Subsidence studies in Indian coalfields by a semi-empirical approach

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Abstract Partial norms based on an empirical approach have been developed for prediction of subsidence in Indian coalfields but these have resulted in overestimation of subsidence values. So a hybrid approach of studying the subsidence behaviour by numerical modelling and fitting in the field data in the results to develop a semi-empirical model has been followed in the present studies. Effects of each of subsidence contributing factors on maximum possible subsidence $S_{\text{max}}$ has been evaluated by varying the value of that factor in the model and keeping other factors constant. The assessment of $S_{\text{max}}$ takes account of the effects of seam thickness, depth of workings, goaf support, extraction ratio, other working seams, overburden rockmass and dip of the seam. A profile function has been suggested for Indian coalfields. The comparison with other methods showed that the predicted values of the subsidence, slope and strain profiles were the close to the field measurements.

INTRODUCTION

Partial norms developed for subsidence prediction based on empirical approach could not yield satisfactory results because of the lack of adequate database covering a variety of situations for such predictions. Subsidence studies using two dimensional material model and those using numerical modelling (Shankar & Dhar, 1989) though helped in understanding the mechanism of mine subsidence in Indian coalfields, could not result in the development of a subsidence prediction model because of the limitations of these approaches. This paper presents a hybrid approach of carrying out the parametric studies by numerical modelling of subsidence and using these qualitative results to the available field database in order to develop a semi-empirical method of prediction of subsidence in Indian coalfields.

DATA

Numerical modelling

Numerical modelling was carried out by using the Displacement Discontinuity Method (Sinha, 1979) which is a subvariation of the Boundary Element Method. Two models were used for numerical modelling. The first is two dimensional, assuming the overburden rockmass as homogeneous, linearly elastic and transversely anisotropic medium.
The second is three dimensional, also assuming a homogeneous, linearly elastic and isotropic medium. The coal seam is assumed to be a thin crack in this overburden rockmass. The mechanical characteristics of the host rockmass above and below the mine workings are highly anisotropic and complex; therefore it has not been possible to accurately simulate the rock behaviour and predict the subsidence deformations caused by underground excavations (Bahuguna et al., 1991). Therefore the simple Boundary Element Method analysis, based on the above assumptions, was used only for the qualitative assessment of the effect of each subsidence contributing factor by varying its value in the model and keeping other factors constant. These qualitative results gave the insight and helped in developing a semi-empirical method by using the field data base.

PARAMETRIC STUDIES

The analysis of parametric studies by numerical modelling showed the following effects of individual subsidence influencing factors:
(a) Parametric studies confirmed that maximum possible subsidence $S_{\text{max}}$ or maximum subsidence $S_0$ was directly proportional to the extracted thickness of the seam.
(b) The effect of partial extraction in board and pillar mines was found to be depending upon the geometry of extraction, mining induced stressed and stiffness of coal seam, or yielding capacity and size of the remnant pillars. The stiffer the coal seam, the lesser is the magnitude of subsidence on the surface.
(c) The subsidence was also found to be depending on the strength and condition of overburden rockmass. Presence of more hard-rock layers in the overburden results in less subsidence at the surface. On the other hand, the discontinuities or planes of weakness make the overburden weaker and result in increased subsidence.
(d) The nature of overburden rockmass was found to be affecting not only the magnitude of the subsidence but also the shape and extent of the subsidence profile. The more fragmented the rockmass is, the larger is the angle of draw, the smaller is the subsidence over ribside and closer to the centre of panel is the point of inflection of subsidence profile curve. This implies that for weaker overburden rockmass the extent of subsidence trough extends to remoter areas and is deeper in the central portion.
(e) The magnitude of subsidence, and the extent and shape of subsidence trough are also found to be dependent upon the width-depth ratio ($w/d$) of the panel. The magnitude of maximum subsidence is found to be increasing with increasing width-depth ratio until critical width is reached, beyond which it stabilizes. Similar effect is observed on the shape of the subsidence trough. For smaller $w/d$ ratios the subsidence trough is found to be shallower than for larger $w/d$ ratios and beyond the critical width the shape of the sides of the trough remains unchanged.
(f) The magnitude of the maximum subsidence is found to be increasing with the depth of the working. This increase gradually decreases with larger depths.
(g) The effect of sand stowing is found to be dependent on the degree of stowing. The higher the degree of stowing, the smaller is the subsidence, whereas in case of caving the magnitude of subsidence is found to be maximal for the given mining and geological condition.
(h) The effect of the dip of the seam is reduction of magnitude of subsidence in dipping seams whereas the shape of the subsidence profile also changed.
Semi-empirical method

The results of the above parametric studies have been incorporated in a field data base to develop a semi-empirical method. The prediction of maximum possible subsidence \((S_{\text{max}})\) and maximum subsidence \((S_0)\) have been discussed elsewhere (Bahuguna et al., 1993) and is based on the following formula:

\[
S_{\text{max}} = mg_f e R_f d_f d'^t
\]  

(1)

where \(m\) is the extracted thickness of the seam; \(g_f = \) goaf treatment factor [0.95 for caving, 0.07-0.1 for sand stowing]; \(e\) is the extraction factor; \(R_f\) is the rock factor for effect of composition and strength of overburden rock mass (Fig. 1); \(d_f\) is the factor for the effect of depth of the workings [0.87 for depths up to 400 m and 1.0 for more than 400 m], \(d'\) is the factor for effect of dip of the seam \([= \cos \alpha, \text{where } \alpha \text{ is the angle of dip}]\); \(t\) is the time factor [to be taken as 1 for finished subsidence]. The maximum subsidence is given by:

\[
S_0 = S_{\text{max}} \left[1 - e^{n(l/d)}\right] \left[1 - e^{n(w/d)}\right]
\]  

(2)

where \(l, w\) and \(d\) are the length, width and depth of the panel and \(n\) is an empirical constant whose average value may be taken equal to 3.0.

![Fig. 1 Rock factor for various types of overburden rock mass.](image)

Prediction of subsidence profile

A profile function was developed for Indian coal mines to predict subsidence along a given line. The point undergoing maximum subsidence \(S_0\) or maximum possible subsidence \(S_{\text{max}}\) lies in the centre of a rectangular panel. The extent of subsidence trough along a profile line passing through the centre stretches outwards up to a distance \(r = \)
$d \tan \phi$ from the ribside where $d$ is the depth of seam on the ribside and $\phi$ is the angle of draw. For dipping seams $d$ will be different on both rib sides. Similarly the angle of draw will be different on static and dynamic end so the total length of the subsidence profile will be $d_1 \tan \phi_1 + w + d_2 \tan \phi_2$ where $w$ is the width of the excavation. The critical diameter $r$ is given by

$$r = r_1 + r_2$$

$$r = d_1 \tan \phi_1 + d_2 \tan \phi_2$$

The subsidence $s_i$ at a point $i$ at a distance $x_i$ from a point undergoing maximum subsidence $S_{\text{max}}$ or $S_0$ has been found to be given by the following expressions:

For subcritical widths:

$$S_i = S_0 \left[ e^{-\frac{M(x_i)}{(r+x_i/2)^2}} \right]$$

For critical and supercritical widths:

$$S_i = S_{\text{max}} \left[ e^{-\frac{M(x_i)}{(r+x_i/2)^2}} \right]$$

where $x_i$ is the distance of the given point from the nearest point on the profile line undergoing maximum subsidence. In the equations above $M$ is a profile constant and is dependent upon the nature of overburden rockmass. This constant governs the shape of the subsidence profile. Nomograms (Fig. 2) have been developed to find the values of $\phi_1$, $\phi_2$ and $M$ for different $w/d$ ratios and different types of overburden (Bahuguna, 1993).

### Prediction of slope, horizontal displacements and horizontal strains

The slope between two consecutive points, say $i$ and $(i-1)$, of the panel centre can geometrically be obtained as:

$$g_i = \frac{S_i - S_{i-1}}{dx}$$

where $S_i$ and $S_{i-1}$ are the subsidence of the $i$th and $(i-1)$th point and $dx$ is the distance between these two points.

The profile of horizontal displacements is similar in nature to the profile curve of slopes. Therefore a linear proportionality may be established between the two curves which suggests that horizontal displacement $u_i$ at the $i$th point from the panel centre may be given by:

$$u_i = B g_i$$

where $B$ is the proportionality constant and $g_i$ is the slope of the ground at the $i$th point. The proportionality constant has been found to be dependent on the nature of the overburden rockmass and the $w/d$ ratio of the extracted panel. The value of $B$ (Fig. 2) may be found out for a given $w/d$ ratio from the developed nomograms (Bahuguna, 1993). Once the horizontal displacements are known, the horizontal strains may be found from the following equation:
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\[ e_i = \frac{du_i}{dx} \]  \hspace{1cm} (8)

where \( e_i \) is the horizontal strain between the \( i \)th and the \((i - 1)\)th point situated at a distance \( dx \) apart and \( du_i \) is the difference in horizontal displacement of these two points.

RESULTS

The results of prediction of \( S_{\text{max}} \) by this approach have been described elsewhere (Bahuguna, 1993). Normalized subsidence, slope and horizontal strains were obtained from the developed model based on the Profile Function Method for 15 mine workings from Indian coalfields and were compared with those profiles obtained from other methods. Comparison of the profile obtained from one mine working only is being given.
here for lack of space. Figure 3 shows the subsidence profiles as obtained from the field measurements and predictions from the present method. Similarly Figs 4 and 5 show the profiles of slope and horizontal strains.

The comparison shows a good agreement of the subsidence, slope and strains profiles obtained from the present method with those obtained from field measurements.

In other cases also generally the predictions from the method given here were close to the measured values. Nomograms for the values of $R_j$, $\zeta_1$, $\zeta_2$, $M$ and $B$ may be found
for other coalfields also, to develop a suitable prediction model on the same lines. The method is simple and easy to use in the field.

REFERENCES


