Analysis for pillar extraction potential (A-PEP)—a risk-based program for underground coal mining

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Research into the safe and economic extraction of underground coal pillars in the Witbank and Highveld coalfields of South Africa highlighted that future practices will have to consider pertinent risks associated with this least safe of all underground coal mining methods conducted in South Africa. To this end, a computer-based program called A-PEP (Analysis for Pillar Extraction Potential) was developed to assess three aspects of this mining practice, viz. risks associated with the physical attributes, operational risk attributes and economic attributes. This intelligent tool can thus be used when planning to conduct underground pillar extraction to ensure that all pertinent risk elements and legislative requirements are considered to conduct this mining method safely before a submission is made to the Department of Minerals and Energy.

Keywords: operational risk management, mine planning, underground coal mining, pillar extraction.

Introduction

The completion of recent research1,2 into the safe and economic extraction of coal pillars in the Witbank and Highveld coalfields highlighted the need for an integrated approach to assess potential risks and hazards associated with the highly dangerous underground pillar extraction mining method. A design methodology3, considering elements of local and international importance relevant to underground pillar extraction mining, presented a structured framework from which to consider the most common dangers of the mining method. Figure 1 shows the elements of the design methodology, which was developed considering local and international elements of importance in considering this mining method.

The design methodology also considered the legal ramifications associated with the pillar extraction method of mining in terms of the Mine Health and Safety Act (Act 29 of 1996). However, it was found that the design methodology, as shown in Figure 1, only addresses some of the legal aspects and that a more integrated approach was needed to achieve a higher level of confidence in designing a pillar extraction panel.

The analysis for pillar extraction potential (A-PEP) planning tool

Having identified critical risk factors through the design methodology shown in Figure 1, a design tool for the Analysis of Pillar Extraction Potential (herein after referred to as A-PEP) was developed. A-PEP is a user-friendly, intelligent tool, which enables the potential for pillar extraction of an operation to be gauged by inputting certain physical, risk and economic factors; based on the risk work discussed above. The A-PEP design tool (for which copyright is reserved by this author and the use of which is subject to a disclaimer) calculates various output parameters based on inputs which would enable an operator to make certain preliminary decisions in terms of:

- Whether or not the potential for pillar extraction exists based on physical and risk ratings
- What type of pillar extraction (full or partial) can be conducted based on the physical and risk ratings
- What type of mining methods can be employed based on the full extraction or partial extraction recommendation and
- If pillar extraction is recommended, the economic benefit that can be achieved is calculated from additional inputs.

The A-PEP design tool could significantly contribute to the decision making process used by operators in the Witbank and Highveld areas to increase their utilization of coal resources by providing an initial indicator as to their potential to conduct pillar extraction before further investigation is warranted. A-PEP takes relevant physical parameters and couples the outputs from these with certain risk parameters to gauge the potential for pillar extraction. If a potential exists (through the overall risk rating based on 9 physical attributes and 10 operational attributes), the estimated economic benefit that could be derived from extracting these pillars is conducted through an economic analysis. A-PEP is a quick and easy to use mine planning tool that requires a minimum number of inputs which are critical to pillar extraction to arrive at a preliminary output indicator. The A-PEP design tool was derived and designed in its final format through the analysis of both a local and international literature survey, by visiting and obtaining pertinent information of both local and international underground pillar extraction operations and by conducting a risk analysis of underground pillar extraction to derive a design methodology.

Physical factors

The physical factors consider the physical attributes and the mining parameters of the original bord-and-pillar development of a coal seam that is considered for
extraction. The user will be asked a series of 9 questions which need to be inputted so as to obtain the relevant mining parameter outputs. A-PEP has been designed as an intelligent programme which considers reasonable limits to the input questions asked which are based on the research conducted. This will ensure that the outputs are meaningful to the Witbank and Highveld coalfields and that reasonable analyses can be conducted. The most notable parameters (for which high risks are attributed) are the depth below surface, the age of the pillars and the overall safety factor. The safety factor formula is based on the Salamon and Munro formula when the width-to-height ratio of the pillar dimension is less than 5, and the squat pillar formula when the width-to-height ratio is greater than 5. A-PEP recognizes that mining height has a significant impact on the health and safety of the pillar extraction mining methods and does not allow analysis where the mining height is greater than 4 metres. Figure 2 shows this output screen, using inputs from a typical pillar extraction operation in the Witbank/Highveld coalfields.

**Risk factors**

The risk factors have been designed specifically to ascertain whether or not the risk from a combination of planning and production (or operational) issues will allow an operator to conduct pillar extraction with a reasonable amount of certainty and safety. These factors have been designed citing pertinent risks and hazards from recent local and international pillar extraction experiences. There are 10 factors which have been identified as issues which are likely to influence a pillar extraction operation significantly. These factors are considered to be representative issues which could endanger the overall safety of the workplace. These 10 factors require an answer of ‘Yes’, ‘No’, or ‘Not Sure’ and are each attributed a numerical value to represent the risk. This is done by checking the relevant option for each factor in A-PEP. When these individual risk factors have been assessed, the risk numbers collectively form the total risk rating. The most pertinent factors are those relating to the undermining surface structures, whether the overlying seams are flooded or contain noxious/flammable gases and whether the roof is massive dolerite. The presence of an overlying massive dolerite (in particular) is a major health and safety risk associated with total underground extraction methods (such as longwalling and pillar extraction). This dolerite sill (which is present mainly over the Highveld coalfield) is of high strength and is able to bridge over large distances. Should the span become too large the sill will break in an uncontrolled and potentially fatal manner. A-PEP thus attaches a high risk should this sill be present and suggests that the situation be investigated further with a geotechnical expert to help facilitate better understanding into the behaviour mechanisms of the sill and thus mitigate the potential hazards associated with it. Figure 3 shows this output screen with a hypothetical scenario of an operation in the Witbank/Highveld coalfields in South Africa.

**Economic factors**

If the total risks are low based on the physical and operational risk inputs (Figures 2 and 3), A-PEP suggests the type of pillar extraction which could be conducted. If the overall risks are low, full pillar extraction is suggested and the overall tonnage available is calculated. Similarly, if the overall risks are high, partial pillar extraction is suggested and the corresponding tonnage based on this extraction technique is calculated. If the overall risks are unacceptably high, A-PEP will recommend that a specialist in the field of pillar extraction is consulted and the programme will not allow the user to continue. If A-PEP allows the user to continue (having recommended a mining method) the user will be allowed to define some of the
important economic parameters used at the specific operation in terms of the total in-section labour costs, total in-section non-labour costs as well as rehabilitation costs to calculate the potential economic benefit that could be derived from conducting pillar extraction. These would be based on the individual operations cost structures. A-PEP has however, been designed around the activity based costing technique rather than the traditional costing approach used by most South African coal mines. Figure 4 shows a hypothetical scenario of the types of costs which A-PEP considers as pertinent in evaluating the potential economic benefit that could be derived from conducting the pillar extraction.

Figure 5 shows a summary of the potential economic
benefit that could be achieved through conducting pillar extraction. In this case the summary is based on the hypothetical inputs of the preceding Figures 2, 3 and 4.

Applications of the A-PEP tool
The A-PEP tool considers issues of significant importance that would prohibit the mining practice from taking place—from the geology of the coal seam to the legal aspects associated with the mining method to the expected operating conditions, should pillar extraction be possible. All inputs into the A-PEP tool are governed by built-in checks to ensure that the inputs are within reasonable parameters as experienced by the South African coal

Figure 4. Economic outputs from A-PEP

<table>
<thead>
<tr>
<th>Overall Extraction Recommendation Based on Total Risk Rating</th>
<th>PARTIAL EXTRACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggested Mining Methods Based on the Total Risk Rating</td>
<td>Checkerboarding, Split &amp; Quarter, Partial Pillar Striping</td>
</tr>
<tr>
<td>With this recommendation, the best possible overall extraction percentage could be</td>
<td>70</td>
</tr>
<tr>
<td>Thus, the potential recoverable tonnage from the information given would be</td>
<td>153369</td>
</tr>
<tr>
<td>Risk rating for Risk Factors from information given</td>
<td>42</td>
</tr>
<tr>
<td>Risk rating for Physical Factors from information given</td>
<td>0</td>
</tr>
<tr>
<td>Total Risk Rating</td>
<td>42</td>
</tr>
<tr>
<td>Total Operating Cost Per Month</td>
<td>429331</td>
</tr>
<tr>
<td>Total Rehabilitation &amp; Capital Cost</td>
<td>178300</td>
</tr>
<tr>
<td>Total expected average production per shift</td>
<td>1750</td>
</tr>
<tr>
<td>Total expected mining life of the panel (months)</td>
<td>4</td>
</tr>
<tr>
<td>Total Expected Income Per Month</td>
<td>1500000</td>
</tr>
<tr>
<td>Total Potential Profit Per Month (Income less operating expenses)</td>
<td>879689</td>
</tr>
<tr>
<td>Total Potential Profit Over Life of Panel (less capital expenses)</td>
<td>332749</td>
</tr>
</tbody>
</table>

Figure 5. Summary of outputs from A-PEP
The tool can be used by any underground coal mining operation in the Witbank and Highveld coalfields of South Africa who wishes to assess their potential for successful pillar extraction. It is a user-friendly package which requires the minimum amount of input to obtain an assessment which is risk based and considers the legal aspects associated with this mining method. The A-PEP tool should not be used in isolation however. The health and safety of employees associated with the pillar extraction method of mining cannot be overemphasized. Even though the A-PEP tool considers planning guidelines for underground pillar extraction, the final planning should include necessary health and safety issues.

Conclusions
The increased utilization of coal resources in the Witbank and Highveld coalfields of South Africa was the primary objective of this research. A design tool known as Analysis of Pillar Extraction Potential (A-PEP) is proposed in this research which encompasses an up-to-date design methodology when examining the potential to extract underground coal pillars. This design tool has considered elements of local and international importance relevant to this method of mining and relies on certain criteria pertaining to physical parameters, risk parameters and economic parameters to provide an evaluation of the benefits that can be derived from the increased utilization of coal resources in the Witbank and Highveld coalfields from pillar extraction. The A-PEP tool models potential economic benefits which could be derived through conducting underground coal pillar extraction through the inputs of the user. It is not a predictor of the behaviour of the physical attributes present, but is rather an indicator of the level of risk the operator is exposed to.

It is envisaged that the A-PEP design tool will best be incorporated into existing mine planning software for what will inevitably become a significant mining method in the South African coalfields in the near future, particularly if the coal mining companies distribute their old bord-and-pillar workings as part of the 26% ownership of mining industry assets to previously disadvantaged South Africans in 10 years as spelt out in the new mining empowerment charter.

Acknowledgement
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References