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An assessment of coal pillar system stability criteria based on a mechanistic evaluation of the interaction between coal pillars and the overburden

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ABSTRACT

Coal pillar design has historically assigned a factor of safety (FoS) or stability factor (SF) according to their estimated strength and the assumed overburden load acting on them. Acceptable FoS values have been assigned based on past mining experience or a statistical link between FoS and probability of failure (PoF). Pillar width-to-height (*w*/*h*) ratio has long been established as having a material influence on both pillar strength and its potential failure mode. However, there has been significant disagreement on using both factor of safety (FoS) and *w*/*h* as part of pillar system stability criterion, as compared to using FoS in isolation. This paper will argue that there are valid technical reasons to bring *w*/*h* ratio into system stability criteria (other than its influence on pillar strength), as it is related to the post-failure stiffness of the pillar, as measured in situ, and its interaction with overburden stiffness. When overburden stiffness is also brought into pillar system stability considerations, two issues emerge. The first is the width-to-depth (W/D) ratio of the panel and whether it is sub-critical or super-critical from a surface subsidence perspective. The second relates to a re-evaluation of pillar FoS based on whether the pillar is in an elastic or non-elastic (i.e., post-yield) state in its as-designed condition, as this is relevant to maintaining overburden stiffness at the highest possible level. The significance of the model is the potential to maximise both reserve recovery and mining efficiencies without any discernible increase in geotechnical risk, particularly in thick seams and higher depth of cover mining situations. At a time when mining economics are, at best, marginal, removing potentially unnecessary design conservatism is of interest to all mine operators and is an important topic for discussion amongst the geotechnical community.

1. Introduction

The majority, if not all, of the established coal pillar design methodologies are statistically derived and typically utilise a "classical" pillar strength formulae divided by full tributary area loading (i.e., full cover depth loading) to provide a FoS against core pillar failure. Pillar *w*/*h* ratio is typically included as a variable within the pillar strength formulae but, otherwise, is not formally used to help validate likely pillar stability outcomes as part of a combined system stability criterion. Similarly, potential design parameters, such as W/H ratio or the presence of thick, massive strata units within the overburden (both of which could significantly influence the overburden load acting on individual pillars within a panel) are seldom directly considered.

Stability outcomes could be potentially very conservative if these additional parameters are not used when designing mining layouts that incorporate load-bearing pillar systems. This could result in reduced mining efficiencies and the unnecessary sterilisation of mining reserves.

This paper will demonstrate that there are a number of valid technical reasons to incorporate these factors into the pillar design process using a series of logical mechanistic arguments, resulting in a more holistic pillar design approach.

2. Coal pillar failure mechanics

In order to understand the technical justification for the mechanistic pillar system design being proposed, it is necessary to briefly consider coal pillar failure mechanics and the key parameters that are involved.

Fig. 1 illustrates the well-established concept for stable and unstable behaviour of a structure (e.g., a coal pillar system) once

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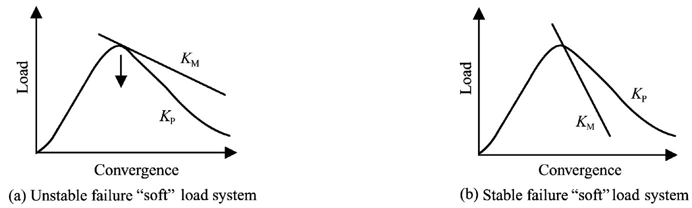

Fig. 1. Illustration of stable and unstable post-failure behaviour.

it reaches its maximum loading-bearing condition. This includes the two critical elements of the post-failure stiffness of the structure (K_p) and the stiffness of the system that is directly loading the structure (K_M). It is not necessary to explain this in significant detail other than to make the following points:

(1) It is necessary for the applied load to exceed the maximum load-bearing ability of the structure in order to drive the system as a whole into a post-failure condition. Without this condition, the structure remains in a pre-failure state and is naturally stable irrespective of the characteristics of the loading system.
(2) In the post-failure state, if the stiffness of the loading system (K_M) is less than the post-failure stiffness of the structure (K_p), the system as a whole becomes naturally unstable because the structure will lose its load-bearing ability at a faster rate than the loading system. While this condition remains, the structure will inevitably progress to a fully collapsed state.
(3) Conversely, if the stiffness of the loading system (K_M) is greater than the post-failure stiffness of the structure (K_p), the system will tend to remain naturally stable despite the maximum load-bearing ability of the structure having been exceeded. This is because the structure will lose its load-bearing ability at a slower rate than the loading system; hence, the system as a whole can attain post-failure equilibrium.

In coal pillar mechanics, the structure is the pillar itself, and the loading system is the overburden above it. Therefore, it is necessary to consider the post-failure stiffness of coal pillars and the overburden stiffness in order to develop a more comprehensive pillar design approach.

Other researchers have used both lab-based testing of coal samples and in situ testing of coal pillars to evaluate post-failure stiffness of coal pillars (see Figs. 2 and 3). More confidence is placed in the in situ test data shown in Fig. 3 because it more accurately represents real-life field conditions present in an underground coal

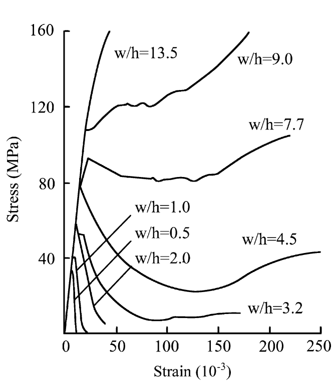

Fig. 2. Stress-strain behaviour of coal for varying width to height (w/h) ratio [3].

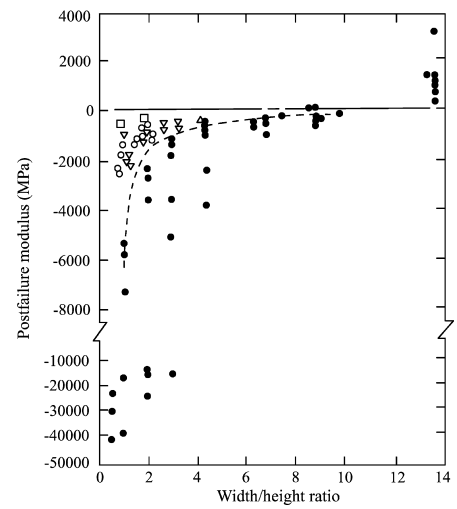

Fig. 3. Post-failure stiffness of coal pillars as a function of width to height (w/h) ratio – NB open symbols represent in situ tests [2].

mine, as compared to the lab-tested samples shown in Fig. 2 and the non-in situ data points shown in Fig. 3. Figs. 2 and 3 demonstrate the following points [1,2]:

(1) Post-failure stiffness decreases as a function of increasing w/h ratio. Both data sets clearly demonstrate this principle.
(2) The in situ test data in Fig. 3 shows post-failure stiffness becomes "asymptotic" when increasing w/h ratio above approximately 2. This is in contrast to the post-failure stiffness of cases that have w/h ratio values of <2, whereby, post-failure stiffness increases rapidly with ever-decreasing w/h ratio (NB increasing post-failure stiffness is detrimental to coal pillar system stability).
(3) Post-failure stiffness transitions from negative to positive (which is highly beneficial to system stability) at a w/h ratio as low as 5, based on an extrapolation of the in situ test data in Fig. 3.

The data in Figs. 2 and 3 allow two other very important statements to be made in relation to the stability and hence design of stable coal pillar systems:

(1) For w/h ratios of >7, coal pillars are almost certain to work-harden as a post-failure behaviour and can, therefore, be classified as "indestructible" (i.e. they retain a confined core at all times and thus cannot collapse in the traditional sense), under normal overburden loading conditions, even though they will still compress significantly if loaded to a high level.
(2) For w/h ratios above 2, coal pillar system collapse requires the overburden to have little or no inherent stiffness in order to overcome the potentially re-stabilising influence of the asymptotically low post-failure stiffness of the pillars.