Dynamic subsidence prediction over longwall mining in Abu-Tartur mines, Egypt

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Abstract The ultimate goal of surface subsidence studies is to use the acquired knowledge of surface subsidence in structural and environmental protection against subsidence damage and disturbance. For this purpose, the accurate prediction of dynamic subsidence plays a much more important role than that of final subsidence. Based on the subsidence data collected through a subsidence monitoring programme conducted over two longwall panels in Abu-Tartur phosphate mines, a mathematical model has been proposed for predicting the final subsidence. In this paper a physical model study is carried out on the limestone specimens to determine the strain rate. The rate of subsidence for the limestone layer which is the upper one in the geological succession at Abu-Tartur area, is calculated and equals $0.797 \text{ m year}^{-1}$. The percentage error between the \textit{in situ} final subsidence and the predicted one from physical model after 2 years from the beginning of working is 7.29%, while this error is 1.81% after 14 years stoppage of the face.

INTRODUCTION

Prediction of ground subsidence associated with underground mining based on the shape of final settlement trough of ground surface could be insufficient. Surface subsidence due to mining is a dynamic process which obeys mechanical principles. Several methods for the investigation of the subsidence process related to elasticity, FEM and BEM have been studied for many years (Berry & Sales, 1961, 1962; Crouch & Starfield, 1983; and Eissa, 1990). However, a marked progress has not been achieved in describing the dynamic subsidence. Applying the principles of rheology, the nature of the process of subsidence can be revealed more effectively in time and space domains. Hence, the results will greatly improve the protection of undermined surface structures. Visco-elasticity was applied to study the time dependent surface subsidence caused by underground mining (Zhuoqiao & Xinjian, 1992). The presented viscoelastic analyses have been given a clear physical interpretation of the time factor $C$, which is a measure of the rock strain rate. Its value can be expressed and defined either by means of laboratory tests on rock specimen or from mine subsidence surveys (Xia & Zhong, 1988).

Konthe (1959) made the well-known assumption, investigating the mine subsidence process, which assumed that the surface will subside when an underlying body of ore is exploited,

$$\frac{dW(t)}{dt} = C[W_k - W(t)]$$

(1)
where $W_k$ is the final subsidence of a surface point, $W(t)$ is the subsidence of a point at time $t$ and $C$ is the subsidence velocity factor, or time factor.

The above relationship was used to describe mining subsidence phenomena, and notable successes have been achieved. It must be mentioned that the time factor $C$, in Konthe's approach could be determined by mine subsidence surveys.

Based on the collected data through the subsidence monitoring programme conducted over two longwall panels in an Illinois coal mine, empirical models have been proposed for predicting final and dynamic subsidence for that region (Peng & Luo, 1991). At Abu-Tartur experimental mine the vertical components of surface movement are measured over two longwall panels separated by rib pillars of width 30 m. A mathematical model to predict the final subsidence is developed (Gomma et al., 1994).

In this paper a simple loading frame is designed to give a static load to the beam shaped rock specimen. A physical model from limestone rock is tested by the loading frame under the action of distributed load (75% of bending strength). The strain is measured at different positions located on the specimen by means of electric wire strain gauges connected to data logger. By means of geometrical similarity the measured strains in the laboratory are transformed to the prototype.

**Subsidence monitoring at the Abu-Tartur area**

Surface subsidence over two longwall panels at the experimental phosphate mine 150 m below the surface have been monitored during the period from February 1980 to December 1981. The two panels shown in Fig. 1 were 500 m long and 60 m wide. The mining height was about 2.3 m and the rate of face advance was 0.63 m/shift (Technical Report, 1983). The measured values of vertical components of surface subsidence are shown in Fig. 1. A mathematical model to predict the final surface subsidence in this

**Fig. 1 Network of the subsidence measurements.**
area was developed. From the proposed model the tilt and curvature were obtained (Gomma et al., 1994).

**Method of obtaining time factor $C$ from mine subsidence surveys**

When a surface point $P$ is undermined by a subcritical, critical or supercritical excavation, the subsidence development curve can be obtained by levelling measurements once per week or per month. Figure 2 shows a typical subsidence development curve. The abscissa represents time $t$, the ordinate is the subsidence value. From a given point $A$ on the excavation existing far beyond the critical area which means that $W_k$ is unchanged hereafter. Below point $A$, this curve can be represented by equation (1), with $W_k$ constant. At any point 13 below $A$, the slope of the tangent to the curve at point $B$ ($\tan \alpha$) is $\frac{dW(t)}{dt}$ as follows:

$$\tan \alpha = \frac{dW(t)}{dt} = C[W_k - W(t)]$$

then

$$C = \frac{\tan \alpha}{W_k - W(t)} \text{ year}^{-1}$$

By measuring $W(t)$ and $\tan \alpha$, the time factor $C$ can be obtained graphically or analytically. With $C$ known, the subsidence at a surface point at any time can be calculated.

![Fig. 2 Typical subsidence development curve.](image)

**Determination of subsidence rate from Konthe’s hypothesis**

From equation (1) the subsidence rate can be calculated as follows:

$$\frac{dW(t)}{dt} = C[W_k - W(t)]$$

because $W_k$ is constant,

$$\int \frac{dW(t)}{W_k - W_t} = \int c dt$$

$$-\ln(W_k - W_t) = Ct + C_1$$
From the boundary conditions the constant \( C_1 \) is obtained, at \( t = 0, W_t = 0 \) then:

\[
\begin{align*}
C_1 &= -\ln W_k \\
\ln(W_k - W_t) - \ln W_k &= -Ct \\
\frac{W_k - W_t}{W_k} &= -Ct \\
W_k - W_t &= W_k e^{-Ct} \\
W_t &= W_k (1 - e^{-Ct})
\end{align*}
\]  

(4)

By substitution from equation (4) in equation (1)

\[
\frac{dW(t)}{dt} = CW_k e^{-Ct} \text{ m year}^{-1}
\]

(5)

It is obvious that equation (4) gives the subsidence at any time \( t \) and equation (5) gives the subsidence rate.

**Experimental work and results**

The upper layer at Abu-Tartur geological succession consists of limestone of average thickness 70 m. which bends due to phosphate ore exploitation. Rock specimens from limestone deposit are tested to determine the bending strength (2.22 kN cm\(^{-1}\)). A rock specimen of size \( 3 \times 3 \times 10 \text{ cm}^3 \) is taken as a physical model and tested by the loading frame shown in Fig. 3 under the action of distributed load which achieves 75% of the bending strength. The strains are measured at different positions on the specimen by means of electric wire strain gauges connected with data logger which has an accuracy of 0.0005 mm cm\(^{-1}\).

The measured strains during four months at the point P located at the centre of the specimen are shown in Table 1. These strains are transformed to the prototype (vertical subsidence) by means of geometrical similarity. The vertical subsidence versus time is shown in Fig. 4. From this figure the following dynamic subsidence parameters are

![Fig. 3 Loading frame and data logger for creep test.](image-url)
Table 1 The values of strains at point P at the centre of limestone specimen and the equivalent vertical subsidence at different times.

<table>
<thead>
<tr>
<th>Time</th>
<th>Strain in the model (mm m(^{-1}))</th>
<th>Vertical subsidence in the prototype (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st week</td>
<td>0.0030</td>
<td>0.49</td>
</tr>
<tr>
<td>2nd week</td>
<td>0.0040</td>
<td>0.65</td>
</tr>
<tr>
<td>3rd week</td>
<td>0.0060</td>
<td>0.89</td>
</tr>
<tr>
<td>1st month</td>
<td>0.0090</td>
<td>1.47</td>
</tr>
<tr>
<td>2nd month</td>
<td>0.0100</td>
<td>1.63</td>
</tr>
<tr>
<td>3rd month</td>
<td>0.0110</td>
<td>1.80</td>
</tr>
<tr>
<td>4th month</td>
<td>0.0135</td>
<td>2.21</td>
</tr>
</tbody>
</table>

obtained: \( \alpha = 30^\circ, W_k = 2.21 \text{ m}, W_t = 1.5 \text{ m} \) at \( t = 1 \text{ month} \). The time factor \( C \) from equation (3) is:

\[
C = \frac{\tan 30}{2.21 - 1.5} = 0.813 \text{ year}^{-1}
\]

From equation (5) the rate of subsidence will be:

\[
\frac{dW(t)}{dt} = 2.21 \times 0.813 e^{-0.813 \times t} = 0.797 \text{ m year}^{-1}
\]

The maximum and final vertical subsidence at station \( F_5 \), (Fig. 1) over the longwall panel is measured by levelling and its value was found to be 1.92 m. Applying equation (4), \( W_t \) after about 2 years from the beginning of working is given as follows:

\[
W_t = 2.21(1 - e^{-0.813 \times 2}) = 1.78 \text{ m}
\]

The percentage error between \textit{in situ} vertical subsidence and the predicted one from the physical model is 7.29%. After 14 years stoppage of the face, the subsidence over the longwall panel at station \( F_5 \) is measured and its value equals 2.17 m. From equation (4), \( W \) at \( t = 14 \text{ years} \) will be:

![Fig. 4 Vertical subsidence vs. time for limestone specimen at point P.](image)
$W(t) = 2.21(1 - e^{0.813 \cdot 14}) = 2.20$ m

The percentage error between the measured subsidence and the predicted one at station $F_5$ is 1.81%.

CONCLUSIONS

The collected data of vertical subsidence over two longwall panels in Abu-Tartur mines have provided us with an excellent opportunity to acquire a better understanding of the nature of surface subsidence process in this area. Accurate prediction of dynamic subsidence plays a much more important role than that of final subsidence. Important relationships between the time factor $C$, final subsidence $W_k$, and the subsidence velocity are obtained. From the physical model study on limestone specimens, the values of time factor $C$ and the rate of subsidence or subsidence velocity, $dW/dt$ are 0.813 l year$^{-1}$ and 0.797 m year$^{-1}$ respectively. After 2 years from the beginning of working, the percentage error between the in situ final subsidence and the predicted one is 7.29%. After 14 years from the face stoppage the percentage error is 1.81% which indicates that the suggested model can be used for accurate prediction of dynamic subsidence at Abu-Tartur area.

REFERENCES


