Pillar Design Aspect in UK Deep Coal Mining, Possibilities and Limitations

Derin Koşullardaki ingiliz Kömür. Madenciliğinde Topukların Tasarımı, Olasılıklar ve Sınırlamalar

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ABSTRACT

This paper introduces basic concepts of coal pillar behaviour in relation **to** pillar **geometry and cover load with an emphasis on pillars** in **deep** UK coal mining conditions. **A Windows based computer package** is developed capable of dealing with multiple **openings in square, rectangular and rib pillar** combinations with a longwall abutment **along one side. Results from the model are** compared in context to other recognised **techniques and UK deep coal mining conditions.**

ÖZET

Bu çalışmada, kömür topuklarının jeo-mekanik davranışları üzerine temel **kavramlar** İngiliz **derin** yeraltı kömür madenciliğinin koşulları (topuk geometrileri ve **arazi yükleri) göz önünde** bulundurularak tartışılmıştır. Kömür topuklarının **boyutlandırılması amacı ile** Windows çalışma ortamına uyumlu bir bilgisayar paket **programı** geliştirilmiştir. **Program,** değişik topuk geometrileri (kare, dikdörtgen ve **şerit şeklindeki),** tekli ve/veya çoklu taban yolları düzenlerindeki uzunayaklar için **gerekli topuk** genişlikleri üzerine boyutlandırma ve stabilité analizleri **yapabilmektedir. Programdan** ve diğer metodlardan elde edilen sonuçlar **karşılaştırılmış, İngiliz** derin yeraltı kömür madenciliği şartları için gerekli topuk **geometrileri üzerine** öneriler sunulmuştur.

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1. INTRODUCTION

In the highly competitive UK. energy sector potential methods of improving productivity and efficiency in coal mining operations have taken on an increasingly important role. The mining conditions encountered in the UK make it vital that before application of new or imported mining techniques a thorough technical evaluation takes place.

The current coal clearance systems utilising single gate roads can limit production capacity. A number of options are open to relieve this problem. The first is to change the number of gateroads located each side of the longwall panel (i.e. utilise multiple-entry gateroads), the second is to abandon the current longwall mining method and to employ a conventional room and pillar mining method. However, high vertical stresses due to the considerable depth is likely to cause roadway instability problems which may impede coal production where particularly weak or highly fractured strata conditions exist. All the important parameters related to the roadway stability and the potential productivity should be considered carefully before the selection of either of these approaches to increasing production

The design of pillars plays a crucial role in the stability of coal workings in longwall mining as well as room and pillar mining. A successful design is the key to both safety and economy. Therefore, particular attention should be given to the design of the pillars, whichever mining systems is used. This paper assesses both new approaches concentrating upon the stability of pillars within potential layouts.

1.1. Alternative methods of mining

The use of a room and pillar mining method under deep coal mining conditions may be considered as an attractive alternative to the conventional longwall mining method. The application of the method in shallow coal mining has showed that rapid, flexible and effective mining can easily be accomplished by means of continuous miners. This method hgs the additional advantage of much lower capital investment in equipment and development. However, the application of room and pillar mining in deep coal mines requires relatively big pillars to accommodate the high vertical loads that can be anticipated. The results of leaving large pillars would be as follows:

- low overall extraction rate,
- large working areas required,
- coal transport could be difficult due to extent of workings,
- support and maintenance of extensive areas could be expensive.

The use of multiple entry gate roadway systems for longwall mining looks a more practical proposition. The advantages of the longwall method at depth are maintained but **increased coal** clearance becomes a possibility. The use of special pillar configurations **(yield-abutment,** yield-abutment-yield) may also overcome some of the notential stability **problems that might be anticipated with pillars** at **depth.**

Since the main aim is to determine the most appropriate method of mining for deep UK coal mining conditions, the above methods are compared in terms of maximum coal recovery and stability requirements.

2. BACKGROUND

The efficiency and safety in either room and pillar, or longwaH mining is highly dependent upon the stability and the size of pillars employed. Effective design of pillars in coal mines involves determining their dimensions according to the expected load history, taking into account geomechanical characteristics of the coal and the surrounding strata. A number of important parameters should be considered when designing pillars. These are

- pre-mining and mining induced-abutment stresses,
- pillar strength and stiffness,
- Interaction between the roof, floor and the pillar.

Pillars are generally classified according to their stability characteristics. Thèse are as follows:

- Abutment pillars (stiff pillars)
- Critical pillars (semi-stiff pillars)
- Yielding pillars
  1 Stable yielding pillars
  2. Unstable yielding pillars

Abutment pillar: This type of pillar is capable of accommodating development loads and additional transferred loads during the service life of working areas without yielding or transferring any significant part of the load. They also need a sufficient width of unyielded core so that stresses are smoothly transferred into the floor without causing any adverse effect (i.e. preventing floor failure). This type of pillar is the essential backbone of the entire mine support system. If they fail, catastrophic and widespread collapse of the mine is inevitable.

Critical pillar: This pillar failure mode occurs where the roof and more particularly the floor conditions are unfavourable. The mechanism is that insufficient width of elastic core remains during the pillar loading, this elastic core transfers highly concentrated stresses into floor strata causing them to yield. As a result, yielding of floor initiates beneath the pillar and gradually develops towards the roadway which suffers from a considerable amount of floor heave and convergence. The critical pillar size should be avoided at all costs by either widening or narrowing the pillar. This case is very similar to footing problems in soil mechanics.

Yielding pillar: A stable yielding pillar can be defined as a pillar which **can sustain** some part of the load being imposed on it and transfer any excess **load** without **loosing its** overall integrity and residual load bearing capacity. It is not necessary **that these pillars** should always have small dimensions but they **are generally designed narrow to maximise**

coal recovery. Any yielding pillar may loose its integrity during loading and/or by spalhng from the ribs thus gradually reducing its original dimensions. Under such conditions a stable yielding pillar can become an unstable yielding pillar and rapidly and totally collapse. To avoid this condition, side meshing in conjunction with rib or cable bolting should be considered.

2.1. Pillar Stress

Stresses imposed on pillars in room and pillar mining have generally been calculated using the tributary area concept. Although the method does not give an exact result, it is relatively simple and generally reliable enough for many cases. The main weakness of this method is that it assumes uniform stress distribution over the pillars. Stress distribution in reality, however, is not uniform over the pillars. The shape of roadways surrounding the pillars have a significant affect on secondary stress distribution around ribside regions. These areas are vulnerable to higher stresses and yielding initiates from the ribside through towards the pillar centre in a progressive manner. This kind of yielding is attributed to pillars with moderate and soft coal, or other weak sedimentary rocks. High strength and brittle rock types generally fail in a rapid or a violent manner (i.e. pillar bump). In this case, the pillar yielding would be sudden rather than progressive.

It is well known that the stress concentration moving away from the roadway reduces considerably. However, simultaneously, the mean stress on a pillar increases due to progressive yielding of the material near the roadway (i.e. effective pillar area is reduced). Although the initial stress distribution is highly dependent upon the roadway shape, yielding of near ribside areas and the decrease of effective pillar area brings about a high but uniform stress distribution in the centre of pillars. Stress measurements carried out in roadways, have shown that the vertical stresses have a lower value in the fractured ribside areas but gradually increase deep into the pillar (2).

Load distribution in pillars and the mechanism of pillar failure was first rationally explained by Wilson (3) in which he stated that when a pillar is first developed an initial yield zone is established around rib whose extent is dependent upon the coal strength, the depth of the pillar and the condition of the roof and floor. The peak stress is encountered at the yield-elastic boundary. If the pillar is wide enough to have a considerable amount of elastic core then the stresses would drop off towards the pillar centre. The yield zone confines the inner elastic core by means of friction developed towards the inner core. This hypothesis was then modified by Barron (4) and revised later by the same author (5). According to Barron , at low confining pressures brittle fracture occurs. This is generally observed in laboratory specimens or pillar ribs. At high confining pressures, on the other hand, the failure mode becomes pseudo-ductile yielding. Barron states that the necessary confinement for this type of yielding can be generated m pillars with large width to height ratios. As a result of this, three distinct zones may form during pillar loading these being a fractured zone, a yielding zone and an intact core

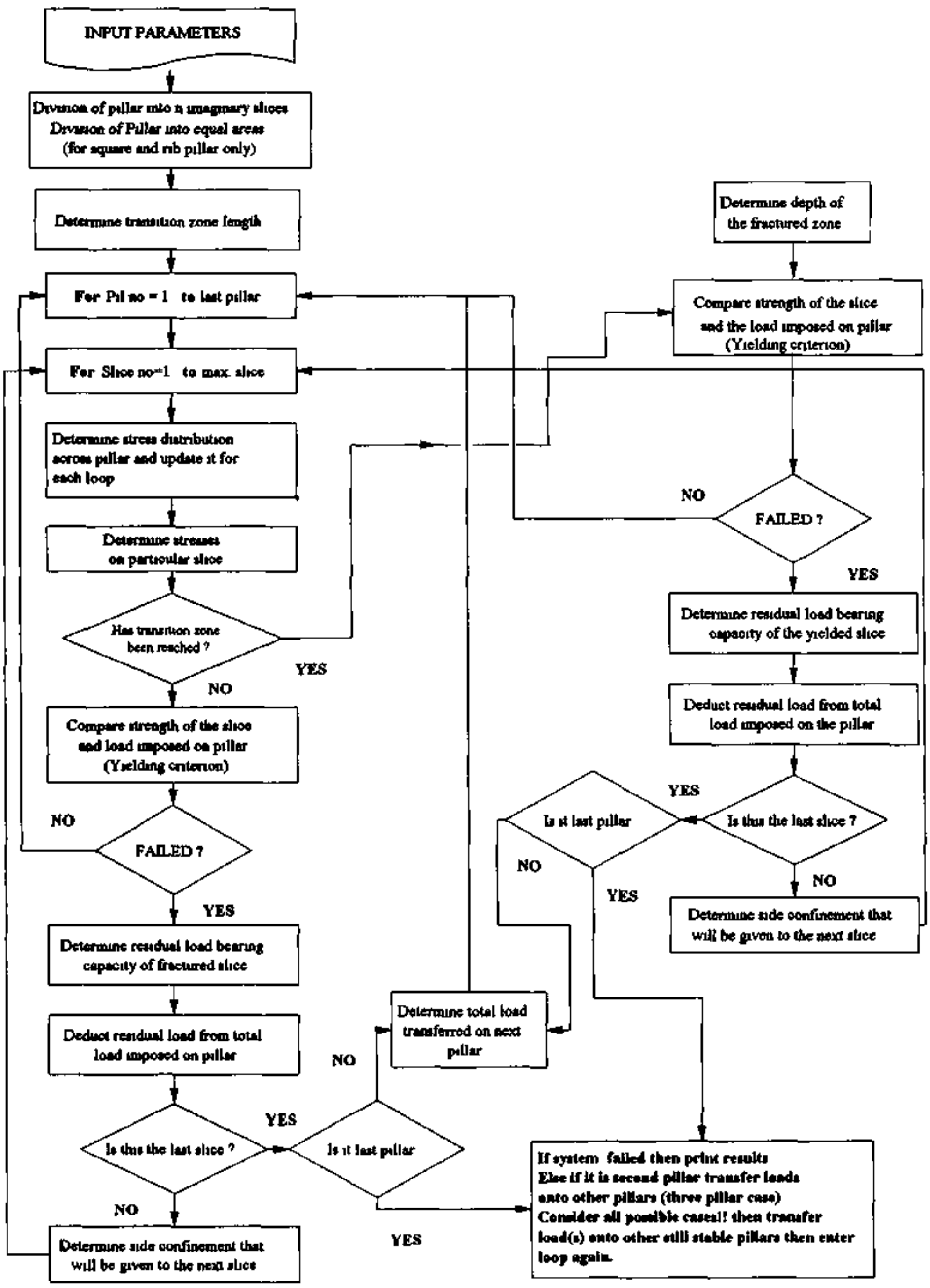


Figure 1 *Simplified flow diagram of the program (longwall mining)*

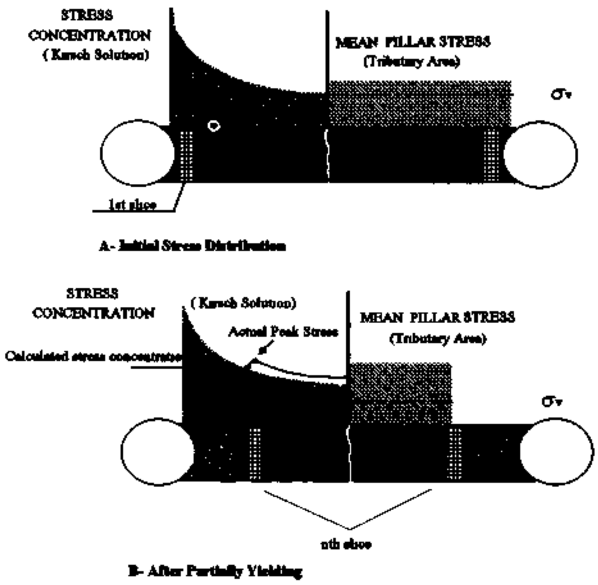


Figure 2 *Stress distribution at midheight of the pillar during pillar loading.*

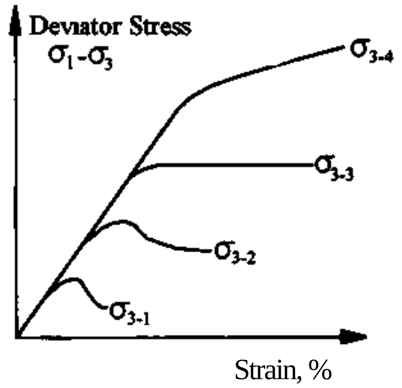


Figure 3 *Stress-Stram curves with various confining pressure.*

The behaviour of rock specimens under tnaxial testing have shown that failure modes are dependent upon the degree of confinement given to the rock specimen during loading (Figure 3).

At low confining pressures (03.1 and 03.2), under an axial stress increment, the shear stress and shear resistance of the rock both increase until the specimen fractures. After fracture, the normal stress continues to act on the fractured surface and produces frictional resistance. As a result of this, the peak stress level at the point of fracture drops to the residual stress level and deformation continues by frictional shding on the fracture surface.

At an intermediate level of confinement (03.3), shear resistance to fracture becomes just equal to shding on the fractured surface. Consequently, there is no drop from the peak strength to a residual level and large deformations can take place with a minimum increase or without increase of axial stress. This type of deformation is termed as pseudo-ductile and, should be kept separated from ductile deformation which can be caused by brittle behaviour followed by shding on the fracture surface.

At high confinement (03.4), the frictional resistance to shding exceeds the shear resistance to fracture. Therefore, the development of new fractures becomes easier than inducing displacement along the existing fractures.

It is postulated that the pseudo-ductile type of failure can occur in coal within a range of confining pressures underground (5). The point of transition between brittle failure and pseudo-ductile yielding is accepted as the intersection of the peak stress determined by a failure criterion and the residual strength criterion (Figure 4, S). In the program, two different failure criteria have been utilised to determine the peak stress. The Hoek-Brown criterion for intact or jointed rock and the Coulomb-Navier failure criterion is utilised for the residual stress.

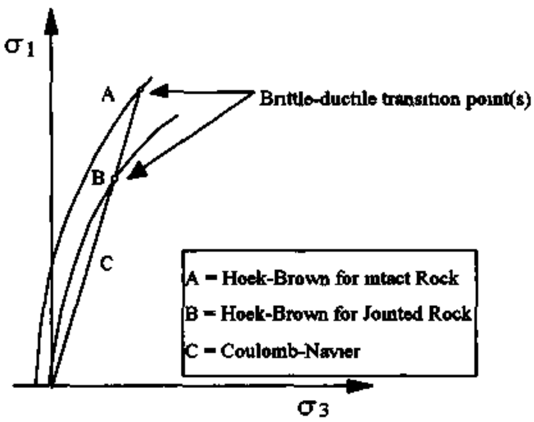


Figure 4 *Brittle-Ductile transition points for intact and jointed rock.*

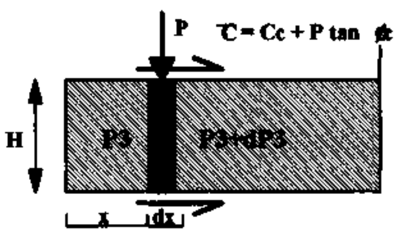


Figure 5 *Forces acting on a slice m fracture zone.*

3. DEVELOPMENT OF TWO DIMENSIONAL LIMIT EQUILIBRIUM SOLUTION

3.1. Computer program (Pil-Sta)

Pil-Sta (Pillar Design for Stability) is a Windows based program which is written in the Visual Basic programming language. It is capable of investigating the stability of pillars in room and pillar mining (single pillar analysis) and longwall raining (single square,- single rib, multiple square shaped chain pillars, rib-chain pillar combinations). Square, rectangular and rib pillars in any selected width and length can be analysed. Solutions are based on the application of the limit equilibrium method taking into account some important features related to coal strength characteristics as well as other actors such as depth, stress condition, room width and panel width. Some details concerning the theory and the method of solution are given below.

3.2. Outline of the model

The program (Pil - Sta) has been developed to investigate pillar stability for longwall and room and pillar mining layouts. The limit equilibrium method used, works by taking the model pillar and dividing it into a number of imaginary slices and then developing force and/or stress equilibrium conditions for each slice in turn until an equilibrium or complete failure condition is reached. The method has previously been applied for stability analysis of individual pillars in room and pillar mining by Barron (4). The original solution which was first suggested by Barron (4, 5), was followed for the development of Pil-Sta. Some modifications were made by the auttorsto simulate pillar analyses for longwall mining. Â new failure criterion was also introduced in the program (ie. Modified Hoek-Brown failure criterion for jointed rock masses. Hoek (6)). The previous version of the Hoek-Brown (7) failure criterion for intact rock is included as an alternative option. A simplified flow diagram for the longwall mining pillar case program is shown in Figure 1. The program is relevant where strong or moderately strong roof-floor conditions exist. Model pillars are assumed to be homogeneous and composed of weak to moderately strong coal.

Pil-Sta calculates vertical stresses according to the tributary area concept and the Kirsch solutions which calculate stress concentrations around elastic circular openings. The effect of other roadways is also taken into account using the principle of stress superimposition. In the program, the mean pillar stress is first obtained from the tributary area and then compared to the stress calculated from the Kirsch solution for each slice. The stress distribution at the midheight of the pillar is taken into account and continuously updated during the execution of the program. Finally, the maximum vertical stress calculated from one of these methods is accepted (Figure 2). This method is only followed for the analysis of square and rectangular pillars in the room and pillar mining version of the program. In longwall mining cases, however, the tributary area concept is used throughout to determine mean vertical stresses on square and/or rib pillars.

3.3. Determination of Side Abutment Loads

In conventional room and pillar mining, pillars only carry cover load and additional load that is transferred due to yielding of neighbour pillars. In longwall mining operations, however, abutment loads are created during the extraction of longwall panels. These loads are simultaneously transferred onto side pillars. Therefore, the longwall pillar system must be capable of accommodating these loads within safety limits. The side abutment load acting upon pillars in a longwall panel could be estimated by two approaches suggested by UK strata control researchers (King and Whrttaker (8), Wilson (9)). The second approach was also adopted to determine side abutment loads on chain pillars by Carr and Wilson (10). The second approach has been found satisfactory and has been used to determine the side abutment load in the program (Figure 6). Longwall side pillars (i.e. chain pillars and/or abutment pillar) must carry the cover load and the abutment load imposed on them. During the panel extraction, if one of the pillars yields, it transfers its part of the load onto the neighbouring pillars. In this case, the neighbouring pillars are responsible to carry their own load, phis additional load transferred from other pillar(s). This load transferring mechanism is also considered in the development of the program.

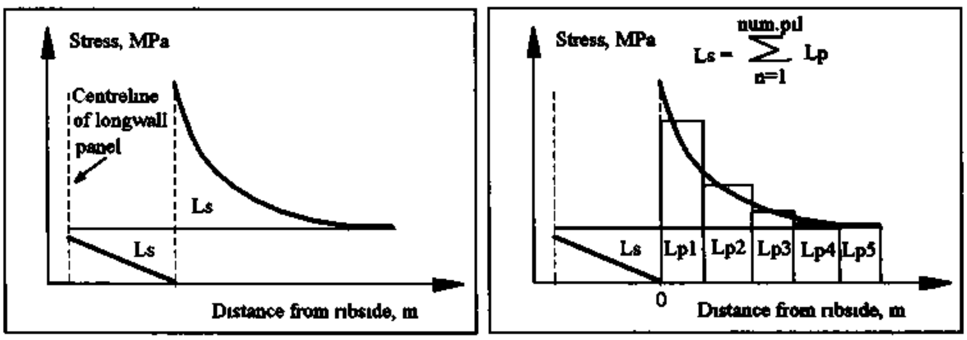


Figure 6 *Determination of side abutment load applied on pillars*

3.4. Comparison with conventional pillar formulas

Figure 7 and Figure 8 show the comparison of the predicted pillar widths for longwall and room and pillar mining situations calculated from various formulas in terms of overburden depth by Peng (11). Using the same input data, <u>minimum</u> pillar sizes suggested by Pil-Sta were also calculated and shown in the same figures. Hoek-Brown failure criterion for intact rock has been used as a yielding criterion for coal for the calculations. According to the results, Pil-Sta suggests smaller width pillars for longwall panels than that from other pillar formulas. Wilson's pillar formulas for longwall panels give similar trends to Pil-Sta. Although a similar trend is also observed for the room and pillar mining case, Pil-Sta suggests larger size pillars than Wilson's strong roof-floor pillar formula.

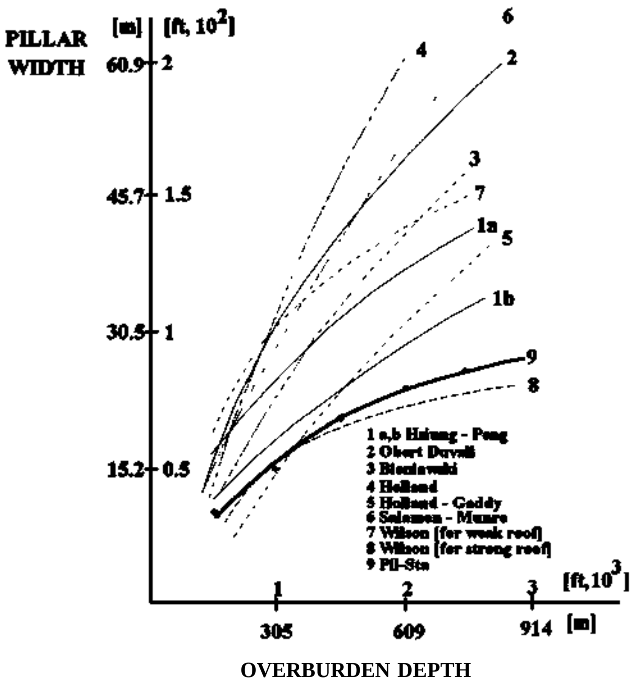


Figure 7 *Comparison of suggested pillar widths for longwall pillars in terms of overburden depth.*

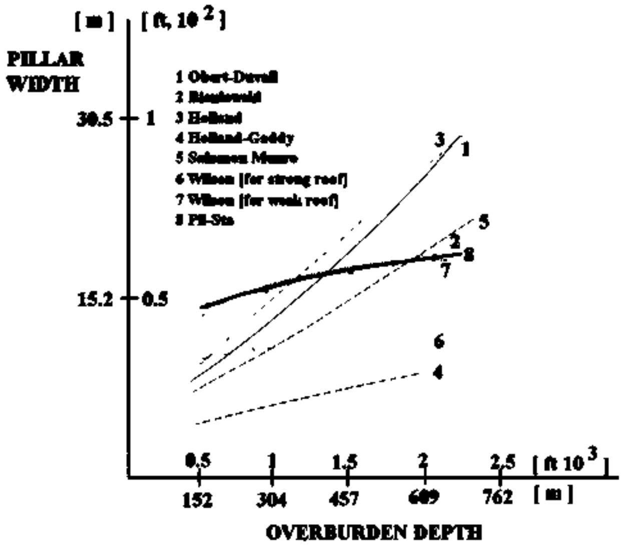


Figure 8 *Comparison of suggested pillar widths for room and pillar mining in terms of overburden depth.*

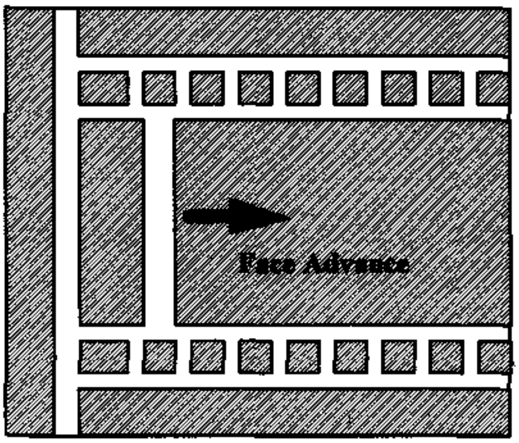
As previously mentioned, the program was developed to analyse pillars where strong or moderately strong roof-floor conditions exist. In soft roof and/or floor strata conditions, however, confinement which is offered by the roof and floor, would be minimal or even negative, and this may cause pillars to yield by tensile rather than compressive failure. Similar types of yielding could also be observed where coal pillars contain thick clay band(s) parallel to the roof and the floor, hi these cases, non-linear finite or distinct element methods would give more reliable predictions.

4. PILLAR DESIGN CONSIDERATIONS FOR DEEP COAL MINING

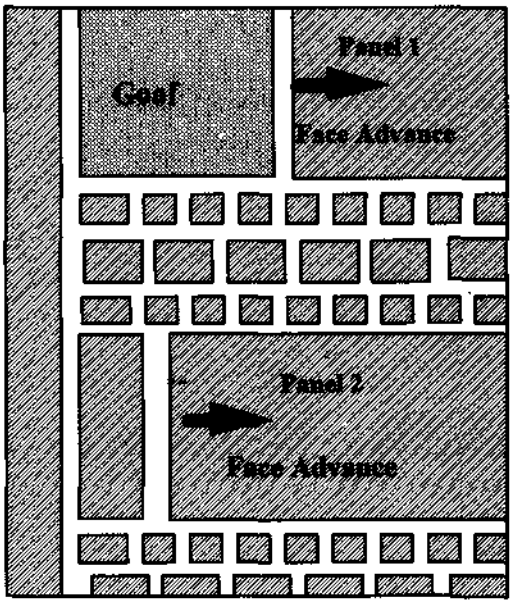
At shallower depths (i.e. 100 ~ 300 m), pillars are subjected to considerably lower stresses which make easier to the application of various types of mining methods. In spite of the generation of horizontal stresses that could help some degree of strata failure due to confinement, a major constraint to design pillars at great depth is the high vertical stresses due to overburden depth. This is relevant to particularly deep coal mining because of the weak nature of the coal and coal bearing strata. Considering the UK coal mining operations which take place at depths around 800 m, the vertical stress due to overburden depth is expected to be around 20 MPa. Therefore, minimum pillar dimensions for a square pillars for room and pillar mining should not be less then 30-35 m in order to preserve safe working conditions. This would yield an approximately 30% extraction rate. On the other hand, under sizing pillars at this depth could easily cause a domino effect with multiple pillar failures posing a serious risk to the mines safety. Furthermore, the size of working panels would be large in area because of leaving large pillars for support. This would in turn bring about increased support costs as well as coal and material transportation costs.

Multiple-entry layouts offer a better alternative to room and pillar mining. Possible mine layouts that could be employed with this method, are shown in the Figure 9. The size of pillars using this method would vary depending upon the combination of the pillars (ie. yield-abutment, yield-abutment-yield, or equal size pillars). The application of the method with yielding pillars in some deep coal mines in the USA has also shown that the degree of floor heave can also be reduced using this mining method as opposed to conventional longwall mining (1).

The applicability of the method for UK deep coal mining is simply dependent upon the sizes of pillars that should be left between the gate entries in order to ensure safe working conditions. Therefore, the computer program (Pil-Sta)has been employed to determine minimum pillar dimensions with various pillar combinations. Modified Hoek-Brown failure criterion for fractured rock has been used as a yielding criterion for coal during the calculations. Although only square and rib pillars were used in the analyses, rectangular pillars are believed to yield similar trends to the results obtained by the application of square pillars. The results of the analyses are illustrated in Figure 10 and Figure 11. According to the results of the analyses, the following conclusions can be drawn:



a- Twin entry Yield-Abutment pillar configuration



b- Multiple entry Yield-Abutment-Yield pillar configuration

Figure 9 *Panel layouts (for longwall mining with multiple-entry gate roads)*

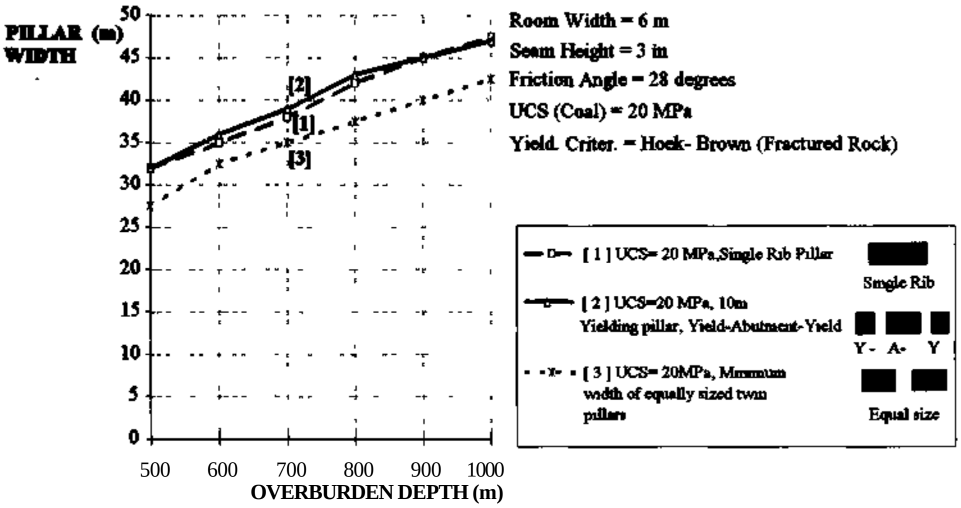


Figure 10 *Overburden depth vs. required pillar widths for different pillar configurations*

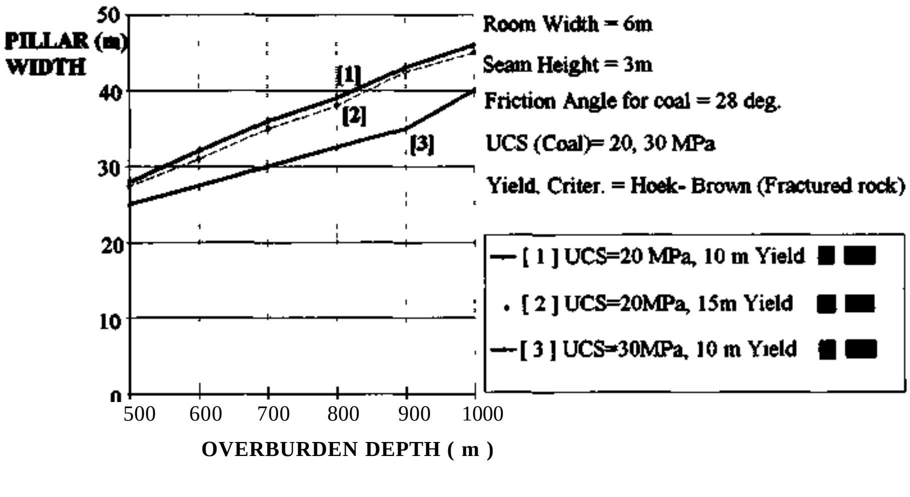


Figure 1 1 *Required pillar widths for various Yield-A butment pillar configurations*

• The residual load carrying capacity of a pillar after partially or totally yielding directly related to the width of pillar and the formation of the zones inside the pillar. If the pillar yielding is due to complete fracture, residual load carrying capacity ofthat pillar would be minimum. On the other hand, if the pillar width is selected large enough to build a confined zone inside the pillar (Le. formation of yielding zone within a pillar), the load carrying capacity of a pillar after total or partial failure would still be maintained in a reasonable level Therefore, while most of the pillar load is transferred on the neighbouring pillars in die former case, little or no load transfer is expected in the latter. Leaving equal sized pillars (e.g. pillars in room and pillar mining) requires that each individual pillar must be capable of carrying its own load without transferring any excess part of it. Otherwise, neighbouring pillars would suffer from the additional loads, and this may cause domino type pillar failures. Therefore, the 'yield-abutment' or 'yield-abutment-yield' pillar systems which are composed of one large (abutment) and one or two small size (yielding) square pillars offer better stability conditions than two equally sized square pillars. According to the Figure 11, the minimum width of each square pillar should be at least 37.5 m in order to not the transfer any excess load onto the neighbouring pillars. On the other hand, the total disintegration of a pillar is not expected, if the pillar width is more than 20-25 m. Hence, undersizing square pillars may cause severe instability problems in gateroads such as roof and/or floor failure due to the excessive vertical stresses.

•The main duty of yielding pillars is to give support to immediate roof which may be fractured and/or detached from the main roof, to maintain safe working conditions. These pillars are not expected to carry the total overburden load. The yielding pillars, however, should be designed in a way that in spite of complete yielding, the integrity of a pillar is still maintained throughout the life of service roadways. Therefore, considering the similar mining conditions, the required abutment pillar width for "Yield-Abutment-Yield' pillar configuration is nearby the same for a single rib (or abutment) pillar left between two longwall panels. Moreover, the Yield-Abutment-Yield pillar configuration offers more gateroads than that of the single pillar case. Yielding pillars, however, may need additional supports such as cable or rib bolting to prevent spalling from the pillar sides in order to maintain its original dimensions.

• As can be seen in the Figure 11, increasing the yielding pillar width from 10 to 15 m results in only a small change in terms of required abutment pillar width for the same depth. However, it is better to design this pillars as small as possible to avoid driving longer crosscuts. Furthermore, instead of designing yielding pillars, there is a possibility of designing critical pillars that may cause floor stability problems (Le. floor heave).

The overall results of the analyses proved that the longwall mining with mum-entry gate roads is a more suitable mining technique for deep coal mining conditions than room and pillar mining, if the objectives are to improve coal production with a high percentage extraction rate while maintaining safe working conditions.

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