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Topographic influence on stability for gas wells penetrating longwall mining areas

Shun Liang [a,b], Derek Elsworth [b], Xuehua Li [a,*], Dong Yang [c]

[a] State Key Laboratory of Coal Resource and Mine Safety, School of Mines, China University of Mining and Technology, Xuzhou, Jiangsu 221008, China
[b] EMS Energy Institute, G3 Center and Energy and Mineral Engineering, Pennsylvania State University, University Park, PA 16802, USA
[c] Institute of Mining Technology, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China

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ABSTRACT

Gas wells penetrating longwall mining areas are prone to fail by shear and distortion due to vulnerability to ground movements caused by coal mining, especially when they pierce layered strata. This work explores the influence of topography on stability for shale gas wells piercing a longwall pillar after sequential removal of the flanking panels. We examine the magnitudes of shear offsets, longitudinal distortions, delamination, lateral and vertical strains along the vertical well trajectories through a longwall pillar and as a result of mining, and evaluate their impact upon the anticipated performance and stability of the wells. Results indicate that the presence of weak interfaces separating monolithic beds is a crucial factor that modulates wellbore instability. Contrast between benign relief and incised surface topography amplifies shear offsets for wells in the overburden by ~20–30%. Well distortions are largest close to the surface or hilltop for mining at shallow depths (100 m) and migrate downwards with an increase in panel depths reaching a maximum in the vicinity of the seam. Tensile failure is more likely to occur for gas wells penetrating the overburden with incised topography, especially for the case with a higher ratio of hill height to the thickness of overburden below the valley floor, with a largest delamination of 42 mm. Incised topography does not cause a significant change in magnitude for axial distortions along well trajectories (limited to $\pm 3 \times 10^{-3}$) but does elevate lateral strains over the horizontal case to different extents. For all topographic conditions, lateral shear offsets and various strains are largest for boreholes that cross the pillar closest to the panel rib and reduce monotonically towards the gateroad, where both the shear offsets and axial distortions reduce to about one-fifth (horizontal) and one-tenth (incised) of the maximum at 7.5 m inboard of the gateroad. Well deformations are most severe when mining is shallow <100 m, then moderate when mining at an intermediate depth ~200 m, and then become large again as the seam deepens >300 m. The spread in the distribution of strain magnitudes between the five horizontal trajectories through the pillar all converge when mining is deeper.

1. Introduction

Gas wells are conduits for the transmission of shale gas, coalbed methane and other natural gas resources from the reservoir to the surface. In regions where the gas resource underlies mineable coal seams, the recovery of that coal may jeopardize the integrity of the well even if an unmined buffer-region is left around the well. This is especially the case where high extraction mining, such as longwall mining, is used as a method of recovery. In this instance the integrity of the wells may be affected by deformation in the overburden, underburden and coal that both precede and follow proximal mining. This issue has been recognized for example in the Pennsylvania Mining Act of 1957 where a barrier pillar surrounding a pre-existing well is required to be of 200,000 ft^2 in tributary area. However, where the recovery is by full extraction (longwall) mining, it is not always feasible to leave an equiaxed (square) pillar due to both mining logistics and the layout of adjacent panels. In this work we examine the rationale for the dimensioning of protective barrier pillars to enable both effective mining and the safe extraction of gas. In addition, the prevention of well failures is important in coal-seam degassing (Karacan et al., 2011; Whittles et al., 2007) where, absent drainage, the accumulation of methane may be significant (Burrel and Friel, 1996; Kral et al., 1998) and these and also gob gas ventholes (GGVs) are important (Karacan, 2013). The effects on gas drainage wells installed prior to mining are clearly greater than for those installed into the gob post-mining — although the general issues of well stability is similar. In this work we examine the rationale for gas well stability under the effects of longwall mining and explore the influence of both topography and seam depth to enable both effective mining and the safe extraction of gas.

A variety of studies have examined the stability of boreholes although most of these have examined the influence of the drilling

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* Corresponding author. Tel.: +86-13952196864; fax: +86-516-83590505.
E-mail address: lsxh2001@126.com (X. Li).

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process and its influence on the resulting stability of the well. These have concentrated on evaluating drilling design, including the provision of mud weight and typically assuming that the rock material is linear elastic, homogeneous, and isotropic in deformability and in strength (Bradley, 1979; Santarelli et al., 1986) and extending these analyses to anisotropic strength representing shales and phyllites (Aadnoy, 1988; Ajalloeian and Lashkaripour, 2000; Aoki et al., 1993; Chenevert and Gatlin, 1965; Donath, 1964; Lee et al., 2012; McLamore and Gray, 1967; Niandou et al., 1997; Ong and Roegiers, 1993; Ramamurthy et al., 1993; Tien et al., 2006). Borehole failure mechanisms are also important in determining the integrity of the well (Aadnoy and Chenevert, 1987; Gough and Bell, 1981; Haimson and Song, 1993; Tan and Willoughby, 1993; Tan et al., 1998; Zheng et al., 1989; Zoback et al., 1985) and may also be used to determine the orientation of in situ stresses. Failure is also influenced by rock lithology and the physical-mechanical or chemical–mechanical interactions between clay minerals and drilling fluids or groundwater (Hale et al., 1993; Tan et al., 1996; Van Oort et al., 1994; Zeynali, 2012), but these effects may be minimized by the application of improved drilling methods (Bennion et al., 1996; Bjornsson et al., 2004; Clancey et al., 2007; Supon and Adewumi, 1991) to maximize the effectiveness of drilling.

Despite a significant number of studies relating to well stability for hydrocarbon wells, relatively fewer results are available to define stability under the influence of strata movement and control, or of the effects of pillar crushing. One reason is that the importance of unconventional natural gas reservoirs underlying mineable coal seams has only become an important issue relatively recently (Wang et al., 2013). However, the evaluation of stability for wells piercing minable coal seams may draw on a significant body of work related to the evaluation of the performance of gob gas ventholes (Karacan, 2009a, 2009b; Karacan and Goodman, 2009; Karacan and Olea, 2013), the failure modes of the surface venthole casing during longwall mining (Chen et al., 2012), localization of mining-induced horizontal fractures along rock layer interfaces in overburden (Palchik, 2005), the influence of coal mining on ground-water supplies (Elsworth and Liu, 1995; Liu and Elsworth, 1997, 1999) and the influence of topography on horizontal deformations (Gebauer et al., 2009) adjacent to the mined panels. Despite these contributions, few analyses exist on the topographic influence on well stability for gas wells penetrating longwall mined seams.

This study examines the stability of wells piercing a horizontal seam and subject to sequential mining first on one side and then the other (Fig. 1). In particular, we incorporate the influence of topography above the mined panels and examine the lateral and vertical strains, horizontal shear and vertical delamination displacements and vertical distortions applied along the candidate paths of wells that extend from the surface/hilltop, through the pillar and to depth. We presume the rock to be laminated and capable of separation at bedding interfaces as a representation of mixed sandstone shale sequences in the overburden and underburden. We use this analysis to evaluate areas where the wellbore is prone to collapse or more specifically disruption by shear offset.

2. Mechanistic model

We idealize the subsurface as a deformable medium comprising laminated units with a slip interface, as shown in Fig. 2. The model closely replicates the morphology of interbedded shales and sandstones adjacent to the coal seams with the deformability properties of the units and interfaces controlling the response. We examine the distribution of displacements and strains along a vertical well trajectory, as induced by longwall mining, and evaluate their impact upon the anticipated performance and stability of the wells.

2.1. Strata deformation and distortion

We follow the distortion, tension and compression, delamination, and lateral shear offsets that occur at interfaces between alternating layers of hard and soft strata. This shear slippage and distortion represents the anticipated failure mode for gas wells that traverse the pillar between longwall panels. Compared with compaction in the vertical direction, shear displacement and axial distortion are likely more damaging to wellbores — although all modes may be examined. We represent this interface between layers of alternating mechanical properties by an interface element (Fig. 2) where the elastic distortion, ε_e, irrecoverable

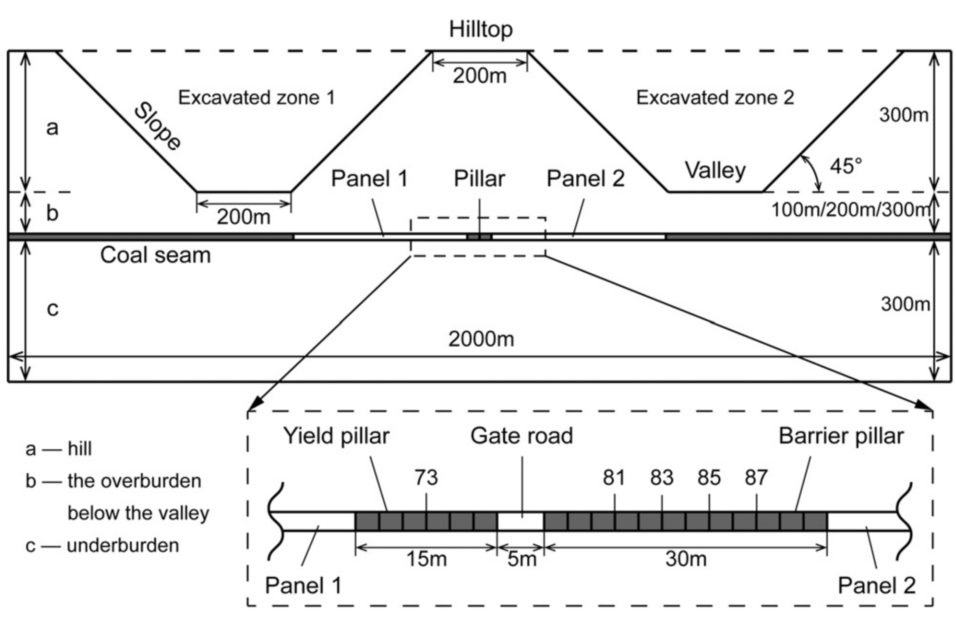

Fig. 1. Two dimensional model with a 2 m thick coal seam at an elevation of 100/200/300 m below the valley-base and with twin panels flanking a central pillar (Pillar geometry between the twin extracted panels is shown in the excerpted frame. Panel 1 is removed first and then panel 2 is also removed afterwards. Pillar widths are in meters and correspond to multiples of element widths of 2.5 m. Numbers refer to grid points in the yield pillar (70–76), intervening gate road (76–78) and the barrier pillar (78–90)).