearing pass (Fig. 2.1.e).

b) But if there is a low initial overstress \( S'1 \) due to a deep initial failed coaltar, it is possible that, between two mining passes, time is not sufficient to initiate a crack; roof is only locally fragilised (small preplasticities). Crack occurs only when there is a longer time without mining after a shearing pass; e.g. distance between successive cracks equals several depths of shearing pass (Fig. 2.1.l).

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2.2 - EVOLUTION OF PRIMARY ROOF FRACTURES. BLOCKS FORMATION OCCURRENCE OF NEW FRACTURES ABOVE THE WORKING ZONE

2.2.1 - Evolution of cracks in the rockroof:

Above fractured part of the seam and above working zone, initiated cracks evolved essentially by extension of cracks lengthwise and upwards. This was observed by successive plotings of traces of the cracks and by endoscopy.

Inclination of upwards extension of the cracks was a little backwards (towards the goal, R3 type according to French-German convention).

2.2.1.1 - Characteristics of cracks evolution when low depth of broken seam (sharp abutment peak near the front).

In the period A when cracks were initiated quite near the front, evolution of the cracks was quite small when cracks were uncovered by the face. One crack among 4 or 3 met another extended crack and the top of the first roofbed. More often, the first roofbed remained continuous up to a certain distance from the face, like a cantilever supported mostly by the scan. Only before caving, one crack among 2 or 3 completed blocks (Fig. 2.2a). There was a very low pressure on the support.

But sometimes, with long stops of the face, blocks were created everywhere above the working zone. Relative movements between these blocks created secondary fractures and small pieces of blocks fell down between front and support (Fig.2.2b).

2.2.1.2 - Crack evolution when deep broken seam in front of a face:

In the period B, when cracks were initiated far away in front of the face, cracks stayed long enough above the fractured seam whose expansion opened and expanded the cracks so that blocks were created.

When such a block was uncovered at the front, it pressed quite suddenly on support. A step could often occur in the roof. It hindered the correct support of the next block (Fig. 2.2c).
Sometimes new fractures F1 occurred near the sharp corner of the blocks base, when relative movements of the latter occurred, particularly with pivoting. These fractures generally inclined downwards the goaf (R4 type), created small blocks which fell down, when they occurred in front of the support.

But moreover, in situation 2.2.1.2., other cracks F2 occurred in these big blocks above the supports. It was noted that the distance between new cracks was quite often close to that of the shearing pass as explained in § 2.1.3. These cracks occurred on places fragilised by abutment peaks after each shearing pass. Sometimes, this propagation was sufficient to divide a big block into smaller ones, similar to blocks described on Fig. 2.2b.

3 - MAIN FACTORS MODIFYING CRACK INITIATION AND EVOLUTION

Two main factors were noticed:

- Fracturing of the seam in front of faces or ribsides (related to cleat orientation and in seam sliding planes).
- Thrust of the roof blocks towards the moving direction (related to face progressing downwards).

3.1 - Fracturing of the seam:

We noted earlier that the depth of fractured seam had a big effect on inducing and evolution of cracks above the seam. But this depth depends itself on:

- orientation of the front with respect to the main coal cleats direction and inclination,
- presence of sliding planes (or soft layers) in the seam,
- rate of advance of the face.

3.1.1 - Cleat orientation and sliding plane

... If the coal is strong enough, the seam is not deeply fractured:

a) when the face is not parallel to the main cleats direction, even if there are sliding beds (thin enough) in the seam,

b) when the face is almost parallel to a cleat direction but

... either if there is no sliding plane, (or soft layer) in the seam. It was so in studied longwall (n°52) during phase A.

... or if there is a sliding plane, but the inclination of cleats and the position of the sliding planes are such that the coal pieces delimited by cleats are blocked (see Fig. 3.1.1.a and 3.1.1.b).
In another studied longwall (n°82), the configuration was according to Fig. 3.1.1.d and the seam was deeply fractured.

If a sliding bed lies at an intermediate position in the seam, the effect can be similar to that of Fig. 3.1.1.d and 3.1.1.e. It was so in studied longwall (n°82) during phase B.

3.1.2 - Rate of advance

If the rate of advance of the face increases, the distance between the abutment peak and the front decreases. In a third longwall (n°44), which was progressing in the same direction as longwall (n°82), the fractured depth was respectively 7, 4.8, 2.5m, for daily rate of advance 3.3, 4.5, 6.5m. The roof behaviour was much better than in both other longwalls, because, when rate of advance was high, blocks were not formed before the roof fissures reached the caving zone. If the first roofbed would be thin, high rate of advance would not be an advantage.

3.2 - Face progressing downwards - Thrust of roof blocks towards the moving direction

In longwall (n°44), mining panel was adjacent to that of longwall (n°52) but exactly in the reverse direction. The face was progressing 6 to 10° downwards. Inclination of the roof fractures was almost perpendicular to the stratification plane.

Even when the rate of advance was small, and the fractured seam deeper, the roof behaviour was still good. This can be explained by the thrust forwards of the roofblocks due to the slope towards the face progression (Fig. 3.2.a). This thrust reduces tensile stresses which induce the cracks in front of the face, and slows down their extension. Even when blocks were formed, they did not move downwards easily because of friction on the fractures in front of them, and because some caved blocks fell down below the roofbase into the back of working zone, supporting the next blocks.

4. - EFFECTS OF THE BASIC PHENOMENA AND CORRESPONDING FACTORS ON A THIN LOWER ROOFED OR ON A MULTILAYERED ROOF OF LONGWALL.

We did not particularly study such types of roof in longwall. We know that often such roofs make mining more difficult.

If the first rocky roofbed is quite thin (0.3m to 0.5m as an example), for any crack initiated in the roof on the seam-roof interface, the distance to reach the top plane of the first roofbed is very short and lengthwise crack extension is also easier than in a thick roofbed. So blocks can be formed in front of the face quite shortly after inducing of cracks. They are often already completed before
being uncovered by mining.

In case of small depth of fractured seam in front of the face and consequently small distance between primary cracks, narrow blocks are uncovered by mining and can fall down before being supported.

On the other hand, when fractured seam part is very deep, the blocks formed above the seam can be wide enough to be sustained by the supports before being completely uncovered by mining. If they break later on the support because of their fragmentized zones, there is no inconvenience for mining.

5. PRACTICAL APPLICATIONS

5.1 - Rockbursts:

When rockbursts occur because, in front of longwall faces or in roadways rib sides, lateral expansion of coal layers is restrained by friction on strong and rough rock layers, it is possible:

- locate the dangerous places by measuring lateral expansions (now with new devices),
- reduce the risk of rockburst by progressively destressing (or detraining) the coal layers in these places (drilling of close wide boreholes, high pressure water flushing, flushed water impulses...).

5.2 - Longwall roof behaviour improving:

Face roof behaviour can be improved by appropriate choice of mining direction and face orientation. After, at first, avoiding to orientate the face on a direction too close to that of the main tectonic disturbances:

- mining direction:
  in any case, downwards face progression (even with a small slope) can improve roof behaviour and mining conditions by reducing:
  - density and expansion of cracks in the roof,
  - relative displacements of roofblocks above mining zone,
  - pression of roofblocks on the support,
  - detraining and fall of fractured seam.

- face orientation:
  When the seam is quite strong and not too thick, if the lower roofbed is quite strong and thick (more than 1.5m as example), it is convenient to orientate the face so that the seam, in front of the face, will be not deeply fractured (see § 3.1.1).

  If the lower roofbed is quite thin (less than 0.5m as example) and particularly if the roof is multilayered, it is convenient to orientate the face so that in front of the face, the seam can be fractured deeply enough (see § 4).

  But face orientation involves roadways orientations and there is to take care of the possible effects on roadways rib sides and roof stability.

6. CONCLUSIONS

This study makes understandable the mechanism inducing cracks in rockbeds as well in the case of some typical rockbursts, as in the case of primary roof fissures in front of longwall faces. It could explain characteristics of these fissures and behaviour of the roofs as observed or measured in the case of thick sandstone bottom roofbed. Possible behaviour of thin multilayered roof could be deduced although this type of roof could not yet be so deeply studied. For both types of roofs, the results suggest some ways of mining to improving roof behaviour.

Results of this basic study would have to be confirmed by observation of various types of longwall roofs. Particularly the case of multilayered roof should be deeper studied. Similar studies - even with less measurements - could make clear the effects of other factors and check some of our results and deductions.

REFERENCES: