The Implications of Chain Pillar Geometries for Chinese Coal Mines

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Abstract: The retreating longwall method using single entry gateroads is the predominant coal mining method in Chinese underground mines. Leaving only a very small pillar between adjacent panels has become the normal longwall mining practice.

It has been found that, rock bolting can improve the roadway conditions, however the general stability against roadway collapse will be determined by the adjacent goaf fracture geometry and chain pillar strength. With the increasing percentage of gateroads supported solely by rock bolting, there is now a key requirement to re-examine chain pillar design issues and the implications for gateroad support practice in China.

This paper describes the current industry practices and experiences with chain pillar design in China and attempts to define some of the chain pillar design implications for current Chinese practice. Considerations for future design of chain pillars with regard to roadway support practices and overall gateroad stability against major roadway collapses induced by re-mobilisation of adjacent goaf are provided.

Key words: chain pillar design, longwall gateroads, computational modelling, roadway failure

Introduction

Retreat longwalling using single entry gateroads is the predominant coal mining method in Chinese underground coalmines. Several different mining practices with regard to the geometry of the chain pillar left between adjacent longwall panels have been used. To date, a number of factors have influenced and constrained chain pillar design in China to such an extent that the practice of leaving only a very small pillar of coal between adjacent longwall panels is now the normal practice. Typically, the tailgate (or sometimes the maingate) of the longwall panel is driven along the goaf side of the previously mined longwall panel, normally after some nominated time interval following extraction. This method typically uses a chain pillar width between 3-5m.

Observations, measurements and past experience have indicated that the stability of gateroads driven in close proximity to longwall goaf areas will be dependent on the caving behaviour of the adjacent goaf and the strength of the chain pillar. Under such mining geometries, rock bolting can improve the roadway conditions, however the general stability against roadway collapse will be determined by the adjacent goaf fracture geometry and chain pillar strength.

Currently only about 16% of gateroads in China are developed with rock bolting as the sole supporting method. However, the Ministry of Coal Industry's current (9^{th}) 5 Year Plan (1996-2000) has a stated industry target of 50% by the year 2000 (Xiu et al. 1997). The significant increasing percentage of gateroads being developed using rock bolting under a wide range of geological and mining conditions, is a situation that would now indicate a key industry requirement to re-examine chain pillar design issues and the implications for gateroad support practice in China.

Detailed stress measurement and roadway behaviour monitoring programs have recently been undertaken in order to develop a detailed understanding of the factors affecting chain pillar behaviour. Computer modelling was also used to assess the stability factors of the adjacent goaf and to determine the expected gateroad conditions for various chain pillar geometries. This information, together with investigations and experience in other countries, has been used in an attempt to define some of the chain pillar design implications for current Chinese practice. Considerations for future design of chain pillars with regard to roadway support practices and overall gateroad stability under various mining conditions have also been provided.

Current Gateroad Support and Chain Pillar Design Practice

Design Influences and Constraints

To date, a number of factors and perceived logistical problems have influenced and constrained chain pillar design in China, including:

- resource maximisation;
- statutory requirements to achieve a defined percentage of extraction;
- the concept of locating the gateroad in a stress relieved zone (away from the influence of the peak vertical abutment in the coal block); and
- the perceived functions of the chain pillar.

The above factors have tended to define the now common practice of leaving only a very small pillar (typically 3-5m wide) between adjacent longwall panels. This is completely different from the pillar design practice used in other major longwall mining countries such as USA and Australia.

Current Industry Situation

Tailgates driven alongside the goaf were traditionally supported by standing supports such as steel arches or steel girders. Problems associated with this mining layout have been recognised as:

- excessive deformation of the roadway and the standing supports;
- severe floor heave;

- high cost of support materials;
- highly labour intensive;
- insufficient roadway opening for ventilation and transportation during longwall retreat; and
- frequent and costly roadway repair work.

Despite these problems, the general stability problem associated with gateroads in close vicinity to goaf areas has been ignored.

The introduction of rock bolting into longwall gateroads, in particular the recent efforts to increase the percentage of rock bolted gateroads, has seen rock bolting being used as a replacement to traditional standing supports in gateroads driven alongside goaf areas. In situ measurement and monitoring and past experience of gateroads driven alongside have shown that rock bolting can reinforce and improve the stability of strata within the immediate area around the gateroad. However, rock bolting can not prevent the potential for roadway collapse due to the development of large caving blocks formed by goaf fractures extending over the gateroad. Likewise, standing supports can not prevent the potential for such roadway collapse. Under such mining layouts, the general roadway stability will be dependent on the fracture geometry of the adjacent goaf and the strength of the small pillar. This concept is shown in Figure 1.

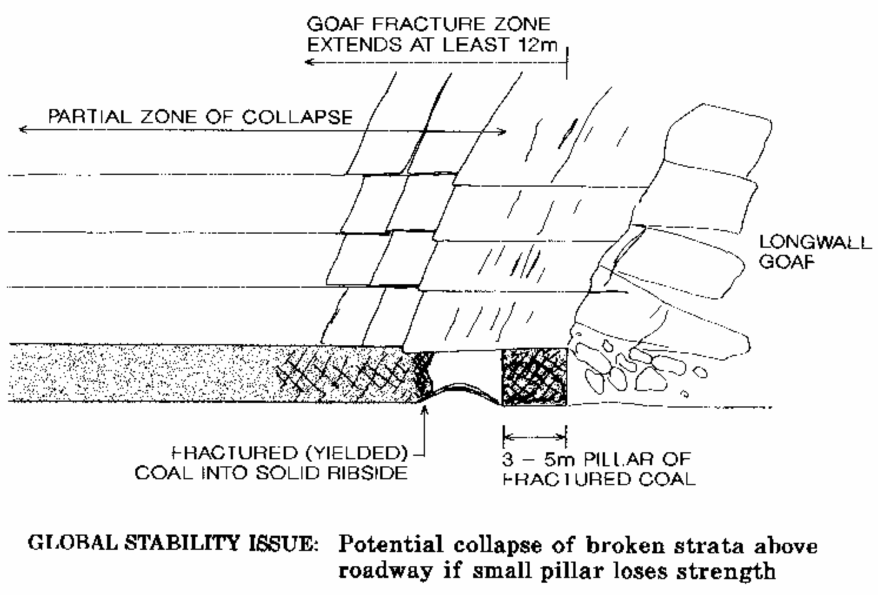


Fig. 1 – General concept of global stability of gateroads driven alongside longwall goaf areas.

Given this current situation, the re-examining of chain pillar geometries and design practices within the Chinese industry has become a necessity.

Site Investigations

Dongpang Mine Investigations

In 1996-97 a program of investigations and geotechnical monitoring was undertaken by SCT and the Ministry of Coal Industry at Xingtai Coal Bureau's Dongpang Mine in Hebei Province. The general layout of the mine is such that gateroads are driven close to the seam strike and, as such are generally horizontal with a "square" profile and a sloping roof line that followed the seam cross dip. Gateroads are single entry roadways and driven by roadheaders. The 3.5m wide tailgates are developed adjacent to existing longwall goaf areas separated by a nominal 3-4m wide pillar of coal.

The dip of the strata varies locally about structures, but is generally 10-15° in an E-ESE direction. The depth of cover varies across the mine quite significantly, with an approximate increase in depth of 40-50m across each longwall panel in the area. The general depth of cover for the investigation area was approximately 430-460 m.

Site Investigation Program

A site investigation program was undertaken to provide an understanding of the roadway behaviour and stress environment in the tailgate roadway as well as to provide the design information for developing and validating the computer model.

The site investigation program consisted of:
- detailed determination of rock properties of the immediate strata;
- measurement of the in situ stress in the investigation area;
- measurement of the stresses acting around the tailgate roadway;
- assessment of the strength of the small pillar;
- monitoring of the behaviour of the tailgate roof and sides using sonic probe extensometers; and
- monitoring the performance of the roadway reinforcement system using strain gauged rock bolts.

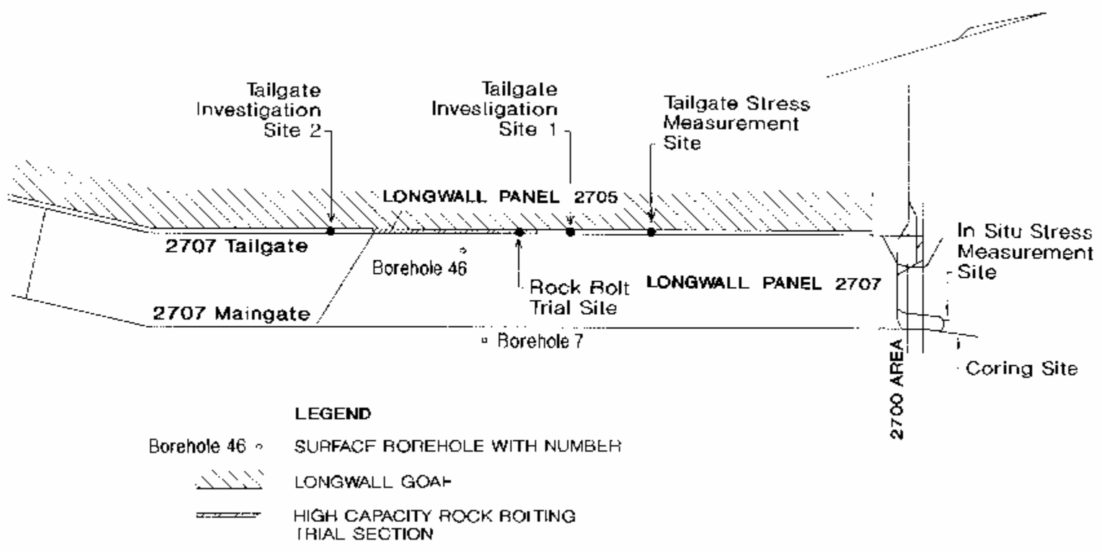


Fig. 2 – Location of investigation sites at Dongpang Coal Mine.

The location of the investigation sites and the layout of the instrumentation are shown in Figures 2 and Figure 3. All instrumentation was installed at the face of the roadway during development.

Rock Properties of the Immediate Strata

Core samples for the rock strength testing were obtained by drilling into the roof and floor perpendicular to bedding, whilst core samples for bedding plane tests were drilled at 30° degrees to bedding in order to achieve a suitable bedding plane sample for testing.

The rock testing was conducted using ISRM guidelines to obtain:

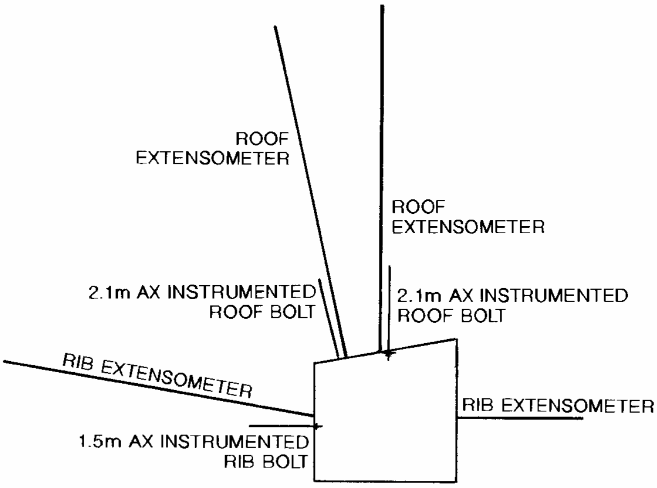
- unconfined compressive strength
- intact and fractured rock triaxial strength at 2, 5 and 10 MPa confining pressures
- Young's modulus (E) or a triaxial deformation modulus at each of the different nominated confining pressures. These moduli were measured in unload/load cycles during the tests.
- Bedding plane cohesion and friction properties at each of the different nominated confining pressures.

The immediate roof strata in the investigation area varied from sandstone to a siltstone/shale unit commonly having depositional joint and fault structures. The thickness of the shale/siltstone was variable in the panel and ranged up to 3-5m in some areas. The results indicate that in the immediate roof, the sandstone rocks are very strong and typically have an UCS greater than 80MPa. The carbonaceous mudstones and siltstones have strengths in the 30-40 MPa range. In areas where the rock is jointed or listricated, the field strength of these rocks would be significantly reduced.

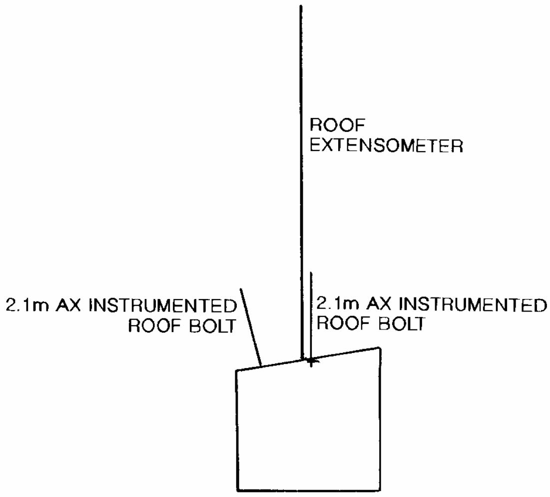
The bedding friction angles are typically 34-45° for the siltstone/sandstone rocks, however the cohesion was found to be variable depending on the particular rock type. The friction angle of the weak clay coated slip bands observed underground were not recovered for testing but were typical of those tested at other sites having friction angles in the 6-10° range.

The immediate floor strata commonly consisted of coal with some sandstone units to approximately 4m below the roadway floor and then typically sandstone strata below this.

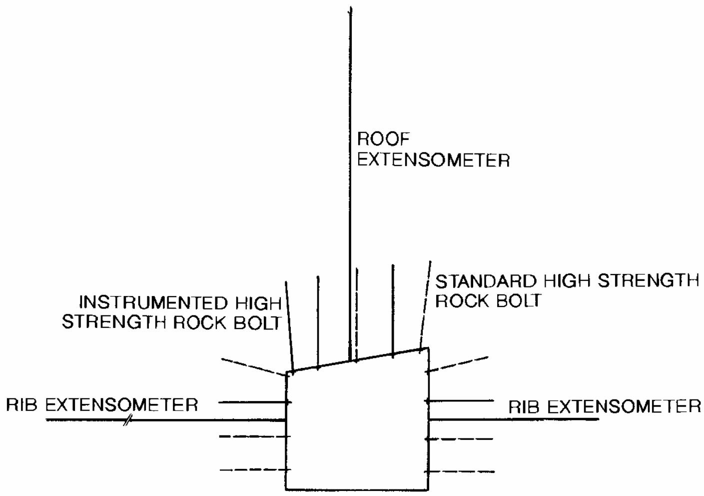
Fault zones and joint zones were observed in the coal and roof strata. Additional roadway deformation was observed to occur in close proximity to these structures. The major faults and joint zones were at a high dip angle (80-90°) and oriented approximately parallel to the gateroad direction. In the tailgate these structures were observed together with additional fractures considered to be mining induced abutment fractures.



a) No. 1 Site.



b) No. 2 Site.



c) Rock Bolt Trial Site.

Fig. 3 – Layout of instrumentation at the investigation sites, 2707 Tailgate, Dongpang Coal Mine.

Roadway Behaviour

Roof extensometers indicated that the roof strata in the tailgate are broken up to at least 6-7m into the roof. Rib extensometers indicated that the depth of yield into the solid rib-side was at least 5-6m and the small pillar was failed and very broken.

Reinforcement System

The standard Chinese roof bolt system had minimal effect in controlling the immediate roof as significant deformation and strain zones occurred within the bolted horizon (ie. within the first 2.0m of the roof).

Stress Measurements

Two sets of stress measurements were made using the overcoring stress relief technique with ANZI stress cells. The locations of these sites are shown in Figure 2. At the first site the in situ stress field was measured. At the second site in the tailgate roadway, the stress was measured at four distances over the solid coal rib and at two distances over the 4m wide pillar (see Figure 4a).

The in situ stress measurements indicated a vertical stress of 10MPa which is consistent with the expected vertical stress at an overburden depth of approximately 430m. The major horizontal stress is oriented at 35-40°N. The magnitude of this stress is 13-15MPa in rock with a modulus of 21-24GPa. The intermediate and minor principal stresses are both steeply inclined with magnitudes of 10.5MPa and 8MPa respectively.

A summary of the vertical stresses measured over the solid coal rib and the small pillar is presented in Figure 4a. The test results indicate that the vertical stress over the solid coal rib increases as a function of distance from the roadway. The vertical stress develops at a rate of 1.2-1.5MPa /m from the roadway rib side. The yield zone in the solid coal rib is 8-10m wide.

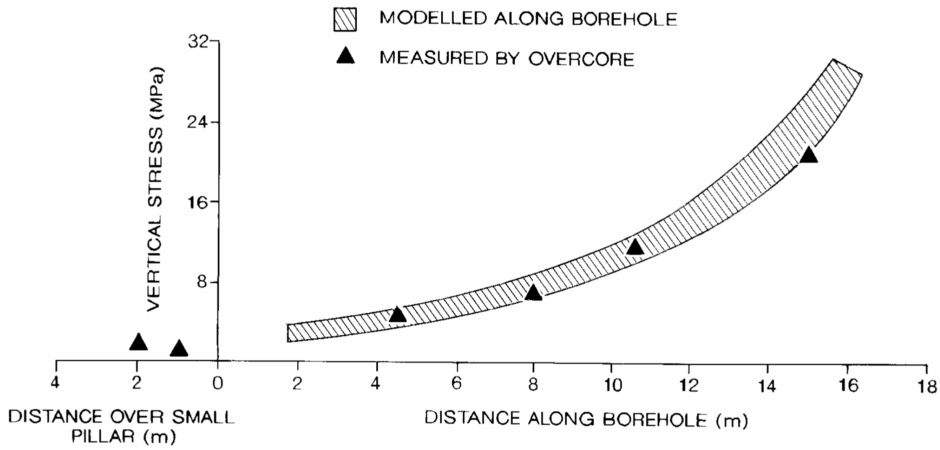
The vertical stress carried by the 4m pillar is less than 1.5MPa. The low vertical stress carried by this pillar indicates that it has failed and is carrying only a very low residual load. The vertical stress above the pillar is likely to be variable along the roadway due to floor heave and pillar width, however the load that is carried by the small pillar is very low.

Computational Modelling

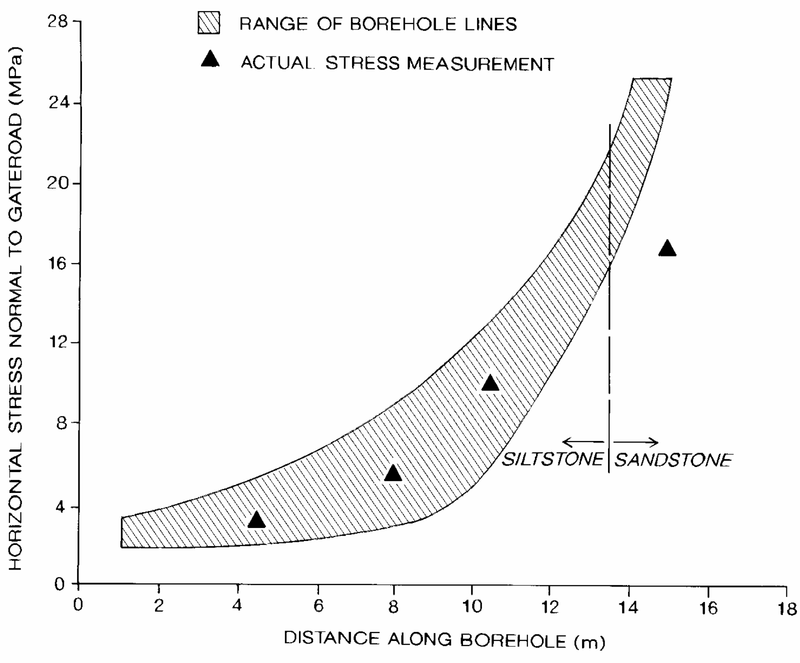
Design Approach

Computational modelling is utilised to evaluate the expected mechanism of rock deformation about the tailgate roadway. The modelling code used was FLAC, however extensive use of SCT rock failure and rock fracture routines has been incorporated into the modelling to simulate the rock behaviour. FLAC has been found to provide suitable capabilities for simulating large displacements and modelling coal mine roadway reinforcement systems such as rock bolts.

A two dimensional model was developed on the basis of the rock property testing and surface borehole logs in the vicinity of the investigation area. Boreholes in the area were used to develop a stratigraphic section from -900m to the surface to form the geology of the computer model of the area.



a) Comparison of modelled and measured vertical stress.



b) Comparison of modelled and measured horizontal stress.

Fig. 4 – Comparison of modelled and measured stress at Dongpang Coal Mine.

A two dimensional model was used to simulate behaviour across adjacent longwall panels (2705 and 2707 panels). A strata dip of approximately 14° was simulated.

The modelling aimed to simulate:

- caving of the adjacent longwall panel;
- abutment stress re-distributions resulting from that caving process;
- rock fracture distributions expected in the rock about the location of the tailgate prior to the development of the tailgate roadway; and
- behaviour of the rock about the roadway and goaf when the tailgate is developed.

The model initially simulated the stress and rock fracture distributions created from extraction of adjacent longwall (2705 panel) around the position of the tailgate roadway for the next panel (2707 panel). The development of the roadway opening was simulated in the model, with various roof and rib bolt combinations. The performance of the roadway relative to the bolting support options and pillar sizes was assessed to define the issues affecting stability of the tailgate area.

Pre-Tailgate Stresses and Rock Failure

The modelled side abutment stress and rock failure areas around the tailgate roadway (prior to development of the roadway) are shown in Figures 5a and 5b. The yield zone in the coal was 8-10m into the rib. Both the measured abutment stress distribution and that predicted by the model are indicated in Figure 4. The range in stress for the modelled data is due to variation in hole location for the measurements and changes in strata position about the stress measurement site relative to the core test section.

Caving related fractures are predicted to exist above the position of the tailgate roadway. Stress measurements and extensometer monitoring confirm the computer model results and indicate that the tailgate area is located in the yield/caving zone of the adjacent longwall (2705 panel).

Post Tailgate Stresses and Rock Failure

The stresses and rock failure occurring about the tailgate (after development) are shown in Figures 6a and 6b for the "4m wide coal pillar" option. The major implication of the rock failure behaviour is the potential for goaf mobilisation over the roadway. A potential fracture/block network is shown in Figure 7a.

The modelling results indicated that:

- significant floor heave and rib squeeze would still be expected;
- the stability of the immediate roof and rib-side is improved with a high strength bolting system;

- irrespective of roadway support used, major caving fractures above the tailgate exist and appear to create the potential of major rock blocks above the tailgate and small pillar;
- the small “4m” pillar has failed and the coal on the solid side had yielded into the rib approximately 8-10m. The actual strength of the small pillar will be very low.

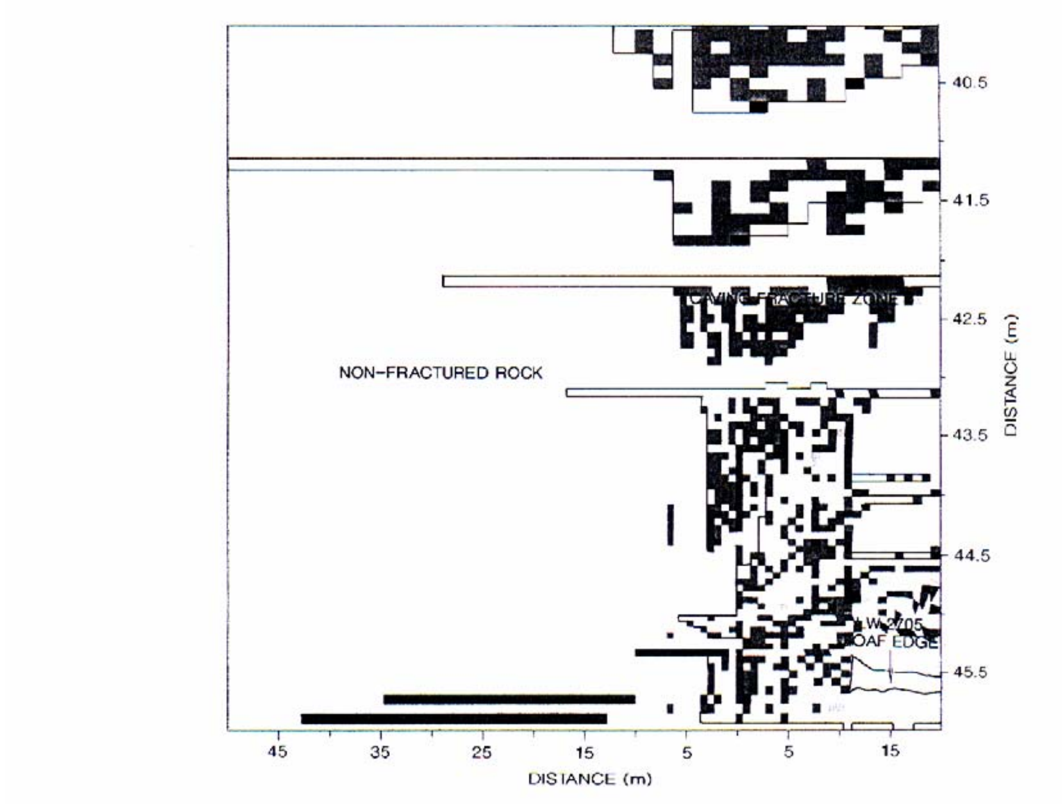


Fig. 5(a) – Rock Failure expected about Longwall 2705 at Dongpang Coal Mine.

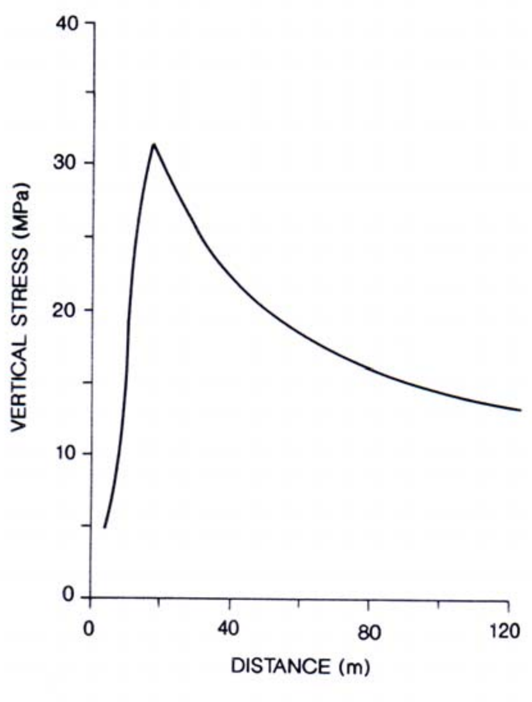


Fig. 5(b) – Vertical stress abutment from Longwall 2705 at Dongpang Coal Mine.

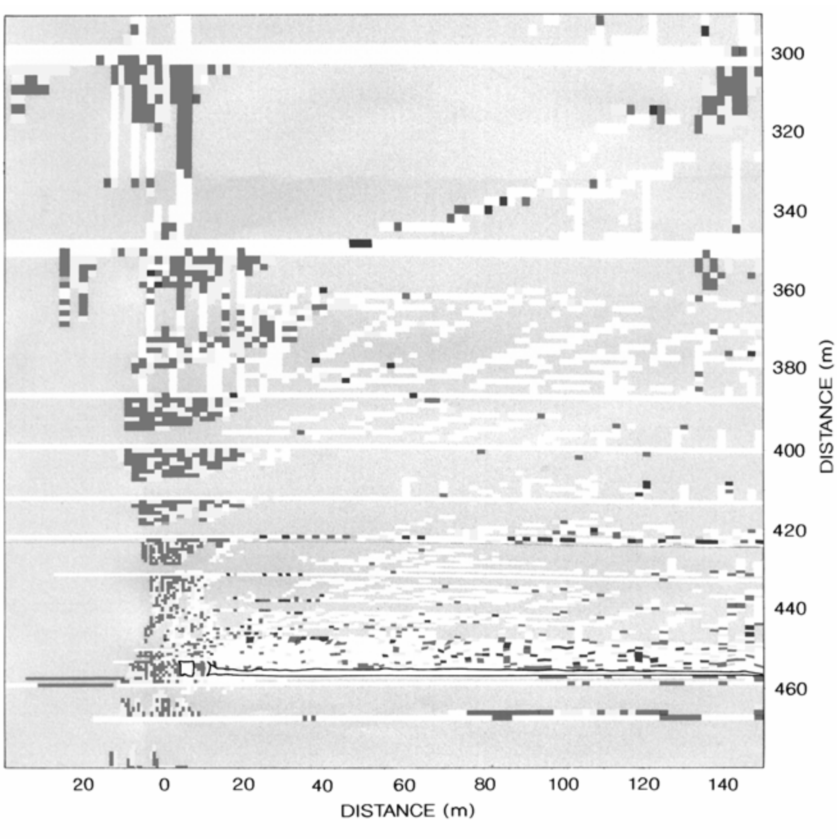


Fig. 6(a) – Rock Failure about a 4m pillar, Dongpang Coal Mine.

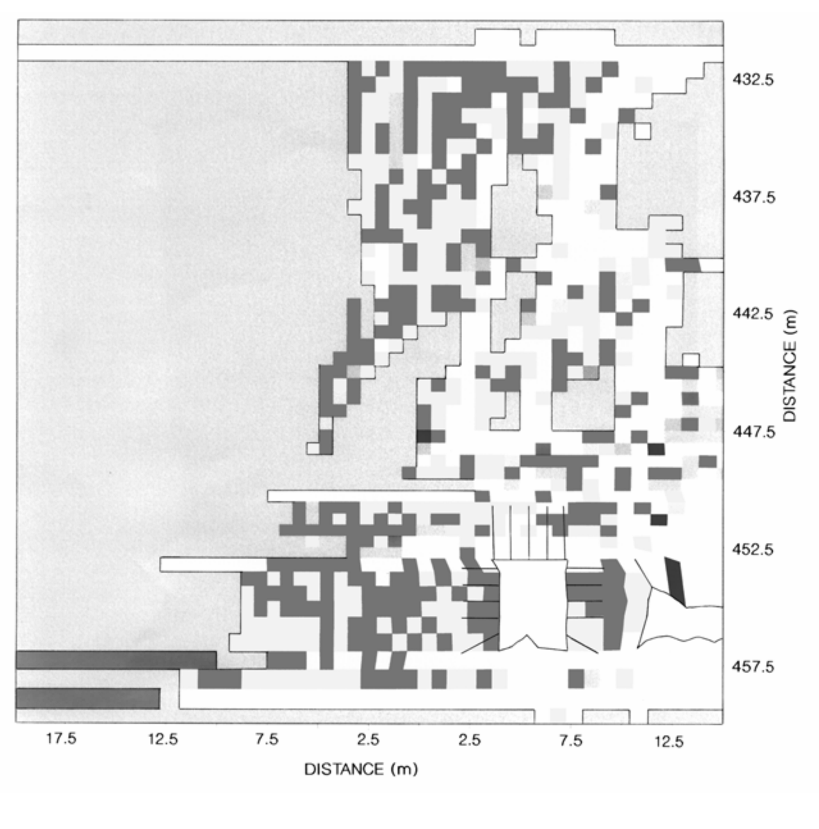
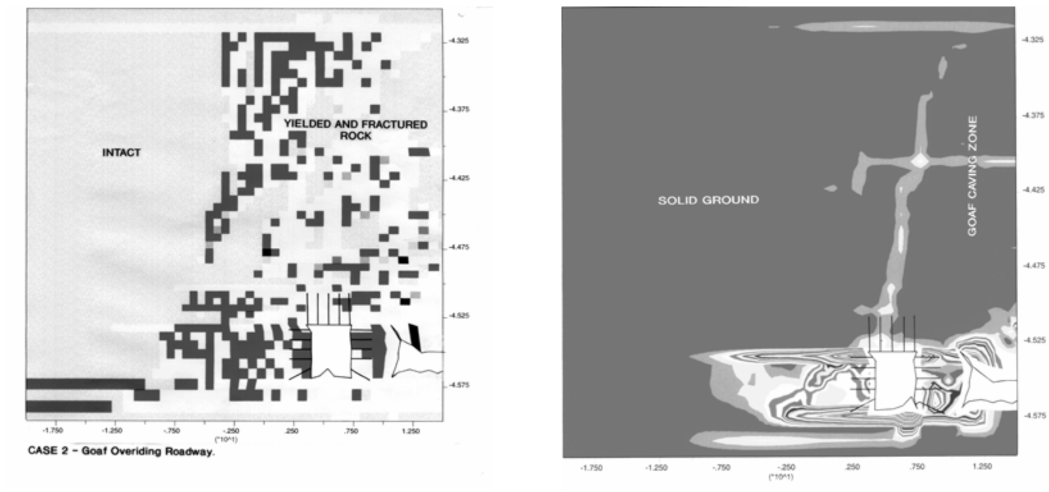
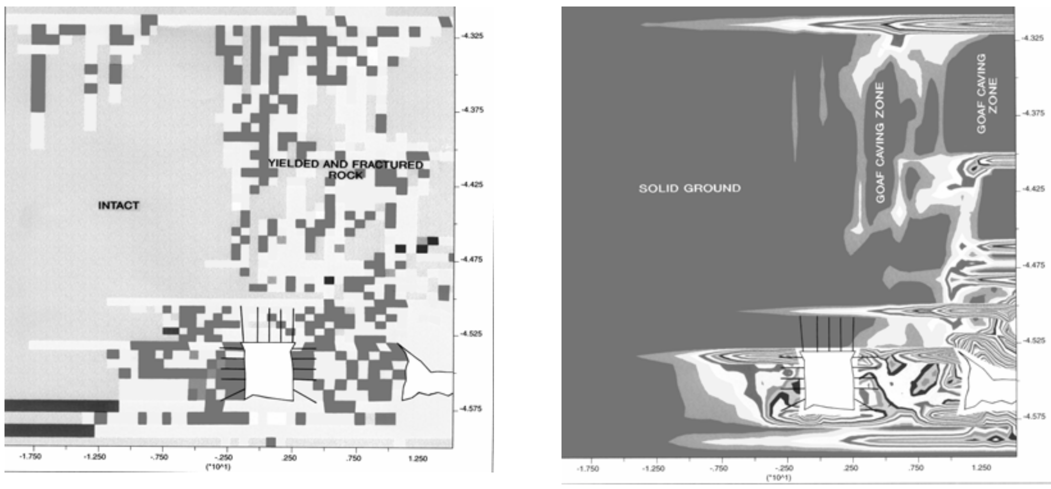


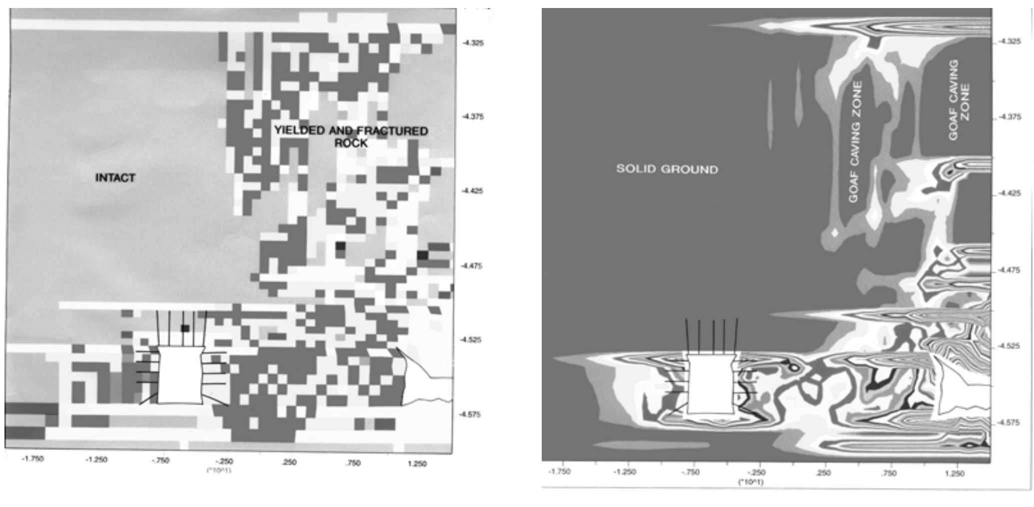
Fig. 6(b) –Rock Failure about a 4m pillar – high strength bolts, Dongpang Coal Mine.



a) 4m Pillar



b) 9m Pillar



a) 16m Pillar

Fig. 7 – Rock failure zones for various pillar sizes at Dongpang Coal Mine.

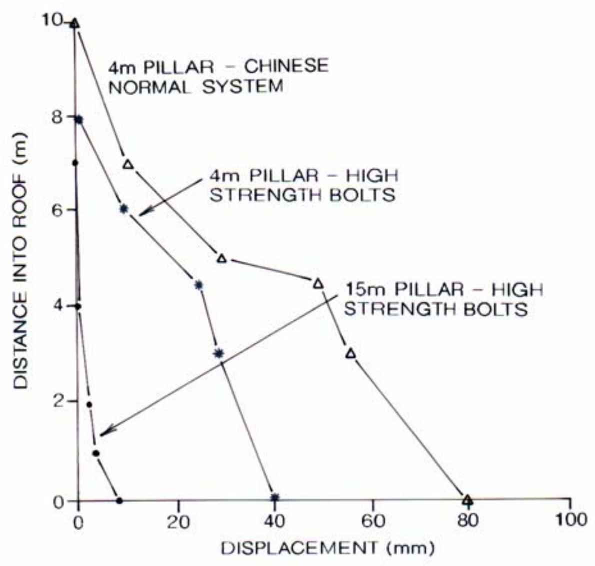


Fig. 8(a) – Roof behaviour for various options at Dongpang Coal Mine.

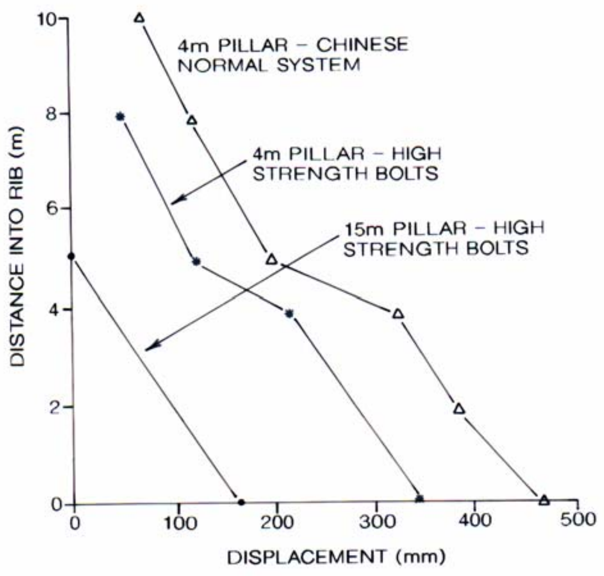
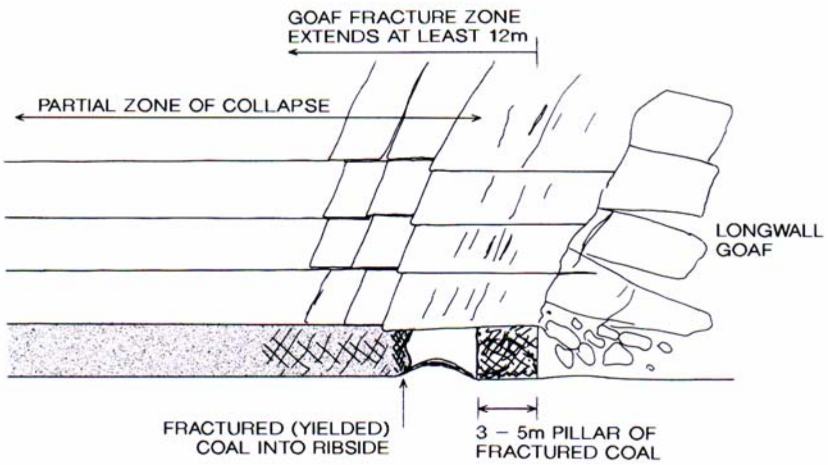
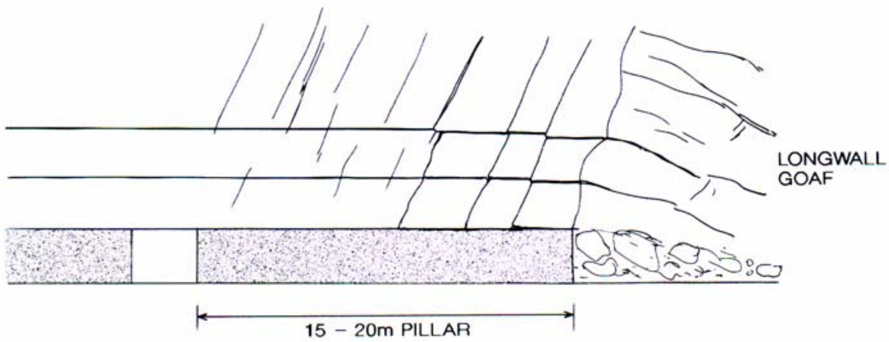


Fig. 8(b) – Rib behaviour for various options at Dongpang Coal Mine.



PROBLEM: Potential collapse of broken strata above roadway if the small pillar loses strength



SOLUTION: Improved saftey of the roadway with the use of a larger pillar to isolate the roadway from goaf collapse

Fig. 9 – Comparison of global stability of gateroads driven alongside longwall goaf areas.

The results indicate that local stability around the tailgate roadway will be improved by high strength bolting, however global stability is controlled by the small pillar and the geometry of caving fractures above the tailgate. Remobilisation of the adjacent longwall goaf could cause a collapse of rock above the pillar and tailgate, and that the roadway bolting patterns would not be capable of controlling the collapse should it occur.

Effect of Pillar Size on Roadway Stability

Due to the concerns of having a small failed pillar adjacent to the goaf, and the presence of caving fractures above the roadway, other pillar sizes of 9m and 16m were also assessed. The results of the rock failure patterns for each are presented in Figure 7. A comparison of roadway conditions with various pillar sizes is presented in Figures 8(a) and (b).

The computer modelling indicated that roadway deformation is much smaller if the tailgate roadway is relocated 15-20m from the goaf (rather than the current practice of a 4m pillar). A 15-20m wide pillar adjacent to the goaf has sufficient strength to significantly reduce the risk of goaf caving into the roadway. This concept is illustrated in Figure 9.

Summary of Results

The investigation site was monitored during both the development of the tailgate roadway and the extraction of the longwall panel. The investigation program has shown that:

- Under the current small pillar design layout, the high capacity rock bolting system can not significantly reduce the overall movement of the pillars and floor or control the stability of the upper roof (ie more than 3-5m above the roadway).
- A high capacity rock bolting system, however, is able to significantly reduce deformation levels and improve the control of the immediate roof and ribs.
- The 3-5m wide small coal pillar in the tailgate fails on development and carries only a very low load.
- Goaf fractures caused by caving and stress abutments from the adjacent longwall (2705 panel) extend over the current tailgate position, potentially forming large caving blocks supported only by the small pillar and the goaf.
- The potential geometry of caving blocks mobilised by the mining of the roadway involves fractures over the solid coal angled back above the roadway and linking with failed bedding planes above the roadway, the small pillar and goaf areas.
- Geological faults oriented along the tailgate facilitate the creation of such caving blocks and reduce the general stability around the tailgate.

Implications for Chain Pillar Design

The results from the investigations undertaken during the Dongpang Mine project (together with SCT's experience gained from overseas investigation programs) have implications that should be considered for chain pillar design and the application of rock bolting systems in Chinese coal mines.

The major design consideration for roadways located away from the influence of longwall goaf areas (such maingates, face installation roadways and main headings) is the integrity of the immediate rock bolted roof. However, for tailgate roadways located in close proximity to goaf areas, major additional design considerations are the stability of the caving zone about the adjacent goaf and the stability of the small pillar. A major design concern with the current small pillar design is the potential for the goaf of the adjacent panel to mobilise and override the tailgate roadway, thereby causing a roadway collapse.

The global stability of tailgates driven adjacent to goaf areas with a small pillar geometry will be dependent on the caving behaviour of the adjacent goaf and the strength of the small pillar and are not significantly influenced by roadway support system. With the small pillar design layout, high strength rock bolting systems can improve the immediate roof and rib conditions but the fundamental overall roadway stability problem of low pillar strength and large caving blocks above the tailgate still remains.

For roadways located adjacent to goaf areas (eg, tailgate roadways), appropriate chain pillar design is required to permit rock bolting support systems to be efficiently and safely used within a suitable stable mining geometry. An appropriate chain pillar size is critical to control caving stability in the area around the roadway. This pillar size would need to be designed depending on the site conditions; however, the pillar will need to be larger than the current practice of using a 3-5m wide pillar. The concept of a larger pillar to control caving stability is shown in Figure 9.

Conclusions

The continuation and expansion of the application of rock bolting support for gateroads in China is a situation that would now indicate a key industry requirement to re-examine chain pillar design issues and the implications for gateroad support practice and overall gateroad stability in China.

With the current practice of locating gateroads alongside goaf areas with a 3-5m wide chain pillar, the potential for roadway collapse is increased and the global stability of such gateroads must be questioned. The use of appropriate pillar design and layout, together with high capacity rock bolting design, can significantly improve roadway conditions for roof, ribs and floor. The potential for a major roadway collapse due to re-mobilisation of the adjacent goaf would be significantly reduced and roadway conditions and mining safety improved. Potential improvements in roadway development and productivity would be also expected.

The investigations at Dongpang Mine have highlighted a number of key chain pillar design issues and the implications for gateroad support practice in China. Further investigations are now required to define chain pillar design implications under a wider range of geological conditions and mining layouts that would typically be encountered in China.

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