Journal of Engineering Sciences, Assiut University, Vol. 36, No. 3, pp.749-758, May 2008

SURFACE SUBSIDENCE PREDICTION OVER WORKING LONGWALL PANEL AT ABU-TARTUR PHOSPHATE MINES

A.A.Elashiry [(a)], W.A. Gomma [(b)] and S.S. Imbaby [(c)]

(a) Demonstrator in Mining & metallurgical Engineering Department, Faculty of Engineering, Assiut University, Assiut, Egypt.

(b)&(c) Professors in Mining& metallurgical Engineering Department, Faculty of Engineering, Assiut University, Assiut, Egypt

(Received January10, 2008 Accepted February 27, 2008)

The phenomenon of subsidence is the movement at the ground surface caused by underground excavations, which can cause severe damage to buildings or structures on the surface and infrastructure. These excavations exert redistribution of the original stresses around the openings. Different methods have been adopted to predict and quantify the subsidence with the subsidence parameters. These methods can be classified into three categories 1) Empirical methods based on the analysis of the field measurement, 2) Mathematical theories, 3) Numerical models including Finite Elements, Boundary Elements and Distinct Elements methods. In this paper, the surface subsidence data were collected over working longwall panel at Abu-Tartur phosphate mines after the face had been advanced 280m. Different mathematical theories namely Bals', Peng's, Knothe's and Peck's theories are applied to predict the subsidence trough over the excavated panel. The obtained results are compared with the measured ones. It was found that Peck's theory coincides well with the measured data. The degree of ground surface tilt, surface curvature and strain are derived from Peck's theory.

KEYWORDS: *Subsidence prediction, longwall mining, Abu-Tartur, mathematical models*

1. INTRODUCTION

The ground subsidence process induced by underground longwall mining is a complicated process, as it deals with the process of subsidence-induced damage to the surface and sub-surface structures as building, pipelines, railways, neighboring underground workings, etc.[1]. The factors which affect the severity of mining induced structure damages due to subsidence over mines may be grouped into three categories, a) mining factors related to mining methods and dimensions of the excavation, e.g. panel dimensions and its depth below the surface, method of support, extracted height and rate of face advance, b) site factors which refer to the geotechnical conditions influencing mining subsidence, such as type of strata, soil and rock properties, structural features, hydrology and previous workings, c) structure factors should also be considered when dealing with possible damage to structures. Some of these factors are size and shape of structure, type of foundation and construction method, etc. [2].

The prediction of subsidence trough and determination of subsidence parameters such as tilt, curvature, strain …etc. are very important for protecting surface structures against damages. Subsidence monitoring and prediction has a history of more than 100 years. Most of the early prediction theories were developed by mine surveyors. On the contrary, over the past twenty years, many mines have started recognizing that new monitoring techniques to develop empirical methods and sophisticated numerical modelling of ground surface subsidence. It was found that these techniques were useful not only for legal liability and environmental control purposes but they may give also better understanding of the mechanism of rock strata deformation which leads to the development of safer and more economical methods [3].

Different methods for studying surface subsidence, reviewed by Brauner [4], are generally divided into three categories 1) Empirical methods, 2) Mathematical theory, and 3) Numerical models. Empirical methods involve the following: a) analysis of data gathered from study of existing subsidence to enable predicting future subsidence effects. This method is a good choice to predict subsidence in the regions where initial data were taken, but their geographic extension is usually restricted [5]. The most of popular empirical methods for predicting mining subsidence is the one developed by the National Coal Board [NCB] in England. NCB method has assumed that the subsidence profile is related to the width to depth ratio of the mined panel and to the seam thickness [6]. b) Physical models entail the construction of a scale model of the strata involved by a material, such as plaster. This expensive technique helped to understand strata mechanics and subsidence mechanisms but it was not a good tool to predict displacement [5].

The mathematical approach to calculate movement in strata affected by underlying working can be kept at a justifiable level only if certain simplified assumptions are made. Thus in many procedures the rock mass is regarded as continuum, the separate constituents of which, are held together by cohesive forces [7]. Another definition is derived from mechanical relations between the loads (surface and body forces, initial stresses) and internal stresses. The mathematical models are able to deal with a wide range of mining conditions than empirical models. Gomma et al. [6] analyzed the elastic ground movement for three conditions of underground excavations, a) nonclosure, (floor and roof never meet), b) partial closure and c) complete closure. The calculated displacements were smaller than those encountered in practice. Mathematical models have not achieved much success to date, mainly due to the difficulty of representing complex geologic properties of the strata in simple mathematical terms. [8].

Numerical models have been made possible by advances in computer technology based on numerical approximations of the governing equations, i.e. the differential equations of equilibrium, the strain-displacement relationships, the stress-strain equations and the strength-stress relationships. They can simulate non-homogeneous, non-linear material behavior and complicated mine geometries, including Finite Elements, Boundary Elements, and Distinct Elements methods are developed [9].

2. SUBSIDENCE MONITORING AT ABU-TARTUR AREA

The phosphate deposit at Abu-Tartur area, located at 150m below the ground surface is exploited by longwall mining method. Three panels, 1200m long and 150m wide, have been developed and only one panel is being mined now by retreat mining method. The layout of the working panel is shown in [Fig. 1].

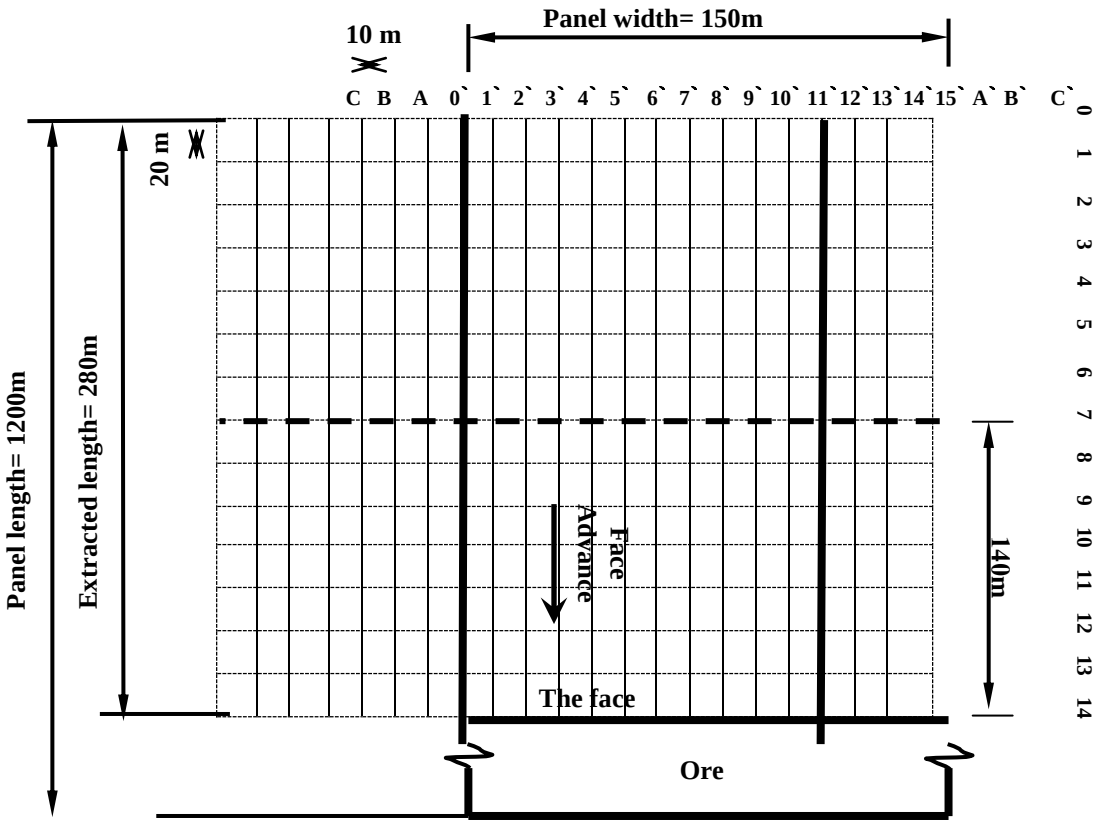


Fig.(1) Layout of working panel at Abu-Tartur phosphate mine and the grid of measurements.

Surface subsidence over working longwall panel has been monitored after the face has advanced 280m. The mining height is about 3m and rate of face advance is 0.63 m/day.

The vertical component of subsidence is measured along transversal profile 7. The measured values are plotted as shown in [Fig. 2].

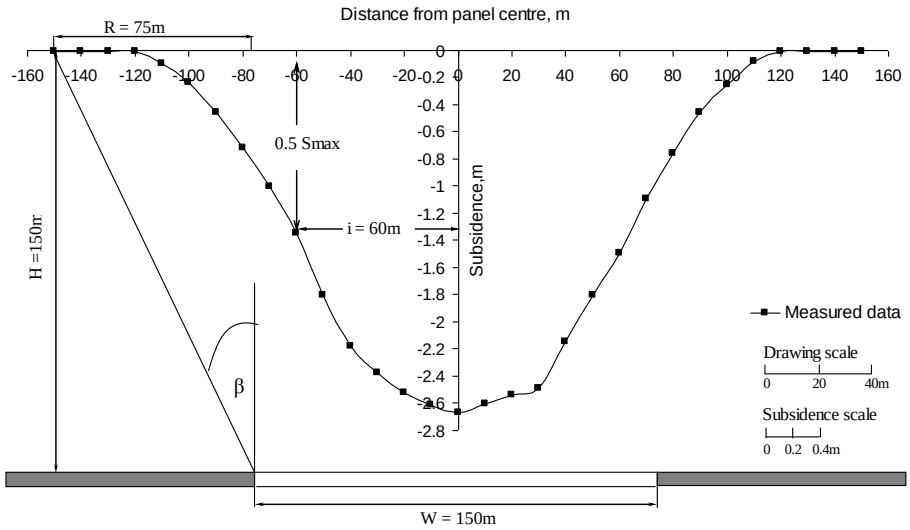


Fig.(2) The measured subsidence at transversal profile 7 over working panel.

3. MATHEMATICAL PREDICTION METHODS

Many mathematical theories are applied to predict the subsidence trough. These theories may be summarized as follows:

3.1 Bals' theory

Bals' theory [9], is based on Newtonian gravitational law, where the influence on the surface is inversely proportional to the squared distance between the extracted particular element from the seam and the surface. It has the following form:

$$S_X = \frac{S_{\max}}{\pi}\left[\tan^{-1}\frac{x+a}{H} - \tan^{-1}\frac{x-a}{H}\right] \quad (1)$$

where: S_x = subsidence at any point x from the panel centre.
S_{max} = maximum subsidence.
H = depth below the surface
2a = width of panel.

The maximum subsidence occurs at the panel centre and is equal to:

$$S_{max} = \eta\, h \quad (2)$$

where: η = Subsidence factor (0.8 – 1 in case of extraction with caving)
h = extraction seam height.

3.2 Peng's theory

The prediction model for Peng's theory used in this formulation is based on the hyperbolic tangent formulation [10]. It has the following form:

$$S_X = \frac{S_{\max}}{\pi}\left[\tanh\frac{2(x+a)}{B} - \tanh\frac{2x}{B}\right] \quad (3)$$

where: B = H cot γ.

γ = 90 - β.

β = angle of draw which depends on the overburden properties.

The area of influence may be determined by the angle of draw. It is an angle between the vertical line at the panel edge and the line connecting the edge of subsidence trough (point of zero subsidence) and the panel edge as shown in [Fig. 3].

where: tan β = R / H.

R = radius of major influence.

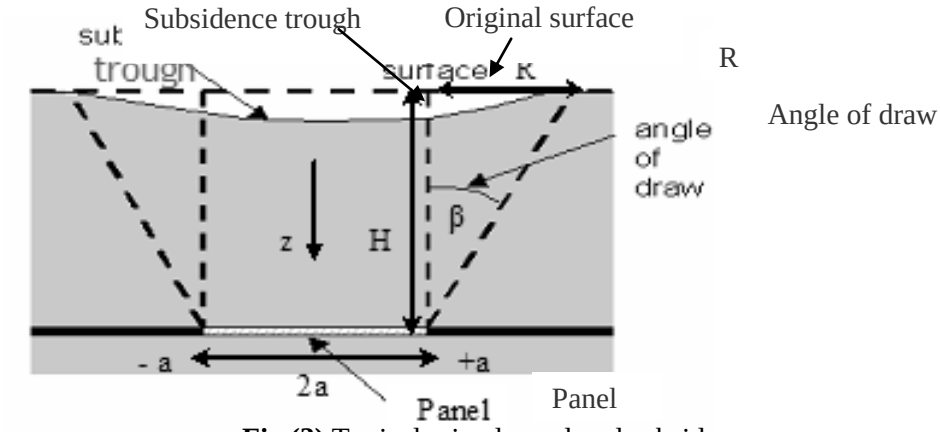


Fig.(3) Typical mined panel and subsidence

3.3 Knothe's theory

Influence Function of Knothe's theory is based on a Gaussian distribution function [9], and has the following form:

$$S_X = \frac{h}{r}\int_{-a}^{+a} e^{-\pi\frac{(x-\xi)^2}{r^2}}\,d\xi \quad (4)$$

where, x and ξ are the horizontal co-ordinates in the surface and at the seam respectively. The Integration of equation (4) when the extraction extends from –a to +a gives the following form:

$$S_X = \frac{h}{2}\left[erf\,\frac{\sqrt{\pi}}{r}(x+a) - erf\,\frac{\sqrt{\pi}}{r}(x-a)\right] \quad (5)$$

3.4 Peck's theory

A transverse surface settlement trough obtained immediately after the mine excavation can be described by the Gaussian distribution as suggested by Peck [11]. It has the following form:

$$S_X = S_{\max}\exp(-x^2/2i^2) \quad (6)$$

where i: is the distance of inflection point of the subsidence trough. Coincidentally the subsidence at the inflection point is one-half of the maximum possible subsidence [12].

4. RESULTS AND DISCUSSION:

The geometrical characteristics at Abu-Tartur working panel are:

W = 2a = width of panel = 150m

h = mining height = 3m

H = average depth of phosphate deposit below the surface = 150m.

The maximum subsidence from measurement at profile (7) as shown in [Fig. 2] is 2.67m, then the subsidence factor will be:

η = Smax / h = 2.67 / 3= 0.89

The radius of major influences (R) from [Fig.2] is 75 m, and tan β = 75 / 150 = 0.5, $\beta = 27^{o}$.

The distance of inflection point of the subsidence trough (i) occurs at distance 60 m from panel centre because the value of subsidence at this point equal approximately to one-half of the maximum subsidence as shown in [Fig.2].

The mined area is a critical case when the width of the extracted area ranges between 0.9 and 2.0 times the depth of cover rocks or when W/H=2tan β [13], then the studying mined area is critical.

Equations (1), (3), (5) and (6) are applied to predict the subsidence trough along transversal profile 7 as shown in [Fig.2]. It has been found that the predicted surface subsidence values using Peck's theory have small differences compared with the measured data as shown in [Fig. 4]. The values of the obtained correlation coefficients (r) calculated by various theories are shown in table (1).

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum (x^2) - \sum (x)^2}\sqrt{n\sum (y^2) - \sum (y)^2}} \qquad (7)$$

Table (1) correlation coefficients values obtained from various theories.

Theory	Coefficient of correlation, r
Bals	0.83
Peng	0.94
Knothe	0.974
Peck	0.992

The coefficient of correlation is a measure of the degree of association between two variables x and y. The correlation coefficient is usually denoted by (r) and measures both the degree and indicates the direction of a relationship, which varies from -1 to 0 to +1[14].

From table (1) r value obtained by the theory of Peck are higher than other theories.

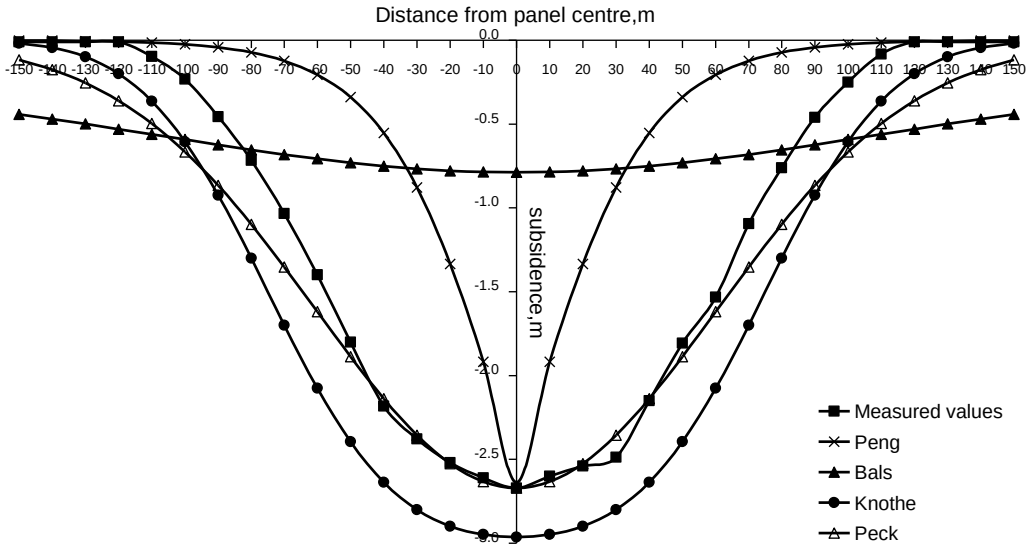


Fig. (4) Measured versus predicted subsidence values along transversal profile 7.

4.1 Determination of tilt, curvature and strain:

Tilt or slope of a subsidence trough is determined by dividing the difference in subsidence values between two points by the distance between them or the first derivative of Sx [7]. Applying Peck's theory (equation 6), the tilt is given by:

$$T = \frac{dS_x}{dx} \qquad T = -S_{\max}(x/i^2)e^{(-x^2/2i^2)} \tag{8}$$

The maximum value of the tilt occurs at the inflection point in each profile. It decreases towards both the centre and the edges of subsidence profile [15].

The difference in surface slope between two adjacent sections divided by the average length between the two sections is called the surface curvature [7]. From equation (8) the curvature is given by the following relation:

$$K = \frac{dT}{dx} \quad K = -S_{\max}\left((1/i^2)e^{(-x^2/2i^2)} - (x^2/i^4)e^{(-x^2/2i^2)}\right) \tag{9}$$

The behavior of curvature profile has a complicated nature, for small openings, convex curvatures occur on both sides beyond the edges of the opening while the concave curvature occurs at the centre of the opening. The magnitude of concave curvature is always larger than that of the convex ones [15].

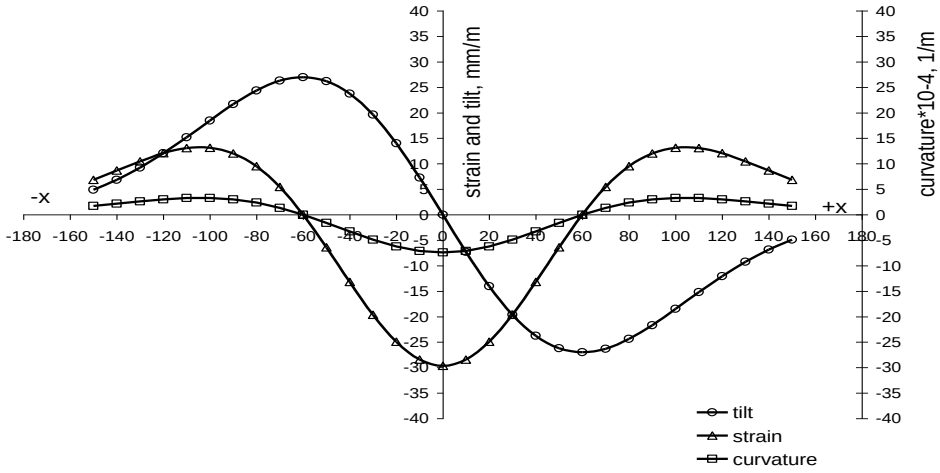
Since horizontal strains are the primary cause of structure damages, this approach was also stressed on the formulation of a strain predicted model. Due to the lack of strain data, the strain was calculated by making use of the investigation carried out by Gomma et al. [6] and can be calculated from the following relation:

$$\varepsilon = y\max / \rho \tag{10}$$

where: y_{max} = the half thickness of the upper layer of overburden which is a limestone rock of average thickness equals to 75 m [16].

ρ = the radius of curvature of the subsidence profile = 1/K

The distribution of tilt, curvature and strain calculated are shown in [Fig. 5]. The point of maximum tilt of the ground lies above a point 60m from the centre of panel (inflection point) and equals to -26.99mm/m. The line of curvature has three peaks , the maximum one lies at the panel centre and equals to -7.4×10-4 1/m. Strain component has two types, compressive (-ε) and tensile (+ ε). Compressive strain is noticed within the excavation limits with a minimum value of –29.7mm/m at the panel centre and from transition point at distance 60m from panel centre to the trough margin. The tensile strain is noticed and has a maximum value of +13.15 mm/m above a point at a distance of 100m from the panel centre. The predicted values of tilt, curvature and strain are higher than that of the dangerous category [17], as shown in table (2).



Fiq. (5) Distribution of tilt, curvature, and strain along the ground surface (Abu-Tartur area).

Damage categories	**Horizontal strain (mm/m)**	**Tilt (mm/m)**	**Radius of curvature (km)**	**Curvature (10^{-4}1/m)**
Very slight	ε <0.5	<2.5	>50	>0.2
Slight	0.5< ε <1	<5	>20	>0.5
Appreciable	1 < ε <2	<10	>11	>0.91
Severe	2 < ε <3	<15	>8	>1.25
Very severe	ε >3	>15	<6	<1.7

CONCLUSION

The movement over the working panel at Abu-Tartur area was predicted by applying different mathematical models. It was found that Peck's theory coincides well with the measured data with a reasonable accuracy (correlation coefficient equals to 0.992). From this theory, tilt and curvature are mathematically derived from the vertical movement, and strain values are calculated from curvature. The distributions of tilt, curvature and strain over the studied area are presented. By comparing the predicted

values of tilt, curvature and strain with the values of dangerous categories, it was found that these values are dangerous. To minimize the dangerous effects, it is recommended to apply the method of ore extraction with filling or stowing in the rest of the working panel and in other unworked out panels to reduce the probable strain values in Abu-Tartur area.

REFERENCES

[1] Cui XM, Wang Jiachen, and Liu Yisheng, "prediction of progressive surface subsidence above longwall coal mining using a time function". International journal of rock mechanics &Mining science, August, 2001.

[2] Newman, D., Agioutantis, Z. and Karmis, M., "SDPS for windows: An Integrated Approach to Ground Deformation Prediction," Proceedings, 20th International Conference on Ground Control in Mining, 2001, Morgantown, WV: West Virginia University.

[3] Chrzanowski, A.S., and Forrester, D. J., "100 years of ground subsidence studies" proceedings (CDROM) of the 100th CIM Annual General Meeting Montreal, Canada, May, 1998.

[4] Brauner, G. "Subsidence due to underground mining. I. Theory and practices in predicting surface deformation," (in two parts), 1973, USDI Bur. of Mines. IC8571

[5] Alejano, L.R., Ramirez-Oyanguren, P., and Taboada, J.,"FDM predictive methodology for subsidence due to flat and inclined coal seam mining". International journal of rock mechanics &Mining science, February, 1999.

[6] Gomma, W.A., Ibrahim, A.R, Imbaby, S.S. and Yousef, W.M., "Prediction of surface subsidence over longwall mining in Abu-Tartur area " , the fourth mining, petroleum& metal conf. faculty of engineering, Assiut univ., assuit, Egypt, 1994

[7] Kratzsch, Helmut, "Mining Subsidence Engineering," Springer-Verlag, Berlin, 1983.

[8] Blodgett, S. and Kuipers, J. R., "Underground Hard-Rock Mining: Subsidence and Hydrologic Environmental Impacts". Centre for Science in Public Participation, Bozeman, MT, 2002.

[9] Eesnay M. "Development of a Subsidence Model for ÇAYIRHAN Coal Mine", Ms.c., Turkey, 2004.

[10] Zacharias. A. and Karmis. M., "SDPS Quick Reference Guide", Blacksburg, Virginia, 2002.

[11] Ng C.W.W., and Lee G.T.K., "A three-dimensional parametric study of the use of soil nails for stabilising tunnel faces," Computers and Geotechnics, Vol. 29,pp. 673–697, 2002.

[12] Peng. S. S., Luo Y. and Zhang Z. M., "Subsidence Parameters – Their Definitions and Determination," AIME – SME Transactions, Vol. 300, Littleton, CO, pp. 60-65, 1995.

[13] James M. Seif, " The effect of subsidence resulting from underground bituminous coal mining on surface structures and water resources", sec 8, Pennsylvania department of environmental protection, five year report,1999, Internet web www.dep.state.pa.us/dep/deputate/minres/BMR/act54/sec8.htm.

[14] Fogiel, M., "the statistics problem solver". Research and education association, New Jersey, 1978.

[15] Peng, S.S., "Coal Mine Ground Control" John Wiley & Sons, Inc. New York, 1986.

[16] Ibrahim, A.R., and Imbaby, S.S., "Rational Support Parameters at mines (Abu-Tatur Mining Conditins)", Al-Azhar engineering second international conference, 1991.

[17] Al-Heib M., Nicolas M, Noirel J.F and Wojtkowiak F., "Risidual Subsidence Analyses After the End of Coal Mine. Work Example from LORRAINE Colliery, FRANCE," Post-Mining, November 16-17, Nancy, France, 2005.

التنبوء بالهبوط السطحي فوق احد المناجم التى تستخدم طريقة الحائط الطويل (مناجم فوسفات أبو طرطور)

أحمد أبو بكر العشيري[1]، وجيه أحمد جمعه[2]، سعيد سعد إمبابي[3]
(1) معيد بقسم التعدين والفلزات، كلية الهندسة، جامعة أسيوط، مصر.
(2) & (3) أستاذ دكتور بقسم التعدين والفلزات، كلية الهندسة، جامعة أسيوط، مصر.

تعرف ظاهرةَ الهبوط السطحي بأنها حركة سطح الارض التي تظهر نتيجة لعمليات التعدين تحت سطح الأرض، والتي بدورها يُمْكِنُ أَنْ تُلحقَ أضراراً خطيره بالمنشأت على السطح ,حيث أن العمليات التعدينيه تؤدى إلى إعادةَ توزيع للإجهادات حول الفتحات المنجمية. وللحصول على القيم المتوقعه للهبوط السطحى يتم تطبيق الطرق الاتيةِ : 1) الطرق التجريبية التى تستند على تحليلِ القياسات الحقلَية، 2) النظريات الرياضية، 3) النماذج العددية والتى تَتضمّنُ طريقة Finite Elements, وطريقة Boundary Elements وطريقة Distinct Elements .وقد تم فى هذا البحثِ تجُمِيعْ قياسات الهبوط السطحي فوق احد المناجم التى تستخدم طريقة الحائط الطويل لإستخراج الفوسفات في منطقة أبو طرطور بَعْدَ أن تَقدّمَت واجهة الحش لمسافة 280 متر وتم تطبيق النظريات الرياضية المختلفة لكل من (Peckو Bale و peng وKnothe) وقد تم حساب الهبوط السطحي فوق هذا المنجم وبمقارنة نتائج الحسابات مع القيم المقاسة للهبوط وجِدَ أن نظريةِ Peckِ تعطى اكثر القيم توافقا مع القيم المقاسة ، وكذلك تم فى هذا البحث حساب قيم الميلَ والانحناء والانفعال المتوقعة فى هذه المنطقة ووجد انها تقع جميعا فى منطقة الخطورة, لهذا ننصح بإستخراج الخام مستقبلا بحشو الفراغ الناتج من عملية التعدين وذلك لتقليل الأخطار التى سوف تنتج من عمليات التعدين فى هذه المنطقة.