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# Superposition model for analyzing the dynamic ground subsidence in mining area of thick loose layer

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ABSTRACT

The dynamic ground subsidence due to underground mining is a complicated time-dependent and rate-dependent process. Based on the theory of rock rheology and probability integral method, this study developed the superposition model for the prediction and analysis of the ground dynamic subsidence in mining area of thick loose layer. The model consists of two parts (the prediction of overlying bedrock and the prediction of thick loose layer). The overlying bedrock is regarded as visco-elastic beam, of which the dynamic subsidence is predicted by the Kelvin visco-elastic rheological model. The thick loose layer is regarded as random medium and the ground dynamic subsidence is predicted by the probability integral model. At last, the two prediction models are vertically stacked in the same coordinate system, and the bedrock dynamic subsidence is regarded as a variable mining thickness input into the prediction model of ground dynamic subsidence. The prediction results obtained were compared with actual movement and deformation data from Zhao I and Zhao II mine, central China. The agreement of the prediction results with the field measurements show that the superposition model (SM) is more satisfactory and the formulae obtained are more effective than the classical single probability integral model (SPIM), and thus can be effectively used for predicting the ground dynamic subsidence in mining area of thick loose layer.


## 1. Introduction

The mining area of thick loose layer is widely distributed in eastern China, central China and northern China. The main geological characteristics of thick loose mining area, in general, are that the overlying bedrock is generally thin, while the loose layer is thick [1,2]. Both observed and theoretical analysis show that there has been widespread deformation of ground surface far away from the mining area and the surface subsidence is continual and slow with a long duration of movement and deformation due to underground mining of coal seam in mining area of thick loose layer. This phenomenon can cause environmental problems and damage to surface and subsurface structures [3]. In order to protect the environment and structures from these damages, precise ground movement and deformation prediction are essential.

The dynamic ground subsidence caused by underground mining is a complex process dominated by time and space [4–8]. The prediction and analysis of ground subsidence due to underground mining have been studied by many scholars in this field and several valuable results have been obtained, such as the time function method of Knothe, the time function method of XM Cui, the time function method of Sroka-Schober, the time function method of Weibull curve, the time function method of C. Gonzalez-Nicieza and the Coordinate-time function method based on probability integral method [9–12].

However, most prediction methods above, in general, consider the overlying strata as a kind of single medium. Lots of research results have shown that the strength and bearing capacity of overlying bedrock are much larger and stronger than that of loose layer, so the overlying bedrock and loose layer will have different subsidence forms due to underground mining. Therefore it will induce an inaccuracy to use a single prediction model for the surface dynamic subsidence in mining area of thick loose layer. For deep rock mass, especially in the case of water contained, the rock mass will show particularly rheological properties. Therefore the viscoelastic creep properties of rock are gradually concerned by many scholars in this field [13–15].

In the present work, the authors attempt to predict dynamic ground subsidence using a superposition model (SM). Detailed analysis was carried out to predict subsidence caused by underground mining of coal seam in mining area of thick loose layer.

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The validation of the model has been performed by predicting the subsidence profiles for the Zhaogu mine area in China. We have found a more reasonably good match between the observed and predicted dynamic ground movement curves than the classical single probability integral model (SPIM).

## 2. Viscoelastic dynamic subsidence model of the overlying bedrock

With the theory of rheology, the nature of the process of dynamic subsidence due to underground mining can be revealed more effectively in time and space. This paper mainly concerns the application of viscoelasticity to the dynamic subsidence of the overlying bedrock. For example, the average depth of the 11,011 working face in Zhao II mine is 690 m. The thickness of loose layer and overlying bedrock is 616 and 74 m, respectively. The overlying bedrock mainly contains of sandstone and sandy mudstone. The bedrock, subjected to water erosion in varying degrees, generally shows soft rock properties. In order to understand the properties of bedrock accurately, creep tests were carried out on the intact rock samples for sandstone and sandy mudstone from five drill holes of Zhao II mine. Fig. 1 is the experimental results, which shows that the two kinds of rock have creep characteristics obviously.

Creep is the time-dependent strain or deformation under constant axial stress. Kelvin visco-elastic creep model is selected to represent the creep behavior based on the creep test results of soft rock mass [16–18]. According to the existing research results, the deformation characteristics of soft rock can be described by the Kelvin model (Fig. 2). In fact, the Kelvin rheological model has been widely used to describe viscoelastic deformation caused by underground mining. In order to predict the overlying bedrock dynamic subsidence due to underground mining, we will use Kelvin model to describe dynamic subsidence of the overlying bedrock due to underground mining by the fully-mechanized caving method [19,20].

### 2.1. Basic assumptions

(1) Coal seam and overlying strata are horizontal
(2) The coal seam and overlying bedrock are all homogeneous medium and consistent with Kelvin rheological model
(3) The vertical strain of the coal seam at any point is proportional to the deflection (i.e., subsidence) of the overlying bedrock at that point.

### 2.2. Dynamic subsidence prediction of the overlying bedrock

According to the viscoelastic mechanics theory and engineering practice, the coal seam is considered as a visco-elastic foundation and the overlying bedrock as visco-elastic cylindrical bending plate on the foundation. Thus, the unit width beam (bedrock) can be used to characterise the cylindrical bending plate (bedrock).

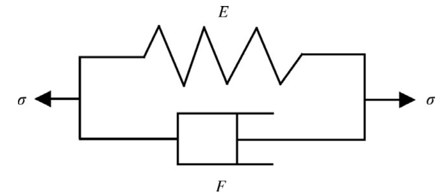


**Fig. 2.** Kelvin rheological model.

Assuming that there is no gap between beam and foundation. According to the assumed conditions, we can choose the semi-infinite mining coordinate system shown in Fig. 3, in which the coordinate origin $O_1$ is located at the intersection of the coal wall extension line and the bedrock upper surface, the axis of $S$ directs the gob, and the subsidence of bedrock is vertical downward.

According to engineering practice, the overlying bedrock beam could be regarded as a homogeneous viscoelastic beam [21]. The line passing through the bending beam is called the morphological line of viscoelastic bedrock beam, which can represent the deformation state of the bedrock beam (Fig. 4). From Fig. 4, we know that the external load of the bedrock beam is composed of three parts.

(1) The upper surface of the bedrock beam bears the overlying thick loose layer weight Ps and the load is uniformly distributed.
(2) The lower surface of the bedrock beam bears the coal seam foundation reaction force $\varphi(s, t)$ and the gangue reaction force $\psi(s, t)$ in the gob.

Based on the existing research results, the deflection (subsidence) equation of bedrock beam can be divided into two parts [22]:

(1) When $s < 0$ or $s > L$, the foundation of the visco-elastic bedrock beam is unmined coal seam, and thus the dynamic subsidence equation of bedrock beam, could be described as follows:

$$W_j(s,t) = \exp(-kt)\exp(-\pi s/L)[A_3(t)\sin(\pi s/L) + A_4(t)\cos(\pi s/L)], s \in (-\infty, 0] \cup [l, +\infty) \quad (1)$$

where $W_j(s,t)$ is the dynamic subsidence of visco-elastic beam at point $s$ at the moment $t$; $L$ the length of mined-out area of the coal seam, m, and $L \approx 2r_j = 2H_j/tan\delta_0$; $r_j$ the major influence radius of bedrock, m; $H_j$ the thickness of bedrock, m; and $\delta_0$ the draw angle of bedrock, °.

(2) When $0 < s < l$, after mining, the gob (mined-out area) generally is filled with gangue, and thus the dynamic subsidence equation of bedrock beam could be described as follows:

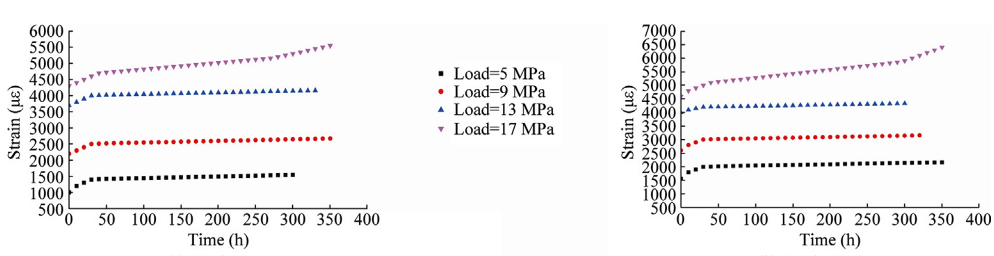


**Fig. 1.** Creep tests of sandstone and sandy mudstone.

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