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Study of Falling Roof Vibrations in a Production Face at Roof Support Resistance in the Form of Concentrated Force

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Abstract. One of the main reasons of roof support failures in production faces is mismatch of their parameters and parameters of dynamic impact on the metal structure from the falling roof during its secondary convergences. To assess the parameters of vibrational interaction of roof support with the roof, it was suggested to use computational models of forces application and a partial differential equation of fourth order describing this process, its numerical solution allowed to assess frequency, amplitude and speed of roof strata movement depending on physical and mechanical properties of the roof strata as well as on load bearing and geometry parameters of the roof support. To simplify solving of the differential equation, roof support response was taken as the concentrated force.

1. Introduction

Operation of powered roof supports of longwall sets of equipment in conditions of hard-to-cave and hard-to-manage roof strata, presented especially by thick fine-grain sandstones and siltstones, is accompanied by increased dynamic loads occurring during regular secondary roof falls. At the same time, the magnitude and the rate of main roof blocks movement depend on physical and mechanical properties of the strata, their thickness, load-bearing features of the roof support and its location in the face.

Such impact of the roof on support elements causes their failure due to improper manufacturing technology [1–3], swelling of cylinders on hydraulic props both due to their design features [4–6] and high rate of the movement process development [7–9], leading inevitably to improper operation of seals and loss of their tightness [10, 11]. The magnitude and intensity of secondary roof convergences depend on roof support resistance and its distribution over the working area width [12].

Also, vibration frequency of a falling rock block may coincide with the frequency of own vibrations of roof support steel structure, and as a result resonance evolves which may lead to its destruction with the external loads not exceeding the rated operating resistance.

Therefore, it is important to know the frequency of external load on the roof support during secondary roof convergence as well as the maximal amplitude and rate of rock strata movement during its impact on the support with the aim to choose the required parameters of support design at the stage of its designing.

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2. Methods

Solution of a partial differential equation describing the beam oscillating process was obtained by a numerical computation at given initial and boundary conditions corresponding to the agreed computational models before and after brittle rock failure.

This method is widely applied when using advanced highly efficient computing systems.

3. Work Description

To study the oscillating process of a roof block at a sudden (brittle) rock collapse, the following hypothesis was assumed as the basis for the schemes of roof block interaction with external environment.

In the process of coal seam cutting a roof block is getting deformed under its own weight, under uniformly distributed load from overlying strata (additional load) and from the concentrated force which is numerically equal to the rated operating resistance of the roof support. This concentrated force is located at a distance from the face equal to the distance from the face to the resultant force from the roof support.

One end of the beam above the face is restrained, the other end on the goaf side is hanging free. This scheme is shown in fig. 1. Maximal beam movements for the given scheme take place at the free end, while maximal stresses are in the restraint.

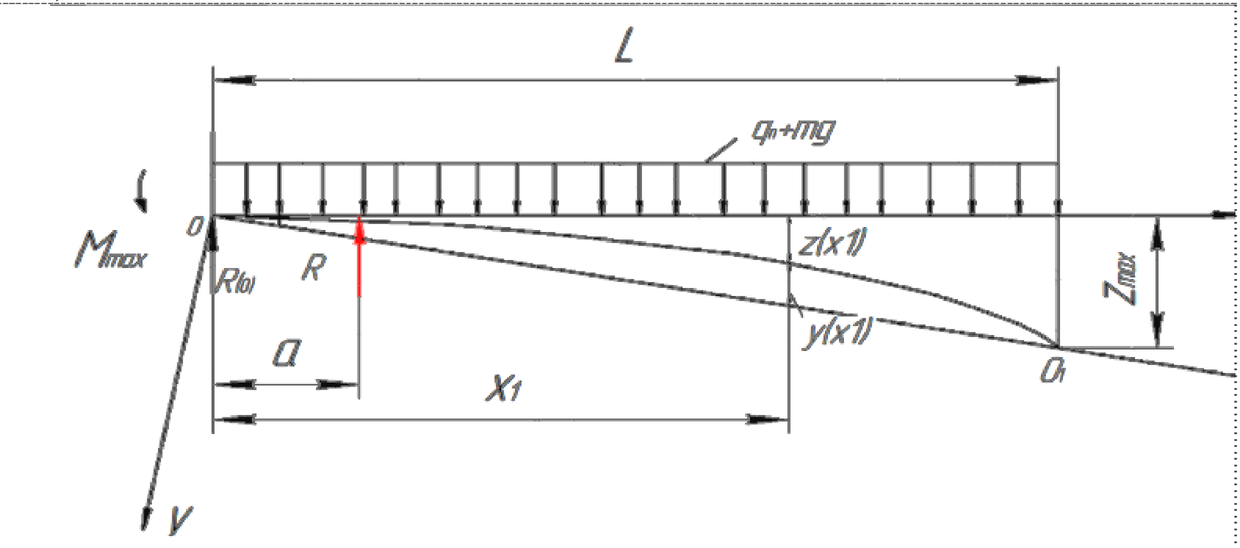


Figure 1. Computational module for loading of (roof) block prior to its brittle destruction.

When admissible stresses are reached in the beam restraint, brittle destruction of roof strata takes place (a secondary roof convergence occurs), and the restraint breaks at once. As a result, the beam tends to straighten and the stored potential energy of the deformed beam converts in the kinetic energy of the oscillating process.

The kinetic energy magnitude is pro rata to geometrical dimensions of the block, the mass of its strata, the size of deformations prior to destruction, and the magnitude of applied forces.

The model for computation after failure of the restraint is shown in fig. 2 and it becomes two-point, since upon straightening of the bent beam it will rest on the overlying roof strata.

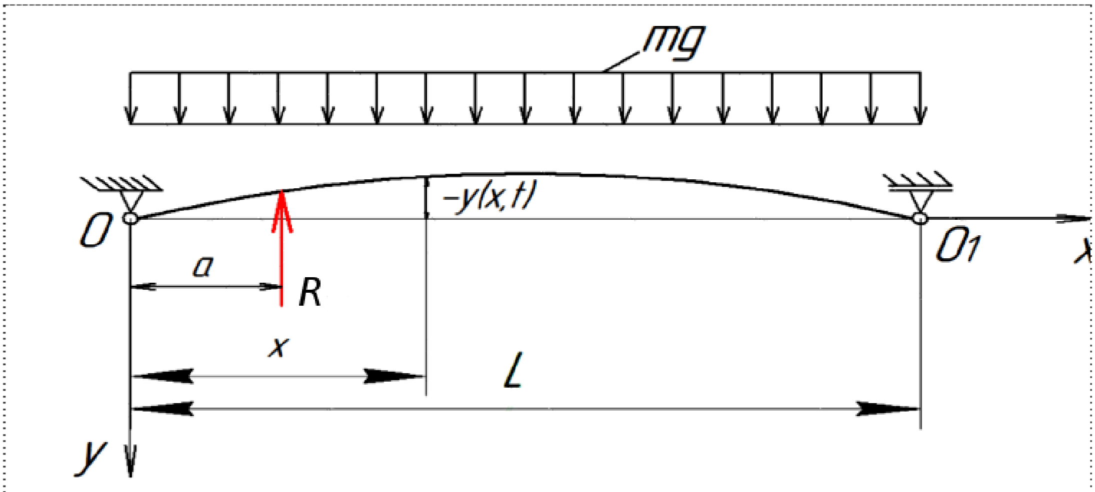


Figure 2. Computational module of the roof block after its brittle destruction.

The schemes show uniformly distributed additional load from the overlying strata side and deflections y corresponding to the deformed block at the moment preceding brittle destruction. The concentrated force corresponding to the rated resistance of the roof support acts on the block from the roof support side.

Legend (fig. 1 and 2):

R – roof support force in the form of a concentrated force equal to the rated operating resistance; a – distance from the face to the total force from forces acting from the support side (concentrated force); qп – magnitude of additional load from the overlying strata side; mg – magnitude of additional load from the blocks's own weight; g - free fall acceleration; m - distributed mass of the roof block; Mmax – maximal clamped end bending moment at the moment preceding brittle destruction of roof strata; R(0) – response in the clamped end at the moment preceding brittle destruction of roof strata; L – length of roof block; zmax – maximal bending of the roof block at the moment preceding brittle destruction of roof strata in z-x1 coordinates; x1 – axis direction for determination of roof block sagging at the moment preceding brittle destruction of roof strata; y and x – direction of axes for determination of parameters of roof block vibrations at the moment after brittle destruction of roof strata.

Vibrations of the roof block after brittle destruction of strata can be described by the non-uniform differential 4th order partial equation

$$\frac{\partial^2 y}{\partial t^2} + \frac{E_0 J}{m} \cdot \frac{\partial^4 y}{\partial x^4} = g\,,$$

where $\partial^2 y/\partial t^2$ – the second derivative of the roof block deflection in time; J – moment of inertia of the block cross-section; E_0 – E- modulus of roof strata; $\partial^4 y/\partial x^4$ – the fourth derivative of the roof block deflection along its length.

The equation of beam deflection at the moment preceding brittle destruction of roof strata (fig. 1) reduced to x – y coordinate system and used in review of oscillating process after brittle destruction is the initial condition for numerical solution of the given differential equation

$$y(x,0) = \begin{cases} \left(\frac{x}{24E_oJ}\right) \cdot [(q_{п} + mg)(6L^2x - 4Lx^2 + x^3 - 3L^3) + 2Rx(x - 3a)], \text{ при } x < a, \\ \left(\frac{x}{24E_0J}\right) \cdot [(q_{п} + mg)(6L^2x - 4Lx^2 + x^3 - 3L^3)], \text{ при } x \geq a. \end{cases}$$

In accordance with fig. 2, the equal-zero deflection and deflection moments in rocker bearings of the beam (roof block) will be boundary conditions in solving of the induced differential equation

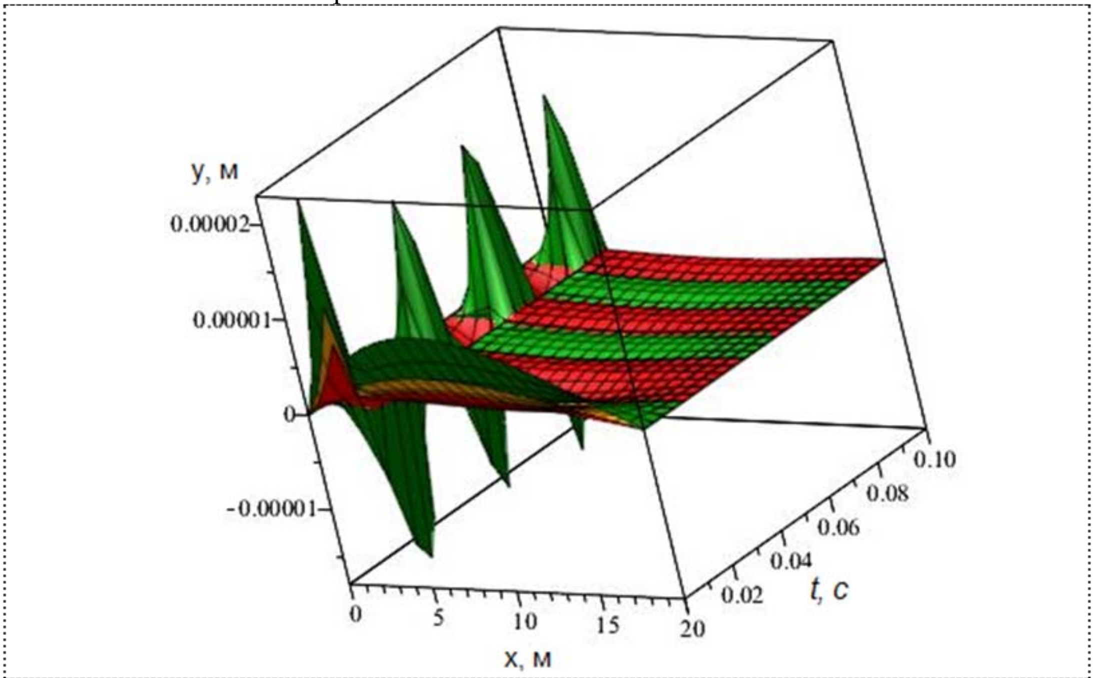
$$y(0,t) = 0,$$

$$y(L,t) = 0,$$
$$\frac{\partial^2 y(0,t)}{\partial x^2} = 0,$$
$$\frac{\partial^2 y(L,t)}{\partial x^2} = 0$$

The roof support response taken in the form of a concentrated force facilitates solving of the given differential equation describing the oscillating process of the roof falling and allows to assess at a first approximation the parameters of block vibrations (frequency, amplitude and rate of displacement) during secondary convergences.

As a result of numerical solution of the given differential equation, there were received dependencies of amplitudes and forms of the roof block vibrations after its brittle destruction in relation to physical and mechanical properties of rock, rock parameters and roof support parameters (fig. 3–5) in which one can see that maximal value of the block vibrations amplitude is located in the point of application of roof support force R.

Also, an increase in the rated operating resistance R of roof support and in the distance from the face to the place of location of resultant response a of the support causes an increase in the amplitude and rate of roof displacement. While an increase in the specific weight of roof strata decreases the amplitude and the rate of roof displacement due to increase in inertial forces.



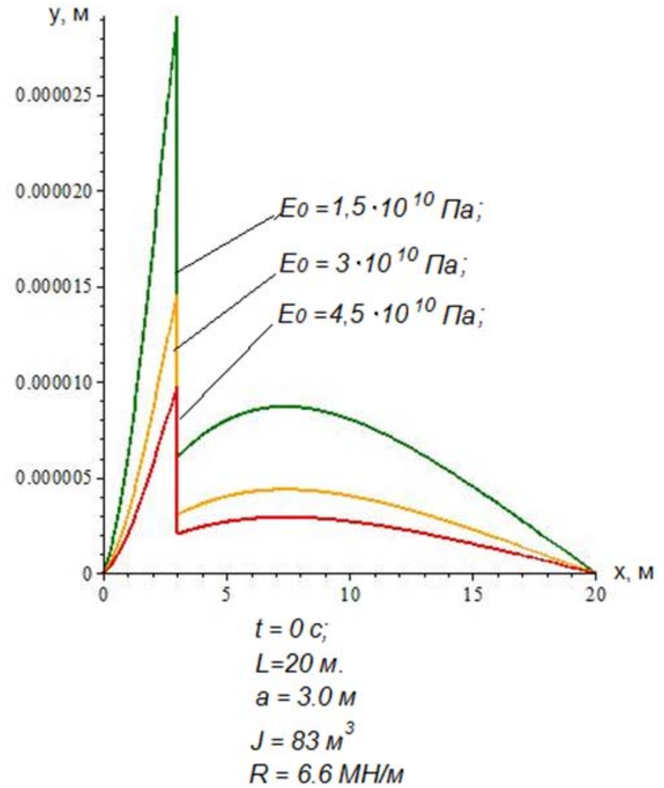
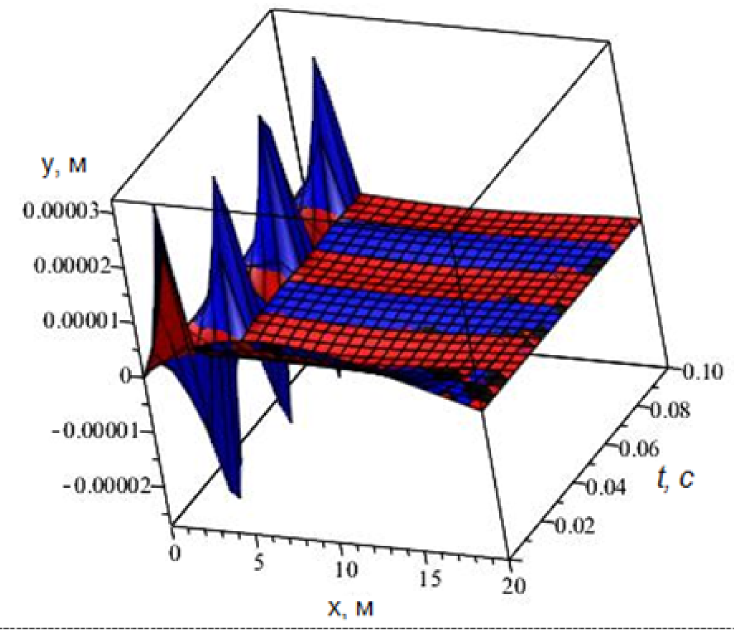


Figure 3. Change in roof vibration amplitude (y) in time (t) and in length of the block (x) depending on elasticity modulus of roof strata (E_0) at the rated operating resistance of roof support R = 6.6 MN/m, at the moment of inertia moment of the block cross-section J = 83 m^3, length of the block L = 20 m and distance from the face to roof support response a = 3.0 m.



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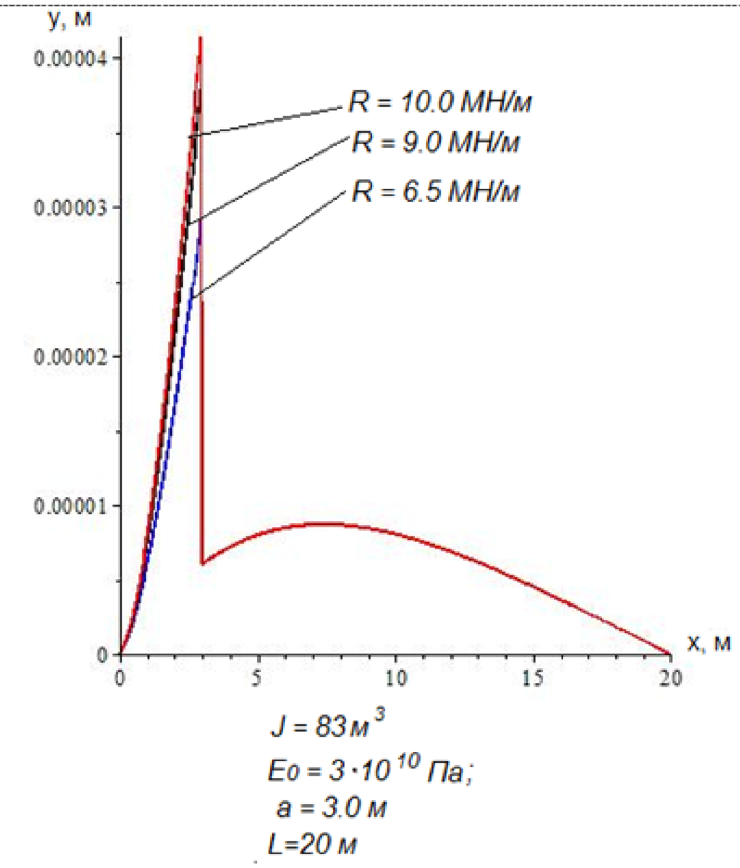
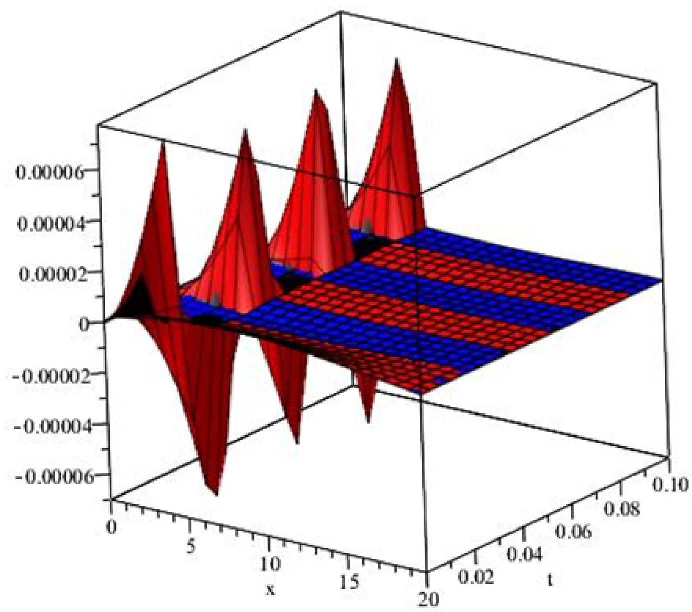


Figure 4. Change in roof vibration amplitude (y) in time (t) and in length of the block (x) depending on the rated operating resistance of roof support R at elasticity modulus of roof strata $E_0 = 3{\cdot}10^{10}$ Pa, inertia moment of the panel cross-section J = 83 m^3, length of the panel L = 20 m and distance from the face to roof support response a = 3.0 m.



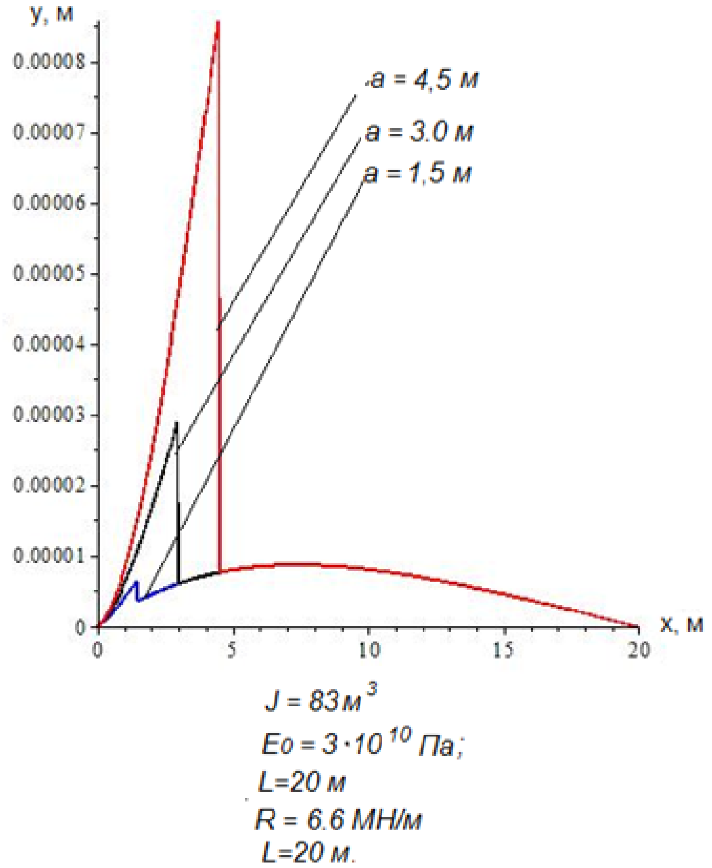


Figure 5. Change in roof vibration amplitude (y) in time (t) and in length of the block (x) depending on the distance from the face to the roof support response a at the rated operating resistance of the roof support R = 6.6 MN/m, elasticity modulus of roof strata $E_0 = 3{\cdot}10^{10}$ Pa, inertia moment of the block cross-section J = 83 m^3, length of the block L = 20 m.

4. Conclusions

The parameters of roof block vibrations during secondary roof convergences are defined by physical and mechanical properties of strata (specific weight m, elasticity modulus E_0), roof block dimensions (length L, thickness h) as well as by force (rated operating resistance R) and geometrical parameters of the roof support (distance from the face to the point of application of the resulting response from support a).

The values of roof vibration parameters for the roof support response in the form of the concentrated force vary within the following range:

- Maximal amplitude in the point of application of roof support response A = 0.00001–0.00008 m;
- Frequency of vibrations f = 25–100 Hz;
- Rate of roof displacement in the place of location of roof support response V = 0.002–0.008 m/sec.

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