Engineering Failure Analysis 82 (2017) 161–178

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Mechanisms of support failure induced by repeated mining under gobs created by two-seam room mining and prevention measures

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ARTICLE INFO

Keywords:
Gobs created by TSRM
Support failure
Numerical simulation
Prevention measures

ABSTRACT

Failure of supports often occurs in fully-mechanized longwall (FML) panels under gobs that are created by two-seam room mining (TSRM). Theoretical and numerical models are constructed to investigate the mechanisms responsible for support failure and to find prevention measures. First, the overall stability of the pillars is determined by using a combination of safety factor thresholds, numerical simulation and field experimentation of topsoil stripping. The spatial relationships between the upper and the lower pillars were classified as: well aligned, partly staggered and completely staggered. This study found that the distributions of stress concentration and stress relief zones in the floor depended only on the locations of the lower pillars: stress concentration is the most intense when the upper and lower pillars are well aligned and the least intense when they are completely staggered. Temporally, the lower pillars failed simultaneously with the upper pillars or earlier. In the case of simultaneous failures, the pattern of strata behavior occurring in the FML panel is similar to that under rooms and pillars left by single-seam room mining (SSRM). In the case that the lower pillars collapse earlier, dynamic load coefficients are high during periodic weighting and support resistance suddenly increased when the face exited the regions under pillars or periodic weighting took place. Furthermore, the cause of support failure in the #131210 panel of the Shigetai coal mine is analyzed and two kinds of solutions have been proposed.

1. Introduction

Shenfu Coalfield, one of the largest coal producing regions in China, extends from the northwest of Shaanxi Province to the southern part of Inner Mongolia Autonomous Region. The coalfield has five to six mineable seams, which are shallow, approximately horizontal, and spaced 0.8–37.8 m apart. Room mining is a mining method that can effectively help control surface subsidence and protect the ecological environment of the surface. It was in wide use during the early production at the Shenfu coalfield, which left behind a large-scale gob group. In mines using room mining, the stability of the roof-pillar-floor system is an important factor influencing the safety of mining in lower seams [1–3]. Many arguments have been found to affect the system's stability, such as average pillar load from overburden, pillar strength, safety factor, etc. The magnitude of average pillar load from overburden is mainly calculated using the tributary area theory (TAT), pressure arch theory (PAT), and the function of relative extraction ratio [4–6]. These methods can be used to estimate the average vertical stress imposed by overburden on upper pillars left by TSRM. R.K. Zipf performed numerical simulations to study how rock properties, BO/IB, the sequence of extraction in two adjacent seams, and other factors affected the pillars' vertical stress concentration factor [7]. Significant research efforts have been undertaken to

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http://dx.doi.org/10.1016/j.engfailanal.2017.08.029
Received 29 March 2017; Received in revised form 24 August 2017; Accepted 24 August 2017
Available online 11 September 2017
1350-6307/

Table 1
Summary of safety factor recommended by Bieniawski Z T and Recio-Gordo D.

Situation	Safety factor
Bord and pillar working	1.5
Pillar extraction	2
Main development pillars	2
Barrier pillars	2.5
Tailgate chain pillars	1.3
Pillars in bleeder roadways	1.5–2.0
Analysis for longwall pillar stability	*ALPS(R) SF* = 1.90–0.016*CMRR*
	ALPS(R) SF = 2.0–0.016*CMRR*
Analysis of retreat mining pillar stability	*ARMPS SF* = 1.61–5.1 *E*-4*H*

Coal Mine Roof Rating (CMRR); H -depth of cover (ft).

characterize coal pillar strength using laboratory testing [8–10], in situ measurements [11–13], back analysis, and even numerical or analytical models [14,15]. The pillar strength formulas, for room and pillar design, provided by these methods, typically involve two arguments: (i) coal strength; and (ii) pillar width to height ratio (w/h), whereas the study focused on a probabilistic assessment of pillar stability using *APS* and an empirical pillar strength formula [16]. A basic re-evaluation of the empirical pillar strength factor, *K*, was conducted using the design rock mass strength (see Table 1 for *K* values) [17–20].

Research has revealed the pattern of stress distribution under pillars [21–24]. A.M. Suchowerska explored the variation patterns of vertical stress in the strata below the pillars in an extra-long panel and performed an analysis of the influences abutment angle, overburden, depth, pillar width, and anisotropic behavior of the rock mass had upon vertical stress evolution [25–27]. Wang examined the stability of the pillars left by shallow, single seam room mining and the characteristics of stress transfer [28,29]. Previous research had used a variety of methods, such as theoretical calculation, numerical simulation, and physical simulation to find the pattern of strata movement below shallow gobs created by SSRM and proper roof control techniques [30–32]. Their findings have offered important guidance on actual mining operations. However, few studies have looked at issues arising from TSRM, such as the characteristics of loads on pillars left by TSRM, pillar stability, distribution pattern of stress in floor, falls of longwall roof under TSRM-created gobs, and prevention measures.

In this study, loads on pillars left by TSRM were calculated based on the results of the aforementioned research and the levels of pillar stability were determined using a combination of numerical simulations and field experiments. The distribution of stress in the floor under the pillars was then calculated for different center-to-center horizontal distances between upper and lower pillars (in other words, the horizontal distance from the centerline of an upper pillar to that of the closest lower pillar and vice versa), which is denoted as *d*. The orders of pillar failures induced by FML mining in the underlying seam were classified based on locations of hard rocks. The patterns of strata behavior in the FML panel, in different cases, were then inferred. Later we discuss the support resistance variations that were recorded through numerical simulations on the basis of the geological conditions of panel #131210 in the Shigetai coal mine. The causes of support failure in this panel and the center-to-center horizontal distance between the upper and lower pillars in overlying seams were determined through a comparison of the field measurements with the simulation results. Preventative measures based on the results are then proposed.

2. Loads on pillars left by TSRM and their stability

2.1. Load on upper pillars

Fig. 1 shows the layout of pillars remaining by room mining, which appear as matrix elements presented in previous studies [30,33]. Existing research on Shenfu coalfield, together with field observations, suggest that the spatial pattern of the pillars is symmetrical and resembles the Chinese character "品" [34,35]. The pillars and the elements were contrasted to number the pillars and mark their spatial relations (Fig. 1). Each pillar is a parallelepiped whose horizontal section is approximately rectangular.

The tributary area theory is the method most commonly used to calculate average vertical stress imposed on coal pillars by overburden. It can be described by the following equation:

$$\sigma_{avs} = \frac{A\rho gH}{S} \tag{1}$$

where ρ is the average density of overburden, *g* is gravitational acceleration, *H* stands for the depth of overburden, and *S* represents sectional area of the pillars.

For pillars with a rectangular horizontal section, Eq. (1) can be rewritten as follows:

$$\sigma_{avs} = \frac{\sigma_v}{1 - r} \tag{2}$$

where σ_v is the vertical component of initial stress, defined by $\sigma_v = \rho gH$, and *r* is the recovery rate in room mining, defined by: