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Effects of gully terrain on stress field distribution and ground pressure behavior in shallow seam mining

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ABSTRACT

This study proposes a novel approach to study stress field distribution and overlying ground pressure behavior in shallow seam mining in gully terrain. This approach combines numerical simulations and field tests based on the conditions of gully terrain in the Chuancao Gedan Mine. The effects of gully terrain on the in situ stress field of coal beds can be identified by the ratio of self-weight stress to vertical stress (η) at the location corresponding to the maximum vertical stress. Based on the function $\eta = f(h)$, the effect of gully terrain on the stress field of overlying strata of the entire field can be characterized as a significantly affected area, moderately affected area, or non-affected area. Working face 6106 in the Chuancao Gedan Mine had a coal bed depth <80 m and was located in what was identified as a significantly affected area. Hence, mining may cause sliding of the gully slope and increased loading (including significant dynamic loading) on the roof strata. Field tests suggest that significant dynamic pressures were observed at the body and foot of the gully slope, and that dynamic loadings were observed upslope of the working face expansion, provided that the expanding direction of the working face is parallel to the gully.

1. Introduction

As the western part of China has become the focus of coal mining activity, mines in the area have recently attracted greater attention [1–4]. The characteristics of these mines include: large depth of coal beds, shallow occurrences (basement to loading ratio <1) and complicated topography [5–8]. Dynamic strata pressure disasters are frequently observed on the working faces in shallow coal seam mines, resulting in severe safety issues [9,10] and gully terrain is a key factor in strata pressure disasters. The effects of gully terrain on the mining process have been previously reported, primarily during investigations of overlying strata breaking movement, mechanisms and factors affecting dynamic strata pressure. Researchers [9–12] investigated shallow seam working faces in terms of factors affecting ground pressure and dynamic loading mechanisms, and provided solutions to the issue of dynamic strata pressure. Researchers [13,14] reported a mechanical model of the initial and periodic breaking of a gully slope stope main roof. Based on the geographical conditions of shallow seams in gully terrain, this model aided the investigation of the support/wall rock interaction in a loaded coalface and support resistance in the decay of the controlling roof. Gully terrain has a significant effect on the in situ stress field of lower overlying strata [15–17] and the ground pressure behavior of the working face. Few studies to date have investigated the characteristics of wall rock stress fields in shallow seam mining in gully terrain, and its effect on the mining process [18].

In this article, we study the effects of gully terrain on the in situ stress field in coal beds, based on the geographical conditions of the gully terrain in the Chuancao Gedan Mine, as well as investigate the slope motion caused by the mining process. Field tests revealed the ground pressure behavior of the working face and the loading properties of hydraulic pressure supports in different gully terrains. Additionally, a statistical analysis of cases that are vulnerable to dynamic strata pressure was reported. This study provides a reference for roof control and the prevention of dynamic strata pressure.

2. Geographical and production conditions

The Chuancao Gedan Mine is located in the Loess Plateau, and is noted for its complicated topography which includes large surface variations. The mining field is covered by unconsolidated sediments, resulting in old layers formed before the Cenozoic

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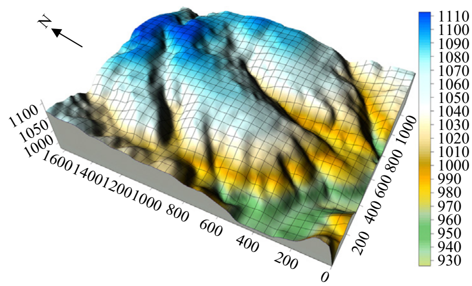

Fig. 1. Surface configuration of a portion of the Chuancao Gedan mining field (m).

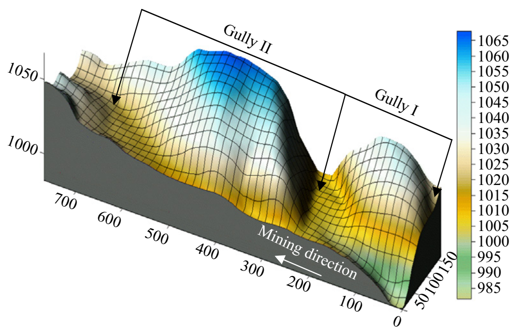

Fig. 2. Topographic features of gullies within the area of working face 6106 (m).

Erathem being almost fully-covered and the presence of bedrock only present in large gullies. Therefore, the Chuancao Gedan Mine is designated as a typical shallow seam in gully terrain. Fig. 1 depicts the surface configuration of a portion of the Chuancao Gedan mining field. Results indicate varying features of gullies in the mining field, including different depths, widths and slopes due to seasonal precipitation.

Working face 6106 has an elevation of 916.3–935.1 m, with two major gullies (Gully I and II) observed within the area of the working face. The maximum and minimum elevation of Gully I is 1041.0 m and 987.5 m, respectively, giving a total elevation difference of 53.5 m. The maximum and minimum elevation of Gully II is 1065.0 m and 987.5 m, respectively, giving a total elevation difference of 77.5 m. Working face 6106 displays heterotrophic expanding and gully propagation directions. Fig. 2 depicts the topographic features of gullies within the area of working face 6106.

3. Characteristics of the in situ stress field of coal beds in shallow seam mines in gully terrain

The surface of working face 6106 was covered by thick, sticky loess with poor mechanical properties. As a result of the mining process, the collapse of the overlying strata was observed as a result of the mining process and leading to a step mining fracture, as shown in Fig. 3. This type of fracture indicates that the vertical stress in the overlying strata plays a key role in strata fracture and surface subsidence in gully terrain. Hence, it is necessary to further investigate the distribution of vertical stress within the overlying strata.

As shown in Fig. 2, a numerical model depicting an area of 200–600 m of working face 6106 expansion (Gully II) was developed using FLAC3D [19–22]. Table 1 displays the mechanical properties of the model surface overlying strata. Fig. 4 shows the vertical stress distribution of country rock in the model, based on the stress balance. Results indicate that the effect of gully terrain on the stress field distribution of country rock was significant, though the effect decreased as the depth of the gully increased. At the bottom of the gully, the vertical stress of the country rock is greater than its gravity; at the crest of the gully, the vertical stress of the country rock is approximately equal to its gravity.

Fig. 5 shows the isogram of vertical stresses in strata with different elevations. Results indicate that the vertical stress in strata 30 m above the gully bottom ranged from 0.87 MPa to 2.73 MPa; the isogram of maximum vertical stress is consistent with that of the gully bottom, indicating a concentration of stress at the gully bottom. The maximum vertical stresses in strata 50 m, 100 m and 150 m above the gully bottom were 2.82 MPa, 3.37 MPa and 4.51 MPa, respectively, while the minimum vertical stresses were 1.53 MPa, 2.32 MPa and 3.74 MPa, respectively. The maximum and minimum vertical stresses were observed at the bottom and top of the gully, while the correlation between the isograms of the maximum vertical stress and the gully bottom degraded with decreasing elevation.

4. Embedment effects of gully terrains on the in-situ stress field in country rock

Study results indicated that the effect of gully terrain on the in situ stress field of the underlying strata was expressed by the increasing vertical in situ stress of the strata at the gully bottom. The ratio of self-weight stress to vertical stress of strata at different elevations (η) indicates the effect of gully terrain on the in situ stress field of country rock. It can be calculated by the following formula:

$$\eta = \sigma_h / \sigma_{\max} \tag{1}$$

where σ_h is the self-weight stress: $\sigma_h = \gamma h$, γ is the average volume weight of the overlying strata and h is the depth of strata at the gully bottom. $\sigma_{\max}$ is the maximum vertical stress.

Fig. 6 shows the ratio of self-weight stress to vertical stress (η) of strata at various elevations.

(a) Step mining fracture above the coalface

(b) Upslope of surface step mining fracture

Fig. 3. Surface step mining fracture in working face 6106.