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Development of a new algorithm for implementing the edge effect offset for subsidence calculations

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ABSTRACT

The Surface Deformation Prediction System (SDPS) program has been developed as an engineering tool for the calculation of subsidence deformation indices through the implementation of various prediction methods. From basic user-defined input parameters, SDPS can determine subsidence indices, such as mining induced displacements, strains, tilt, etc., at any elevation between the seam and the horizontal or varying surface topography. A fundamental parameter in obtaining reliable ground deformation results is the determination of the edge effect offset. The value assigned to the edge effect offset corresponds to a virtual offsetting of boundary lines delineating the extracted panel to allow for roof cantilevering over the mined out area.

The objective of this paper is to describe the methods implemented in updating the edge effect offset algorithm within SDPS. Using proven geometric equations, the newly developed algorithm provides a more robust calculation of the offset boundary of the extracted panel for simplistic as well as more complex mining geometries. Given that an extracted panel is represented by a closed polyline, the new edge offset algorithm calculates a polyline offset into the extracted panel with respect to the user defined edge effect offset distance. Surface deformations are then calculated using this adjusted panel geometry. The MATLAB® program was utilized for development and testing of the new edge effect offset algorithm. After completing rigorous testing regimes, the new offset algorithm will be integrated into SDPS further increasing the speed and reliability of the program resulting in a retrospective increase in capability and flexibility.

1. Introduction

High-recovery underground coal mining methods, such as longwall mining, room-and-pillar mining with secondary extraction and longwall top-coal caving, have the potential to initiate deformations within the surrounding rock strata often referred to as subsidence. As mining operations continue to develop within the reserve, mining induced movements within the strata propagate from the seam through the overburden to the surface [5]. These mining induced deformations can potentially damage surface and subsurface infrastructure such as buildings, roadways, railroads, pipelines and wells, as well as natural structures and formations like rivers, streams, wetlands, aquifers, etc. through the development of abrupt steps, troughs, tensile fracturing, compressive rupturing, etc. [3,6,4].

Due to the potential impact to subsurface and surface structures and resources, the ability to accurately predict the potential and magnitude of mining induced subsidence is a complicated process. The prediction of subsidence indices such as vertical and horizontal displacements, tilt and strain are crucial during mine planning and reserve development as subsidence and mitigation plans are required by state and federal regulatory agencies to ensure the integrity of surface and subsurface structures and resources.

Due to the complex nature and number of input parameters utilized in subsidence prediction, such as seam depth and inclination, surface topography and geological faults [8], mine operators and planning engineers have been provided with a variety of modeling tools and software packages for the evaluation of mining induced subsidence and mitigation design plans for all stages of mining production. The Surface Deformation Prediction System (SDPS) provides users with a platform of subsidence analysis tools which have been validated through academic studies and industry designs. Although developed over 30 years ago, SDPS have been continually updated with new analysis and prediction features providing the mining industry with a reliable and versatile program. The influence function, as implemented in SDPS, is a mature methodology for the calculation of ground deformations and is

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widely used by academics, industry professionals, and regulatory agencies in the prediction and evaluations of mining induced subsidence [7]. Through the application of user-defined parameter groups such as overburden depth, extent of the extracted area, angle of influence, subsidence factor and edge effect offset one is able to perform a series of subsidence prediction calculations with respect to empirically derived equations or calibrate their parameters with respect to site-specific measurements and observations [1].

The objective of this paper is to present a self-sufficient algorithm that is able to estimate the edge effect offset for a given mine plan and provide a consistent offsetting calculation for users in contrast to the variety of offsetting methodologies present in third party programs.

2. Influence function method

Through the application of a Gaussian bell-shaped influence function, SDPS is able to calculate strata deformations at any point in the three-dimensional space and, therefore, at any point along the surface and at any elevation between the seam and the surface. The influence function as implemented in SDPS for rectangular extraction areas is shown for a two-dimensional case with a unit thickness in Eq. (1).

$$P(s) = \frac{\tan(\beta)^{*} S_{max}}{h} \int_{x_1}^{x_2} \exp\left[-\pi \frac{(x-s)^2}{\left[\frac{h}{\tan(\beta)}\right]^2}\right] dx \quad (1)$$

where

h = the overburden depth,
β = the angle of principal influence,
s = the coordinate of the point for which subsidence is calculated,
x = the coordinate of the infinitesimal excavated element ($x_1 \leqslant x \leqslant x_2$),
x_1, x_2 = the boundary limits of a rectangular extraction panel,
S_{max} = the maximum possible subsidence factor.

Eq. (1) is used to determine the amount of vertical movement, P(s), at any position, s, above the panel. The overburden depth, h, is the vertical distance between the top of the excavated seam and the ground surface given in feet or meters, Fig. 1. The angle of principal influence, β, is the angle between the horizontal axis and the line connecting the projection of the inflection point position of the subsidence trough, at the seam level, with the surface point of "zero influence", i.e., where subsidence is about 0.6 percent of the maximum subsidence value [9]. Maximum subsidence, S_{max}, is the maximum expected vertical displacement for a given extraction area.

In order to provide a more accurate means of predicting mining induced deformations, Eq. (1) can be modified by incorporating an edge effect offset, d, as shown by Eq. (2) and Fig. 2. This offset is defined as the distance between the inflection point of the subsidence profile, designating the location of the transition from tensile to compressive strains, and the rib of the excavation. One is able to determine the offset distance as a function of the post-failure behavior of the rib line as well as the stiffness of the immediate roof. Similarly, empirical relationships have been developed relating the edge effect offset distance to the ratio between the panel width and panel depth. If the rib line maintains its stability, then the inflection point translates from the edge of the rib toward the center of the excavated panel (gob). However, if the rib line

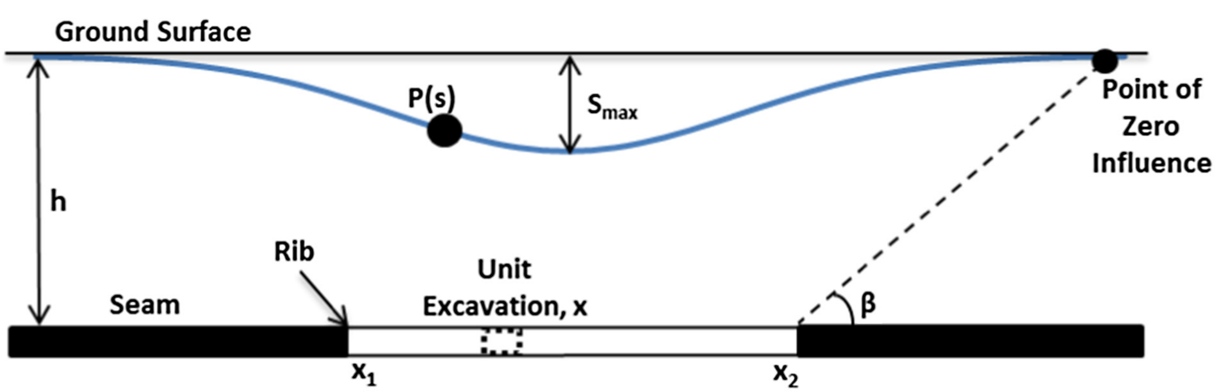

Fig. 1. Subsidence curve with input parameters.

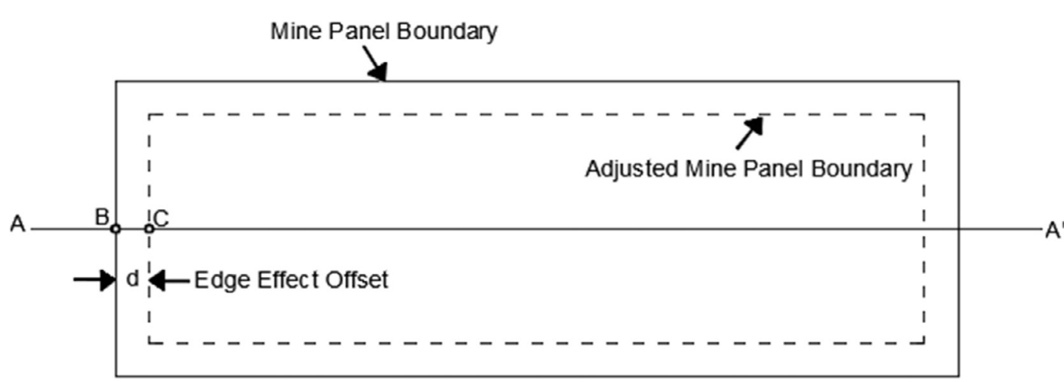

Fig. 2. Adjustment of panel boundaries by the edge effect offset, d.

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