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Characterising the multi-seam subsidence due to varying mining configuration, insights from physical modelling

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ABSTRACT

Multi-seam mining-induced subsidence profile is observed to be different from that of single-seam mining. Understanding the characteristics of multi-seam subsidence is the first step in achieving reliable subsidence predictions. Characteristics of multi-seam subsidence are investigated by means of several sand-plaster physical models. Geological and site specific parameters are kept constant in all the models in order to compare the multi-seam subsidence parameters for different mining configurations. Based on observations from the physical models, it is concluded that the panel configurations of the two seams have significant impact on the multi-seam subsidence development. Based on the relative location of the panels the multi-seam mine area can be divided into different zones, to which suitable subsidence characteristics can be assigned. Dividing the mine area into different zones enables characterisation of the strata movement and multi-seam subsidence for various multi-seam configurations. The proposed characterisation of the multi-seam subsidence can also be utilised in subsidence prediction methods in order to achieve reliable prediction results.

1. Introduction

Evaluating the influence of longwall coal mining on the ground surface is of great importance in mining regions. The ability to predict mining-induced subsidence enables engineers to foresee and take suitable measures to minimize possible damage to surface and underground infrastructure as well as potential disturbance of aquifers, rivers and other environmental features. These predictions are particularly important in the case of multi-seam subsidence, where enhanced magnitude of subsidence is expected.[1,2] Prediction methods, which are available for single-seam subsidence, are inaccurate in predicting the multi-seam subsidence.[3–5] This is due to differences in profile, shape and magnitude of multi-seam subsidence in comparison with that of single-seam subsidence. It has been suggested that there is a distinctive strata movement characteristics associated with multi-seam subsidence.[6]

1.1. Field observations of multi-seam subsidence

Various researchers and industry reports have explained the differences between the single and multi-seam subsidence shape and magnitude from field experience and observations in different countries.[3,7,8] The magnitude of the incremental multi-seam subsidence is often observed to be significantly greater than the subsidence caused by single-seams and in some instances greater than the lower seam thickness.[9–11] Li et al., 2010,[3] based on field observations from various countries, proposed that this increase in the magnitude of the multi-seam subsidence is due to the reduced strength of the overburden strata as a result of the first mining activity. They called this overburden modification and proposed that it needs to be considered in evaluating the multi-seam subsidence.

Observations from various multi-seam operations in Australia illustrated deeper and steeper subsidence profiles above the areas of overlapping panels in comparison with that of single-seam cases.[3,12] Closure of the pre-existing fractures at the goaf of an upper panel has been stated as a reason for this observation.[7] It also has been observed that depending on the mining configuration, the shape of the subsidence profile significantly varies. The multi-seam incremental subsidence profile is more concentrated, i.e. narrow and deep, with steep decline over the edges of the panels in cases where the edges of the panels in the two mining horizons are stacked on top of each other (stacked configuration) in comparison with staggered edges (staggered configuration).[13,12]

In addition, from the published subsidence reports it can be seen that the location of the maximum incremental multi-seam subsidence changes due to the positioning of the panels and is different from single-seam cases.[3,7] MSEC 2014[7] suggests that in staggered configurations, the maximum incremental multi-seam subsidence predomi-

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nantly occurs within the area above and in the vicinity of the edges of the upper panel. They suggested that this observation is likely to be related to closure of existing voids and fractures in this area after extracting the lower panel.

The change in the extent of the subsidence (angle of draw) as a result of multi-seam extraction was also reported in the subsidence observations for Australian coalfields.[14] MSEC 2012 [15] mentioned that the multi-seam cases, in general, show wider subsidence than the single-seam cases. Subsidence observations from Blakefield South Mine in New South Wales, Australia also indicate that the angle of draw changes based on the relative location of the panels in the two mining horizons. This angle is different and, in general, greater over the staggered edges than the stacked ones.[13,12]

Effects of the interburden thickness have also been highlighted by various researchers based on the field observations.[10,15,7] Most of these studies have suggested more substantial multi-seam interactions in case of thin interburden layers and vice versa.

The abovementioned multi-seam subsidence observations lead to the realization that one of the most important factors in the multi-seam subsidence is the positioning of the panels in the two seams.[16] In fact, as Galvin 2016 [17] stated, the multi-seam subsidence profile depends on the extent of superpositioning of the workings, mining method, nature and thickness of the interburden layers. Galvin 2016 [17] concluded that the multi-seam subsidence, in general, requires to be investigated on a site-specific basis.

The extent of superpositioning of the workings, relative location of the panels and thickness of the interburden can be referred to as a general term of multi-seam mining configuration. A feasible way to investigate the effect of multi-seam mining configuration on the subsidence parameters is to keep site specific variables constant while monitoring variations of subsidence parameters due to the changing mining configuration. Under this condition, effects of multi-seam configuration can be investigated and the subsidence parameters can be characterised for different mining configurations. In this study, physical modelling techniques are utilised for this purpose. In the physical models, geological and site specific parameters, such as, strength of the material, thickness of the bedding planes, bedding planes characteristics, extraction thickness and the extraction method are kept constant. This enables monitoring of the effects of multi-seam mining configuration. Four different multi-seam mining configurations are modelled and the results are compared. In the light of the physical modelling results, the multi-seam subsidence is characterised in a way that is applicable to various mining configurations. In this study, multi-seam subsidence only refers to longwall mining from below previously extracted panels are investigated.

2. Physical modelling of multi-seam subsidence

There are various examples of physical modelling of mining-induced ground movements in the literature.[18–21] Different researchers used various test set ups, construction material and measurement devices based on the purpose of the experiments. However, to be able to capture realistic behaviour of rock mas via physical modelling techniques, physical models are required to be built in accordance with the principles of similarity theory. The dimensions of the model, strength and density of the material in the physical model need to satisfy the following condition.[22,23]

$$\frac{C_\sigma}{C_\rho \times C_L} = 1; \tag{1}$$

where

$$C_L = L_p/L_m,\ C_\sigma = \sigma_p/\sigma_m,\ C_\rho = \rho_p/\rho_m \tag{2}$$

In these equations, C_σ is the strength similarity constant, C_ρ is the density similarity constant and C_L is the geometry similarity constant.

Table 1
Similarity ratios for the physical models.

	Density	Strength (UCS)	Geometry (panel width)
Similarity constants	$C_\rho = 1.41$	$C_\sigma = 319.5$	C_L=226
Prototype case	2700 kg/m^3	16,700 (kPa)	150 (m)

These similarity constants can be calculated by dividing the uniaxial compressive strength (UCS), density and dimensions of the target prototype case (σ_p, ρ_p and L_p) by that of the scaled physical model (σ_m, ρ_m and L_m). In the study presented here, sand-plaster-water mixtures were used to simulate the rock layers. The similarity ratios of this material used in this study and the prototype case are noted in Table 1. Several measurement devices were used to monitor the required multi-seam subsidence parameters. These include Terrestrial Laser Scanner (TLS), Optical Non-contact Displacement Transducers (optpNCDT) and a digital camera. The model set-up and the location of these devices are illustrated in Fig. 1.

2.1. Physical models construction procedure

The modelling material was casted in the physical modelling frame in layers. A thin layer of fine sawdust is used to simulate the bedding planes. Each longwall panel is modelled using a number of wooden blocks and panel extraction is simulated by sequential withdrawal of the wooden blocks. Also, sufficient time was given between extraction of each panel to allow the deformations to be fully developed. Details of the physical modelling construction steps, material properties and excavation process follow the same procedure as explained in the previous works of the same authors.[6,21] Readers can refer to these works for detailed information about the requirements, measurement techniques and the procedure of performing physical modelling of multi-seam subsidence.

3. Case studies

To investigate the multi-seam subsidence characteristics, three different mining configurations were modelled using physical modelling techniques. These models are shown in Fig. 1c as stacked configuration (Fig. 1c-1), extension of the lower panel in stacked configuration (Fig. 1c-2), staggered configuration with thin interburden (Fig. 1c-3) and staggered configuration with thick interburden under upper panel chain pillars (Fig. 1c-4). Please note that the model shown in Fig. 1c-2 is the extension of the lower panel in the stacked configuration. This extension results in the lower panel exceeding the complete length of the upper panel. These models were designed to monitor the effects of changing mining configuration on the ground subsidence parameters. To be able to refer to different areas in various models herein, certain terminologies are used as shown in Fig. 1b and c. Please note that the terms “thin interburden” and “thick interburden” are only used to refer to different mining configurations in this study with varying interburden thickness. However, in general, these terms can be quantified based on the ration between the interburden thickness and extraction thickness, which is also applicable to the models used in this study. Design parameters of each model are noted in Tables 1 and 2 respectively. Total height, length and thickness of the physical modelling test frame were 1.5 m, 2 m and 0.15 m respectively for all the models. Also, flat ground surface geometry was used in all the models. In the following sections, the results are presented in the scale of the physical model. The conditions can be converted to the field scale using the appropriate similarity constants as noted in Table 2.

The TLS and optpNCDT were only used for staggered configurations (Fig. 1c-3,4). In these models, the TLS were used for cavity