

## ROADWAY SUPPORTING TECHNOLOGY APPLIED TO THREE SOFT COAL SEAM AT YANLONG MINING AREA IN CHINA

by

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*The compressive strength of coal in Yanlong mine area of China is less than 3 MPa. Basically, it is powdery. The roof and floor rocks are mudstone. Therefore, this coal seam is a typical “three soft” coal seam. Anchor and cable cannot be used due to low anchoring force. This paper describes how to support this type of soft coal roadway. The deformation characteristics of soft coal roadway were investigated. Results show the conventional U-shaped steel support is not subjected to uniform load, which bearing capacity can be improved by structural compensation, such as addition of horizontal and vertical beams made of U-shaped steel. In addition, by drilling pressure-relief holes in the ribs of a soft coal roadway, the stress distribution of surround rock in the roadway can be improved, which can transfer the high stress in the surrounding rock to deeper parts and reduce the pressure on the artificial support. A support method is to combine the strengthened U-shaped steel support with pressure-relieving drill holes, providing an economic and efficient way to support the very soft coal roadways.*

*Key words: soft coal seam, pressure-relieving drilling holes, high stress, coal roadway, u-shaped steel support*

### Introduction

As an important material base of national economy, it is no exaggeration say that fossil energy is the lifeline for rapid development of the country [1]. In the composition of fossil fuels, compared with other countries, China's demand for coal is stronger. There are *three soft* coal seams in some mines in China, within which the strength of coal rock is lower than average. In these coal seams, the stability of roadway surrounding rock will become very difficult, when it encounters high stress, and at the same time, is subjected to blast or the dynamic disturbance caused by roof failure [2]. The so-called *three soft* coal seam refers to soft roof, soft coal and soft bottom of the coal seam. At present, there is no unified definition of *three soft* coal seams. It is generally considered that the uniaxial compressive strength of rock in the roof and floor is less than 15 MPa and the one of coal is less than 6 MPa. In such conditions, failure of the original support from start to appear successively at many mines, the surrounding rocks of roadway show obvious characteristics of soft rocks such as large deformation and long duration [3-5].

Based on the original concept of supporting, that the surrounding rock of *three soft* coal seam is soft and broken, and the anchor and cable supporting ability is low, people now use a *U-shaped-steel + bolt-mesh-anchor* combined supporting method [6-11]. At the same time,

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according to surrounding rock loose ring support theory, people propose a supporting form of *bolt-beam-net + anchor cable* [12, 13]. But these two methods are still only valid for the *three soft* coal seams with enough coal strength. Besides, for the crushed *three soft* coal seam, based on the idea that *strong top to help the sides, and strong sides to help the top*, the powerful composite support scheme was proposed, which conclude U-shape tent, anchor rod, anchor cable, steel belt, grouting and I-beam single steel support (wearing shoes) [14-17]. In conclusion, the existing researches, on the supporting methods of the *three soft* coal seams, still give priority to the anchor net supporting technology. However, if the coal seam is thick and the coal is powdery, their strength shall be so low that the anchor and cable will lose bolting ability. At this time, we must study more new supporting methods so as to adapt to such conditions.



**Figure 1. Topographic map of Yonghua No. 1 mine in Dragon mining area, China**

are carbonaceous mudstone and shale, and the main roof is siltstone. The floor rock is carbonaceous mudstone having abundant plant fossils. Therefore, this coal seam is a typical *three soft* coal seam.

Sun [18] studied the reliability theory of mine supporting systems and found that roof bolting has only limited applicability. In the worst case, the bolt will be pulled out, when the pre-tension is applied. Therefore, the bolting method cannot be used. Xie *et al.* [19] analyzed the structural stability of U-shaped steel support and its control technology. When the yielding steel support made of U36 steel was installed in the mine, it did not achieve the ideal supporting performance. Field observations showed that the largest cross-sectional deformation of coal roadway could exceed 30% about one half month after development. Usually, 70 ~ 90% of the coal roadways require repairs, and most of the roadways need repeated repairs and re-supports, which slowed down roadway development, and increases supporting cost and potential safety hazards.

As for various types of steel supports in Chinese coal mines, the U36-shaped steelsupport is a conventional support having the highest bearing capacity. But it is not strong enough for soft coal roadways. This paper provides guidelines for enhancing the supporting capacity of the whole U36-shaped steelsupport through structural compensation and optimization. At the same time, a method of drilling holes for pressure-relief is adopted so that the high stresses in the surrounding rocks can be transferred to farther away. The combination of these two methods provides a way to ensure the stability of the soft coal roadways.

### Stress analysis of U-shaped steel support

The ANSYS software was used to model the conventional U36-shaped steelsupport in soft coal roadways. The model with boundary condition is shown in fig. 2, which is 75 m wide by 75 m high with the roadway at the center. The vertical displacement on the lower

Dragon mining area in China is located in the geologically complicated tectonic zone of Songshan Mountain, having 72 mountain ridges. Therefore, coal seams in this area are extremely non-uniform and very weak with well-developed fractures, which is the typical characteristic of *tectonic coal*. Figure 1 shows the topographic map of Yonghua No. 1 mine in Dragon mining area.

The major coal seam 21 mined in the Dragon mining dips  $9^{\circ} \sim 20^{\circ}$ . It is so soft, less than 3 MPa in compressive strength, that it can be crushed easily by hand. The immediate roofs

boundary was fixed, while the horizontal and the top boundary were free. The vertical stress was applied on the top boundary, and the horizontal stress was applied on the left-side and right-side boundaries. The Mohr-Coulomb yield criterion was used. The model of U-shaped steel support consisted of two nodes beam element, and the overlap parts of the steel support were simulated with equivalent material processing method, *i. e.*, the lap part and clamps of the support were replaced by the equivalent cross-section bar. The vertical stress  $\sigma_x$ , horizontal stress  $\sigma_y$ , and lateral pressure coefficient were 8.38 MPa, 12.56 MPa, and 1.5 MPa, respectively. Mechanical parameters of surrounding rock were shown as tab. 1. Six layers were considered.

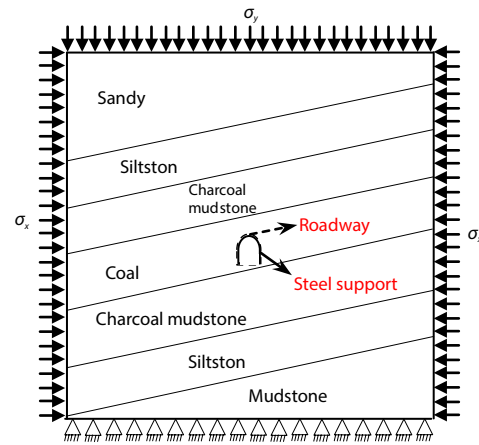


Figure 2. Model with boundary condition

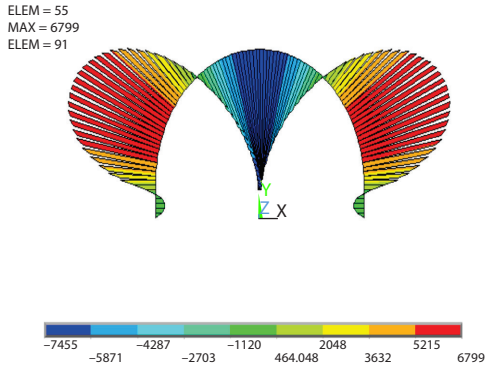
Table 1. Mechanical parameters of surrounding rock

No of layer	Lithology	Thickness [m]	$E$ [GPa]	$\mu$	$C$ [MPa]	$\phi$ [°]	$\gamma$ [kN·m <sup>-3</sup> ]	Position
1	Medium sandstone	6.0	41.5	0.22	3.2	31	26.2	Hard roof
2	Sandy mudstone	3.5	29.3	0.20	2.9	29	24.6	Immediate roof
3	Mudstone	0.5	16.7	0.32	2.1	27	24.1	False roof
4	Coal	5.9	6.0	0.30	0.4	20	13.0	Coal
5	Sandy mudstone	3.0	29.3	0.20	2.9	29	24.6	Immediate floor
6	Medium sandstone	9.0	41.5	0.22	3.2	31	26.2	Hard floor

Figure 3 shows the bending stress distribution of the U-shaped steel support. The bending stresses of the top and side parts are larger. These parts deform easily due to lack of constraint. Table 2 shows the four kinds of schemes about enhanced U-shaped steel support mode.

Table 2. Four kinds of schemes about enhanced U-shaped steel support mode

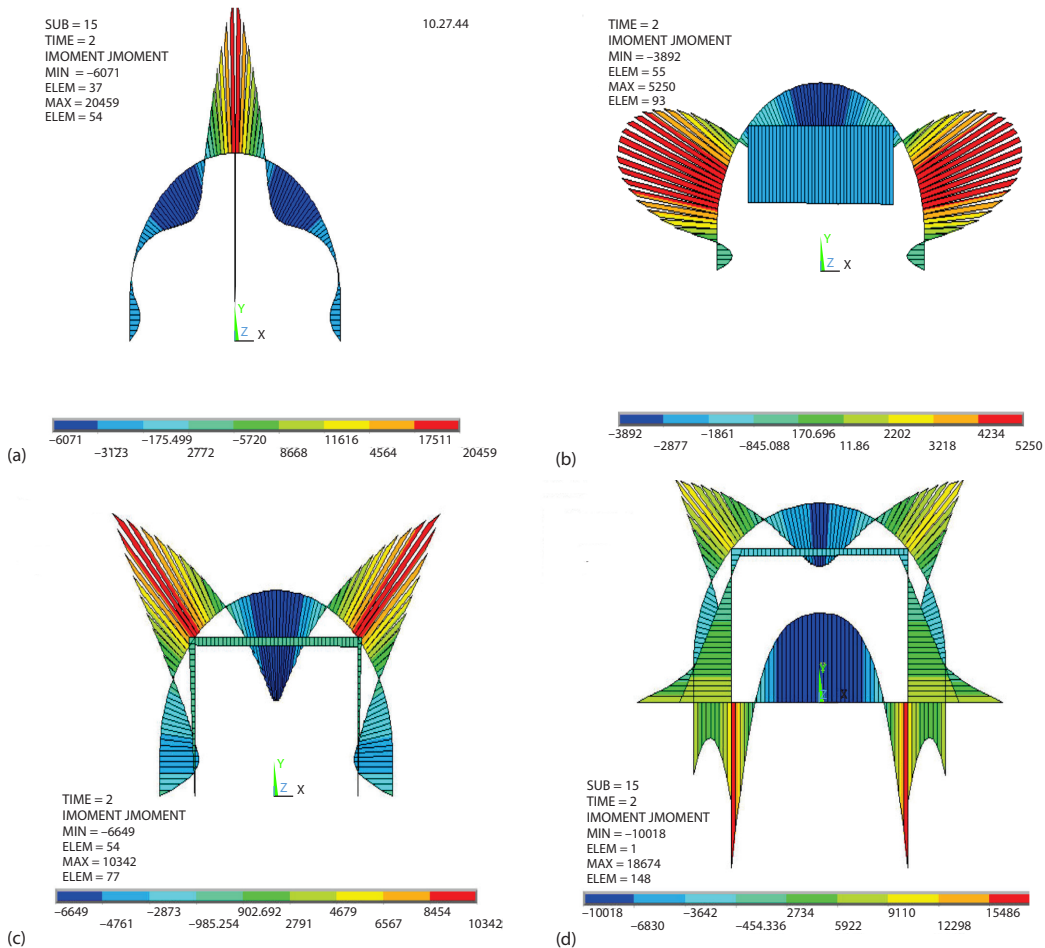
Scheme number	Support description	Schematic diagram
1	U-shaped steel support with a vertical beam	
2	U-shaped steel support with a horizontal beam	
3	U-shaped steel support with a horizontal beam and two vertical beams	
4	U-shaped steel support with two horizontal beams and two vertical beams	



**Figure 3. Bending stress distribution of conventional U-shaped steel support**

The bending stress distributions of the four kinds of enhanced *U*-shaped steel supports are shown in fig. 4.

From figs. 4(a)-4(d), a conclusion can be made, through the addition of some vertical and horizontal beams to the *U*-shaped steel support, the stress distribution can be altered and deformation limited to a certain extent. As a result, the bearing capacity of the overall support can be improved. In comparison, scheme 3 and scheme 4 have obvious advantages, and both can improve the stability of the steel support. However, scheme 3 is easier to implement in the field because it has no lower horizontal beam.



**Figure 4. Bending stress distribution of four kinds of schemes about enhanced U-shaped steel support mode; (a) Scheme 1, (b) Scheme 2, (c) Scheme 3, and (d) Scheme 4**

### Numerical and experimental analyses of pressure-relief drill holes

The FLAC3D software were used to analyze the stress distribution in the surrounding rocks of the coal roadway after pressure-relief holes are drilled. Figure 5 shows the model of pressure-relief drill holes, while fig. 6 shows the abutment pressures around the coal roadway before and after the holes are drilled.

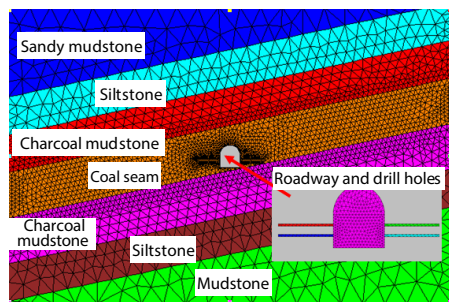


Figure 5. Pressure-relief drilling model

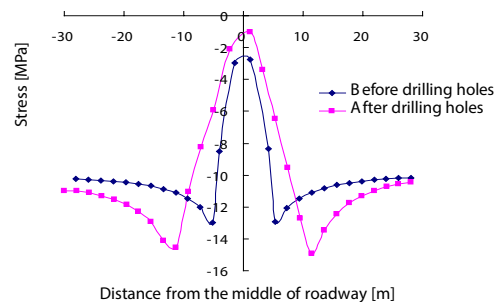


Figure 6. Abutment pressure distribution of the roadway

Figure 6 shows that there are high stress zones in the surrounding rocks before the pressure-relief holes are drilled. These high stresses are effectively released and significantly reduced after drill holes are completed. Consequently the coal roadway is located in the low stress area, while the highest stress is transferred to the deep portions of the surrounding rocks. As a result, the stability of roadway is enhanced.

Due to its softness, hole wall is rough. Some drill holes are closed up completely one month after drilling. In order to study the deformation characteristics of drill holes, two devices were employed to measure borehole deformation. The hole diameter deformation and the hole volume change meters are shown in figs. 7 and 8, respectively.

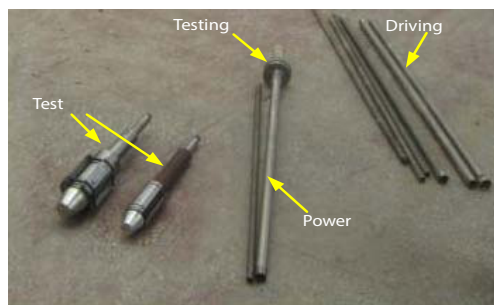


Figure 7. Hole diameter deformation meter



Figure 8. Hole volume change meter

The hole diameter deformation meter is made of a test head, combination rods, driving rods, a testing unit, and power rotary, that can determine the change in drill hole diameter. The hole volume change meter is made of bag, vent, control valves, water injection pipe, and water meter. When the hole diameter is reduced it squeezes the water out of the water bag and the amount of water squeezed out is a measure of the volume change of the drill hole. Multiple sets of experimental data show that the rate of volume changes of the drill hole basically decreases gradually from outside to inside. About forty days after drilling, the maximum rate of shrinkage in drill hole cross-section was 60% ~ 65%. By this time re-drilling of the hole should be considered.



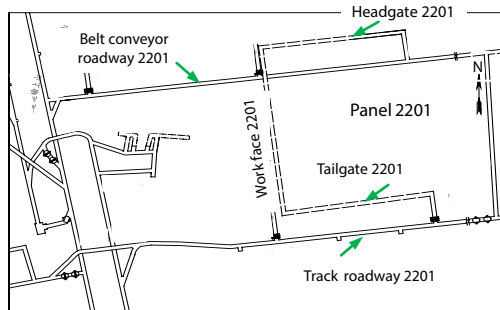


Figure 9. Test site details

### Support design in underground coal environments

The test site was located at the gateroads of Panel 2201, Yonghua No.1 mine in the Drag-on mining area as shown in fig. 9.

#### Structurally enhanced support

Originally, the conventional U36-shaped steelsupport was used in the gateroads of this panel. The original gateroad support is shown in fig. 10.

Based on the results of theoretical and finite element analyses, plus consideration of the on-site condition, the structurally enhanced U36-shaped steelsupport was used in the gateroads. The location of the U-shaped steel horizontal and vertical beams on both sides was considered from the point of view of effective use of space. The specific dimensions of the structurally enhanced support are shown in fig.11. The roadway cross-section, 4.2 m wide by 3.23 m high, has been increased for the new support. The vertical and horizontal beams are connected to the conventional U-shaped steel support by a section of U-shaped welded steel. This way it maintains stable through the use of both support and friction.

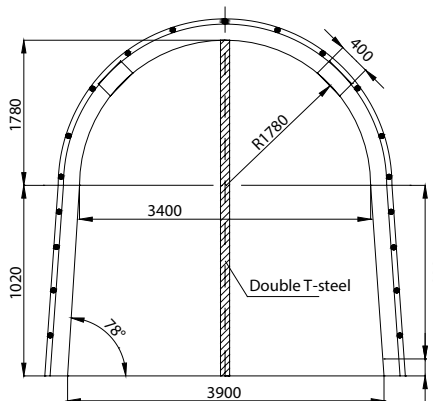


Figure 10. Original support design [mm]

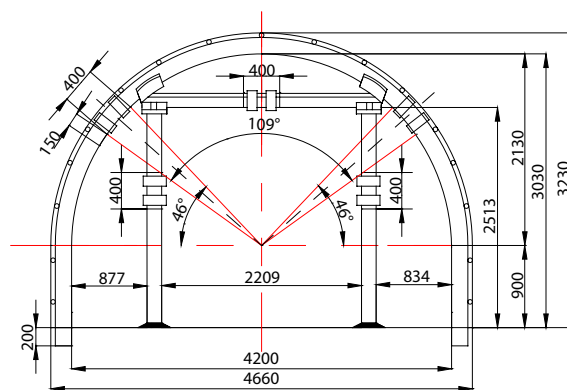


Figure 11. New support design [mm]

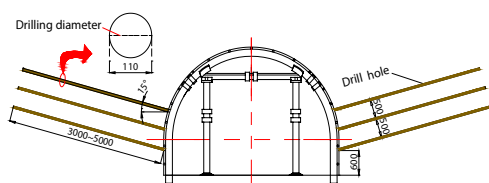


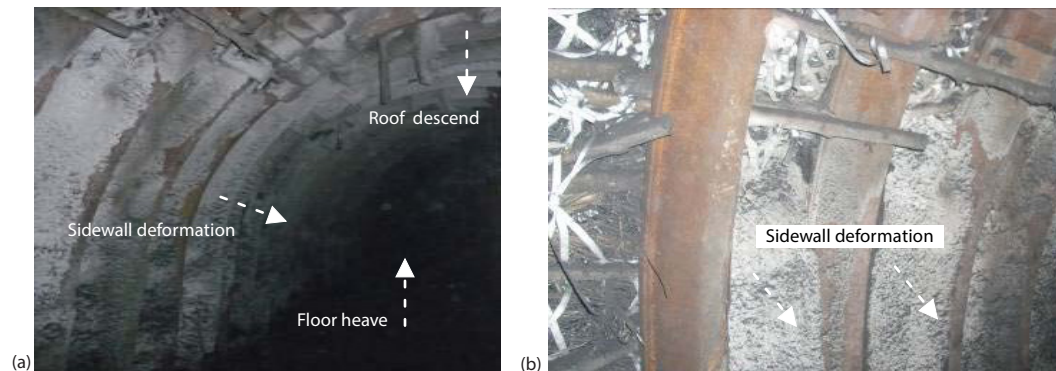
Figure 12. Lay-out of drill hole in the gateroads [mm]

#### Pressure-relief drill holes

The holes were drilled between two steel supports spaced at 500 mm. In each row, the hole spacing was 500 mm. The angle of the drill hole was 15° upward, and the depth was 3000mm ~ 5000 mm. The lay-out of drill holes at the gateroads is shown in fig. 12.

#### Field experiment and evaluation of support effective

Figure 13 shows the gateroads supported with the conventional U<sub>36</sub>-shaped steelsupports one half month after development.



**Figure 13. Original support with conventional U-shaped steel tents one month after development; (a) roadway deformation, (b) broken coal rib squeezed out into the gateroad**

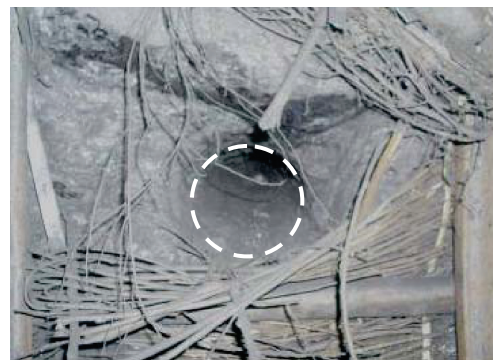
From fig. 13, it can be seen that the cross-section of the gateroads supported by the original support design became smaller, and the whole U36-shaped steelsupport sank into the floor, in particular the roof deformation is larger. There was some floor heave, and some broken coal rib was squeezed out into the gateroad. But the U-shaped steel support has not damaged seriously, although gateroad deformation continued one month after development.

In view of this situation, a supporting method with the following installation sequence was developed: roadway development, installation of the conventional U36-shaped steelsupport, drilling pressure-relief holes in the ribs, setting up the structurally enhanced auxiliary support, and finally re-drilling of pressure-relief holes.

The hand-held pneumatic drill model ZQS-65/2.5 was employed. The diameter and length of drill rod were 69 mm and 1000 mm, respectively, while the diameter of drill head was 110 mm. The pressure-relief holes were drilled 20 m out by the development face. Figure 14 shows a miner drilling a pressure relief hole, while fig. 15 shows a pressure-relief drill hole. The time lapse for re-drilling the hole was usually one or one and one half months later.



**Figure 14. Miners drilling the pressure-relief hol**

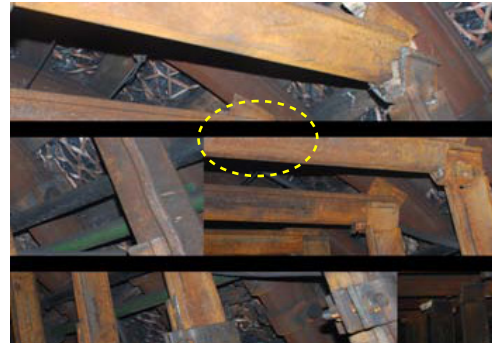


**Figure 15. A pressure-relief hole**

The structurally enhanced auxiliary support is set up after the pressure-relief holes are completed. A special crew was arranged for drilling the pressure-relief holes and setting up the auxiliary support. Therefore, this crew can work simultaneously with those for roadway development, greatly improving the efficiency of roadway development. The structurally enhanced U36 steel support is shown in fig. 16. Some special U-shaped steel connecting parts are



**Figure 16. Structurally enhanced U36 steel support**



**Figure 17. Connecting parts of U-shaped steel support**

welded in the vertical and horizontal beams in order to keep the auxiliary parts connected to the U steel shed arc. The connecting parts are shown in fig. 17. The horizontal and vertical beams are both made of two parts of U-shaped steel, connected with two clamps with certain amount of retraction.

In order to monitor the roadway deformation, the *cross point* method was used to measure roadway deformations between roof and floor, and between two ribs. The results indicated that two months after development, the maximum deformation of roadway cross-section is less than 8%. Consequently the roadway deformation has effectively been controlled.

### Conclusions

- The bearing capacity of the surrounding rocks in soft coal roadways is so low that its stress is mostly born by the installed support. In a coal roadway, it is very difficult to improve the strength of coal seam. Therefore, the key to solve this problem is to improve the supporting strength of material or transfer the stress in the surrounding rock away from the support.
- The conventional U-shaped steel support is subjected to uneven load and thus its overall bearing capacity is limited. Localized stress concentration may damage the support or cause the support to punch into the floor. This research has demonstrated that the bearing capacity of the whole support can be improved by structural compensation, such as addition of horizontal and vertical beams made of U-shaped steel.
- By drilling pressure-relief holes in the ribs of a soft coal roadway, the stress distribution of surround rock in the roadway can be improved. This simple method can transfer the high stress in the surrounding rock to deeper parts and reduce the pressure on the artificial support.

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