Subsidence due to coal mining in India

R. P. SINGH & R. N. YADAV
Indian Institute of Technology, Department of Civil Engineering, Kanpur 208016, India

Abstract In India, every year loss of life occurs due to subsidence of land in coal mining areas. Subsidence is very prevalent in the Raniganj coal field which is a major coal producing area. The occurrence of thick coal seam at shallow depth is the main reason for the subsidence and as a result collapses have occurred in many coal mines in recent years. In the present paper, a review of coal mining subsidence in India will be presented. The Indian scientists have made efforts to predict the subsidence using empirical relations but it was not found to be successful since the geology of the coal mining area is found to be quite variable. We have made efforts to predict the subsidence occurring in the Indian coal fields in general and in particular in the Raniganj coal field using a visco-elastic model. Computed subsidence profiles of Ratibati and Shivadanga coal mines of the Raniganj coal field have been compared. The results show a reasonable match of the predicted and observed subsidence in the case of the Ratibati coal mine. In the case of the Shivadanga coal mine the predicted subsidence profile is found to be larger than the observed profile. However, the bottom of the observed troughs is found to match with the predicted troughs. Detailed analyses have been carried out to investigate the effect of mine parameters on the subsidence.

INTRODUCTION

Subsidence is an inevitable phenomenon of ground movement caused by various manmade and natural activities. The economic prosperity by the exploitation of the hidden resources in the earth is always accompanied by the adverse impacts of subsidence. Subsidence due to underground coal mining has been reported from almost all parts of the world and India being a major coal producer has been facing very severe problems of subsidence in some of its coal fields.

In the present work, we have made efforts to predict subsidence using a visco-elastic model. This model incorporates both continuous and discontinuous profiles. Detailed analyses have been carried out to predict subsidence due to underground coal mining. The validation of the model has been done by taking parameters and observed values from Ratibati and Shivadanga coal mines of the Raniganj coal field. The subsidence profiles for these coal mines have been predicted. We have found a reasonably good match between the observed and predicted subsidence profiles.
COAL MINING IN INDIA

Coal mining in India has a history of over 200 years starting from Raniganj (West Bengal) in 1774. Coal is a prime source of energy, indispensable input in steel and chemical industries. About 60% of the national commercial power requirements are fulfilled by coal. Coal production in India has rapidly increased in the last four decades. The largest reserve of coal is found in Bihar state which covers about 33.53% of the total coal reserve in India, and the second largest coal producing state Orissa covers about 23.57% of the total coal reserves in India. About 90.3% of coal is found in the states of Bihar, Orissa, West Bengal and Madhya Pradesh. The major coalfields in India are: Raniganj, Jharia, East Bokaro and West Bokaro, Panch-Kanhan and Tawa valley, Singrauli, Talcher, Chanda-Wardha, Godavari valley, and Karnpura (Fig. 1).

Fig. 1 Location map showing coal reserves in India.
SUBSIDENCE PROBLEM

Jharia (JCF) and Raniganj (RCF) coal fields are facing significant subsidence problem due to underground coal mining. Extraction of thick seams at shallow depths has damaged the ground surface in the form of subsidence and formation of cracks reaching up to the surface, enhancing the chances of spontaneous heating of coal seams leading to mine fires. The JCF has experienced over 70 mine fire spread over an area of 17.32 km$^2$. In JCF, the coal mining started in the beginning of the twentieth century and is still practised. The board and pillar method of underground mining is very common, this method is used in more than 90% of Indian coal fields. In JCF, about 57% of the area is affected by subsidence, fire areas, overburden dumps and abandoned quarries; and subsidence affects 33% of the area. Mining activities in RCF have degraded a sizable land area and have endangered about 42 localities (townships, villages and other residential areas). The subsided area in the Raniganj coalfield covers about 43.43 km$^2$ (CMRS, 1991).

SUBSIDENCE PREDICTION

Various efforts have been made by scientists from the UK, USA, China, Australia and other countries to predict the subsidence of coal mines using numerous methods such as the profile function methods (Kumar et al., 1983), the influence function methods (Ren et al., 1989) and the void diffusion method (Hao & Ma, 1990). Apart from these methods, many theoretical studies have been carried out using stochastic (Litwiniszyn, 1964), elastic (Salamon, 1977; and Berry, 1977), and visco-elastic (Zeng & Kou, 1992) methods. Recent efforts include the use of finite element methods (Reddish, 1984; Jones & Kohli, 1985; Siriwardne & Amanat, 1985, 1988) and distinct element method (Calthard & Dutton, 1988) in the prediction of subsidence. In India, numerical modelling for the prediction of subsidence caused by ground water withdrawal (Mishra et al., 1993) has been carried out. Efforts have been made by the Indian scientists to use the best known empirical method developed by the National Coal Board (NCB) in the UK, however, it was not applicable in the Indian coal field areas, since the NCB method are applicable for the longwall coal mines whereas in India most of the coal mines use the board and pillar method. Generally, Indian scientists have made efforts to predict subsidence based on empirical methods which are restricted only to continuous subsidence profiles and are highly dependent on local conditions. In India, coal is found at numerous places, the geology of these coal fields is highly variable from one field to another. A theoretical model based on physical concepts and an understanding of the mechanism of subsidence are needed in order to anticipate continuous as well as discontinuous subsidence profiles in Indian coal fields.

SUBSIDENCE MODEL

The coal mine subsidence model considered is shown in Fig. 2(a), which is representative of continuous as well as discontinuous subsidence profiles. In this model, a coal mine is considered as a beam or plate (coal layer), resting on a visco-elastic
medium (the overburden and the rock strata underlying the coal seam) which deforms only due to transverse shear due to the excavation of the coal. Thus, the layers of a coal mine model are represented by a semi-infinite medium. Various components of the coal mine (Fig. 3(a)) model are:
(a) dashpot — represents the time-dependent property of infilled material,
(b) shear layer — ensures inter-dependence of springs and dashpots,
(c) spring — represents the time-independent property of infilled material,
(d) overburden — depicts rock strata over excavated underground mine.
If we consider the displacement of the ground surface $w$ due to a line load $P$ (Fig. 2(b)), $\mu$ is viscosity coefficient related to the shear deformation of infilled material, and $\eta$ is an visco-compressibility coefficient of infilled material, the governing equation for subsidence of the earth’s surface is written as (Singh & Yadav, 1995):

$$\frac{\partial^2}{\partial t^2} (\nabla - \lambda^2) w = 0$$

where $\lambda^2 = \eta/\mu$. The vertical displacement of the ground surface is given by equation (1).

**FLEXIBLE OVERBURDEN**

The subsidence outside ($w_0$) the loaded region $|x| > b$ and inside ($w_i$) the loaded region $-b \leq x \leq b$ is given by the following equations (Singh & Yadav, 1995):

![Diagram of visco-elastic model and forces acting on shear layer element.](image-url)
Subsidence due to coal mining in India

![Stratigraphic Column with physical parameters](image)

**Fig. 3** Borehole strata with physical parameters from the Raniganj coal field.

\[ w_0 + P t \eta^{-1} \sinh(\lambda b) e^{-\lambda x} \quad x \geq b \quad \text{(outside the loaded region)} \]  
\[ w_i = P t \eta^{-1} \left[ 1 - e^{-\lambda b} \cosh(\lambda x) \right] \quad -b \geq x \geq b \quad \text{(inside the loaded region)} \]

RIGID OVERBURDEN

The subsidence outside the overburden \( x \geq b \) is written as (Singh & Yadav, 1995):

\[ w_i(x, t) = w_0 e^{-\lambda(x-b)} \quad x \geq b \]  

and the subsidence inside the overburden region \(-b \leq x \leq b\) is written as (Singh & Yadav, 1995):

\[ w_0(t) = \lambda \eta^{-1} \frac{P b t}{(\lambda b + 1)} \]  

The ground surface will subside similar to a stepped subsidence profile.

MODEL PARAMETERS

The average value of the above parameters are easily available from the two coal mines (Ratibati and Shivadanga) in the Raniganj coal field, however it was very difficult to get
actual parameters for the two coal mines. In the present work the above parameters used for the prediction of subsidence profiles for two coal mines are taken from the literature (Venkateshwarlu, 1986; and CMRS, 1991). Apart from these parameters, the calculation of subsidence also requires the viscosity coefficient related to the shear deformation of the infilled material \( (\mu) \), and the visco-compressibility coefficient \( (\eta) \) of infilled materials which have been taken from Venkateshwarlu (1986). The borehole strata chart along with the average parameters of the layers are shown in Fig. 3.

RESULTS AND DISCUSSION

The actual observed subsidence profiles at Ratibati and Shivadanga coal mines are shown by star (*) symbol, respectively in Figs 4(a) and 4(b). The maximum subsidence occurs at the centre of each mine, and the observed subsidence is found to be up to 1 m at Ratibati and up to about 1.5 m at the Shivadanga coal mines. The effect of subsidence on the surface is seen up to about 120 m in the case of Ratibati and up to about 240 m in the case of Shivadanga. The nature of the observed subsidence profiles in the two mines is very similar with little difference in the bottom of the subsidence troughs (Figs 4(a) and (b)).

We have taken a generalized coal mine model representative of coal mines of the Raniganj coal field and carried out numerical studies to predict the subsidence profiles at the Ratibati and Shivadanga coal mines. The coal mine parameters used for the two mines are given in Table 1. The average strength of the rock strata given in Fig. 3 is taken for the two coal mines. From our detailed analyses, we have found a reasonably close match between predicted and observed profiles in the case of subsidence with rigid overburden for the Ratibati coal mine and the case of subsidence with flexible overburden for the Shivadanga coal mine. However, the values of the elastic parameters of the overburden in the two mines are taken as equal. We have shown the computed

![Fig. 4 Observed and predicted subsidence profile at (a) the Ratibati coal mine, and (b) the Shivadanga coal mine.](image-url)
Table 1 Coal mine parameters used for the Ratibati coal mine and Shivadanga coal mine.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ratibati coal mine</th>
<th>Shivadanga coal mine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction width ($w$)</td>
<td>122 m</td>
<td>214 m</td>
</tr>
<tr>
<td>Overburden thickness ($H$)</td>
<td>42.5 m</td>
<td>104 m</td>
</tr>
<tr>
<td>Extraction thickness</td>
<td>3.8 m</td>
<td>2.4 m</td>
</tr>
<tr>
<td>Extraction length</td>
<td>189 m</td>
<td>220 m</td>
</tr>
</tbody>
</table>

Subsidence due to coal mining in India

subsidence up to 200 m from the centre of the Ratibati coal mine with the solid line in Fig. 4(a). The predicted (computed) subsidence profile is found to be stepped and quite similar to the observed profile (Fig. 4(a)) for the Ratibati coal mine. The predicted subsidence in the case of the Shivadanga coal mine is shown in Fig. 4(b) (solid curve) which is found to be smooth in the case of Shivadanga (flexible overburden) coal mine, the bottom of the computed and predicted subsidence troughs are similar, however the nature of the subsidence profile is quite different (Fig. 4(b)). This may be attributed to the difference between the parameters used for calculation and the real data. The value of the physical parameters used are only average and do not account for any change with time and other factors and also various inhomogeneities present in the overburden.

The strength of a rock mass changes with time, therefore the subsidence in a coal mine is also time dependent. From Fig. 5(a), it is found that the subsidence increases with time, however the subsidence attains a maximum value which remains almost constant with the increase in time. It is clearly seen that the subsidence changes only at the initial period of two years and afterwards it becomes stabilized (Fig. 5(a)). The subsidence is found to increase with the decrease of overburden thickness for a particular width of coal seam (Fig. 5(b)). For a particular overburden thickness of coal mine, the subsidence is found to increase with the increase of extraction width (Fig. 5(b)).

Fig. 5 (a) Variation of subsidence with time. (b) Effect of overburden thickness and extraction width on subsidence.
CONCLUSIONS

The present study was carried out to predict the subsidence profiles due to underground coal mining in Indian coal fields. For the validation of the proposed visco-elastic model for Indian coal mines, the subsidence has been investigated in the Ratibati and Shivadanga coal mines. In both the mines, the nature of the predicted subsidence profiles has been found quite similar to that observed in the field. The maximum computed subsidence has also been found to be in good agreement with the observed data in both areas. In the case of the Shivadanga coal mine, the overall nature of the subsidence is similar, however, the predicted subsidence profile is spread over a larger area compared to that observed. The present results also show the pronounced effect of the width of the extraction and the overburden thickness on subsidence. The results discussed in the present paper will be very useful for coal mining planning in India.

Acknowledgements The part of the work is supported through a research project sponsored by the All India Council of Technical Education (AICTE), New Delhi.

REFERENCES


