ROCK MECHANICS TECHNOLOGY LTD

ASSESSMENT OF SAFE MECHANISED DEPILLARING METHODS FOR ANJAN HILL, CHIRIMIRI COLLIERY SOUTH EASTERN COALFIELDS LTD INDIA

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1. INTRODUCTION

The management of Chirimiri, Anjan Hill is proposing to extract pillars in the Anjan Hill zero seam, bord and pillar workings with a modern Joy continuous miner (CM) and Joy auxiliary equipment.

Rock Mechanics Technology LTD (RMT) were asked BY Joy Mining Machinery to assess and report on the extraction of the pillars at Anjan Hill by continuous miner methods, employing best practice from a rock engineering point of view. The objective is to advise on the extraction of the Anjan Hill, zero seam to a relatively high percentage extraction, having due regard for safety first, without losing track of the success and profit of the project.

This report discusses requirements for successful pillar extraction using continuous miners and proposes methods for this at Anjan Hill based on experience with these methods of extraction in South African Collieries.

2. BACKGROUND

The Anjan Hill, zero seam reserve extends over an area of approximately 27 hectares of which approximately 13 hectares were formed recently on bord and pillar development with a Joy continuous miner and the remaining approximately 14 hectares by conventional drill and blast method over the past four years. The coal seam is "incropped" on its boundaries by the weathered overburden on the slopes of Anjan Hill.

The zero seam is the top most seam of a sequence of coal seams in the Chirimiri reserve. The zero seam is immediately overlain by weak laminated strata consisting of shale, mudstone, thin coal seams and clay. Two prominent sandstone beams form part of the overlying strata higher up. The zero seam have an immediate siltstone/shale floor of approximately 500mm which is partially pulverised by the mechanised equipment and a medium to fine grained sandstone making up the rest of the parting between the two seams. The next seam below the zero seam is a local seam some 15m lower down.

The pillars in the zero seam were not designed with pillar extraction by modern mining methods in mind and the size of the pillars do not correspond well with the extraction methods available. The pillars were designed according to the required size for the pillars in local seam some 15 metres below the zero seam workings, superimposing the pillars for the two seams and designing according to the maximum cover depth for the pillars in the local seam.

3. RISKS OF DEPILLARING

The main risks associated with a depillaring operation can broadly be categorised as

- Falls of ground in the depillaring area. These may be large-scale associated with the development of caving or smaller scale associated with structured or previously weakened ground that has not been adequately supported. Such falls of ground may directly injure personnel or trap the CM. In the latter case lack of auxiliary equipment to remove it may expose personnel to further risk.

- Excessive abutment loads on front-line pillars leading potentially to a pillar run or more likely to a deterioration in roof and rib stability immediately outbye of the de-pillaring front.

- Delayed caving leading to potentially damaging air-blasts when large areas of roof do cave. Such air-blasts can directly injure personnel, knock out seals/walls and push carbon monoxide into the current workings.

In addition to the above, we note that de-pillaring will result in surface subsidence. Because of the position of the Anjan site below a hill-top, there may be some risk of destabilising the hill side leading to rock fall. This aspect is not covered in this report, which is concerned with the underground behaviour and risks.

4. OVERBURDEN STRATA

The support of the overlying strata falls broadly into two categories namely:

- The support of the immediate roof strata or micro environment. The coal pillars in combination with installed roof support and the mining sequence achieve this.

- The support of the super incumbent strata or the macro environment. This is achieved through the coal pillars, the mining sequence and the panel layout.

4.1. Local roof conditions as part of the micro environment

The two 5m roof cores taken in-seam on level 6, indicate two major characteristics of the immediate roof of the Zero seam, firstly that it is weak and consists of interbedded coal and mudstones up to the cored height of 5m and secondly that the lithology varies rapidly over short lateral distances. These are shown in Figures 1 and 2.

The roof is not prone to weathering as was observed in the back bye areas of the zero seam and thus it is not considered to be problematic in terms of the laminations breaking up due to the exposure to the atmosphere.

As the immediate roof consists of weak material, roof falls are likely to occur as sections of the pillar are extracted rather than on completion of the whole pillar. This type of goaf behaviour has been observed at the neighbouring mine, Bartunga, and holds an immediate danger to the workforce involved in extracting the pillar.

Peng et al, 1987 describe a similar roof and classifies it as a class II to class III where there is no main roof or the thickness of the immediate roof is between one and four times the mining height. He states that under these conditions there is a small effect of periodic weighting on longwall powered supports and the load requirement is generally small. In terms of pillar extraction, it means a similar immediate roof will cave readily and will not tend to hang up and shift a limited amount of weight of the overburden strata onto the frontline pillars.

A weak friable roof will have less of an overhang before caving and thus create a lower abutment stress but its ability to stay up across large spans such as intersections are less. Micro fractures will be formed parallel to the caving line in close proximity to the working face and will be time dependent.

A strong immediate roof or a strong layer higher up in the roof will vary in its length prior to breaking and then lengthen again with face advance. This will create higher abutment stresses on the front line pillars but will be able to bridge large spans and will have less fracturing in the competent layer at the working face.

This stronger layer takes the form of a sandstone beam, between 20m and 34m thick and generally 5m to 10m above the coal seam. Higher up in the strata, a second significant sandstone beam of more than 70m in thickness caps the mountain as can be seen in the contour plots with geological sections in Figure 3. This second sandstone beam will most probably act as deadweight over the area of extraction as it is in a narrow range, within the 75° angle above the 800m contour. In the absence of a confining horizontal stress, this mass of rock will also tend to angle the vertical stress and fracturing of the roof and sidewall can be expected on the northern side of each roadway due to the riding effect created by this off-centre dead weight. This is one of the reasons that the direction of pillar removal is from left to right and that the fenders are attacked from the northern side. It may be necessary to provide some support to the southern ribsides of the pillars/fenders to protect the CM operator and cable handler.

The amount of bending or convergence of the roof depends on the nature of the strata. Laminated roof material bends significantly before actually breaking. Rigid sandstone bends less.

Convergence is associated with face advance and less convergence will be experienced with rapid face advance.

Roof conditions necessary for a pillar extraction operation are:

- The local roof strata must be able to bridge roadways and constantly widening diagonal spans at intersections safely. If it is not competent enough to bridge, the systematic roof support must reinforce the strata to that extent. The diagonal of a square-cut intersection is approximately 1.4 times the roadway width. In the absence of horizontal stress, with only gravity acting on the rock, this means the roof sag can be up to 4 times as great as with normal roadways. Cutting the junctions just 1,0m too wide, widening the diagonal span further, can increase the sag in the roof up to 6 times.
- The local strata must be capable of undergoing convergence deflection of up to, say 50 mm, during depillaring without failing.
- Together with the upper strata the local strata must allow early and regular caving to minimise cantilever effects and keep induced abutment stresses on the pillar line at a low level.
- The width of roadways will influence on the behaviour of the roof. Although productivity in primary mining is improved through wide roadways, for secondary mining narrow roadways improve roof control and the CM is able to stay in a pillar for longer improving the overall percentage extraction.
- A thick, weak and friable roof such as the zero seam roof can be very heavy in relation to pack or elongate support and because of the lack in stiffness of such types of support will allow the immediate roof to converge significantly before active resisting movement. This movement can be enough to destroy the integrity of the strata and prevent the strata from effectively bridging the roadway span.
- The presence of a strong and resilient rock such as sandstone in the main roof will hinder readily caving. This causes extra weight to be thrown onto the pillar mined, possibly creating difficult conditions in the face area.

4.2. Overburden strata as part of the macro environment

The composition of the overburden strata is one of the critical factors affecting the formation of caving during depillaring.

The critical panel width necessary to cause caving of the competent overburden strata depends on the depth of mining and the thickness of the competent strata.

Correctly carried out, the caving will relieve stresses on the abutments and improves the overall stability.

The panel width varies with a average panel width between Level 24 and level 6, where the pillars were formed by CM development, of 230m to 250m and an average width of over 400m for the back bye areas developed by conventional methods. The panel width is in the order of twice the width of the cover depth, ensuring that each pillar will be loaded by its full tributary load and softening the stiffness of the system.

The depth of mining on average varies from approximately 50m of cover on the southern side of the panel to approximately 80m of cover on the northern side of the panel. An average maximum cover depth of approximately 120m is sitting above A rise, which is the centre of the panel. This cover depth over the centre of the panel decreases towards the southern and northern edges of the panel but increases towards the back of the panel to a maximum of approximately 130m, i.e. the eastern side of the panel.

Because of the irregular contour/shape of the mountain above the zero seam workings, the mining depth is variable over a short distance and a single line of pillars with the same centre distance have varying cover loads acting on it.

In the case of generally weak and incompetent immediate roof strata, the high compressive stresses that act near abutments are sufficient to cause failure of the lower roof strata. The stress-induced fractures will tend to develop in the direction of near vertical maximum compressive stress.

Because the lower roof strata in the mined out area are in tension due to the relaxation of the vertical stresses; gravitational collapse of the intensely fractured roof strata can take place readily. Caving of the immediate roof will be continuous and depending on the strength of the first overlying sandstone beam, probably terminate against the lower horizon of this sandstone beam.

A large span would be necessary to cave the more competent sandstone beam higher up in the strata. A limitation to creating such a large span will be under-loaded snooks and fenders left behind in the goaf, especially on the southern side of the panel.

The location of the Anjan site under a hill-top is an unusual feature. A complete analysis of the effects of this would be complex and beyond the scope of this report. Overall it is expected that since the overburden is less confined it will be less likely to bridge and transfer excessive loads to pillars.

4.3. Overburden loading

The loading of the pillars in the zero seam is variable due to the irregular contour/shape of the overlying mountain. The contours are oblique to the layout of the panel and pillars are of a uniform size but pillars in the same line are not subjected to the same loading conditions.

On the southern side of the panel the loads on the pillars are approximately 10 times less than the Salamon strength of the pillars and on the northern side of the panel, they are approximately 2.5 times less than the Salamon strength of the pillars. Thus, in order to initiate and control a caving situation the extraction will have to be increased on the southern side of the panel.

In a longitudinal direction along the panel, approximately East West, the loading is more consistent as can be seen from Figure 4. If the transfer of load due to the goaf hanging up is ignored for the moment, then each row of pillars to be extracted should behave in similar way to the previous line of pillars that was extracted.

Thus to enable a uniform goaf developing, that is more controllable and predictable, it may be beneficial to increase the percentage extraction on the left-hand side of the panel compared to the right-hand side. However, if one increases the percentage extraction on the left-hand side of the panel there is a greater risk of the localised falls of ground due to the weak nature of the immediate roof. Experience may be required to find a balance between controlling the caving and controlling the immediate roof.

5. PILLARS

Table 1 provides a summary of factors affecting pillar stability

Geological	Mine design
Depth	Mining sequence
Overburden thickness and physical characteristics	Pillar size and strength
Coal bed thickness and physical characteristics	Road widths and roof spans
Immediate roof and floor stratigraphy	Percentage extraction/volumetric
Discontinuity influence	Mining layout
In situ stress fields	Geometric layout of workings Support methods Time

Table 1. Factors affecting pillar stability

The pillars in zero seam have been designed to be superimposed on the local seam pillars, 15metres below the zero seam. Only parts of the zero seam have been undermined by the local seam in the back areas corresponding to level 1 to 6. An abutment from the pillars in the lower seam will only be expected in the back bye area.

The current pillar size in the zero seam is 27.5m square pillars on 33m centres with 5.5m roadways mined to a height of 4.5m. This results in a Salamon strength of 12.2 MPa per pillar, a width to height ratio (w:h) of 6.1 and an areal percentage extraction of 30.6%.

The roof and floor contacts are not well defined and the contact planes are welded which will tend to confine the pillar sides and reduce pillar scaling. Weathering on the pillars is not considered problematic.

The load on pillars during pillar extraction will change constantly due to the dynamic nature of the mining process as shown in Figure 5. The faster the rate of extraction (on a regional basis and not on an individual basis) the higher the achievable percentage extraction will be.

During pillar extraction the adjacent pillar will be subject to increased loading due to abutment stresses transferred from the extracted area. In South Africa, a pillar Factor of Safety of 2.0 or above with the Salamon strength equation is recommended to cater for this. The pillars at this site satisfy this requirement. Numerical modelling could be used to further investigate this aspect of pillar loading.

The balance of panel width or number of pillars in a row to be extracted must be balance against the time it takes to extract one row. Spending too much time on a row of pillars will have a further damaging effect on the abutment pillars thus the angle of retreat is kept perpendicular to the primary direction of the panel to keep the row of pillars as short as possible.

The strength of rocks is time dependant and to some extent, depends on the duration of loading. The coal pillars will support loads exceeding their ultimate strength for short periods. The success of pillar extraction and the actual value of the safety factor therefore depend on the rate of extraction. The time taken between forming the first undersized fender in a pillar and the same pillar's complete removal should be no longer than 24 hours.

Time taken for weekends, change of shift, aligning the CM for a cut or tramming the CM from one position to the next, increases the risk of premature failure. The same applies for pillars on the caving line. The longer they are left to stand under increased load, the weaker they will become. The discontinuities in the pillars as observed in the zero seam will further weaken them over time.

Doing primary mining such as developing additional roadways on the flanks, in combination with the secondary mining or depillaring, is not recommended. Once the pillar extraction process starts, the focus should stay on extracting the pillars as fast as possible.

Care should be taken when there has been a long break-off in production such as a major breakdown or a weekend. Pillars should not be left partially extracted and fenders should not be, as far as possible, be left to stand over weekends. The fracturing developing in the fender over a period will drastically weaken the pillar. The same can be said for fracturing developing in the immediate roof. When an attempt is made to extract the last remaining part of the fender, the strength would have been drastically reduced which might result in premature or unexpected failure of the pillar and/or roof. Returning to extract a fender left for an extended period is not recommended.

A riding effect of the roof on the pillars will be caused by the mountain top sitting off-centre to the panel centre. Smaller (reduced size) pillars such as the fenders and snooks will be affected by this riding effect. The less than competent roof will probably break-up instead of riding on the pillars ripping the pillars apart further reducing the strength of the pillars, fenders or snooks.

The caving action or failure mode of the overburden can be either sudden and violent or gentle and controlled depending on the stiffness of the system.

A stiff loading system exerts a high load for a low rate of deformation or closure. A soft loading achieves a high rate of deformation for a small increase in load. Figure 6 shows two load lines at different gradients. Load line A shows a higher load for the same displacement and is stiffer than load line B that, for the same displacement, achieves a lower load.

The failure mode is determined by comparing the stiffness of the loading system with the post peak pillar stiffness. Neither of these two parameters is easily determined and is estimated at best from past experience. Some contributing factors affecting the stiffness of the loading system and pillars are summarised in Table 2 and briefly discussed.

Stiff systems	Soft systems
Stable, controlled failure	Violent, uncontrolled failure
Deep mining	Shallow mining
Competent roof - dolerite, massive sandstone	Incompetent roof - laminations, Shales, clays, etc.
Narrow panel width	Wide panel width
Massive rock mass	Jointed rock mass
Squat pillars	Fenders and snooks
High rate of extraction	Slow rate of extraction

Table 1 - Stiff systems vs. soft systems

For a gentle and controlled caving, the stiffness in the rock mass must be greater than the stiffness in the pillars.

The presence of geological discontinuities such as was observed at Anjan Hill, have two contrasting effects on the rock mass. The discontinuities assists the caving process by dissecting the rock mass into weaker blocks but it also destroys the stiffness of the rock mass or the loading system. At Anjan, the unconfined nature of the overburden under the hill-top will also tend to reduce the effective stiffness.

Figure 7 shows the effect of varying the stiffness of the loading system on a pillar's post peak strength behaviour at a set stiffness. Load line A is typical of a weak or broken rock mass. There is excess energy available in the loading system beyond the pillar's peak strength that will result in uncontrolled failure. Load line B represents a much stiffer system where there is a shortage of energy beyond the pillar's peak strength that will continue to fail the pillar but in a controlled way or temperate.

The ratio of the width of the pillar compared to the mined height of the pillar, generally referred to as the w:h, is important for predicting not just the pillar strength but also the mode of failure of the pillar. Figure 8 shows the peak strength of the pillar increasing for an increase in the w:h and the post peak strength behaviour of the pillar changing. As the w:h of the pillar increases, there is an increase in the peak strength behaviour of the pillar. The post peak strength increases from 1:1 where the pillar behave brittle and result in violent failure through 1:5 where the post peak stress-strain behaviour is almost ductile/plastic to 1:7 where strain hardening is taking place.

Figure 8 also compares the stiffness of a loading system at a set stiffness, to pillars at various w:h for the same convergence or displacement. In the case of load line B, there will be excess energy available for the post peak stiffness of a pillar with a w:h of 2:1, resulting in uncontrolled or violent failure beyond the peak strength of the pillar. For the same load line acting on a pillar with a w:h of 3:1 there is a shortage of energy for the post peak stiffness of the pillar and failure will still continue but in a controlled fashion.

Pillars with a low w:h have almost no residual strength causing them to fail rapidly and shed their entire load to adjacent pillars when they fail. Depending on the size of the adjacent pillars this additional load can cause them to fail resulting in uncontrolled failure over a large area with subsequent airblasts.

For the same pillar height, the larger the area of the pillar, the stiffer the pillar. For the same pillar area, the greater the pillar height, the softer the pillar. As a pillar becomes more squat, where there width of the pillar increases in relation to the height of the pillar, their residual strength increase, reducing the chance of rapid failure.

Squat pillars are pillars where the w:h is such that it can carry very large loads with a strain-hardening characteristic, providing a stiff resistance to load.

In South Africa, a pillar with a w:h of greater than five is considered to be in the squat range. According to Mark, pillar failure can be divided into three categories:
- Slender pillars (w:h<3) which are subject to sudden collapse in a violent uncontrolled fashion
- Intermediate pillars (3<w:h<10) in which pillar failure is slow and controlled and can occur over extended period of time
- Squat pillars (w:h>10) which are dominated more by roadway failures (sidewalls, roof and/or floor) affecting pillar stability than actual pillar instability

The current pillars in the zero seam are only a problem in that they are over-designed for effective depillaring. The art is in the size of the fenders and the remnant snooks that are left behind. It is advisable not be in a situation where the snooks are too large to be left unmined but too small to safely extract.

Discontinuities have a weakening effect on pillars and the weakening effect depends on the w:h of the pillars. The greater the w:h the more likely the discontinuity will be contained within the pillar as shown in Figure 9. The zero seam coal contains many such natural discontinuities, which adversely affects the strength of the coal, and this is not taken into account in most empirical methods for calculating pillar strengths. Material properties are an Achilles heel shared by empirical pillar methods and numerical methods.

From laboratory tests in South Africa, it was shown that the reduction in strength as specimen volume increase could be explained through the increase intensity of discontinuities in the larger samples. Through numerical modelling, it was showed that as the w:h ratio of a pillar increased, the effect of discontinuities became less noticeable.

The strength of the pillars is greater than the strength of the coal. Thus, in the elastic mode there will be insignificant spalling or fracturing on the pillar as is currently seen in the zero seam. As the pillar approaches its peak strength, due to the greater depths or excessive loading from the goaf, fracturing will develop on the ribsides of the pillar with subsequent scaling of the ribsides. This scaling will be aggravated by the presence of the cleating and the discontinuities in the pillars of the zero seam.

The stiffness of loading system is a function of the panel width, number of pillars in the panel and the overburden strata system.

Factors, which will influence pillar stiffness during failure, are the height and the width of the pillar and the strength of the coal pillar.

5.1. Fenders

Most methods share the common trait that fenders and snooks are left behind to provide medium to short-term local support whilst the pillar is being worked. These remnants of coal must obey the rules applicable to coal pillars in terms of providing stability. The remnants only differ in design in terms of the period stability. They do not provide ultimate stability, only temporary stability.

A fender is commonly formed after the first cut is made on a pillar when two equal sized rectangular pillars are left behind. The equivalent width of theses rectangular pillars, compared to square pillars, are given through:

$$Width_{equivalent} \approx 4.\frac{Area_{pillar}}{length_{perimeter}} \qquad (1)$$

If more than one pillar is to be worked at a time, the size of the fenders must be sufficient to support the overburden in the worst possible situation.

Fenders should be at least 10m wide to ensure adequate protection during the extraction process. The width to height ratio of the fenders should be at least three for the mining height of 4.5m.

5.2. Snooks

A snook is a small remnant of coal that acts as a crush pillar and provides short-term support to give temporary stability in working area. Snooks are intended to stabilise the micro environment without upsetting the balance in the macro environment.

If the size of snooks is excessive, they can prevent regular caving of the intermediate roof strata. This results in the development of potentially unstable situations, wherein several tens of metres of roof strata are supported by undersized pillars.

The ideal width to height ratio for crush pillars/snooks is approximately 1.

Snooks must be kept to a minimum. Snooks in weak roof can cause the immediate roof not to break at the breakerline but to run through to the first solid abutment.

Confinement provided by initial roof failure around the perimeter of a pillar plays an important role in the strengthening of the pillars. If the snook sizes are too large, this debris confining the pillar can further increase their strength and prevent them from crushing. A similar situation was observed at Bartunga where a small snook was confined on all sides by the goaf, for two thirds of the height of the pillar.

5.3. Mining height

The mining height inside the pillar, where systematic support must be installed, must be kept within the working height of the Quadbolter. Thus, the CM must not cut higher than 4.5m. Once the fenders are being extracted, the operator can lift the CM's cutting head to maximum height to cut down any reachable coal in the roof without cutting down the systematic roof support in the pillar split.

For the same pillar height, the larger the area of the pillar, the stiffer the pillar. For the same pillar area, the greater the pillar height, the softer the pillar.

The jointing in the coal will further weaken the stiffness of the pillar for an increase in height as can be seen in Figure 10. An increase in mining height will have an increase on the amount of scaling from the sidewalls and a greater chance of trapping the CM inside a lift.

Timber props for "policemen" will become more difficult to install and where timber prop breakerlines are considered at these heights, their effective loading characteristics will decrease with an increase in height.

The higher the mining height the more coal will be left behind in the pillar for a low w:h ratio. The lower the seam the more likely the pillar will not crush and hold up the roof.

5.4. Extraction angle

The angle of extraction can be varied according to local geological conditions and behaviour of the strata but once depillaring commences, the angle of extraction should be adhered to.

For a narrow panel (5-7 roads) to be extracted with a CM, such as the zero seam workings, a perpendicular stooping line is recommended. Timing when extracting pillars is crucial and the longer the line of pillars, the more damage caused on the pillars as rock strength is time dependent.

6. ROOF SUPPORT

6.1. Systematic support

If depillaring commences and the systematic support is found to be inadequate, it is more costly and unproductive to install additional support than it would have been if adequate support were installed from the start. Prior to starting de-pillaring the area should be assessed and prepared by installing the support expected to be required for the depillaring operation.

Effective support of geological discontinuities is of utmost importance before depillaring commences. Support of these discontinuities at a later stage would have allowed movement to occur along the discontinuity planes.

Areal sidewall support of discontinuities and stress-induced fractures should be considered for the ribsides. They are a hazard to personnel in section, especially at a mining height of 4.5m. During depillaring, the stresses in the sidewall are magnified, increasing the stress fracturing and can push out large wedges of coal on the discontinuity planes.

6.2. Caving (goaf) breakerline

A goaf breakerline can fulfil several roles:

- It controls the goaf edge and prevents it extending into the current working area.
- It prevents the ingress of fallen goaf material into the current working area.
- It prevents access to the goaf through acting as a barrier.

Of these the first is by some margin the most important function. Through stiffening the sagging roof it causes a breakline, preventing the goaf from extending into the current working area. It is a line where the goaf must stop as shown in Figure 11.

Different types of breakerlines can be used to perform this function. They can be categorised as: (McCosh et al, 1989)

- The coal pillar itself, which provides adequate strength and stiffness to the immediate roof.

- Conventional timber props or packs, which are cheap and readily available. They can only be set prior to extraction of a specific pillar and must be cut to fit the specific height at that point. Due to the slenderness and difficulty in installing, the props become ineffective beyond a 2.5m to 3m mining height. The wood does not provide a very stiff support of the immediate roof and allow a considerable amount of convergence to take place. More often than not, the contact between the timber pack and the roof is not positive or active and the roof must converge before the pack starts resisting movement. They are also easily damaged or removed through the ingress of goaf material. Where it is required to recover the timber breakerlines after each cut, it becomes a retarding and hazardous operation working so close to the goaf edge. In addition as the mining height is similar in the panel finding a suitable length of timber can be time consuming. Advantages of the timber props are that they do give an indication of the onset of caving and forms a solid barrier between the workings and goaf edge preventing access to the goaf.

- Remote operated mobile breakerlines, which are the ideal breakerline but capitally expensive. Modern mobile breakerlines can provide a yield load of 500tons+ per unit and in most instances, three units are used per breakerline.

- Tendon type breakerlines or more commonly known as roofbolt breakerlines.

The advantages of roofbolt breakerlines are:

- The quality of installation and its effectiveness are independent of the extraction height
- The breakerline can be sited to suit strata control requirements
- The breakerlines can be installed well before pillar extraction commences
- Modern roof support consumables provide a very stiff support.

An example of the effectiveness of roofbolt breakerlines is shown in Figure 12 (v. d. Merwe & Madden, 2002). A roofbolt breakerline before the caving (left-hand picture) and the same one after the caving (right-hand picture). The chevron tape hanging from the roof indicates the positions of the roofbolts. Note the "policeman sticks" in the upper picture.

For Anjan Hill, zero seam, it is proposed that roofbolt breakerlines in combination with coal pillar edges are to be used to control the goaf line. In addition, timber props, installed in selected positions, will act as indicators or "policemen" by visually deforming with roof convergence as shown in Figure 13. Hazard tape or other barriers a few metres outbye the breaker line can be used to define an exclusion zone preventing access to the goaf.

The breaker line will consist of a double line of five roofbolts per line. These roofbolts will be full column grouted, 2.4m bolts as per the specification for the roof support used currently for the in zero seam. It will be installed on the goaf edge side of all open-end pillars, no more than 0.5m inside the pillar edge, no more than 0.5m away from the ribside and the rows no more than 1m apart, as shown in Figure 14. When the goaf is hanging up, violent failure can be the result. Breakerlines should be increased from the normal two rows to three rows to prevent an overrun of the goaf.

Single timber props ("Policemen") will be set in such a position that it will give a visual warning as to the onset of caving as shown in Figure 14. Their position shall be such that they cannot be knocked out by the ingress of goaf material or hinder the CM or shuttle car in the extraction of the pillar.

7. SUGGESTED DEPILLARING METHODS

7.1. Method 1 - Pocket and fender method

This method is the preferred method of the Anjan Hill management team as this is the most common method of pillar extraction in Coal India, SECL. The management and the Indian workforce are familiar with the method and the subsequent strata behaviour and so is some of the Joy Mining team personnel from experience with this method in South Africa.

The depillaring will be done on the retreat, moving across the panel from left to right. This means that the pillars with the least cover load will be extracted first moving across towards the pillars with the higher cover load, into the riding created by the off-centre loading of the mountain top.

A roadway 5.5m wide is developed at the centre of the pillar, in a direction perpendicular to the face line, parallel to the pre-developed rises. With the regulated minimum cut-out distance of 10 metres, three separate cuts will have to be made to enable the roadway to traverse the width of the 27.5m pillar as shown in Figure 16. Whilst cut A1 is supported, the continuous miner can start with cut B1. The heading in A1 must be supported by the time that B1 is completed so that the CM can tram back to cut A2. If the heading in A1 is not support for whatever reason the CM must stop production and wait until the heading is supported. Under no circumstances should the CM start cutting on pillar C1 when pillar A has not been completely extracted. This is to limit the amount of pillars on smaller safety factors.

The Quadbolter and the CM must change out and the CM moves back to make cut A2. This cycle repeats itself until the CM can come back and cut A3 through. After cut A3, the CM must move back to complete B3 in order for the Quadbolter to support A3 and set the goaf breakerline in position.

In adverse conditions such as the goaf hanging up, spalling of the ribsides can increase and become dangerous for the operator and cable handler of the CM. Thus, rib support in the form of 3 x 2.4m fully grouted bolts with W-Straps can be used to contain the ribsides on the right hand side of the centre cut or the southern side of each pillar, keeping the operator and cable handler protected as shown in Figure 17.

Out of the 27.5m square pillar, two rectangular fenders have been created, each 11m wide by 27.5m long, with a Salamon Strength of 9.4 MPa and a w:h of 3.5, which should be strong enough to break off a unforeseen goaf occurring whilst the CM and operator are inside the pocket. The areal percentage extraction at this stage is 44.5%. Note the position of roofbolt breakerlines.

Pre-splitting of the coal pillars to maintain production should be kept to a minimum to prevent premature failure of the fenders and possible goaf overruns. No more than one cut should be made ahead of current pillar being work on. No more than two pillars should be worked at any time. For example, a seven-road section with a six-pillar line, the pillars can be numbered A - F from left to right. Pillar A and pillar B are worked as a pair and on extracting of both these pillars then only can the pair C and D be started on. The same applies for E and F.

After the installation of the systematic support in pillar A, the CM can return to the pillar and start with the fender extraction. It should be noted that when the fender extraction is started, the CM should not be stopped until the fender is completely extracted. If any lengthy stoppage occurs in excess of 2 hours, the remaining part of the fender and surrounding area should be carefully assessed and preferably be abandoned. The undersized fender would have been standing at increased load levels and when further attempts are made to extract it, it may initiate failure of the fender or roof, resulting in a collapse on the CM. Experience gained from prevailing the local conditions once the depillaring process start, will give an indication if this 2-hour limit can be extended.

The CM makes an approximately 6.6m wide, diagonal cut into the fender on the left hand side. The position of this cut depends on the condition of the goaf. If the goaf is tightly behind the pillar, there is a limited amount of additional weight on the pillar and the cut can be made closer to the goaf side, approximately 7m from the edge of the pillar for the right-hand lift first, at an angle of approximately 30° as shown in Figure 18(a). This will leave a triangular pillar approximately 3.5m from the pillar edge, with an area of approximately 10m² and a w:h ratio less than 1.

If the goaf is hanging up, leave a slightly larger snook to give more temporary stability to the pillar. The right-hand lift should be taken approximately 12m from the edge of the pillar. This will leave a triangular pillar of approximately 30m², approximately 6m from the pillar edge as shown in Figure 18(b).

The depth of the cut should be restricted to approximately 10m, allowing a web of coal on the edge of the pillar to provide additional support and preventing the CM from cutting into any rib-support. The part of the fender that is left has an area of 225m² and a w:h of approximately 2.5. The fender percentage extraction is at 55% and the overall pillar percentage extraction is 50%.

If additional coal is left in the roof, the operator can lift the CM's cutting head and cut to the full reachable height without cutting down the roof support in the split. This will increase the volumetric extraction and assist in the crushing of the remaining coal webs as the w:h ratio is increased. Taking the additional roof coal in the fender will increase the time spent on the pillar and a fender might not be totally extracted within the time available. The emphasis should be on the completion of the fender within the time available on not on maximizing the extraction. This is applicable for all the diagonal cuts into the fender.

The CM should not be left standing inside the fender for extended periods, such as with a trunk conveyor stoppage. The crushing of the rib-sides are enough to pinch/trap the CM inside the fender, especially on the first cut. Tram the CM backwards and forwards as often as possible between shuttle cars to ensure that the CM can still come out of the cut without any obstruction.

Step 3 of the mining sequence is to make the second diagonal cut into the fender. This is done by leaving a web of approximately 2m from the previous diagonal cut. The CM starts cutting the right hand lift approximately 15.5m from the pillar front edge as shown in Figure 19. The second lift is taken assessing local conditions and if necessary leaving a rib of coal between the first and second lift.

Step 3 reduces the fender area to 131m² for the remaining fender at a w:h of approximately 1.6. The fender percentage extraction is at 68.5% and the overall pillar percentage extraction increases to 55.6%.

Step 4 is to take the final cut into the fender. This decision must be made based on an assessment of local conditions, experience and goaf behaviour. A decision must be made if one or two lifts will be taken. Taking only a single lift leaves a slightly larger snook for the protection of the CM under a goaf that is hanging up. If goaf conditions are favourable, two lifts can be taken. The CM is partially in the intersection and it is vital that the operator and cable handler should stay clear of the intersection area. The third diagonal cut into the fender should leave a approximately 2m web between this lift and the previous lift as shown in Figure 19.

Step 4 leaves a triangular pillar or snook of approximately 35m² at the end of the fender with a w:h of approximately 1. The fender percentage extraction is at 80% and the overall extraction on the pillar increases to 61.2%.

A cut, consisting out of two lifts, each lift 3.3m wide and 10m deep to a height of 4.5m at a coal R.D. of 1.4, equates to approximately 380 tonnes of coal or 190 tonnes per lift. Three cuts are necessary to remove a fender resulting in 1140 tonnes of coal, which is more or less within the capability of the Joy team to produce in one shift. If the additional coal is taken in the roof it will increase the volume of coal removed but increase the time to remove the pillar.

It is emphasised again that once a fender extraction process is started it should be a continuous operation until the fender is completely extracted. If there is a change of shift, it should be a "hot seat change". Fenders cannot be left partially extracted for extended periods longer than 2 hours. Any attempt to extract the last part of the fender after a long layoff can be disastrous.

The next fender is extracted by changing the CM into the Rise (roadway) to the right of the pillar and repeating steps 2 to 4. The theoretical percentage extraction after both fenders have been removed will be approximately 78%.

7.2. Advantages of the pocket and fender method

- Well-known method of extraction
- Higher percentage extraction in theory

7.3. Disadvantages of the pocket and fender method

- South African Joy team not that experienced in pillar extraction
- Exposes CM to goaf overruns
- CM deep into pillar at certain stages and difficult to recover if collapse occurs.
- No CM emergency removal unit with auxiliary equipment ("Tooth Extractor") available currently.
- CM operator and cable handler inside the pillar
- Time taken for change-out between CM and Quadbolter
- Change-out between CM and Quadbolter in terms of logistics
- Additional systematic support
- Additional breakerlines to be set
- Working more than one pillar at a time increasing the extraction time on a weakened pillar.
- Experience with this method has shown that spillage of the coal occurs whilst being cut and is left behind. The coal while technically extracted from the pillar is not

loaded by the CM. Thus, on plan, the coal is extracted but it never went out of the mine.

A large South African mining group, SASOL COAL, was employing a similar method of pillar extraction at similar dimensions on all their mines up to 1999. On average, there was a CM burial for every two panels extracted. From investigations into the cause of the CM burials, it was concluded that in a number of cases, due to a high horizontal stress and the increase of load on the last fender, the last remaining snook on the fender (6mx4m) had been pushed over resulting in a goaf overrun. In Chirimiri case, there is an absence of horizontal stress but an angled vertical stress due to the mountaintop sitting off centre to the panel centre and thus can also create this toppling effect on the smaller fenders and snooks.

Section personnel from the SASOL group also reported that the caving was violent and often came with very little warning or else did not give them time to react. This often happened long before any fracturing in the sidewalls, due to excessive loading of the pillars, were observed.

The group also found that due to the large size of the pillars necessary at a depth of 200m+, it was unacceptable for the CM to be completely inside the pillar whilst extracting the fender.

7.4. Recommended modifications of the pocket and fender method

Permission from the DGMS to be able to do an extended cut to 13m will enable the pillar to be split in two cuts. Each cut will be approximately 12.5m long, leaving a web of coal of approximately 2.5m at the end of the split. This web of coal will act as a breakerline and will be much stiffer than any support that can be installed. It will also minimize tramming as of the CM as the CM will only have to be removed twice before starting to extract the fender. Cut 1A should be supported by the time that cut B1 has been completed, otherwise the CM must tram to cut C1.

For the pillars with additional cover load, i.e., the pillars on the north western side of the panel, a larger snook should be left on the last part of extracting the fender. For step 4, only a single lift is recommended.

Additional support must be installed in the intersections created by splitting of the pillars to accommodate the larger intersection span at the position of cut 1 for all the pillars. This can be done on development or with any spare time that the Quadbolter have. A 9-bolt pattern, 3 rows of 3 bolts each are placed as secondary support in this specific intersection.

The larger intersections created on primary development should be pre-supported to the minimum requirement of 1.1 bolts/m2 as stated in the report, SECL05 dated September 2002.

7.5. Method 2 - Angled pocket method (adapted NEVID method)

This method is an adaptation of the NEVID method adapted and used successfully by SASOL COAL in South Africa, for the partial extraction of coal pillars at a depth of 150-200m.

The method utilizes the same pillar layout as is currently in zero seam and after the primary development, as with the pocket and fender method, the panel has an extraction ratio of 30.6% and the pillars will be at a w:h of 6:1 and a Salamon strength of 12.2 MPa.

The method is made up out of a series of alternative diagonal cuts or pockets, cut into neighbouring pillars as shown in Figure 21. The depillaring would be done on the retreat, moving across the panel from left to right. This means that the pillars with the least cover load will be extracted first, moving across towards the pillars with the higher cover load, into the riding created by the off-centre loading of the mountain top.

Consider a panel of pillars typical of the zero seam layout with 7 roadways and 6 pillars per row. The pillars are numbered from left to right, 1 to 6. Cuts or pockets are made diagonally into the pillars. A cut consists of two lifts taken by the CM, each lift being 3.3m wide and 10m long, with the lift closest to the goaf edge always taken before the lift closest to the solid.

The number 1 cut is made, 10 metres deep at the back of the pillar in the centre, for example pillar 1, at a 30º angle as shown in Figure 22. Roof coal can be taken on this cut.

For cut number 2, the CM is pulled back and a 30º cut is made into the pillar behind pillar 1, as per the example pillar 7, and shown in Figure 23. This is a high-risk cut and no roof coal should be taken on this cut to shorten the exposure time in this position.

The CM trams around pillar 1 to the northern side of the pillar, and takes cut no. 3 on the left-hand side, into the top corner of pillar 1 at a 45º/135º angle with the direction of the Rise. The centre of this cut is approximately 20m from the pillars bottom corner. The cut should not extend into cut no. 2, from a previous cycle, but it is a definite possibility. Depending on local conditions, roof coal may be taken on this cut.

A snook is formed on the pillar corner of pillar no. 1. The w:h ratio of this snook is less than 1. Depending on prevailing conditions, this snook can be increased in size by taking only one lift for cut number 3, this being the cut closest to the solid. If the goaf is hanging up, pillars are taking load or the frequency of jointing increase, the conditions are not favourable and the cut in the pillar corner area should be restricted.

The CM pulls back and takes cut no. 4 on the right hand side, into the top corner of pillar no. 2 at an angle of 60º/120º with the direction of the Rise. The centre of this cut is approximately 20m from the pillars bottom corner. It is not planned that cut no. 4 and cut no. 2 from a previous cycle, should not meet but it is a definite possibility. It is a high-risk area and no time should be wasted in this position through taking any roof coal.

A snook is formed on the corner of pillar no. 2 as shown in Figure 23, with a w:h ratio of approximately 1. In combination with the snook formed after cut 3, these snooks are supporting the intersection. Due to the predominant dip direction of the slips being in a westerly direction, as surveyed previously in zero seam, if a slip is running parallel to the North-South level in front, the weak side of the slip is resting on these snooks. The roof should be carefully monitored through instrumentation and visual observations.

No time should be wasted in this area. Cut no. 4 should be completed as soon as possible. If conditions are favourable then the full cut can be taken. If the goaf is hanging up, pillars are taking load or the frequency of jointing increase, the cut 4 should be restricted to only one lift and this the lift closest to the solid, i.e. the right hand lift.

If there is, for whatever reason, a hold-up in production for a period of more than 30 minutes whilst cut 3 or 4 are made, the cut should be abandoned. If the delay was on cut 3, cut 4 should be restricted to one single lift on the solid side of the pillar. Experience with local conditions once extraction starts can extend this 30-minute period to a maximum of 1 hour.

For cut no. 5, the CM pulls back and takes the cut at an angle of 60º/120º cut on the right-hand side, into pillar no.2, with the centre of the cut more or less 11.5m from the pillar corner, leaving at least a 2m rib between cut no. 4 and cut no. 5.

The sixth cut is optional in a high-risk area and prevailing conditions will determine if a full cut, half cut (1 lift) or no cut at all is made at this position. The CM pulls back from cut number 5 and takes the cut at 45º/135º cut on the left-hand side, into pillar no.1 leaving at least a 2m rib between cut no. 3 and cut no. 6. The centreline of the cut is approximately 9.5 from the pillar corner. No roof coal should be taken for cut no. 6 and no time wasted in this position. The rectangular core of the pillar left behind has a dimension of approximately 8m x 15m with a w:h of 1.8 and a Salamon strength of 7.2MPa

In terms of determining the strength of the pillar, the sequential numbering for the cuts and the actual cuts for the decreasing pillar size differs, thus only for calculation purposes, the steps are renumbered as shown in Figure 24 and referred to in Table 3. Figure 24 should not be confused with Figure 23.

Cut	**Pillar Area** (m^2)	**Cut Area** (m^2)	**Extraction** (%)	**Tonnes Cumulative** (tonnes)
0	756.25	0	30.6	
I	688.65	67.6	36.8	426
II	621.55	67.1	42.9	849 (423)
III	549.25	72.3	49.6	1305 (456)
IV	484.75	64.5	55.5	1711 (406)
V	399.5	85.2	63.3	2248 (537)
VI	314.35	85.2	71.1	2785 (537)

Table 2 - Percentage extraction at various stages of extraction

7.6. Advantages of the angled pocket method

- More conservative method in terms of inexperienced workforce.
- The core of the pillar stays intact and instead of shifting the load to the sides of the pillar, the load stays in the centre of the pillar and is gradually increased due to reduction of pillar size.
- Less scaling of ribsides reducing the chance of CM being pinched on the first lift and increased safety to workforce.
- Higher productivity through higher equipment utilization and increased production time. Less tramming and time lost due to changing out of machinery.

- Improved CM safety during the extraction process.
- The CM does not enter the pillar completely and recovery in case of the CM being buried is easier.
- More protection for CM in terms of a goaf overrun. A solid pillar is always close by.
- Higher production because CM changes out less and cuts are made at an angle instead of being perpendicular bringing the production cost down.
- Less bolting at the face required once depillaring commences. Bolting can be focused on installing breakerlines and intersection support ahead of the depillaring action.
- Crushing of the pillars with a gradual convergence instead of cyclic loading associated with caving at irregular intervals.
- CM operator and cable handler are never inside the pillar
- Fewer personnel at the face
- No additional breakerlines once the pillar is being extracted in comparison with method 1, cut 3 when a breakerline must be set.

7.7. Disadvantages of the angled pocket method

- Workforce unfamiliar with method and partially inexperienced with pillar extraction in general
- In theory or on plan, less coal is being extracted.
- More than one pillar is being worked at a time weakening the pillar and allowing micro fracturing to develop. This is similar to method 1 but due to the larger core area of the pillar in method 2 it is more stable
- Back to back cuts (Christmas tree), overlapping cuts into the pillar create additional large intersections.
- Large additional intersections that requires systematic support
- Larger core of pillar being left behind and areas with less cover load will tend not to crush the pillar and the goaf might be delayed and a possibility of undersized pillars failing collectively causing airblasts.

7.8. Alternative considerations for the angled pocket method

Cut number 1 can be made at 45º which will increase the percentage extraction and increase the size of the snook left behind on the lower left-hand corner of the pillar as shown in Figure 25. This larger snook will increase the intersection stability. The sharper angle of cut will also decrease the overlap between cut no. 1 and 2 thus have a smaller intersection span.

Cut no. 6 can be moved down slightly to stagger cut no. 5 and 6 and provide more protection especially for the cable handler. The CM operator and cable handler must now be careful of the intersection and avoid at all cost standing in the intersection when cut no. 6 is made.
The operator of the CM can lift the cutting head of the CM inside the pillar to maximize the extraction but only on cut no.'s 1, 3 and 5. This increased height will assist in reducing the w:h ratio of the snooks and expedite the caving process. Care should be taken on cut 3 and 4 as the snooks are already at a w:h ratio of 1 or less.

8. BEST PRACTICE

With pillar extraction, one does not have the benefit of being protected by steel canopies as with other high extraction methods. In pillar extraction, discipline, the quality of the roof support and the orderliness of development are the substitutes for powered support.

The workforce should be kept to the bare minimum. No loitering must be allowed in the line, up to three roads back from the face line. No person should be allowed inbye of the last line of solid pillars except for the Supervisor, CM operator and cable handler.

Due to the excessive loads on the frontline pillars, together with the cleating and discontinuities, scaling and spalling on pillar sidewalls will increase dramatically. When walking down a roadway, stay in the middle of the roadway. Do not sit or stand next to the rib sides.

Avoid intersections at all times. They become one of the most dangerous places in the section during pillar extraction, especially if the corners have been cut away. When the picks on the cutting drum are changed, keep clear of the intersections and do not park the CM in the intersection. The same applies for maintenance, oil filling and shift changes.

Take note of installed roof monitoring instrumentation and what they are indicating. Log and report any movement indicated by the telltales. Take regular measurements with the sonic extensometer in the back areas and not on the frontline pillars. Stay clear of instrumentation installed in intersections on the front line pillars.

Install breakerlines and additional support in existing and planned intersections ahead of depillaring commencement. If depillaring commences and the systematic support in the pre-developed roadways is found to be inadequate, there is not much spare capacity in the Quadbolter to install additional support. Thus, the systematic support should be installed to the required density on development, including all overcut roadways and intersections. If no breakerlines are installed, production should be stopped until all breakerlines are installed on the frontline pillars.

Because of the 3.3m cutting head width on the CM, a 5.5m or 6.6m roadway is cut employing a two-lift system. When pillar extraction is done, always take the first lift, closest to the goaf side. On the second lift, evaluate conditions and if necessary take the second lift so that a metre or two of coal web is between the first and second lift.

It is difficult and time consuming to make perpendicular cuts with a CM thus during extraction keep perpendicular cuts to a minimum.

The CM operator and cable handler are the two people most exposed. They should always stand in a safe place, out of the way of the spalling ribsides, moving shuttle cars and in such a position to be able to see what the goaf is doing.

A mine layout plan showing the actual size of pillars, intersections and roadways should be drawn up to highlight high risk areas and where additional support might be required. All poor roof, roof falls, ribside spalling, geological discontinuities and unsupported or under supported areas be added to the plan. The pillars must be assigned a sequential number and the proposed pillar extraction layout overlain on this.

The first two rows of pillars to be extracted, on level 24 and level 23, should be extracted to the maximum to enable a wide enough span for the initiation of the caving process.

Visual inspections of subsidence on surface can give an indication of caving characteristics. The position and condition of cracks on surface will show that complete caving is taking place and in relation to the underground workings. The toppling of the overburden will show horizontal displacement instead of vertical displacement on surface cracks.

9. CONCLUSIONS AND RECOMMENDATIONS

1. The risks involved with a depillaring operation in Anjan Hill, zero seam are substantial as with any depillaring operation around the world. Depillaring by continuous miner is more hazardous than conventional bord and pillar development. It is an unfamiliar method to more than half the personnel that will be involved in the extraction process. It will therefore require risk assessments and training in the proposed method with a good understanding from every person involved. A high level of awareness in combination with strict operational controls and risk assessments on a continuous basis, will be required to make it a safe and successful operation.

2. It is difficult to predict the conditions that will be encountered with any degree of certainty. However, based on the available information it is anticipated that:

    - The immediate roof of the Zero seam is weak and consists of interbedded coal and mudstones up to the cored height of 5m. As the immediate roof consists of weak material, roof falls are likely to occur as sections of the pillar are extracted rather than on completion of the whole pillar.

    - The combination of a thick, weak immediate roof and high discontinuity frequency will create caving up to the sandstone beam almost immediately upon removal of each pillar. Depending on the degree of weathering and jointing on the sandstone beam affecting its competence, the sandstone will tend to hang up and transfer the weight of the remaining overburden onto the pillars.

    - A soft loading system is expected making the goaf more prone to be violent due to the shallowness in relation to the wide panel width and relative weak immediate roof. The presence of discontinuities throughout the area, although assisting the caving, will further contribute to the soft loading system. If the sandstone higher up in the strata is competent and stays up it will improve the stiffness of the system and the caving will become more controlled.

3. Experience of de-pillaring with continuous miners in South Africa demonstrates that rapid mining and speedy reaction to changing conditions are required for the safe and successful operation of the system.

4. One of the two de-pillaring methods described in section 7 should be adopted at Anjan Hill.

5. Training and supervision should be put in place. It is suggested that a strata control training course be drawn up and presented to all operators, crew, artisans and supervisory staff. Basic principals need to be reinforced. An experienced rock mechanics engineer should be on-site for the start of the de-pillaring operation to evaluate the pillar and goaf behaviour and make necessary changes to the system.

6. Prior to starting de-pillaring the area should be assessed and additional support placed in areas where this is required. Breakerlines and additional support in existing and planned intersections should be installed ahead of de-pillaring commencement. Where the intersections are oversize (say larger than 65m2) they should be identified and clearly marked on a plan. Additional support must be placed in these intersections, especially on the corners. Areas where no or inadequate support has been installed must be clearly identified, documented and pre-supported.

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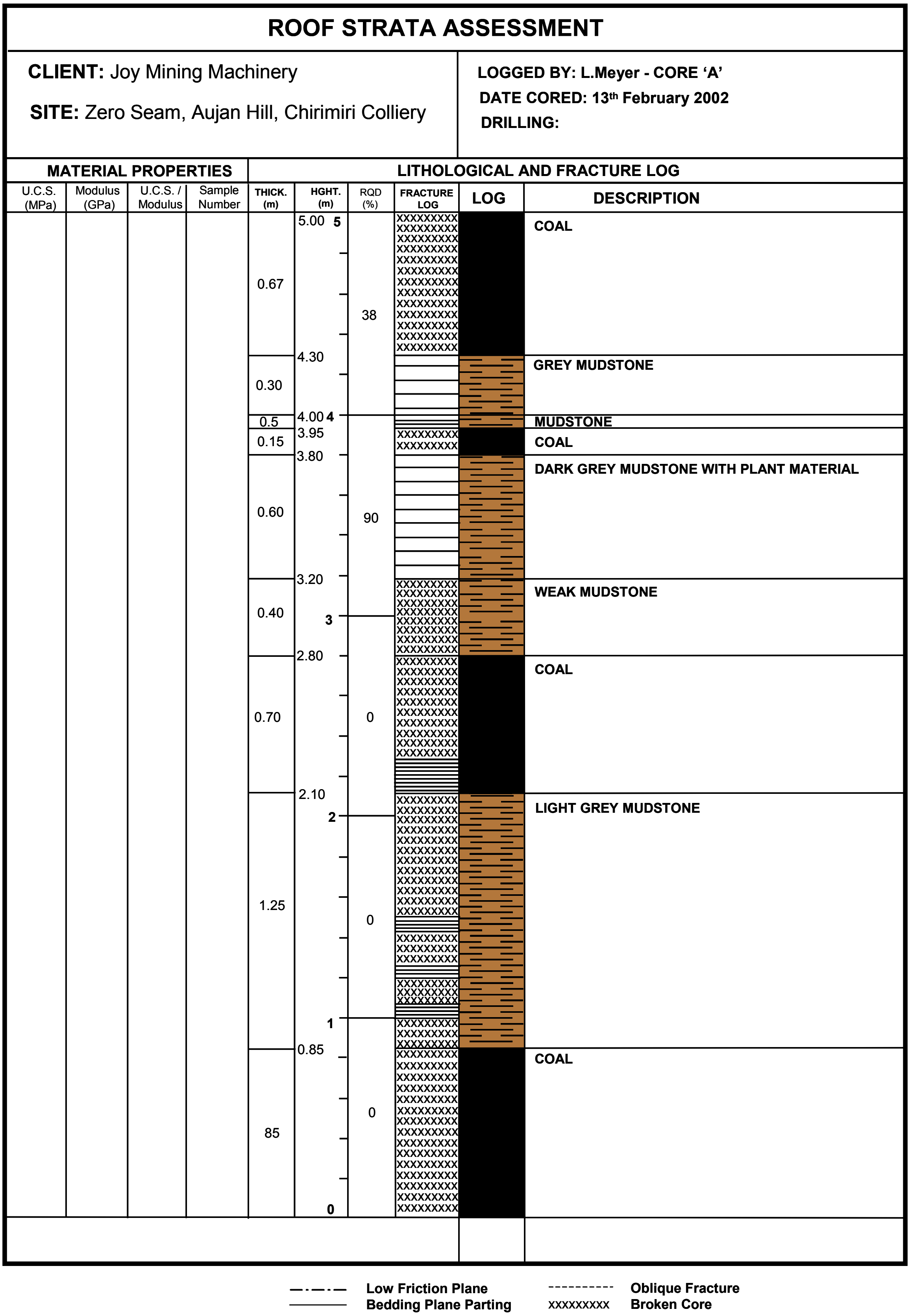

Figure 1 – Immediate roof lithology, core A

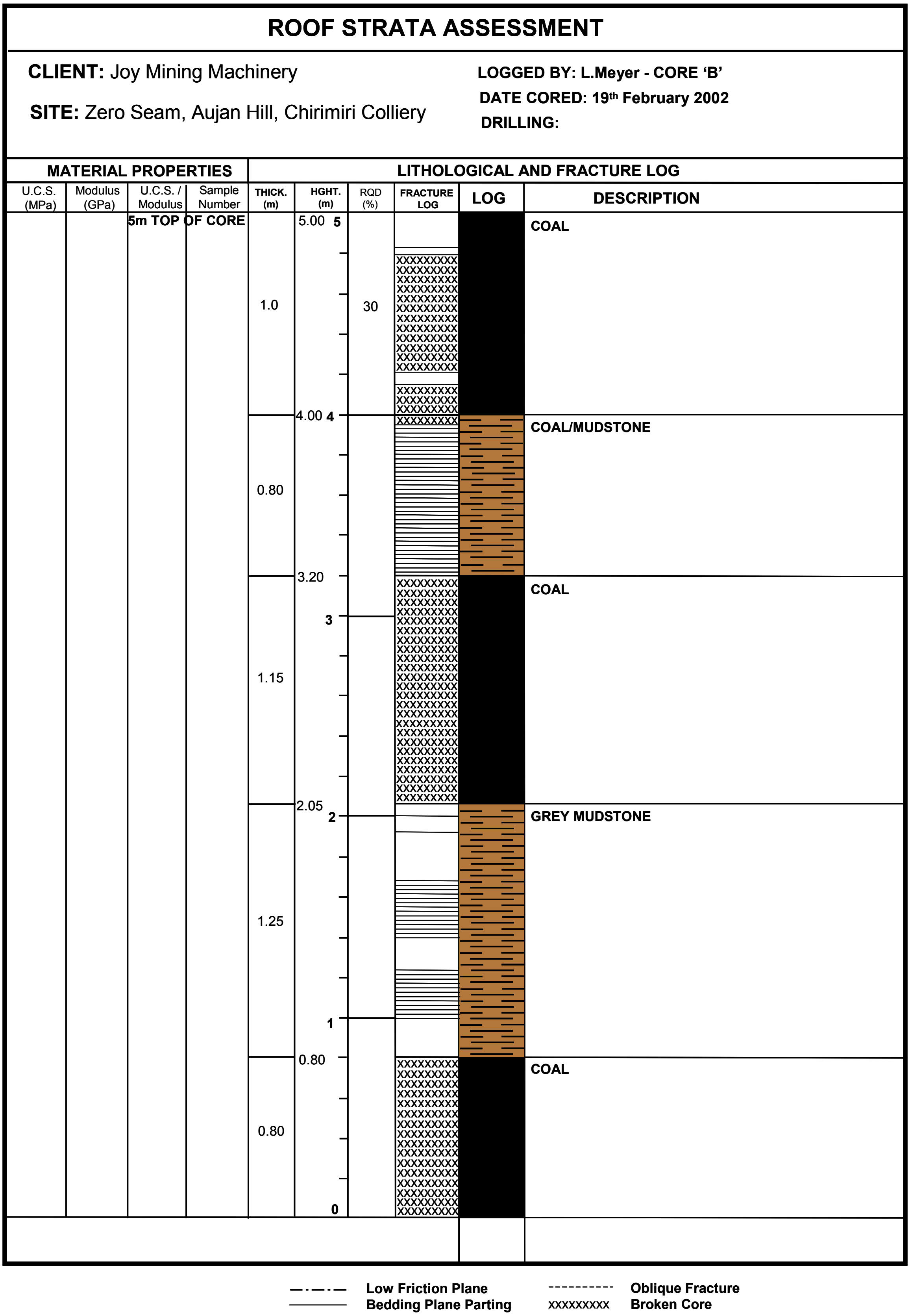

Figure 2 – Immediate roof lithology, core B

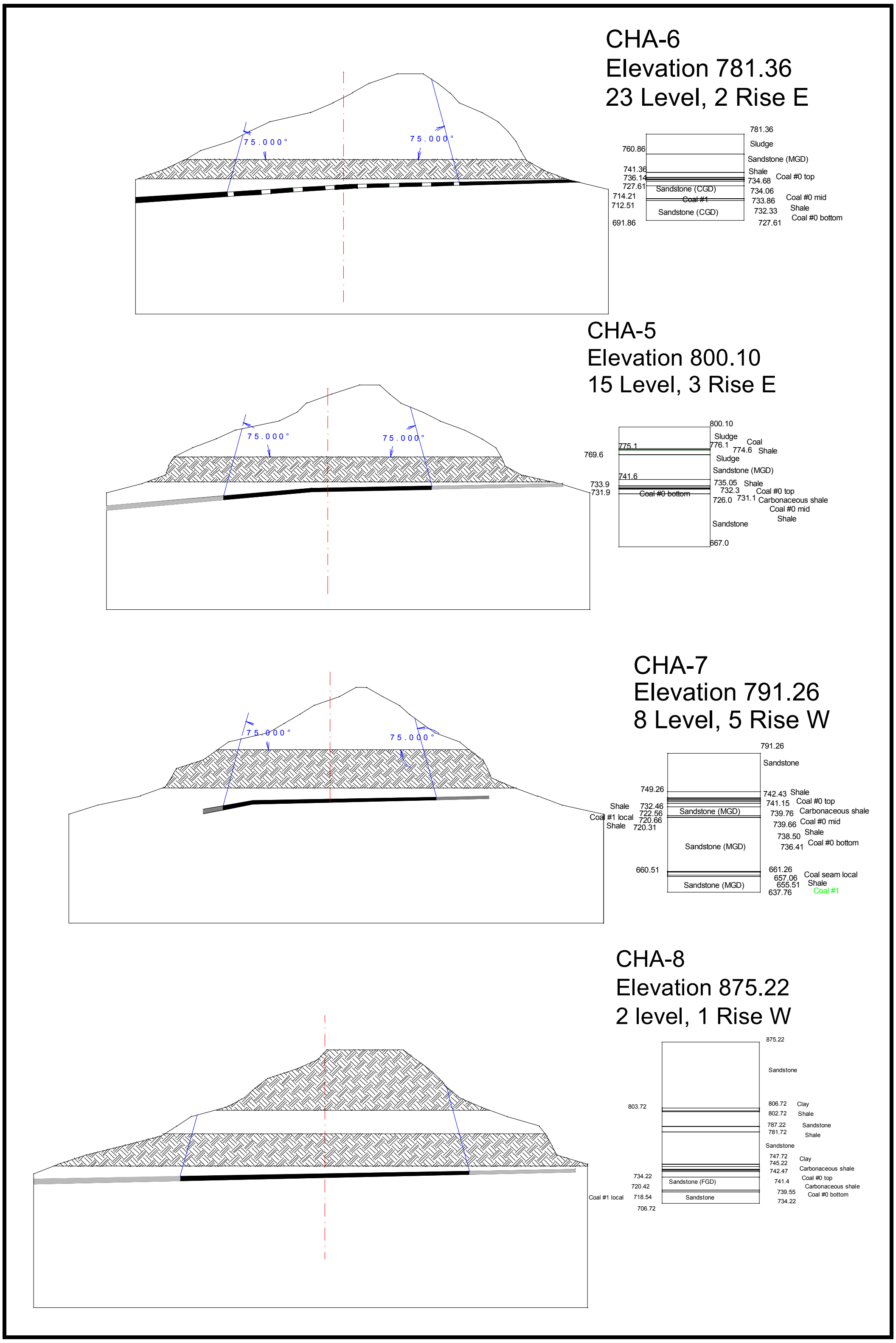

Figure 3 – North/South contour profile in relation to Zero seam workings and sandstone in the upper strata

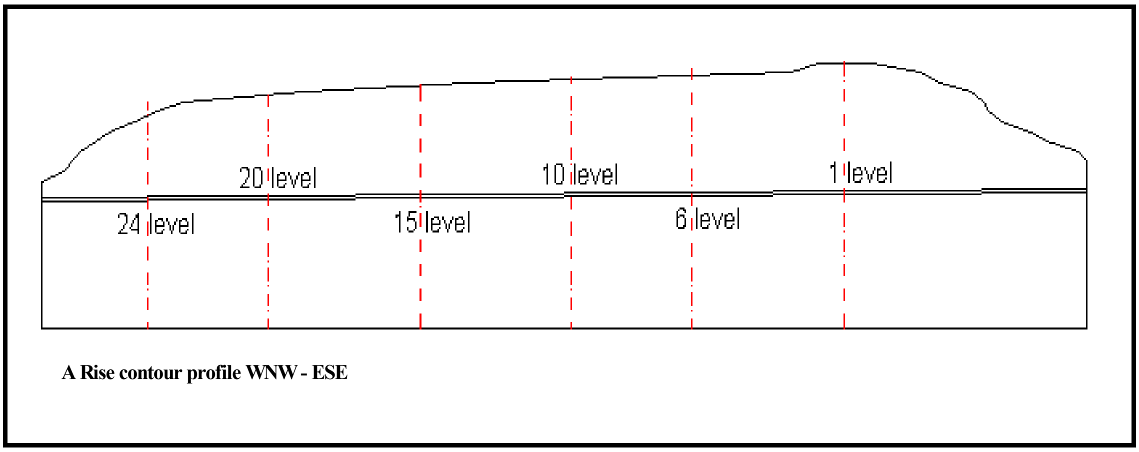

Figure 4 – East/West contour profile in relation to Zero seam workings

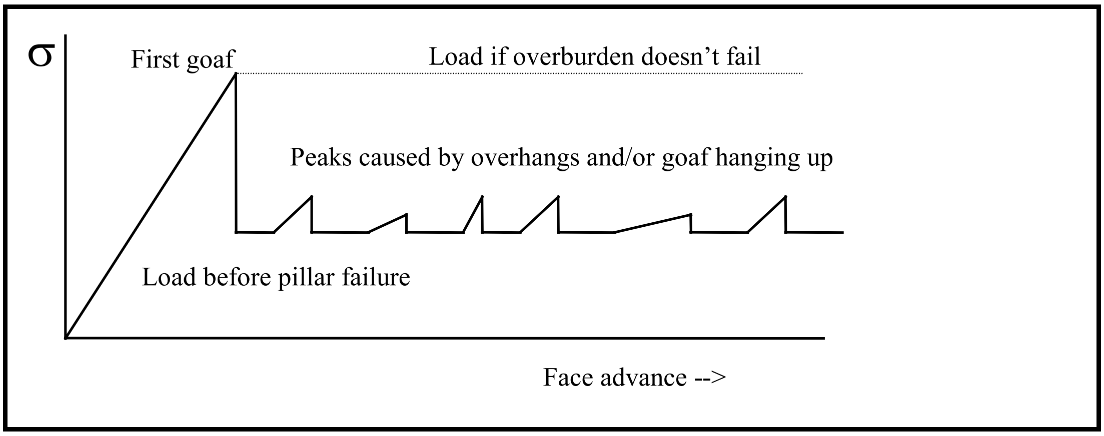

Figure 5. Vertical load on pillars during pillar extraction (v. d. Merwe, 1997)

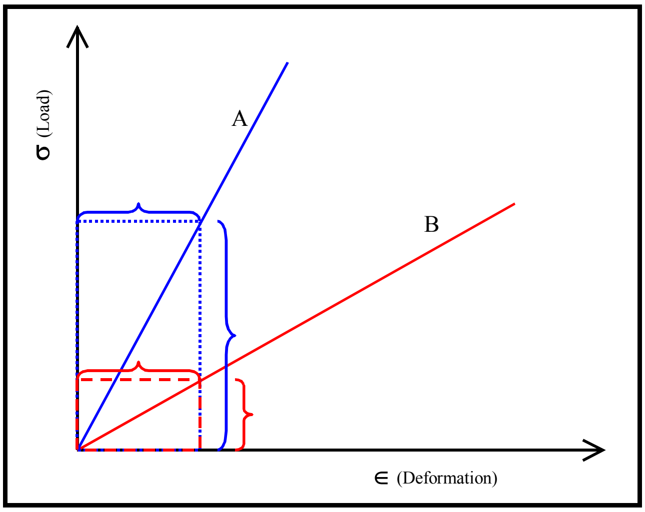

Figure 6 – The stiffness concept

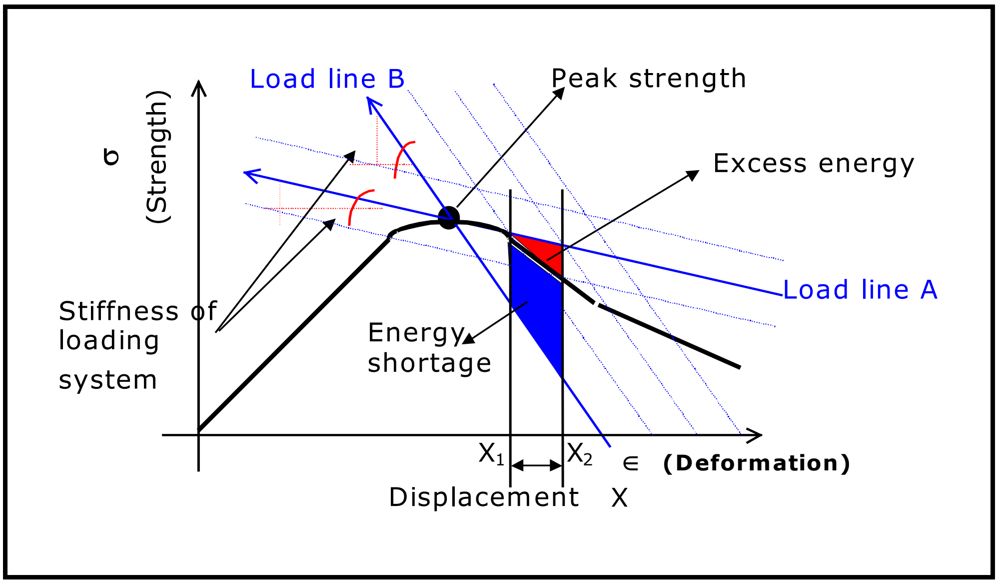

Figure 7 – Influence of varying loading system stiffness

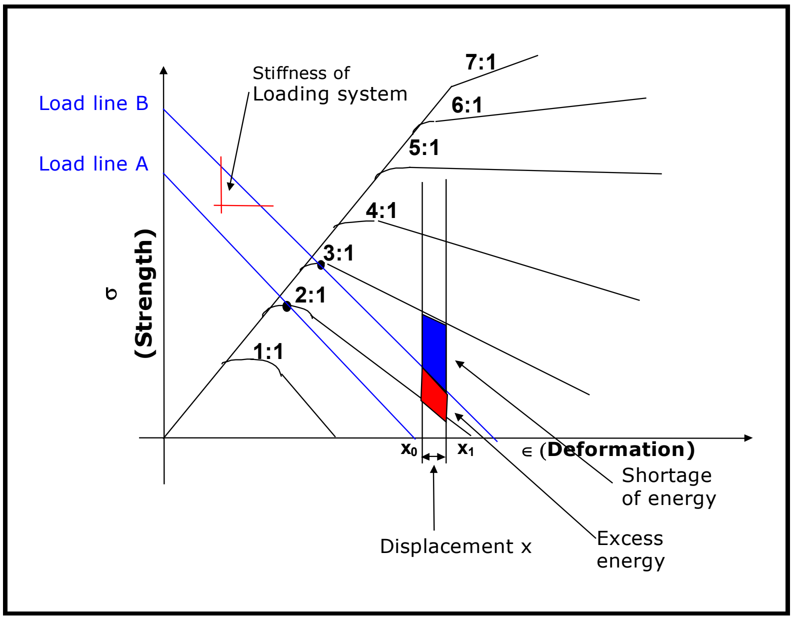

Figure 8 – Influence of w:h on pillar post peak stiffness

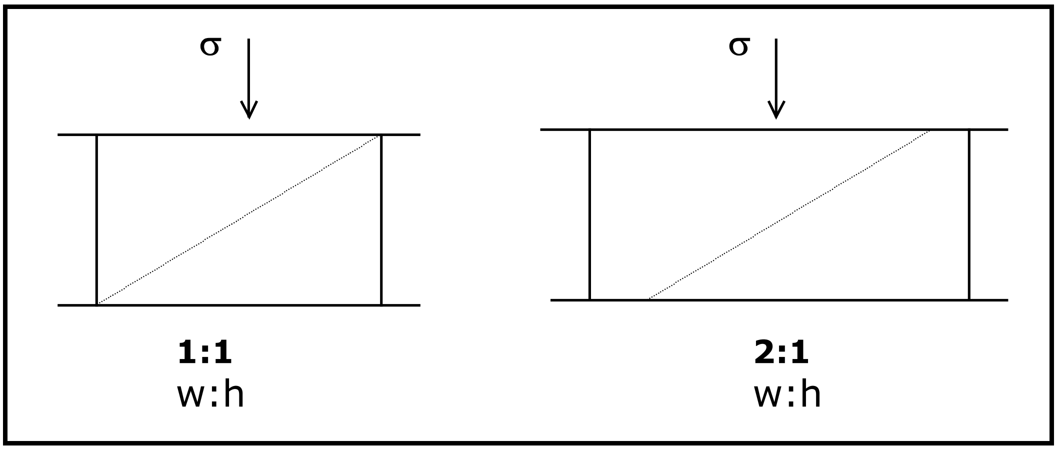

Figure 9 – Containment of discontinuities in pillars

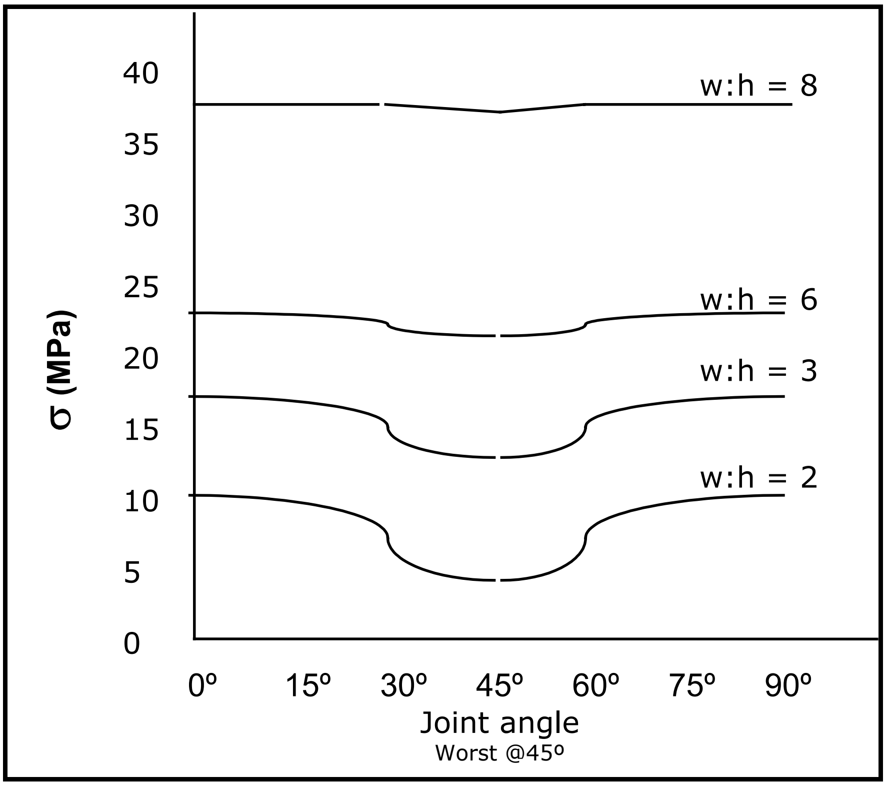

Figure 10 – Confinement of discontinuities on larger pillars

Figure 11 A & B – Roofbolts acting as a caving breakerline in A and no breakerline at all in B, (Madden, 1989)

Figure 12 – Effectiveness of a roofbolt breakerline, (v. d. Merwe & Madden, 2002)

Figure 13 - Timber props acting as only convergence indicators, (Madden, 1989)

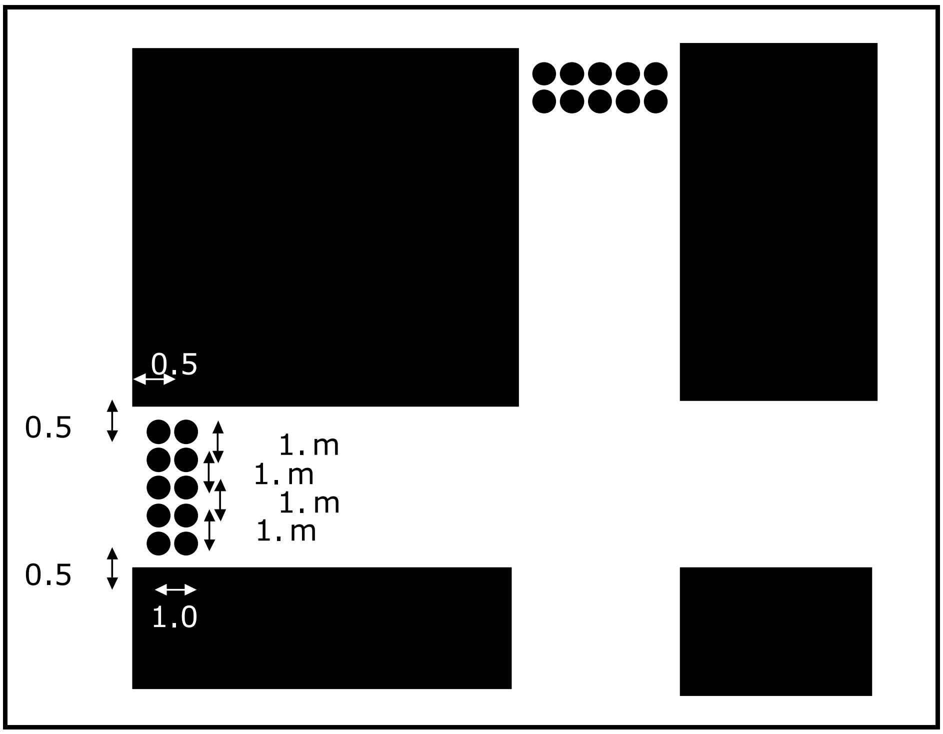

Figure 14 – Roofbolt breakerline dimensions

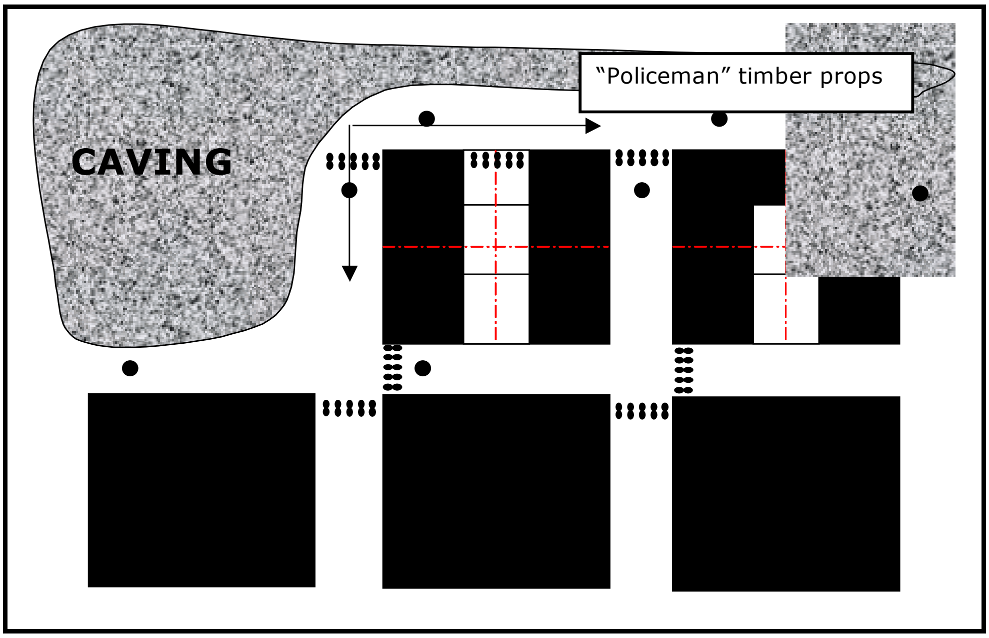

Figure 15 – Timber prop positions

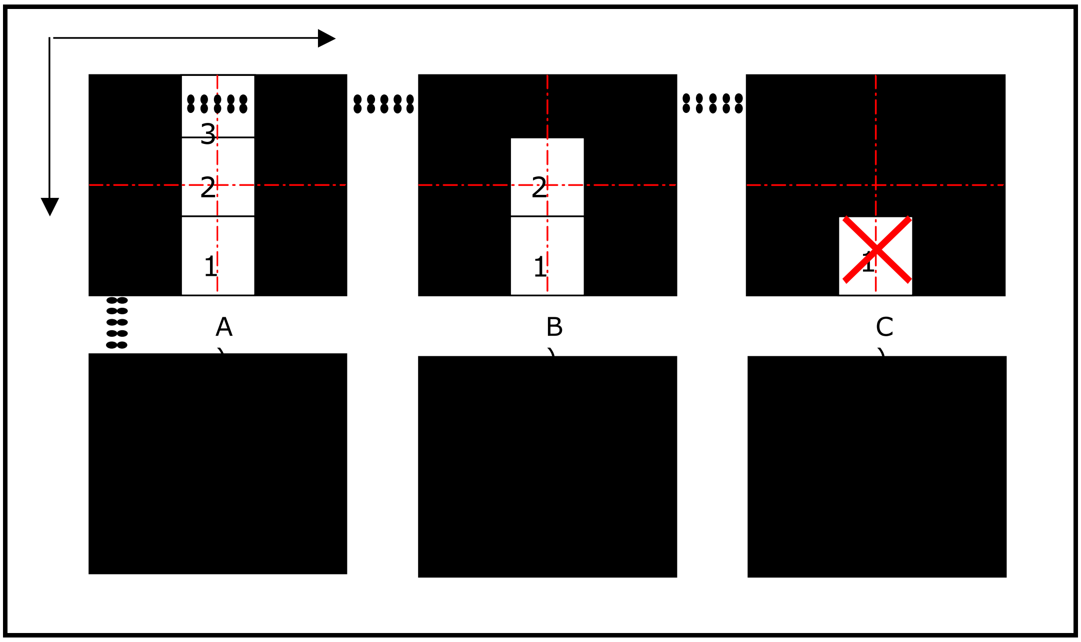

Figure 16 – Depillaring sequence, method 1, step 1

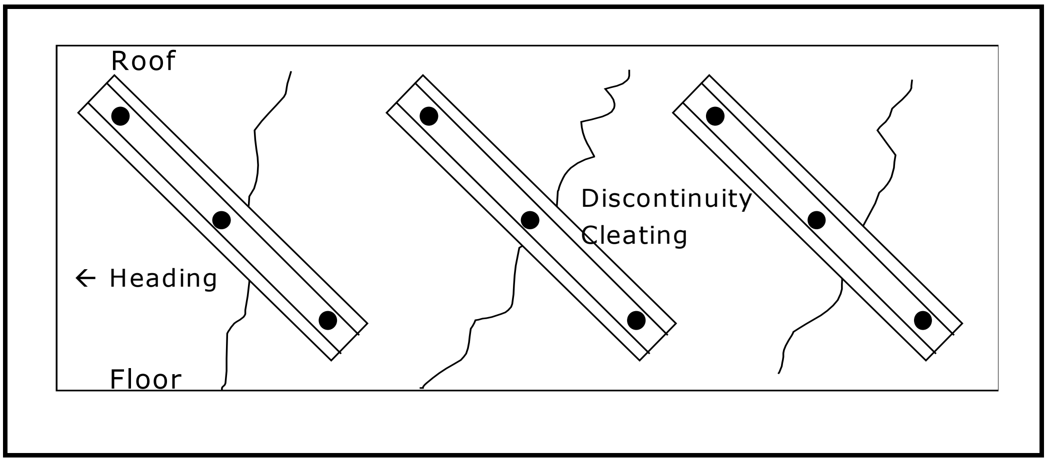

Figure 17 – Rib support

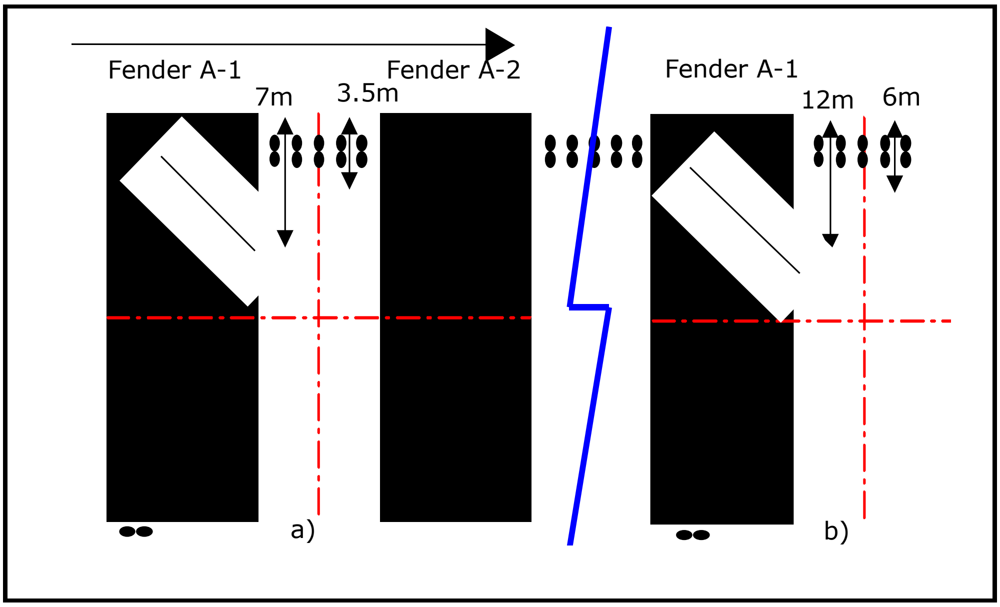

Figure 18 - Depillaring sequence, method 1, step 2

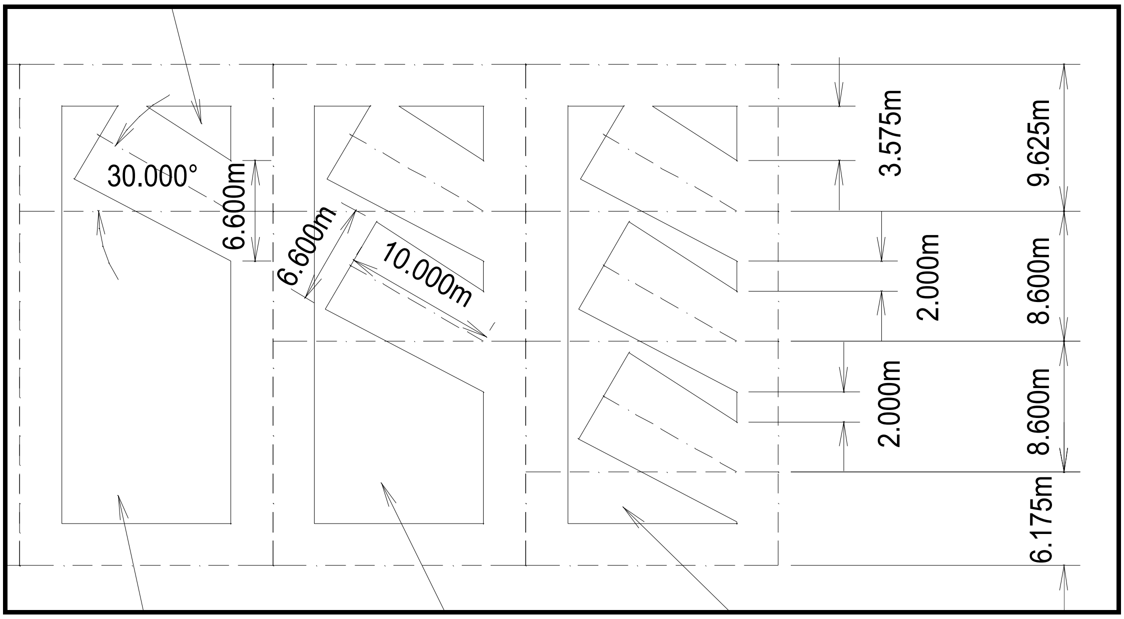

Figure 19 – Sequential cuts into the fender with dimensions, method 1, steps 2-4

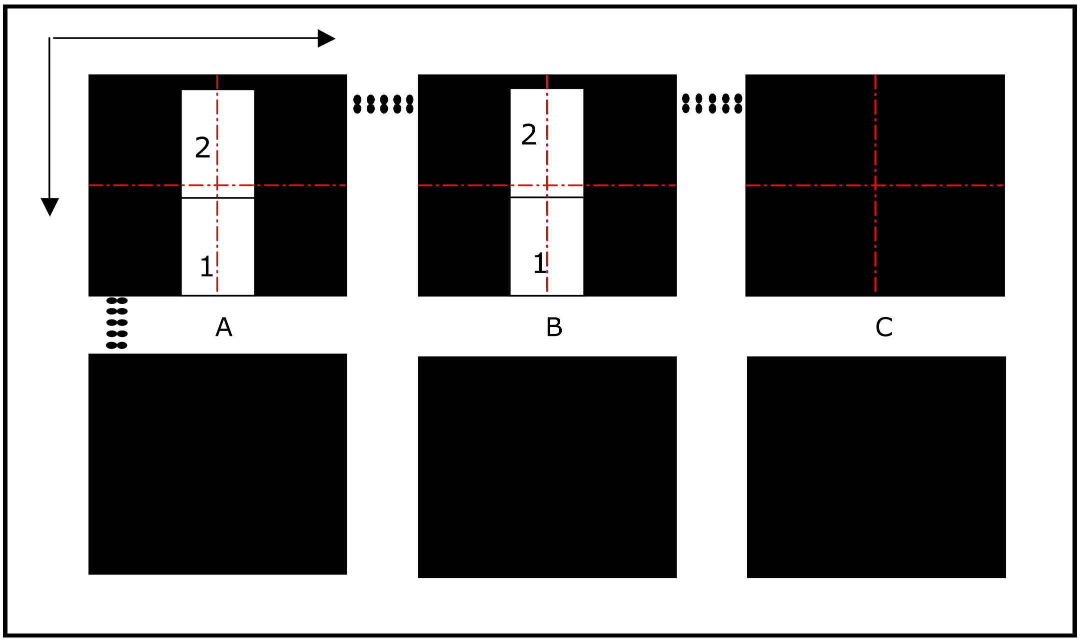

Figure 20 – Modification to depillaring sequence, method 1, step 1

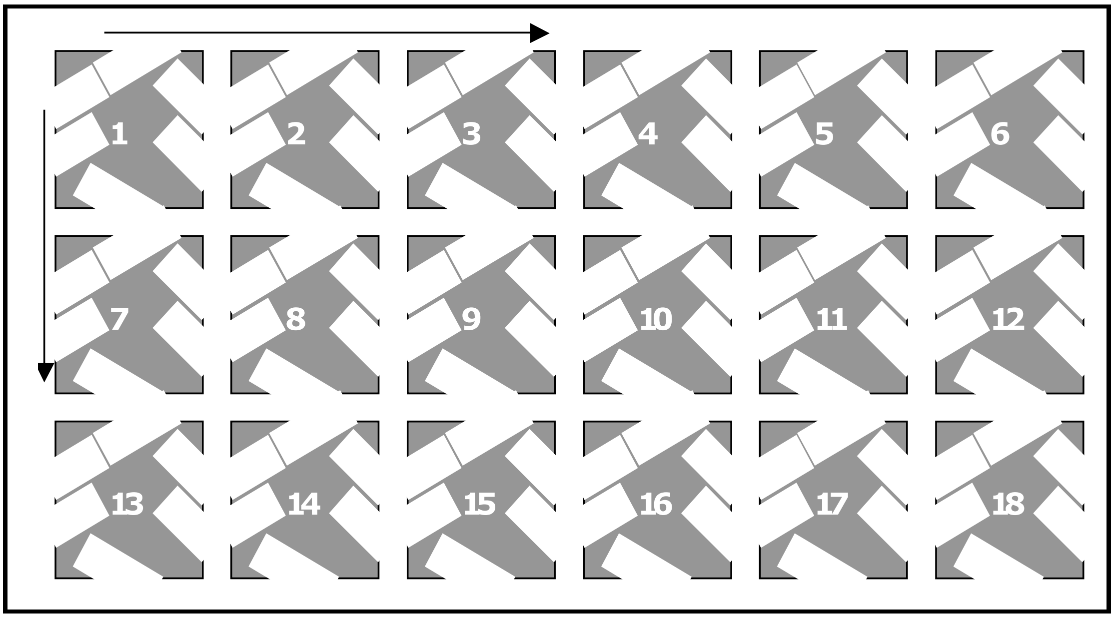

Figure 21 – Pillar layout for angled pocket method

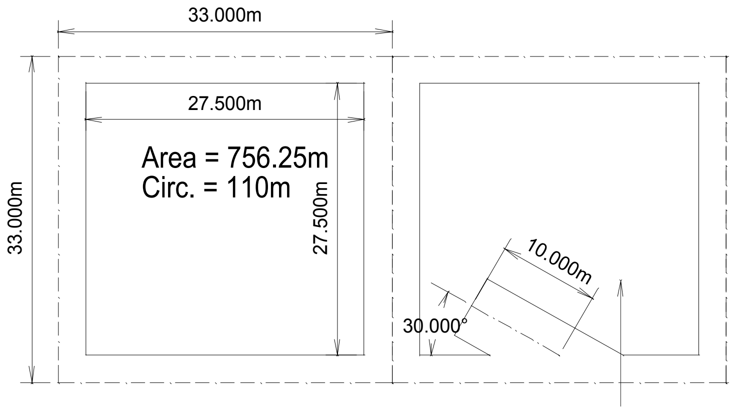

Figure 22 – Pillar dimensions at start of sequence

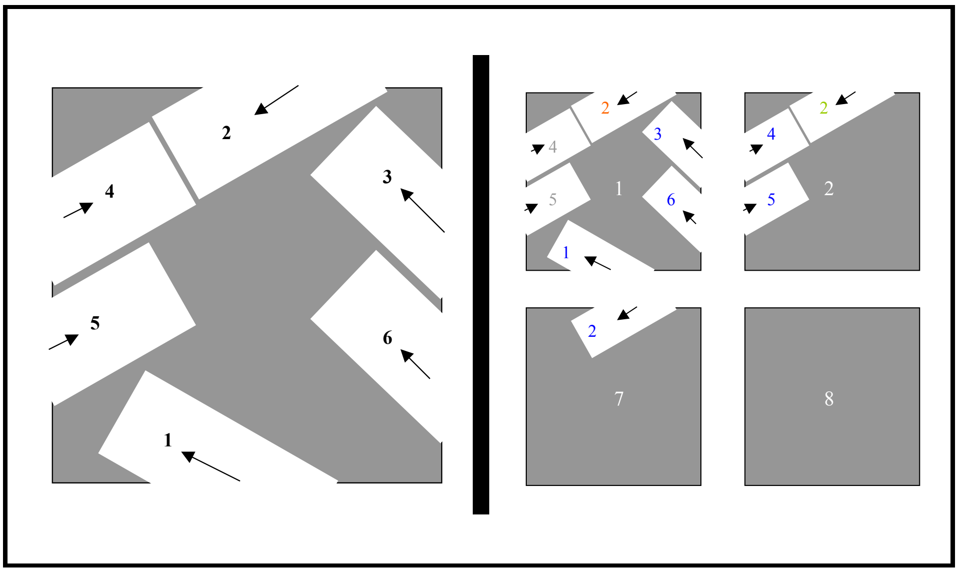

Figure 23 – The cutting sequence for each pillar

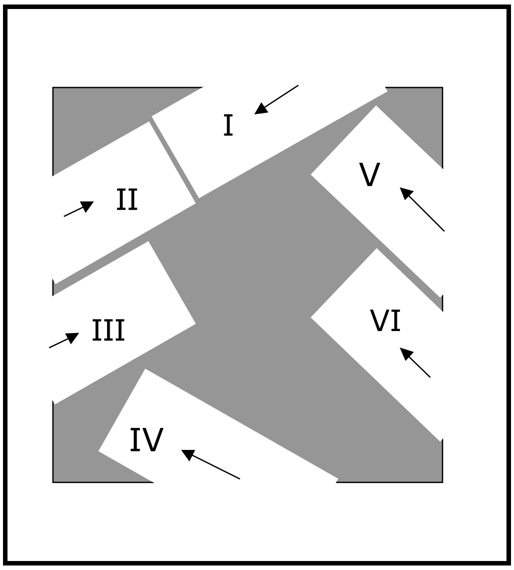

Figure 24 – Cutting sequence renumbered for calculation purposes

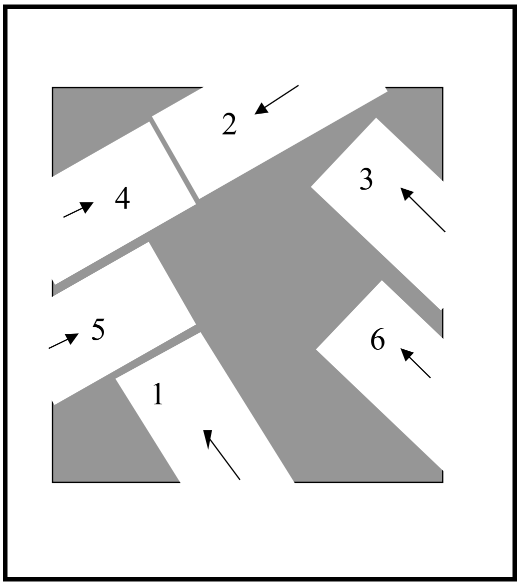

Figure 25 – Angled pocket method alternative