

Research Article

Research on Technology of Supporting in Super-Large Section Cut in Working Face with Large Mining Height

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For the support problem of the super-large section cut in working face with large mining height, the 1105 cut pilot chamber of Zhaogu No. 2 Mine, the roof strata structure detection and the strata movement rule research were conducted. The results prove that concentrate fracture area, gradually sparse fracture area, and rare fracture area regularly distributed from the surface to the deep area of the roof of 1105 cut, and less fracture exists in the rock stratum of roof above 3.5 m, and the stratum of roof within the range of 4–6 m is stable. Authors propose the long bolt and cable combined supporting technology and optimized the design plan applying theoretical calculation and computer numerical simulation. The scheme has been applied in the field of the 1105 super-large section cut in Zhaogu No. 2 Mine. The monitoring results show that the scheme can effectively control surrounding rock of roadway, and the support with long bolt has good effectiveness.

1. Introduction

As the coal mine high yield and high efficient working face advance and further improve the degree of mechanization, especially the use of large mining heights, working face equipment is becoming larger and larger, and the open cut span of working face is also increasing, which increases the difficulty of support and maintenance. The support problem of the super-large cross-section open cut has become an important problem in the field of coal mine safety [1–11]. In terms of technology, the research on the prevention and control measures of rock burst has also been constantly improved, and the pressure relief method has made rapid progress. A variety of methods have been successfully used to prevent rock burst at home and abroad [10, 12, 13]. In this study, the large-diameter boreholes in the coal roadway pressure relief mechanism and reasonable parameters further research will be conducted. At the same time, it analyzes the layout direction, diameter, hole spacing, hole depth parameters, and their reasonable combinations of large-diameter boreholes, so that to provide extremely important theoretical support for the practical application and

popularization of large-diameter borehole pressure relief technology and has great practical application value.

2. Project Overview

The 1105 working face is the first large mining height working face of the Zhaogu No. 2 Mine, with an elevation of –636 to –618 m, which is a typical deep buried layout. The No. 2 coal seam is mainly mined at the 1,105 large mining height working face. The average thickness of the No. 2 coal seam is 6.32 m. The false roof is mainly mudstone and carbonaceous mudstone less than 0.5 m, which are only scattered in this area and generally fall with the mining. The thickness of the direct roof is generally 1.0–6.5 m, which is dominated by mudstone roof and accounts for 70% of the coal bearing area. The distribution area of sandstone is about 20% of the coal bearing area and sandy mudstone accounts for 15% of the coal bearing area. The old roof thickness is 0.94–19.85 m, and the average thickness is 7.46 m siltstone. The mechanical strength of the roof sandstone is medium, and the mudstone siltstone is medium-low, which belongs to the roof with medium-low management degree. The floor of

the second coal seam is dominated by mudstone and sandy mudstone, with a thickness of 9.1–17.27 m, with an average of 12.84 m. The comprehensive coal and rock layer of the working face is shown in Figure 1.

The cutout of the 1105 working surface is a rectangular section with a design length of 180 m, a height of 4.62 m, a normal section width of 9.2 m, and a nose and tail section width of 10.2 m. During tunneling construction, the small section guide adit shall be tunneled first, the width of which is 4.8 m, and the support shall be expanded to the normal section before installation.

3. Supporting Mechanism of 1105 Super-Large Section Open Cut

3.1. Fine Detection of Roof Rock Structure. Thickness of roof strata and the intensity have an important effect on roof stability, but due to the complexity of coal-forming environment and geological changes, different positions of roof rock strata thickness and strength can produce a very big change; in order to get the roof strata structure features of 1105 cut, thirteen roof detection boreholes are uniformly arranged in the guide tunnel of the off-cut, and the rock structure peeping instrument is used to detect the roof layering, layer thickness, rock cracks, and lithology to provide a basis for the design of the later off-cut support. The fine detection results of the roof rock formations show that the lithology within 10 m above the roof of the 1105 notch is relatively simple, the lower part is sandy mudstone with low strength and low cohesion, and the upper part is fine-grained sandstone; along the axial direction of the notch, the roof sandy mudstone layers at both ends are thinner than the middle part of the cut, and the ends of the fine-grained sandstone layers are slightly thicker than the middle. There are many cracks in the shallow part of the roof. The closer the roof is to the surface, the more fractured the surrounding rock is. From the surface of the roof to the deep part, there are different characteristics, such as dense fracture zone, sparse fracture zone, and rare fracture zone. In most boreholes, the fractures above 3.5 m are not particularly obvious. Based on the above rock structure characteristics, the length of anchor rod should be increased after the brush cross-section, and the anchorage end should be extended above the fissure dense area to ensure the stability of the roof in the shallow fissure dense area.

3.2. Movement Law of Rock Stratum on the Roof of Guide Tunnel. After the excavation of the guide tunnel, the original design plan is adopted for the combined support of bolts and cables. The bolt specifications are 20 mm × 2400 mm rebar resin bolts, the row spacing between the top bolts is 800 mm × 800 mm, and the anchor cable specification is 21.6 mm × 8250 mm anchor cable, with a row spacing of 1,600 mm × 1,600 mm. After the excavation of the roadway, the stress of the surrounding rock on the roof is transferred and concentrated, and the layered roof is prone to separation failure after

deformation. In order to grasp the separation failure area of the guide tunnel of the cutoff cut and judge the support effect, it is the bolt (cable) parameter that optimizes and determines the reasonable length of the anchor rod to obtain basic field data. Set up rock movement measurement stations on the roof of the guide tunnel and install 2.0 m, 4.0 m, 6.0 m, and 10.0 m at each measurement station. Observe base points at different depths. The monitoring curve of multibase displacement in the roof of the guide adit is shown in Figure 2.

The monitoring data show that the overall deformation of the roof increases rapidly after the opening of the open-hole guide adit and gradually slows down. After 20 d, the deformation of the roof is stable at about 150 mm. The deformation of the roof mainly occurs within 4 m of the depth of the roof, accounting for about 80 of the overall deformation of the roof. Among them, the displacement of roof in the range of 2–4 m is about 50 mm because the common short bolt is not long enough to control the stability of rock stratum in this range. The displacement of the roof rock in the range of 4 m is close to coincide with the displacement of the rock in the range of 6 m, and the displacement change trend is synchronized, indicating that the rock formation in the range of 4–6 m from the roof of the 1105 cutoff cut is relatively stable. The anchor end of the rod is extended to a range of 4–6 m, and the rock formation with a large displacement within the range of 4 m is suspended on the stable rock formation. Mechanically calculate stability of roof rock beam. After roadway excavation, the roof will bend and sink to a certain extent under the action of overlying strata load. With the increase of roadway section, the total subsidence of the roof will increase and the stability will be greatly reduced. The ultimate span formula of the simply supported beam of material mechanics was used to calculate the subsidence amount of the roadway roof, and a coordinate system is established as shown in Figure 3. The deflection at the left and right hinge supports of the boundary condition was equal to zero.

The bending moment equation of the beam is

$$M(X) = \frac{ql}{2}x - \frac{1}{2}qx^2, \quad (1)$$

where M is the bending moment of the beam, q is the load of overlying strata, and l is the rock beam span.

Substitute formula (1) into the approximate differential equation of the deflection curve of a straight beam:

$$EI\omega'' = -M(X), \quad (2)$$

where ω'' is the second derivative of beam deflection, E is the elastic modulus of roof rock mass, and I is the moment of inertia of the roof rock beam.

The deflection curve equation of the roof beam is

$$\omega = \frac{qx}{24EI}(l^3 - 2lx^2 + x^3). \quad (3)$$

Therefore, it is judged that the maximum deflection must be in the middle of the beam span, that is, at $x = l/2$. At this time,

legend	Thickness (m)	Lithology	Description
	10.37	Siltstone	Dark gray, Containing plant fossils, Argillaceous cement
	6.5	Mudstone, Sandy mudstone	Dark gray, Containing plant fossils and a large number of siderite nodules
	6.32	Coal	Black, Blocky, Metallic luster
	7.3	Sandy mudstone	Black gray, Contains plant fossils and nodules
	5.41	Mudstone	Dark gray, Containing plant fossils, Silica cement

FIGURE 1: Comprehensive histogram of working face.

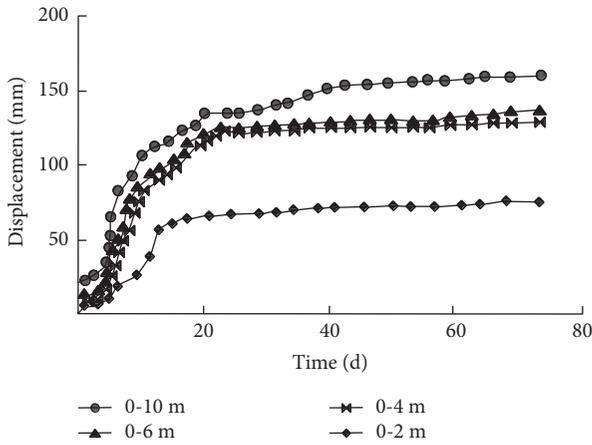


FIGURE 2: Multibase point displacement monitoring curve in the deep part of the guide tunnel roof.

$$\omega_{\max} = \omega|_{x=l/2} = \frac{5ql^4}{384EI} \quad (4)$$

As the height of the roof rock beam remains unchanged, the moment of inertia of the roof rock beam is proportional to the span l of the rock beam, namely,

$$I = \frac{h^3}{12}l \quad (5)$$

Substituting equation (5) into equation (4), that is, the maximum deflection of a rock beam with a roadway roof is

$$\omega_{\max} = \frac{5ql^3}{32Eh^3} \quad (6)$$

It can be seen from equation (6) that the maximum sinking deformation of the roadway roof is proportional to the third power of the roadway span l . For the 1105 cutoff, the previous monitoring data show that the deformation of the guide way roof is about 150 mm, which is extended to normal. After the cross-section, the deformation of the top plate of the open cut will increase by 6–9 times, and the safety of the top

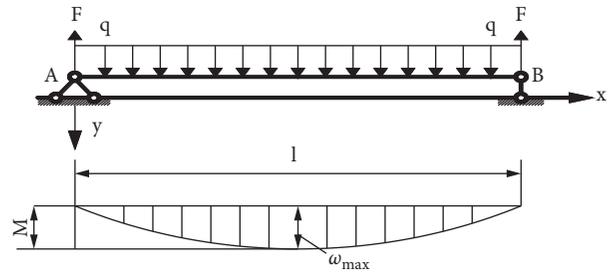


FIGURE 3: Mechanics model of simply supported beam of roadway roof.

plate cannot be guaranteed. Therefore, for the support of the super-large cross-section open cut, it is necessary to adopt measures such as erecting a column to reduce the span.

4. Large Section Open Cut Support Plan

4.1. Numerical Calculation of Long Bolt Support Scheme. Use FLAC numerical simulation software to calculate and compare the supporting effect of the long bolt support scheme and the original guide tunnel support scheme and further study the deformation displacement and stress distribution of the surrounding rock of the super-large section cutout. Establish a calculation model for the 1105 cut, the cut length is 180 m, and the average thickness of the coal seam is 6.32 m. The cutout section is rectangular, 9.20 m wide, and 4.72 m high. Both sides of the cut are solid coal. The calculation model selects the x -axis direction as the advancing direction along the working face and the y -axis direction as the vertical direction. In the x -axis direction, take 50 m to the left from the center line of the roadway and 50 m to the right. In the direction of the y -axis, take 36.5 m toward the top rock layer, add a uniform load to the upper boundary, and take 30.0 m toward the bottom rock layer. The constitutive relationship of the surrounding rock of the cut hole adopts the Mohr–Coulomb model. The mechanical parameters of coal and rock in the model are given in Table 1. Figure 4 is

TABLE 1: Mechanical parameters of rock and coal in the calculation model.

Rock formation name	Density (kg m^{-3})	Shear modulus (GPa)	Bulk modulus (GPa)	Cohesion (MPa)	Internal friction angle($^{\circ}$)	Tensile strength (MPa)
Medium sandstone	2420	9.477	10.264	12.18	40.33	3.536
Coarse sandstone	2392	4.450	5.632	8.37	44.52	1.758
2-1 coal	1450	2.130	6.389	4.2	32	1.050
Sandy mudstone	2560	3.23	4.18	6.51	36	1.12
Mudstone	2593	2.02	3.70	5.01	38	0.64

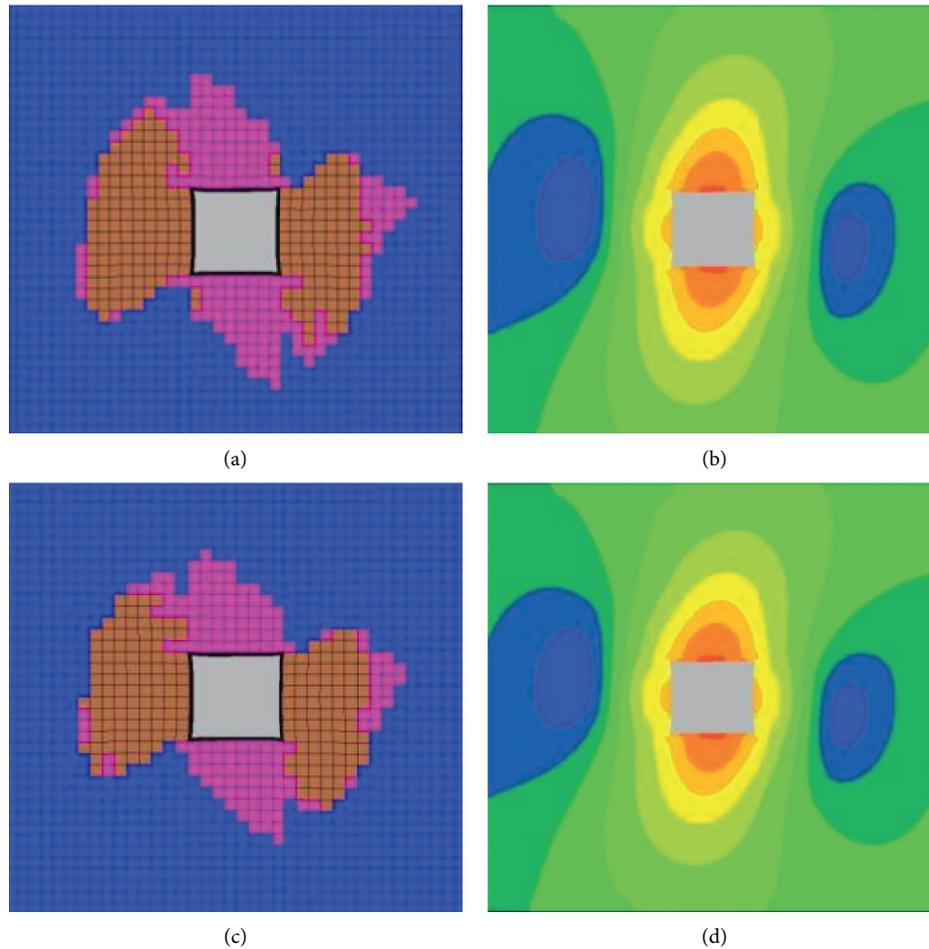


FIGURE 4: Simulation of the plastic zone and stress distribution of different lengths of bolt support in the surrounding rock. (a) Ordinary bolt support scheme shaping area. (b) Stress distribution of ordinary bolt support scheme. (c) Long bolt support scheme shaping area. (d) Stress distribution of long bolt support scheme.

a simulation diagram of the shaping zone and stress distribution in the surrounding rock with different length bolts.

Figures 4(a) and 4(b) show that the maximum shaping area of the top plate in the middle of the original support plan is 5 m, and the shaping range of the top plates near the two banks is gradually smaller than the middle. Due to the many cracks in the shallow part of the eye roof and the decrease in rock strength, the stress at 2 m from the roof reaches 10 MPa, and the stress at 3.2–6 m reaches 20 MPa. Figure 4(c) shows that the plastic failure of the top plate near the two sides is only 2 m, and the plastic failure of the top

plate in the middle of the cut reaches 4 m, which is 1 m less than the plastic failure range when ordinary bolts are used (Figure 4(d)). It shows that as the distance between the top plates increases, the stress rises significantly. The stress rises to 10 MPa in the range of 1–2 m and reaches 22.5 MPa above 6.2 m.

The above analysis shows that the surrounding rock shaping zone of the long bolt support scheme is smaller than the surrounding rock shaping zone of the original scheme. The ordinary bolts are all located in the plastic zone, while the long bolts can be anchored to the stable rock formation outside the plastic zone.

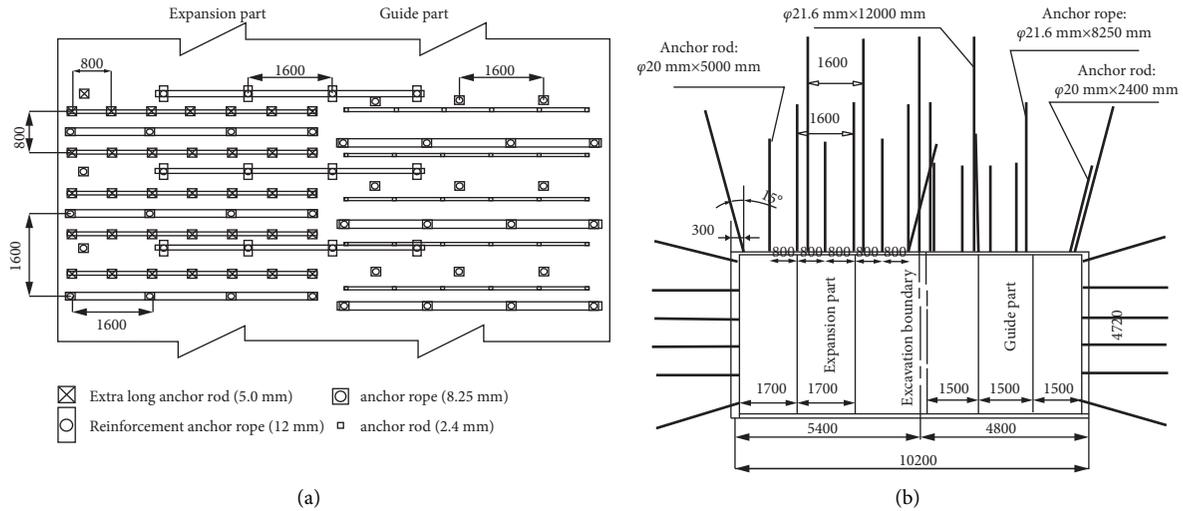


FIGURE 5: Layout of 1105 incisional eye support. (a) Layout plan of 1105 notch roof support. (b) Section view of top plate support layout of 1105 cut.

4.2. 1105 Super-Large Section Open Cut Support Plan. According to the results of fine detection of roof strata and numerical simulation of rock strata movement, the support scheme of 1105 super-large section cut holes with superlong bolt and anchor cable combined with rows of single pillar is determined.

- (1) Roof support: the roof of the cutoff guide tunnel adopts 21.6 mm to construct 6 anchor rods, as shown in Figure 5(a). In addition, two rows of single pillars are erected to support the roof. The top plate after the cutout is enlarged, uses 20 mm × 5000 mm superlong bolts with a row spacing of 800 mm × 800 mm, and each row at the top is constructed with 7 bolts; the anchor cables are in the middle of the cutout except for the anchor cables used on the roof of the guide tunnel. In addition, a 16 mm × 12,000 mm reinforced anchor cable is installed, with a row spacing of 1,600 mm × 1,600 mm, and a pallet of 12 mm × 400 mm × 400 mm, 12 mm × 200 mm × 200 mm × 200 mm steel plates, and 50 mm × 200 mm. Use wooden pads together. At the same time, erect two rows of single pillars to support the roof.
- (2) Lane support: the bolt specifications are 20 mm × 2400 mm rebar resin bolts, with a row spacing of 700 mm × 800 mm, and each row is constructed with 6 bolts. As shown in Figure 5(b), the pallet is made of W-shaped steel belt and 10 mm × 150 mm. The 150 mm anchor rod tray is used in conjunction with the anchor rod and steel ladder to hit the stubble mesh. The metal mesh is welded with 5.6 mm steel bars, the mesh size is 900 mm × 1700 mm, the mesh is overlapped by 100 mm, and each grid is tied with 14[#] lead wire.
- (3) Supplementary materials: each top bolt uses one Z2360 resin anchoring agent and one CK2360 resin anchoring agent; each anchor bolt uses one Z2345

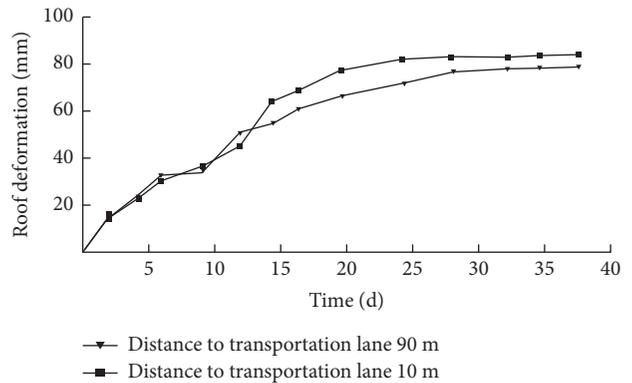


FIGURE 6: Deformation curve of the top plate of the open cut.

resin anchoring agent and one CK2345 resin anchoring agent; each anchor used two pieces of Z2360 resin anchoring agent and two pieces of CK2360 resin anchoring agent. The steel ladder is made of 14 mm round steel bars, the length of the steel ladder is 4160 mm, and the width is 70 mm.

5. Support Effect Monitoring

5.1. Displacement Monitoring of Open Cut Roof. In order to master the activity rule and supporting effect of the surrounding rock controlled by the long bolt and anchor cable supporting scheme and to provide data for the further improvement and optimization of supporting parameters in the future, the surface displacement of surrounding rock was observed during the construction process of extending the wall to the normal section. It can be seen from Figure 6 that after the secondary construction of the cutoff cut adopts the long anchor rod and the anchor cable support scheme, the overall roof deformation is small, and the displacement of the cutoff cut near the end of the mining roadway is greater than the top displacement in the middle of the cutoff cut and

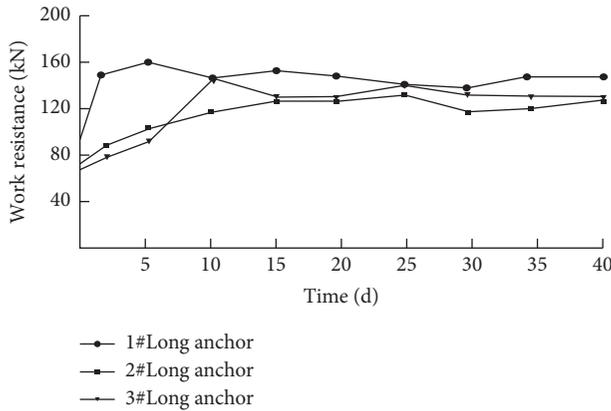


FIGURE 7: Working resistance curve of long anchor rod.

is closed to the end of the transportation roadway. The deformation becomes stable when the deformation reaches about 90 mm, and the roof deformation in the middle of the cut (90 m away from the transportation lane) becomes stable when it reaches 75 mm, which is less than the deformation of the guide tunnel roof of the cut (about 150 mm).

5.2. Simulation Diagram of the Plastic Zone and Stress Distribution Generated in the Rock. During the construction process from the cut to the normal section, the support resistance of the superlong bolts used was monitored. In Figure 7, the 1[#], 2[#], and 3[#] long bolts are the supporting resistance curves of the long bolts at the center of the cut at 10 m, 90 m, and 150 m away from the transportation roadway. The initial anchoring force of the extralong bolt is in the range of 50–100 kN, and it starts to receive the force stably when it reaches about 100–150 kN, and the overall supporting effect is good.

6. Conclusion

- (1) According to the fine detection of the rock structure and the study on the law of rock strata movement, the shallow fractures in the roof of the super-large section 1105 of Zhaogu No. 2 mine densely developed, the fractures above 3.5 m are gradually sparse, and there is basically no separation in the ceiling within the range of 4–6 m. In order to ensure the stability of the rock strata, long bolts should be used to anchor the shallow surrounding rocks to the stable rock strata.
- (2) Superlong bolt combined with anchor cable support technology effectively controls the surrounding rock deformation of the super-large cross-section in Zhaogu No. 2 mine, solving the support problem of the super-large cross-section in Zhaogu No. 2 mine.
- (3) The superlong bolt combined with anchor cable support technology is suitable for the roadway with great difficulty in surrounding rock control, such as the intersection of roadway with large broken

overhanging roof area in the shallow section of large section. This technology has strong pertinence and wide application scope.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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