
GEOMECHANICS

Mitigation of Shock Wave Effect Produced by an Explosion in Mines by Changing Safety Barrier Penetrability

V. M. Fomin^{a*}, B. V. Postnikov^a, and V. A. Kolotilov^a

^a*Khristianovich Institute of Theoretical and Applied Mechanics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, 630090 Russia*

**e-mail: fomin@itam.nsc.ru*

Received March 11, 2020

Revised March 15, 2020

Accepted September 11, 2020

Abstract—Shock wave travel in a roadway with impermeable safety barriers is modeled numerically in the equilibrium and non-viscous formulation. Inclined and arched barriers are studied at the varied porosity in a range from 0 to 0.8. The inclined and arched barriers decrease the load exerted on the barrier structure by the shock wave owing to formation of a reflected wave which is oblique, or radial in case of the arched barrier. An increase in porosity of the barrier can additionally weaken the shock wave effect but barriers with high penetrability make the defensive screen inefficient, which is confirmed by the higher differential pressure at the shock wave front after passing the barrier.

Keywords: Shock wave, roadway, explosion, penetrable barrier.

DOI: 10.1134/S1062739120056983

INTRODUCTION

Coal mines represent a complex spatial branched system of channels, the total length of which reaches hundreds of kilometers. This system is not isolated, as there is a constant infiltration of gases through the walls. Complete numerical modeling of all gas-dynamic processes occurring inside a coal mine after the explosion of dust and methane-containing mixtures presents significant difficulties, both from the viewpoint of computational resources involved and used mathematical models. In this regard, it is necessary to distinguish the most important details of the ongoing processes, apply simplified methods and models for describing the gaseous medium of roadways and underlying coal seam.

The explosion of dust and methane-containing mixtures is a significant hazard in a coal mine [1]. It is difficult to determine the time and place of such an event; therefore, protection measures are used in practice to prevent the formation of conditions for the occurrence of an explosion in a roadway and to control its consequences, i.e., to reduce the intensity of shock and detonation waves. One of these means of protection is the installation of sequentially located penetrable barriers [2, 3]. The operation of a screen consisting of displaced penetrable barriers, the porosity of which corresponds to the cross-section of industrial screens, was investigated by numerical simulation in [4].

This paper aims at studying the influence of the geometric shape of penetrable barriers and their porosity on the development of shock wave processes in a roadway. The roadway geometry and location of barriers are based on the data from [4]. The inclined barriers representing flat screens at an angle of 45° relative to the side of the roadway and arched barriers (their shape is determined by a quarter of the circular arc) are studied. When choosing the barrier shape, the ease of fabrication of the proposed shapes and the property of angular configurations to form oblique shock waves near their frontal surfaces were considered. This reduces the force effect on the barrier structure significantly, in contrast to the case when the shock wave front and the barrier surface are parallel. The geometry of the barriers under study is shown in Fig. 1.

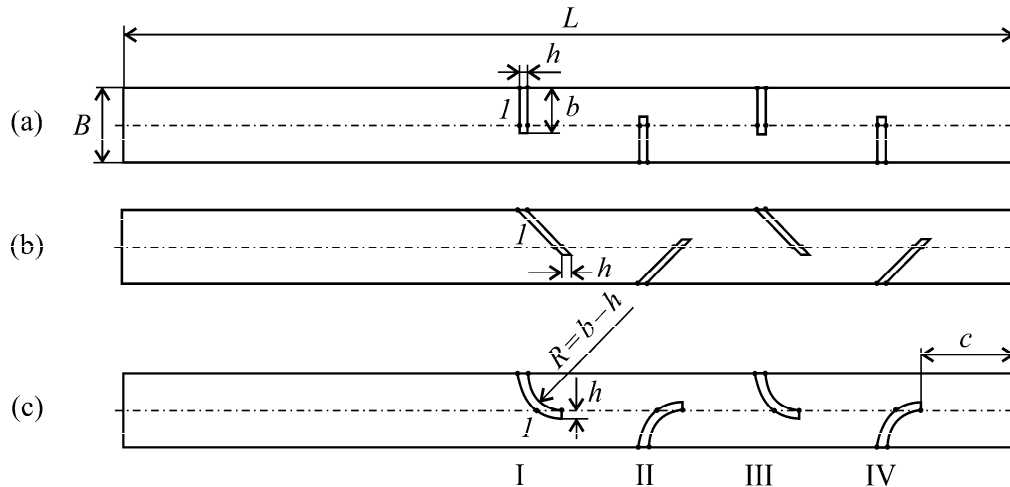


Fig. 1. Computational domain geometry for (a) flat barriers, (b) inclined at an angle of 45° and (c) formed by a circular arc: I–IV—barriers; $B/L=0.08$, $b/B=0.6$, $h/b=0.2$, $c/B=0.8$; l —the point at which the pressure change was analyzed in detail.

The problem was solved in a two-dimensional formulation in the equilibrium and non-viscous approximation. Chemical reactions in the interaction area were not taken into account. The system of equations describing the problem for a two-dimensional nonstationary case includes the equations of continuity, conservation of momentum, conservation of energy. The gas was assumed to be ideal with constant heat capacity. The presence of water and coal dust was accounted integrally [4]. The calculations were carried out in the ANSYS Fluent software package using the density-based AUSM Flux Type solver, a module for calculating flow in a porous medium, an explicit scheme of the second-order accuracy. Unstructured computational grid consisted of 900 thousand cells, time step—0.1 ms.

For comparison with the data obtained in [4] for flat barriers, inclined and arched barriers were calculated at a porosity of 0.4. The influence of barrier porosity on the development of shock wave process in the roadway is demonstrated by the example of arched barriers. The porosity ϕ was taken from a number of numerical values 0, 0.2, 0.4, 0.6, 0.8. The zero porosity case corresponded to a solid barrier. The resistance law of a porous body in the form of $\Delta p / \Delta x = C_0 V^2$ was used in calculations (Δp is the differential pressure on section Δx ; V is the mixture velocity).

To calculate the coefficient C_0 , it is assumed that hydraulic resistance of the barrier $\zeta = \Delta p / (\rho V^2 / 2)$ is the function of its porosity ϕ : $\zeta = [0.707(1-\phi)^{0.375} + 1 - \phi]^2 / \phi^2$, which corresponds to the data [5] for perforated sheets. This approximation can be considered acceptable, given the two-dimensionality of the calculation and the use of integral characteristics of the medium.

Before calculation, a pressure differential at the left boundary of computational domain was set equal to 0.6 MPa, the pressure was 0.1 MPa in the screen area. At the initial moment of time, the pressure beyond the shock wave front was $P=0.7$ MPa. The formed shock wave moved from left to right in the direction of the first barrier, just as in the case of flat barriers [4], then the shock wave front was reflected from the first and subsequent barriers. The shock wave passed through penetrable barriers with a certain deceleration according to the resistance law of the medium for a given porosity (Fig. 2a). The inclined or arched frontal wall of the barrier caused reflection of the shock wave towards the right side of the roadway. A configuration of shock waves characteristic of Mach reflection was subsequently formed along the right side (Fig. 2b). The shock wave reflected from the right side of the roadway moved in the direction of the internal angle formed by the left side and the barrier, where a sharp repeated increase in pressure took place. In the case of an inclined and arched barrier, the first and second peaks of pressure are less than that one for a flat barrier.

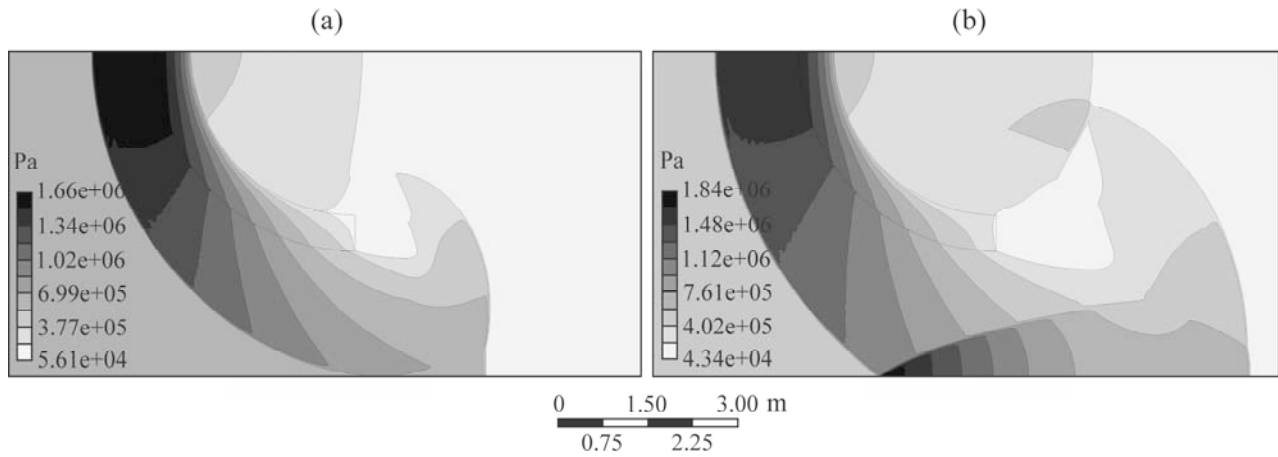


Fig. 2. Pressure field. The area of anomalous pressure moving in the opposite direction along the right side of the roadway near the first arched barrier. Time since the beginning of calculation: (a) 49 ms; (b) 52 ms.

Calculations have shown that at point *1* on the frontal surface of the first barrier located along the symmetry axis of the roadway, for a porosity of 0.4, the arched barrier experiences the lowest load (Fig. 3). Different porosity values were calculated for this barrier (Fig. 4).

The loading intensity of the barrier decreases approximately 2 times, as porosity increases. For a porosity of 0.8, the pressure was 0.85 MPa versus 1.56 MPa for a flat barrier.

The mitigation of shock wave front by the screen decreased, as porosity increased above 0.5. Figure 5 shows the pressure values beyond shock wave front for the points located uniformly on the symmetry axis of the roadway between the rear end of the fourth barrier and the end of computational domain (Fig. 1). At a distance of 0.125 behind the fourth barrier, the pressure is lower than at other points, which is explained by the location of this area in the barrier “shadow”, where the pressure rises due to complex interference of shock waves reflected from the sides of the roadway. At a point 0.500 away from the fourth barrier, a local pressure maximum was observed for a porosity of 0.6, which is associated with a feature of the shock wave flow pattern for this particular porosity. In this case, the waves reflected from the roadway sides and the shock wave passing through the barrier converge at the point under consideration, which causes a local pressure rise.

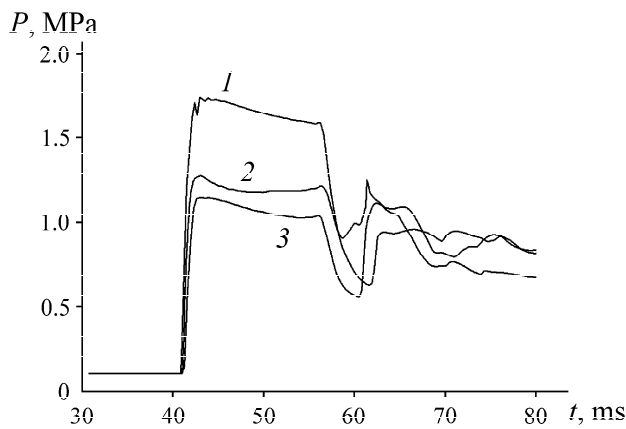


Fig. 3. Pressure versus time at point *1* of the first barrier for different geometries: 1—flat; 2—inclined; 3—arched.

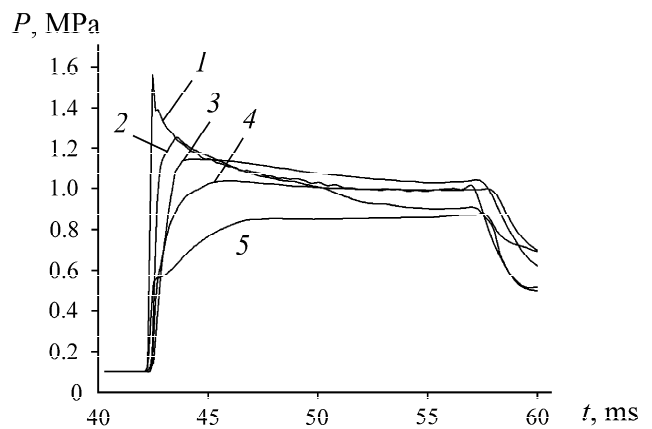


Fig. 4. Dependence of pressure at point *1* of the first arched barrier for different porosity values: 1—0; 2—0.2; 3—0.4; 4—0.6; 5—0.8.

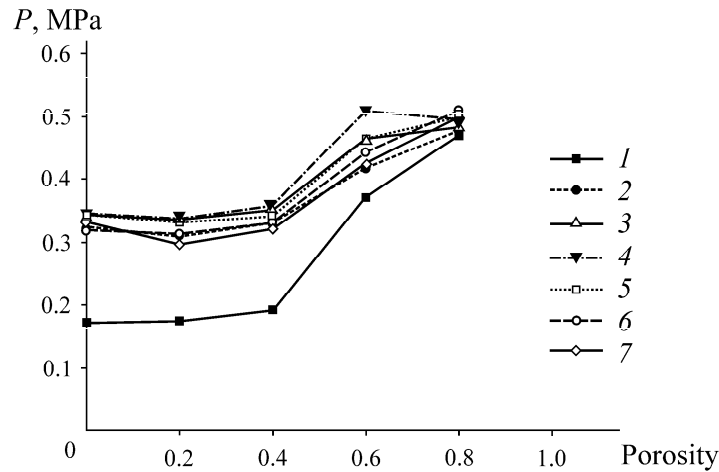


Fig. 5. Dependence of the maximum pressure on the symmetry axis of the roadway behind the screen on porosity for different distances behind the fourth barrier: 1—0.125; 2—0.250; 3—0.375; 4—0.500; 5—0.625; 6—0.750; 7—0.875.

CONCLUSIONS

The calculations showed that it is possible to mitigate a shock wave load on structural elements by changing the geometry of gas-penetrable barriers of the screen. A smaller load near the symmetry axis of the channel is experienced by an arched barrier, compared to flat and inclined barriers. Further decrease in the load on the first and subsequent barriers of the screen is possible by increasing the barrier porosity. At the same time, as the barrier porosity increases above 0.5, the effectiveness of a screen as means of reducing the intensity of shock waves caused by an explosion decreases significantly.

REFERENCES

1. Kurlenya, M.V. and Skritsky, V.A., Methane Explosions and Causes of their Origin in Highly Productive Sections of Coal Mines, *J. Min. Sci.*, 2017, vol. 53, no. 5, pp. 861–867.
2. Shalaev, V.S., Shalaev, Yu.V., and Florya, N.F., Explosion Protection of Roadways of Coal Mines. Concept, *Ugol'*, 2014, no. 9, pp. 82–85.
3. Shalaev, V.S., Shalaev, Yu.V., and Florya, N.F., Explosion Protection Equipment for Roadways of Coal Mines and its Testing, *Bezopasn. Truda Prom.*, 2015, no. 5, pp. 46–49.
4. Fomin, V.M., Postnikov, B.V., Kolotilov, V.A., Shalaev, V.S., Shalaev, Yu.V., and Florya, N.F., Modeling Shock Wave Processes in a Mine Opening with Permeable Barriers, *J. Min. Sci.*, 2019, vol. 55, no. 1, pp. 18–22.
5. Idel'chik, I.E., *Spravochnik po gidravlicheskim soprotivleniyam* (Reference Book on Hydraulic Resistances), Moscow: Mashinostroenie, 1992.