A METHOD FOR ESTABLISHING SITE SPECIFIC COAL PILLAR DESIGN GUIDELINES

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ABSTRACT

Coal mine pillar design formulae available to mine planners are typically based on relationships determined for specific site conditions. Application of these methods is difficult when other factors, relating to mining or geological conditions, not specifically addressed in these relationships are encountered.

A review of pillar design methods, coal strength properties and relevant field monitoring of pillar behaviour has shown pillar strength and deformational characteristics are extremely sensitive to in situ behaviour of the rock and other material components that make up the coal pillar system.

A method has been developed that has been found to provide excellent correlation between existing field data using the strength and deformational characteristics of materials determined in selected laboratory tests. This method is based on definition of the loading conditions, accurate modelling of the strength, confining conditions and deformation occurring in the roof, floor and coal seam and definition of the in situ strength of coal based on underground monitoring of appropriately sized coal pillar.

The design method is considered to provide an accurate and rigorous pillar design method that will give mine planners a more rational mine design capability which is based on the mine geometry and geological setting of the operation.

It is envisaged that availability of such a method will allow significant optimisation of pillar layout and more closely define the geological and mining issues that relate to pillar design optimisation.

INTRODUCTION

Coal mine pillar design formulae are typically based on empirical relationships determined in a specific set of geological conditions. Application of such formulae in geological environments other than those in which they were determined may lead to either loss of coal resource through over design or unnecessarily difficult and even potentially dangerous working conditions through under design.

Developments in mining technologies have altered mine geometries so significantly that traditional pillar design experience is often less appropriate in the changed geometries. For instance, pillar design formulae originally developed in bord and pillar environments may not necessarily be applicable to longwall mining conditions.

The approach to pillar design described in this paper is aimed to account for the effects of geological environment on the behaviour of coal pillars. This approach has developed as a result of recent advances in in situ monitoring and computational modelling. These have provided the necessary detail of in situ pillar behaviour and the ability to relate this behaviour to the properties of the materials that compose the pillar (i.e. floor, coal, roof).

APPROACH TO PILLAR DESIGN

The approach undertaken by Strata Control Technology has been based on the results of in situ monitoring of coal pillars to determine their behaviour in a range of geological and mining environments under various mining induced loading systems.

With this experience of pillar behaviour to work from, it has then been possible to examine the mechanics of pillar behaviour in more detail.

The approach used has been to treat the coal

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pillar system, whether for pillar extraction, longwall mining or any other form of coal mining, as a composite of materials, each with definable mechanical properties, that interact together to contribute to the overall behaviour of the pillar system.

The mechanical properties of each of the materials at a particular mine site are characterised in detail in laboratory tests. These properties are then used in a computational model that is able to accurately reflect individual material behaviour to simulate overall pillar system behaviour.

The aim of the modelling is not so much to determine pillar strength, but rather to determine the stress and deformational characteristics for a range of pillar geometries in the geological and mining environment under study.

The results of modelling are then confirmed by in situ monitoring of actual pillar behaviour in that particular environment.

The approach used has been found to give insight into pillar behaviour well beyond simply ultimate strength considerations. This is particularly useful for design purposes where pillar strength is not the primary concern - for example:

- in chain pillar design, tailgate condition rather than pillar strength can be the controlling factor in pillar design;
- in multi-seam workings, minimisation of peak pillar stresses is an important consideration;
- in gated road stress relief headings, post-peak strength of intermediate pillars is of primary concern; and
- in long term developments, control of floor heave will be pillar design criteria.

IN SITU PILLAR MONITORING

The method used to monitor in situ pillar behaviour is based on measurement of the stress changes that occur immediately above a pillar as it becomes loaded by adjacent mining extraction. This method gives information not only on pillar strength and deformational behaviour but also on mining induced pillar loading characteristics.

A series of three dimensional stress monitoring instruments are located in a line across the pillar approximately 1–2m above the coal. The vertical stress changes measured by these instruments closely reflect the vertical stress changes occurring in the pillar while still allowing pillar yield to be monitored without degradation of instrument response.

That would occur if the instruments were located within the yielded material.

Rib displacement are measured using horizontal extensometers to indicate depth of pillar edge yield and complement stress monitoring results.

Vertical pillar compression can be measured using a system of water level devices able to measure the elevation of a point above the centre of the pillar relative to some remote reference level.

Figure 1 shows an example of instruments located above a small coal pillar in the central development headings of a continuous miner total extraction panel. At this site, the coal seam was 9m thick with the mining horizon located near the bottom of the section.

Stress monitoring instruments were located in a sandstone band approximately 2m into the roof before the pillar was formed. Rib measurements, located in the coal rib, were used to measure the development of rib yield.

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holes were sheared off at various depths up to 3m, precluding measurements deeper into the rib.

Vertical stresses not only over the extracted goaf area but also over the remaining stump dropped to be almost zero following lifting off. This would be consistent with coal yield right across the pillar remnant.

In this case, the original pillar - width 11.5 m and W/H ratio 4 - had not yielded, despite being within 10m of the goaf edge. It yielded only when its width was reduced by lifting off. Ultimate pillar load capacity of the original pillar would therefore have been in excess of 21 MPa.

MATERIAL PROPERTY DETERMINATION

The materials that make up a pillar system consist predominantly of coal but also of roof and floor strata and the interfaces or boundaries between and within individual strata units.

Elastic and strength properties are readily determined in laboratory tests on core samples. Elastic properties of interest are elastic modulus and Poisson's ratio. Strength properties of interest are the confined intact and confined residual strength envelopes. These have been determined in multi-stage triaxial compression tests.

The mechanical properties of interfaces between strata units can be determined most easily in shear tests. Properties of interest are the normal and shear stiffnesses and the strength envelope of each surface.

Because of the 9m coal section at the monitoring site, coal properties are the major component of the coal pillar system. Figure 3 shows an example of the confined intact strength properties determined for the coal.

![Example of coal strength envelope.](image)
STRENGTH REDUCTION WITH SPECIMEN SIZE

Test specimen size is well recognised in the rock mechanics and mining literature as having an effect on unconfined rock strength. The effect of size on confined strength is less well defined.

The approach used for modelling confined strength has been to assume that the cohesive component of intact rock strength - the unconfined strength - is affected by specimen size while the frictional component - that which results solely from confinement - is not. The unconfined strength determined in laboratory tests has been reduced using the size effect relationship described by Bieniawski (1966) for coal and Hoek and Brown (1980) for other rock materials.

Residual strength properties are considered to be specimen size independent.

COMPUTATIONAL MODELLING

Pillar behaviour has been modelled using the computational modelling program FLAC (Cundall and Board, 1988). This program uses an explicit time-marching finite difference solution scheme capable of representing complex material behaviour in a way that is mechanically realistic. Furthermore, because equilibrium is not a prerequisite for solution using the time-marching scheme, unstable and inherently dynamic behaviour can be modelled with relative ease.

Figure 4 shows an example of a model used to study pillar behaviour at the monitoring site described above.

The geological section, and material properties, at the site are represented in the model. Horizontal symmetry allows a half model to be used to reduce computation time.

The aim of the modelling is to provide insight into the mechanics of pillar behaviour in the geological environment under study. A full range of pillar loadings can be applied by moving the upper and lower boundaries of the model together to simulate increasing pillar load. This process is effectively what happens in situ as pillar load increases with, for example, an approaching coal.

CONCLUSIONS

The method developed to determine pillar strength and deformational behaviour involves:

1) Characterising mechanical properties for the materials that make up a pillar system - coal, host strata and interfaces between.
2) Using a computational model to simulate pillar behaviour for a range of geometries and, if appropriate, mining horizons.
3) Monitoring the behaviour of pillar in situ to confirm the pillar system characteristics determined.

Pillar design can then be based on an assessment of individual pillar loading requirements with regard for site specific pillar strength and deformational characteristics.

REFERENCES

