EVALUATION OF PILLAR-ROOF INTERFACE AND ITS EFFECT ON PILLAR STABILITY IN RIO DESERTO COAL MINE #101

Viktor LÖNNIES[1]; Tristan JONES[2]; André ZINGANO[3]

[1]Luleå University of Technology, viklnn-1@student.ltu.se; [2] Luleå University of Technology, tristan.jones@ltu.se; [3]Universidade Federal do Rio Grande do Sul, andrezin@ufrgs.br

ABSTRACT

Rio Deserto coal mine #101 is currently mining the well-known Barro Branco coal seam in the state of Santa Catarina. The mine is currently experiencing problems related to the pillars in one of their slightly-inclined panels. Inspections have shown that several pillars have developed damages on the down-slope side, tending to occur in the upper corner. The inspections also revealed a very thin and soft clay layer located between the pillar and the roof. It is believed that the clay interface is affecting the pillar strength which caused the damages. Evaluations of the clay layers' influence on the pillar stability is conducted by numerical modelling using FLAC. Initially a calibration of the model is made using information from extensometers installed by mine survey. Afterwards, the combination of different sets of interface and coal-strength values were evaluated while observing the modelled pillar behaviour. The results indicate that with a very small shear movement (1-4 mm) along the interface, the developed pillar damages are almost symmetrical on both the up-slope and down-slope sides. Structures in the coal, such as joints and cleats, can contribute to non-symmetrical damages, but not enough to make the model perfectly match field observations. Furthermore, the results show that the observed damages are best reproduced when the shear movement between the roof and pillar is forced to ~15 mm. Shearing along the interface is therefore believed to be the main mechanism behind the pillar damages. The forced shearing can potentially be explained by factors not considered in the model such as horizontal stresses, disturbances by mining and presence of water within the clay.

Keywords: Roof-pillar interface, pillar, coal, numerical modelling

RESUMO

A Indústria Carbonífera Rio Deserto Ltda. lavra carvão da camada Barro Branco em sua unidade de operação chamada Mina 101, no estado de Santa Catarina. Atualmente, a mina enfrenta problemas relacionados com o comportamento dos pilares nas áreas em que seus painéis de lavra apresentam ligeira inclinação. Inspeções mostraram que muitos pilares desenvolveram maior deformação no lado da descida do painel, deformação esta com tendência a ocorrer no canto superior do pilar. As inspeções também revelaram uma camada de argila muito fina e macia, localizada entre o pilar e o teto. Acredita-se que a interface de argila está afetando a resistência do pilar na interface pilar-teto, causando esta maior deformação. Avaliações da influência da camada de argila sobre a estabilidade do pilar são conduzidas por modelagem numérica usando o software FLAC. Inicialmente, uma calibração do modelo é feita usando as informações dos extensômetros instalados na mina. Em seguida, a combinação de diferentes conjuntos de valores de interface e resistência do carvão foram avaliadas enquanto observava-se o comportamento do pilar modelado. Os resultados indicam que, com um movimento de cisalhamento muito pequeno (1-4 mm) ao longo da interface, os danos desenvolvidos no pilar são quase simétricos em ambos os lados de subida e descida do painel. Estruturas no carvão, como juntas e fraturas, podem contribuir para danos não simétricos, mas não o suficiente para tornar o modelo perfeitamente combinado com as observações de campo. Além disso, os resultados mostram que os danos observados são melhores reproduzidos quando o movimento de cisalhamento entre o teto e o pilar é forçado para ~ 15 mm. Acredita-se, portanto, que o cisalhamento ao longo da interface pilar-teto seja o principal mecanismo por trás dos danos no pilar. A força cisalhante potencialmente pode ser explicada por fatores não considerados no modelo, como tensões horizontais, vibrações e distúrbios pelo desmonte e a presença de água na camada de argila.

Palavras-chave: *Interface pilar-teto. Pilares. Carvão. Modelagem numérica.*

1 INTRODUCTION

The underground coal mine #101 is located ~25 km outside the city of Criciúma. The mine is operating using the technique of continuous room-and-pillar mining and covers an approximate area of 1500x1000 meters. The yearly production reaches roughly 600,000 tonnes and mining operates at a depth less than 100 meters measured from ground surface. The geology in the area consists mainly of alternating layers of sedimentary rocks such as silt- and sandstone. The layers are repeated with different thicknesses and a varying degree of fracturing. In the panel of interest, the coal seam is not entirely horizontal, but instead dipping with 7° to the south-east. The coal seam is also very fractured having a RQD of 29% while the overlying siltstone is more competent with a RQD of 72%.

After excavation of a new panel, pillars started to develop damages such as cracks and fractures. The damages developed on the upper half of the pillar with a clear focus in the corner between the pillar and roof. A majority of the damages was found on the down-slope side of the pillar. However, some damages were also observed on the up-slope side. Damage inspections by the mine also found a thin clay layer located between the pillar and the overlying siltstone (Figure 1). The layer is soft and the thickness between 20-40mm. It is believed that the clay interface is affecting the pillar strength and caused the damages.

Figure 1 Left: Pillar damages and steel mesh used for support. Right: Clay interface between pillar and roof.

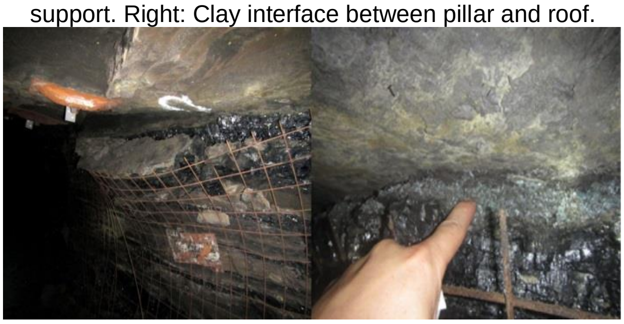


Photo: André Zingano (2015).

Focus for this project has been to evaluate the influence from the clay layer on pillar stability using numerical modelling and FLAC. In addition, the possibility of influence from structures within the coal is also evaluated. The project is carried out as a master thesis project and is the result of collaboration between Luleå University of Technology (LTU) in Sweden and Universidade Federal do Rio Grande do Sul (UFRGS) in Porto Alegre. The project is also possible due to scholarship granted by the Luiz Englert foundation.

2 THEORY

For many coalmines there is a clear distinction regarding the rock material for the coal pillars and the host rock. The different rock materials naturally also have different mechanical properties. The mechanical properties can be established in a laboratory and then applied in the design. But the interface connecting the material layers are very seldom taken into account in the design. Previous research showed that the compressive strength for a rock sample could vary as much as 100% due to the interface properties (Peng, 1978). In his research it depended on how the rock sample was connected to the testing machine, But the theory can also be applied to how a pillar is connected to the host rock.

Wagner also conducted similar research in which he added a lead sheath between the rock sample and the testing machine. Unfortunately the results were never fully published but it was concluded that not only large changes of strength occurred but also different failure modes (Wagner & Eng, 1980).

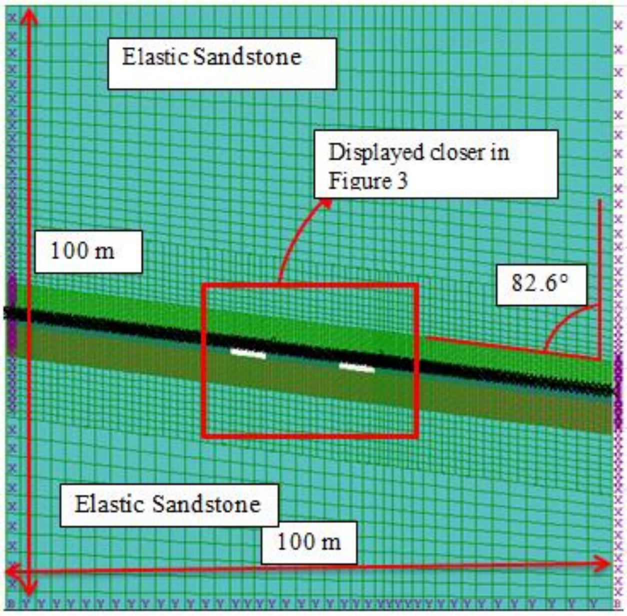
The most recent research is by Lu, Ray, Morsy & Peng (2008) where they investigated how the confinement effect changes together with the interface strength. Using numerical modelling they evaluated how the interface strength affected the average minimum principal stress and also the effect from changing the width-to-height ratio for a pillar. It was found that a low strength interface significantly reduced the effect from increasing the W/H ratio on the minor principal stress. It can therefore be concluded that the interface can have a large impact on the pillar strength and the stability.

3 METHODOLOGY

The pillar is analysed using FLAC developed by ITASCA. Initially a pillar from the panel of interest is selected and created in the software. The pillar width is set to 12 meters and the depth is set to 50-60 meters below ground surface. The height of the pillar is similar to that of the coal seam which is 2.1

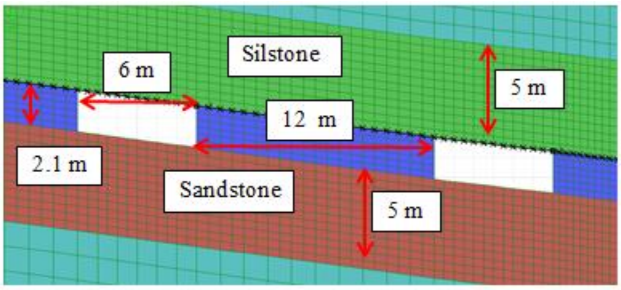
meters. The pillar is surrounded by two drifts, each with a width of 6 meters. An interface is created between the coal seam and the overlying siltstone to represent the thin clay layer. The interface allows for sliding movements between the two materials. However, it does not allow for separation, rotation or dislocation of the materials. The zooning conditions are set to medium for the entire model. In areas within, above or beneath the coal seam is the zooning densified two and four times. The material properties applied to the model are those evaluated by UFRGS, mainly through uniaxial and triaxial testing. In addition, text book and assumed values and also used. Gravitational stresses are applied to the model which can be seen in Figure 2 and 3.

Figure 2 - Left: Overview of the entire model. Right: Close-up view over pillar.



Source: LÖNNIES (2017).

Figure 3 - Close-up view of pillar and drifts



Source: LÖNNIES (2017).

Initially a calibration of the model using convergence measurements conducted by the mine survey is performed. This calibration verifies that the rock mechanical properties applied are useful and that the model is behaving like the pillar in the field. The calibration is done by reducing the elastic strength parameters for the coal and overlying siltstone meanwhile measuring the vertical displacement in the pillar and the drift. It is believed that the contribution to the measured convergence from the underlying sandstone is small or non-existent. Therefore are the rock mechanical properties for the sandstone set constant. The elastic strength parameters are reduced in sets until the convergence in the model is similar to that measured in the field.

Following the calibration three different scenarios are modelled separately. The first scenario evaluates combinations of different coal strengths and a range of values related to the clay interface. Meanwhile observing the amount of damages in the pillar and the pattern they develop in.

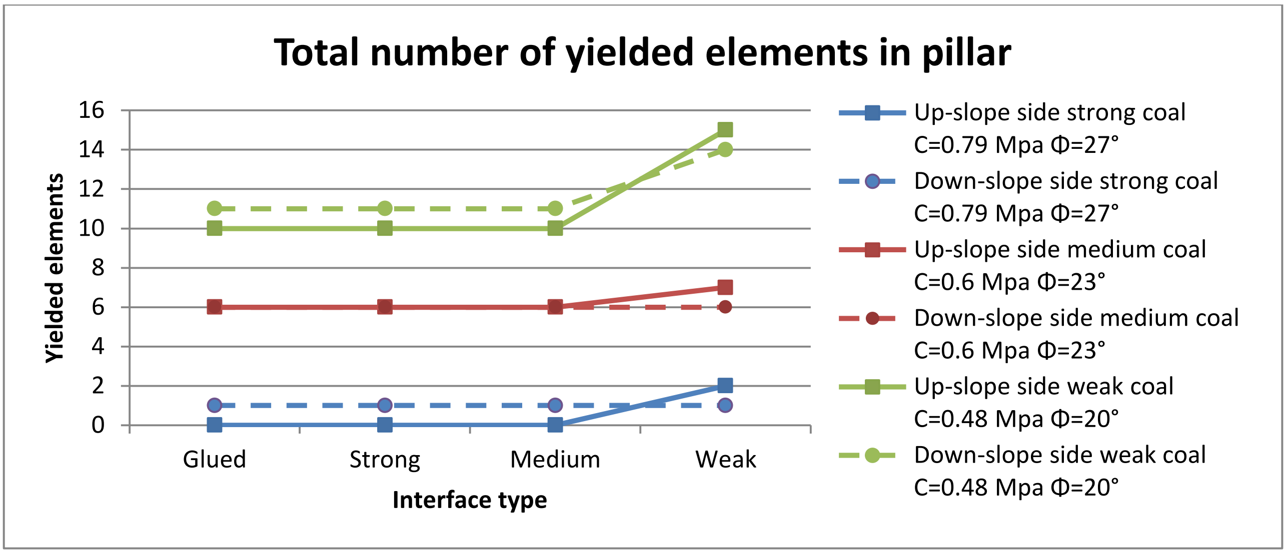
The second scenario evaluates how structures such as cleats and joints can contribute to the observed pillar damages. The structures are modelled as a ubiquitous joint material with different strengths. Four different types of cleats with the orientation of 90°, 135°, 180° and 225° towards the dip of the coal seam are modelled together with different cleat strengths (cohesion and joint friction angle). The orientations are chosen to represent cleats that are perpendicular, parallel and orientated +-45° towards the coal. No field measurements or observations of cleat orientations are available. Therefore simulates this scenario how different potential orientations of the primary cleat combined with the interface affect the pillar.

In the final scenario a horizontal velocity is added to the model. This results in a dextral movement along the interface and therefore simulates the effect from a shear movement within the clay layer. Once again, different strength parameters are used in the combination with different velocities.

4 RESULTS

The first scenario modelled, with a varying coal and clay strengths, results in a larger amount of pillar damages (yielded elements) for a weak coal strength compared to a strong coal. There is little or no difference between the amounts of damages on the up- and down-slope side of the pillar. It is also observed how the amount of damages is constant for a glued, strong and medium strength interface. The amount of damages in the pillar only increases when the clay interface strength is significantly reduced (Figure 4).

Figure 4 - Comparison between the number of yielded elements developed on each side of the pillar for different coal strengths.

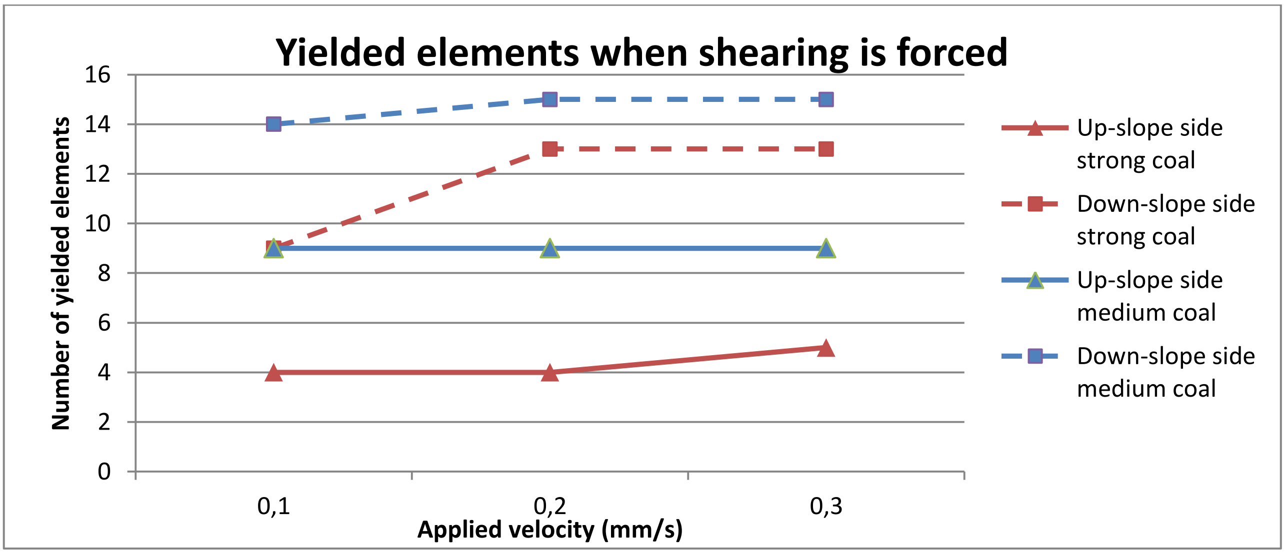


Source: LÖNNIES (2017).

For the second scenario the resulting damages are increasing when applying a cleat orientation of 225° towards the dip of the coal seam. This result in a damage pattern with more damages on the down slope compared to the up slow side. This pattern is similar to that observed in field.

In the final scenario the result show that an increased shear movement (8-25 mm) along the interface reproduce a damage pattern much similar to the field observations. The results indicate an increase of 225% when comparing damages on the down- and up-slope side of the pillar (Figure 5).

Figure 5 - Yielded elements with different applied velocities.



Source: LÖNNIES (2017).

5 ANALYSIS

From the first scenario modelled it is obvious that the clay interface may have a negative impact on pillar stability. This is most visible when comparing a strong clay interface together with a weak interface. The clay interface is observed to reduce the minor principal stress within the pillar, resulting in a reduced overall strength. This is in line with previous research conducted by Peng (1978), Wagner & Eng (1980) and Lu, Ray, Morsy & Peng (2008). However, the effect is most visible on the up-slope side of the pillar resulting in a damage pattern that is not matching the field observations.

Structures such a cleats/joints can result in a damage pattern similar to that observed in the field. A cleat orientation of 225° results in more damages on the down-slope side than on the up-slope side. The specific cleat orientation is however very unlikely to be found in field, and although the damage pattern is somewhat satisfying, it is not perfectly matching the field as focus tends to be towards the centre of the pillar.

For the final scenario the applied velocity increases shear displacement along the interface up to between 8-25 mm. There are 3 main reasons to why this shear movement can develop in reality. The first reason covers the fact that only gravitational stresses were applied to the model. If tectonic stresses are present at this depth, they would increase the shear stress along the clay layer. This would results in an increased likeliness for a shear movement.

In addition, the panel of interest is surrounded with already mined out areas to the north and south. This means that horizontal stresses would deviate around these areas and concentrate in the area of the damaged pillars. Once again, this would effect in an increased shear stress.

Furthermore, no water was added into the models. Water has a negative impact in geotechnical engineering as it reduces effective stresses. Meaning, if water is present within the clay layer the normal stresses preventing slip would be reduced. This obviously also contributes to an increased likeliness for a shear movement.

A final contributing factor might be the faults intersecting the panel of interest. They are believed to enable space for the shear movement to occur. Furthermore, the large amount of faults is believed to divide the roof into smaller blocks which are more likely to move.

6 CONCLUSION

The results indicate that the damages observed in field are best reproduced when increasing shearing along the interface up to 8-25 mm. Hence, shearing along the clay interface is believed to be the source mechanism behind the observed pillar damages. Other major conclusions and findings in this project can be summarized as:

- A weak interface between pillar/roof may have a negative impact on pillar stability
    - It reduces the minor principal stress in the pillar which affects the pillar strength
    - It is most noticeable on the up-slope side of the pillar thus is the presence of the clay layer alone not believed to be the cause for the pillar damages
- Structures (cleats) in the coal can reproduce similar damages to the field observations
    - The reproduced damages are not perfectly matching the in-situ observations.
    - Cleats with the orientation 225° are unlikely to be found in field
- Best results are obtained when the shear movement along the clay layer is forced
    - 3 potential non-investigated contributing factors may be the presence of horizontal tectonic stresses, disturbance by previous mining and influence from water.
- The pillars are in an early state of failure
- The project generated new suitable rock mechanical properties for the coal and siltstone.

7 RECOMMENDATIONS AND FUTURE RESEARCH

The mine has developed plans for production in an adjacent panel in the centre of the mine. It is recommended to investigate the eventual presence of the clay layer as early as possible before starting production. Furthermore, it is also advisable to investigate the inclination of the coal seam. If no clay layer is present, or if the coal seam is horizontal, there is no need for additional actions. However, if both conditions are fulfilled the following is worth considering.

As a result of its location, the panel is surrounded by already mined-out areas in several directions. There is likelihood for a high stress concentration. As discussed earlier, this may increase the risk for shear movements. The mine should also try to investigate the eventual presence of water in the new area as this may have a negative impact for effective stresses and resistance to shearing.

It might also be worth considering re-evaluating the sequence of mining for the new panel. The current procedure has been to start mining at the lowest point moving upwards. An opposite sequence in which mining starts at the highest point in the panel and move down might be more beneficial. It might require additional pumping and water handling but could be advantageous from a stability point of view. This needs to be investigated further.

It might also be possible to support and reinforce the pillars to prevent damages. A common supporting method for coal mines located in the USA is to combine right-angle-irons, steel mesh and bolts. The right-angle-irons provide support to both the wall as well as the roof. Meanwhile, the steel mesh retains rocks and it can undergo large deformations which might be induced by the shear movement (Figure 6).

Figure 6 - Recommended support method using bolts, mesh and right-angle-irons.

Source: JENNMAR (2016).

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