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# Soft–strong supporting mechanism of gob-side entry retaining in deep coal seams threatened by rockburst

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ABSTRACT

When gob-side entry retaining is implemented in deep coal seams threatened by rockburst, the cement-based supporting body beside roadway will bear greater roof pressure and strong impact load. Then the supporting body may easily deform and fail because of its low strength in the early stage. This paper established the roadside support mechanical model of gob-side entry retaining. Based on this model, we proposed and used the soft–strong supporting body as roadside support in the gob-side entry retaining. In the early stage of roof movement, the soft–strong supporting body has a better compressibility, which can not only relieve roof pressure and strong impact load, but also reduce the supporting resistance and prevent the supporting body from being crushed. In the later stage, with the increase of the strength of the supporting body, it can better support the overlying roof. The numerical simulation results and industrial test show that the soft–strong supporting body as roadside support can be better applied into the gob-side entry retaining in deep coal seams threatened by rockburst.



## 1. Introduction

In order to retain the roadway for the next section working face after the upper section working face has been mined, gob-side entry retaining uses different supporting schemes (filling bodies, rock refuse, single props, etc.) to support the lateral roof in the gob behind the working face or in the roadway [1–5]. Gob-side entry retaining is usually implemented in the internal stress field of abutment pressure around the working face, where it is less influenced by ground pressure and easy to keep stability [6–8]. The implementation of gob-side entry retaining not only has an important role in improving mining rates, decreasing the cost of tunneling and extending the service life of mines, but also optimizes the use of abandoned waste rock and reduces ground pollution, which is consistent with the development of green mining and mining science [9].

When gob-side entry retaining is implemented in deep coal seams threatened by rockburst, the roadside support will bear great roof pressure [10,11]. If cement-based supporting body (using cement as the main cementing material) is used as roadside support, it easily deforms and fails under the roof pressure due to its lower strength at the early stage [12–15]. Therefore, it is urgent to further study how to perform the roadside support when gob-side entry retaining is implemented in deep coal seams with the threat of rockburst.

Based on the geological and mining conditions in Suncun coal mine of the Xinwen Mining Group, this paper proposed soft–strong supporting body as roadside support when gob-side entry retaining was implemented. Firstly, the mechanical models of cement-based support and soft–strong support were established in order to reveal the roadside supporting mechanism of gob-side entry retaining in deep coal seams threatened by rockburst. Secondly, the supporting capacity of cement-based supporting body and soft–strong supporting body was analyzed by using numerical simulation. Finally, in order to verify the effects of these two kinds of supporting schemes, an industrial test was carried out in the Suncun coal mine.

## 2. Mechanical model of roadside support for gob-side entry retaining in deep coal seams threatened by rockburst

As shown in Fig. 1a, after the upper section working face has been mined, the immediate roof will cave and fall in the gob, and the basic roof will break inside the coal wall and sag down while rotating. In Fig. 1, the height of the roadway is $h$, the thickness of immediate roof is $m_z$, the fracture length of basic roof is $L_A$ and the distance between outer boundary of supporting body and coal wall is $L_K$. When cement-based supporting body is used as roadside support for gob-side entry retaining, it can be treated as spring

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with greater stiffness due to its smaller shrinkage. The mechanical model is established as shown in Fig. 1b.

Fig. 1b shows, in the mechanical model, the deformation of the cement-based supporting body is $\Delta S$ as same as the given roof convergence, the stiffness of the cement-based supporting body and coal seam are $K_1$ and $K_3$, respectively, then the compatibility equation of deformation is as follows:

$$\Delta P = K_1 \times \Delta S \tag{1}$$

$$P = P_0 + \Delta P \tag{2}$$

$$\Delta S = \frac{L_k[h - m_z(K_A - 1)]}{L_A} \tag{3}$$

where $\Delta P$ is the support resistance increment of the supporting body (kN); $\Delta S$ the amount of compression of the supporting body (m); $K_1$ the stiffness of the supporting body (kN/m); $P$ the support resistance of the supporting body (kN); $P_0$ the setting load of the supporting body (kN); $K_A$ the expansion coefficient of gangue in the goaf.

As shown in Fig. 2a, when the supporting scheme for gob-side entry retaining uses soft–strong supporting body that contains a combination of the filling bodies A and B, the filling body A is expandable soft material with greater compressibility, and its strength can gradually increase with itself process of compression deformation. However, the filling body B is cement-based supporting material with the characteristics of smaller amount of compression and high strength. In brief, the total amount of compression of the soft–strong supporting body is the sum of those of filling bodies A and B. When filling bodies A and B can be seen as two kinds of springs with different stiffness, and the roof pressure applied on filling body A is equal to that of filling body B, then the compatibility equation of deformation is as follows:

$$\Delta S = \Delta S_2 + \Delta S_3 \tag{4}$$

$$\Delta P = K_1 \times \Delta S_3 = K_2 \times \Delta S_2 \tag{5}$$

$$P = P_0 + \Delta P \tag{6}$$

The total stiffness $K$ of soft–strong supporting body is:

$$K = \frac{\Delta P}{\Delta S} = \frac{K_1 \times K_2}{K_1 + K_2} \tag{7}$$

where $\Delta S$ is the total amount of compression of the soft–strong supporting body (m); $\Delta S_3$ the amount of compression of filling body B (m); $\Delta S_2$ the amount of compression of filling body A (m); $K$ the total stiffness of the soft–strong supporting body (kN/m); $K_1$ the stiffness of filling body B (kN/m); and $K_2$ the stiffness of filling body A (kN/m).

Since all stiffness of filling bodies A and B is positive, from Eq. (7), it should be noted that the total stiffness of soft–strong supporting body is smaller than $K_1$ and $K_2$.

From Eqs. (1) and (7), it can be obtained that, when the cement-based supporting body is used as roadside support, the stiffness of the support ($K_1$) is comparatively large and its support resistance increases rapidly with the increase of the amount of compression. However, when soft–strong supporting body is used as roadside support, its stiffness is smaller than that of the cement-based supporting body and its support resistance increases more slowly with the increase of the amount of compression. The stiffness curves of cement-based supporting body and soft–strong supporting body are shown in Fig. 3.

The lateral roof of working face has a great of impact energy on roadside supporting body when gob-side entry retaining is implemented in deep coal mining. So, according to conservation of energy, the energy balance equation can be given by,

$$G = F\Delta S \tag{8}$$

where $G$ is the impact energy of the overlying roof on the supporting body (kJ); and $F$ the roof pressure on the supporting body (kN).

Therefore, the roof pressure on the supporting body is obtained by,

$$F = \frac{G}{\Delta S} \tag{9}$$

From Eq. (9), it should be noted that, with the increase of deformation of the supporting body, the roof pressure on the support gradually decreases. At this moment, the relationship between the deformation of the support and the roof pressure on the support is depicted in Fig. 4.

Fig. 5 is the combination of the Figs. 3 and 4. It can be seen from Fig. 5, when the cement-based supporting body is used as roadside support, the stiffness curve of cement-based supporting body and the roof pressure curve intersect at point $A$. At this point, the amount of compression of the supporting body is $\Delta S_a$ and roof pressure is $F_a$ during the early period of lateral roof movement. It means, while the amount of compression of the supporting body is smaller, the roof pressure is larger, then the body easily deforms and damages under the roof pressure because of the lower early strength of cement-based supporting body, and the gob-side entry retaining fails.

However, when soft–strong supporting body is used as roadside support, the stiffness curve of soft–strong supporting body and the roof pressure curve intersect at point $B$. At this point, the amount of compression of the supporting body is $\Delta S_b$ and the roof pressure is $F_b$. It should be noted that, while the amount of compression of the soft–strong supporting body is larger, the roof pressure is even smaller, compared with cement-based supporting body. Since filling body A has excellent compression deformability and the large amount of compression, it makes a major contribution to the deformation of the total supporting body ($\Delta S_b$), which is helpful to relieve the roof pressure and reduce the impact load generated by strong roof movement. It is also helpful to improve the strength of filling body B. Furthermore, during the later period of lateral roof movement, the improvement of strength of filling body B can support the overlying roof. The support resistance of the total filling body is mainly from the filling body B. Thus, it can be seen that,

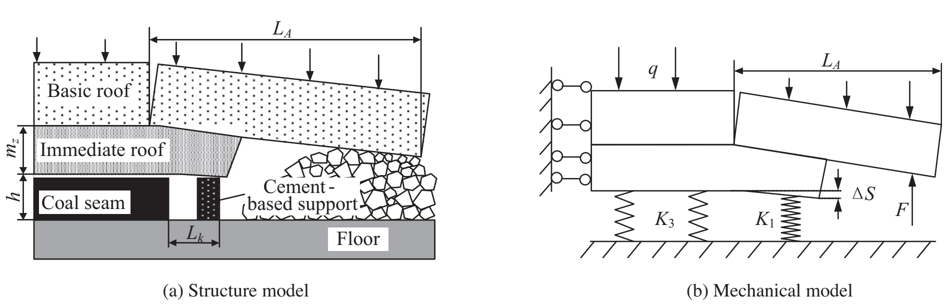


**Fig. 1.** Mechanical model of cement-based support for gob-side entry retaining.