Indian J.Sci.Res. 7 (1): 145-156, 2014 ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

A NEW MODEL FOR ESTIMATING THE FINAL CEILING AND WALL CONVERGENCE OF GALLERIES INCOAL MINES (A CASE STUDY: GALLERY K21, TAZAREHMINE, SHAHROOD, IRAN)

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ABSTRACT

Convergence and time-dependent stability in the galleries of underground tunnels are caused by the displacement of the ceiling, floor and walls. By estimating the displacement values, the applied load to the support system can be determined. In the present study, a new estimation model for the ceiling and walls convergence of the underground coal mines galleries by means of the measured values in the K21 gallery of Tazareh Mine has been presented. The multiple linear regression analysis was used to find the coefficients of the independent parameters by considering all effective parameters in the convergence, in a way that the linear relation would exist between independent and relative parameters. A comparison between the values calculated by using the presented model and the measured values in different monitoring stations showed that the new model was highly suitable for convergence assessment of the coal mine galleries.

KEYWORDS: Convergence; MLR; Tunnel; Coal; Mine

In rock galleries, two kinds of instabilities often occur; in the first case, gallery instability happens with a sudden destruction. In this case, discontinuities divide the rocks surrounding gallery into particles that can move or rotate. In the second case, where instabilities often occur in the layerswith 100 m or more depthand with high initial stresses, unlike the first case, instability occurs with progressive convergence.

A new method in gallery design depends on the exact analysis of rock support interaction. In many cases, preparation of design information before the gallery construction is so hard. Investigation of some of the rock mass properties is only feasible by “back analysis” of field data.For the analysis of convergence measurements and assessment of face advance effect, finite element models with axis symmetry have been studied for grounds with different strength properties and accordingly, curves have been gained for the assessment of gallery convergence as a function of the distance from the face(Panet and Guenot 1983).Then, convergence Equation is completed. As a result, time-dependent convergence due to face advance has been noticed in relation with creep convergence and yield zone propagation. Nonetheless, in such Equations, the effects of rock-support interaction have not been applied(Guenot et al. 1985).In 1987, an approach was presented for data interpretation of convergence measurement, close to gallery face so that all important aspects of gallery advance, such as face condition, staged construction and rock-support interaction, were noticed (Sulem et al. 1987).In 1993, relations were stated for the assessment of convergence in deep circular galleries based on Maxwell, Burgers, Standard and Kelvin’s time-dependent behavior prediction models(Filcek and Kwasniewski 1993).In 2000, Hoek & Marinos presented a relation for the assessment of convergence in circular galleries in swelling ground under hydrostatic stress condition. In this relation, convergence was calculated as a function of gallery initial diameter, rock mass strength and in-situ stresses(Hoek and Marinos 2000).After that, in 2001, approaches were also introduced for the assessment of convergence based on density theory (Divsalar et al. 2001).Deformation of sidewall was increased as bench excavation advancing beyond prediction during the excavation of soft rock by NATM. Such deformation could not be predicted in numerical analysis in the prior design stage. To find out whether such deformation could be reproduced, it was studied by several numerical analysis methods used for tunnel excavation in soft rock. These analysis methods were applied to large-scale cavern excavation in sedimentary soft rock, and the applicability of each technique was evaluated by comparing with the measured data in the field(Jongpradist et al. 2004).Antiga et al. studied the effects of non-hydrostatic mode of stress on the convergence and shape

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of failure propagation zone in circular galleries by numerical analyses. These approaches had particular complexities due to their numeric nature(Antiga et al. 2007).In 2008, a method was developed based on analytical relations and respective solutions for convergence calculation of a gallery in viscos elastic-plastic environment (Sandoval Ocaña 2008).

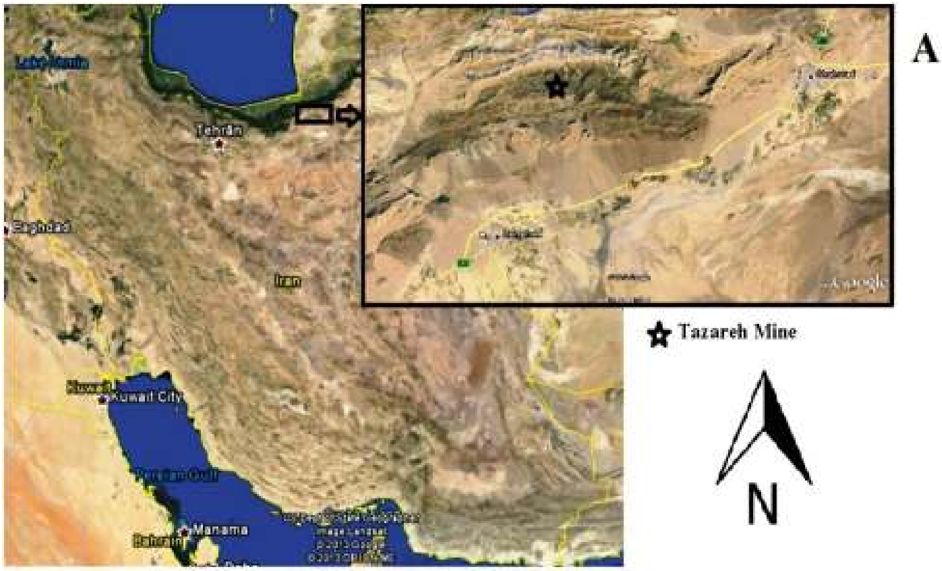
There are some researches addressing convergence in tunnels; Serrano et al. provided new findings on the theory of non-associated plasticity as applied to the study of convergence in tunnels(Serrano et al. 2011). Their work focused on elasto-plastic rock masses with linear and non-linear strength criteria and associated and non-associated flow laws. Also, ANN-based solution for the convergence of lined circular tunnels was presented by(Mahdevari and Torabi 2012; Rafiai and Moosavi 2012). Adoko et al. presented a new predicting tunnel convergence using multivariate adaptive regression spline (MARS) and artificial neural network (ANN)(Adoko et al. 2013).They concluded that MARS was more flexible and computationally efficient and MARS could be a reliable alternative to ANN in modeling nonlinear geo-engineering problem such as the tunnel convergence. Kontogianni and Stiros also presented a method to predict convergence in shallow tunnels in 2002(Kontogianni and Stiros 2002).One of the most widely used methods in tunnel support analysis and design is the convergence–confinement method (CCM)(Gill et al. 1995).Applications of this method are presented by(Carranza-Torres and Fairhurst 2000).Gonza´lez-Nicieza et al. presented a modification of the CCM and directly introduced the effect of depth and the shape of the tunnel cross-section on the determination of the radial displacement of the tunnel(González-Nicieza et al. 2008).The influence of the rock strength on the tunnel convergence was investigated by(Shrestha and Broch 2008) and the evaluation of ground convergence and squeezing potential in tunnels excavated by TBM and the correlation of tunnel convergence with TBM operational parameters were investigated by (Farrokh et al. 2006; Farrokh and Rostami 2008). Mahdevari et al. developed an approach based on support vector machines algorithm for the prediction of tunnel convergence during excavation(Mahdevari et al. 2013).Ground reaction curve (GRC) has been used successfully for the assessment of tunnel wall convergence and displacement based on the pressure on support(Oraee et al. 2009).

The only analytical and experimental equation for calculating convergence in coal mine galleries was presented by(Birön and Arioglu 1983) in 1983 for Germany's coal mines, and almost all researches in this context investigated the small convergence in roadway and transporting tunnels with non-analytical equations. Analytical equations were neglected in pervious researches. In this paper, based on statistical strong argument, an analytical equation for calculating the convergence of coal mine galleries has been presented which can use design support systems and compare them with results obtained by other approaches.

TAZAREH COAL MINE

Iranian coal resources mostly occur in two main basins, one in northern and the other in central Iran, Alborz and Central basins, respectively(Solaymani and Taghipour 2012). Coal resources are estimated to be about 7–10 Gt in Iranand mostly occur in these two main basins(Yazdi and Esmaeilnia Shiravani 2004).The coals are used locally for heating, charcoal and lime production in these regions(Goodarzi et al. 2006). The Tazareh coal mine is the most important productive coal mine in the eastern Alborz(Seyed-Emami et al. 2006). It is situated north of the main road from Tehran to Mashhad, about 30 km northeast of the historic town of Damghan and 45 km west of Shahrood. Figure 1 shows the location of this underground mine (The mine entrance is located at 36° 24' 23" N, 54° 25' 20" E)(Google 2013). This colliery complex has been extended 26.5km in length and 1.5km in width. Coal layers have an inclination of 35 to 50 degrees. The layer thickness in the K21 gallery is 45 to 75 centimeters. Layers hanging wall consists of fine to coarse layered structure Quartz Sandstone with the uniform structure of Siltstone and Argillite. The footwall of coal layers also consists of Siltstone and rarely Sandstone and Argillite. The coal formations also consist of frequency of Sandstone, Siltstone, Argillite and coal layers. Due to non-uniformity, these layers have been failed by overburden pressures.

Figure 1: Tazareh Mine Location (Google 2013)



In this study, gallery K21 in the Mine has been studied because of the availability of the proper data in comparison with other galleries and also, geometrical-mechanical properties. Geomechanical properties of coal, hanging wall and footwall of gallery K21 have been presented in Table 1. The geomechanical parameters of the intact coal rock have been measured in laboratory with Hoek-Brown equations(Hoek and Brown 1997).The geo mechanical parameters of rock mass have been calculated.

Assessment of K21 gallery convergence by field measurements and the existing relations

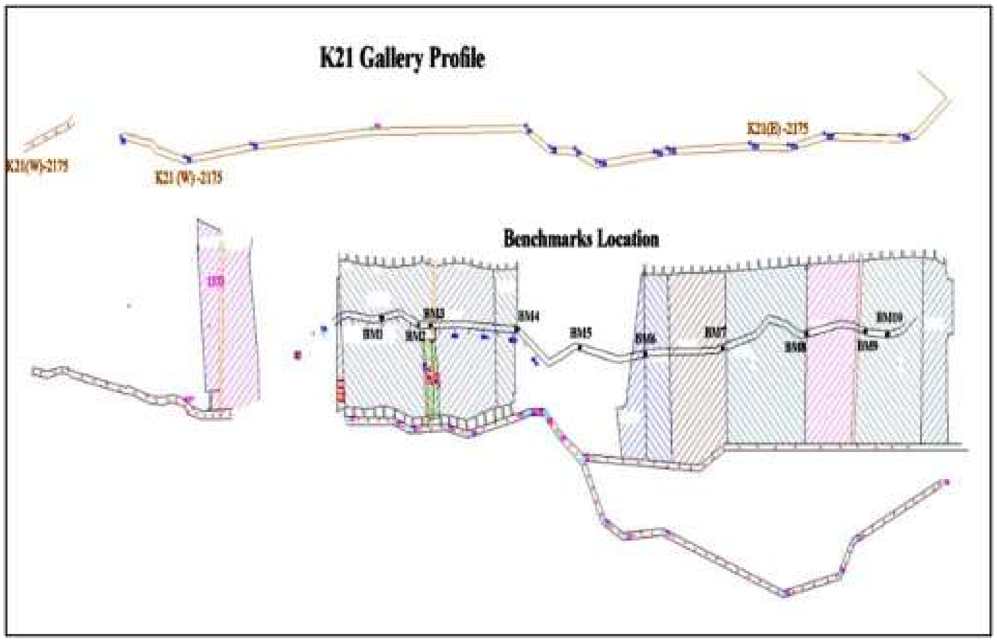
Convergence and stability in the galleries of underground mines are caused by the displacement of the ceiling, floor and walls. Pressure applied on support can be predicted by calculating the convergence and therefore, an appropriate support design can be developed.

To study the effective parameters in gallery deformation and develop a new model for convergence estimation, 10 stations (BM1 to BM10) were selected. Gallery profile and benchmark stations are shown in figure 2. Gallery cross section in each station was surveyed and cross section area was recalculated by the surveyed data using AutoCAD software (Figure 3).

Table 1Geomechanical parameters of coal, hanging wall and footwall of gallery K21.

Parameter	Units	Hanging wall	Coal	Footwall
Intact rock UCS	MPa	30	28	30
Disturbance factor	---	0.5	05	0.5
Intrinsic shear strength	MPa	0.27	0.26	0.27
Internal friction angle	degree	31.29	30.77	31.29
Rock mass tensile strength	MPa	-0.036	-0.033	-0.036
Rock mass compressive strength	MPa	2.21	2.06	2.21
Rock mass Deformability modulus	MPa	910	970	910

Figure 2: Profile of K21 Gallery of Tazareh Mine and the location of Benchmark stations studied



The initial cross section was also gained based on frame geometry properties. Gallery convergence was calculated by investigating cross section change and applying equation 1 and also equations related to the galleries of the German coal (Equation 2).Ceiling heave was studied by monitoring tunnel height change and applying equations 3 and 4; wall convergence was investigated by studying tunnel width change and applying equations 5 and 6.The results have been shown in Table 2(Birön and Arioglu 1983).

$$K = \frac{A_1 - A_2}{A_1} \times 100 \qquad (1)$$

$$K = -78 + 0.666H + 4.3mK_t + 7.7\sqrt{10K_f} \qquad (2)$$

$$K' = \frac{h_1 - h_2}{h_1} \times 100 \qquad (3)$$

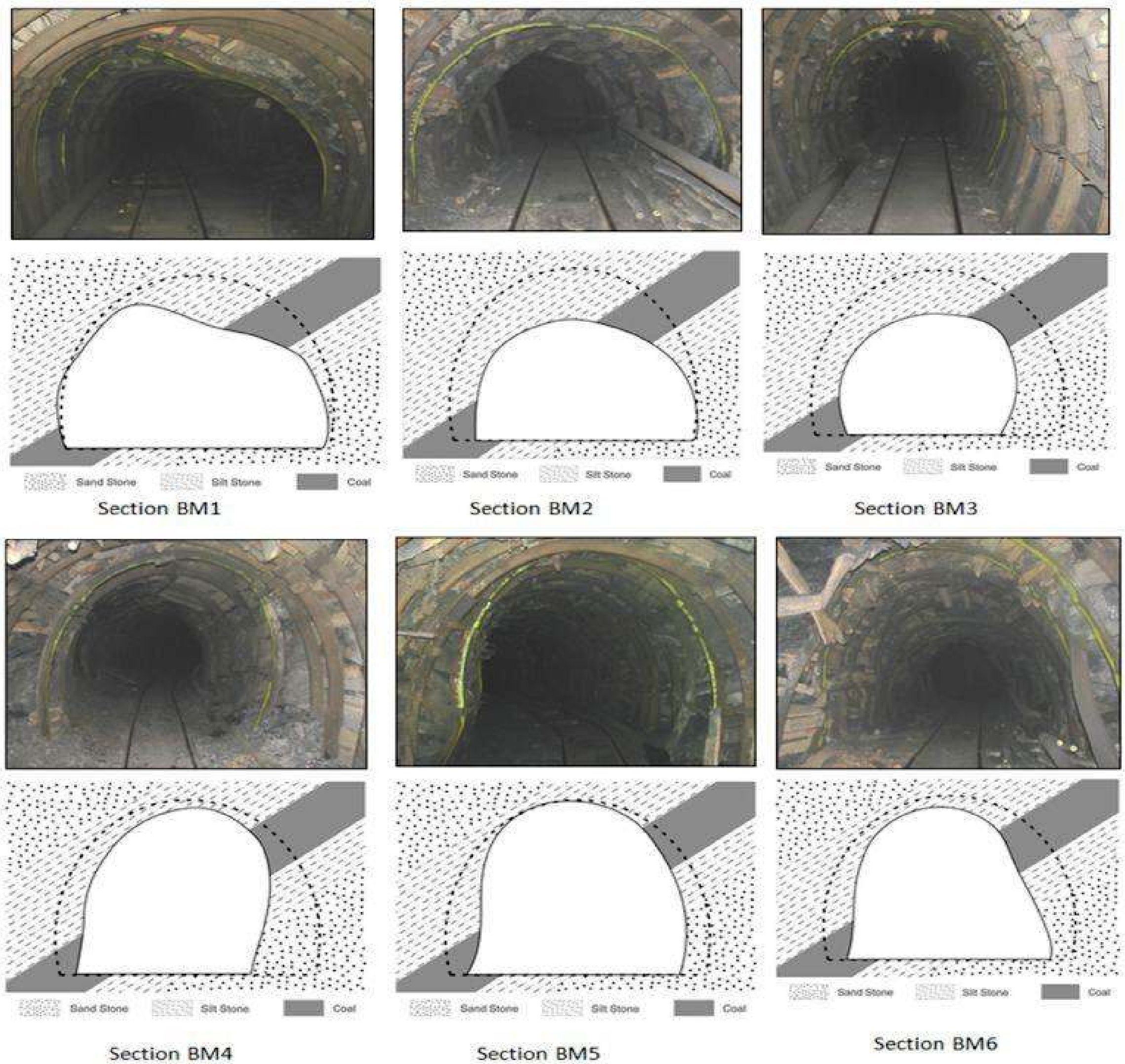
$$K' = -58 + 0.039H + 3.7mK_t + 6.6\sqrt{10K_f} \qquad (4)$$

$$y = \frac{L_1 - L_2}{L_1} \times 100 \qquad (5)$$

$$y = 3.5 + 0.23K \qquad (6)$$

Where K is the final convergence of the gallery, A_1 is the initial cross section in square meters, A_2 is the secondary cross section (surveyed) in square meters, K_f is a coefficient as a function of gallery floor rocks in Table 3. $K_t$is a coefficient as a function of support system of stope near gallery as given in Table 4. H is gallery depth in meter and m is the thickness of the coal layer in meter. K' is the ceiling heave, y is the convergence of walls, h_1 is tunnel initial height, h_2 is tunnel secondary height (surveyed), L_1 is tunnel initial width, and L_2 is tunnel secondary width (surveyed).

Figure 3: Comparison of planned and measured cross sections



The results of comparison are shown in Figures 4, 5 and 6. There is not a high correlation between the calculated and measured values of the final convergence, ceiling heave and walls convergence of the gallery. Thus, it can be seen that the use of Equations 2, 4 and 6 for convergence prediction of walls and ceiling of galleries of coal mines and then, the design of sliding steel set cannot be valid for gallery K21 of Tazareh Mine.

Effective parameters in convergence, ceiling heave and convergence of walls

To further develop Equations 2, 4 and 6, it was assumed that the following parameters were important in the gallery K21 convergence:

1) Gallery depth (H)
2) Thickness of coal layer (m)
3) Conditions of gallery floor rocks (k_f)
4) Slope of coal layer (a)

It was assumed that layer slope influenced the calculation of gallery final convergence. The slope of layer in gallery K21 in Tazareh Mine was changed from 37 to 50 degrees. Not considered a slope parameter in Equation 2, it was one of the factors in Figure 4.

Table 2: The measured and calculated values of the final tunnel convergence, ceiling heave and the final Wall convergence parameters in gallery K21

Station	Parameter	Calculated Values (%)	Measured Values (%)	Difference (%)
BM1	K	19.4	35.8	16.4
	k'	-27.68	10.37	38.05
	Y	7.96	28.31	20.35
BM2	K	24.66	27.14	2.48
	k'	-25.82	26.53	52.35
	Y	9.17	13.89	4.72
BM3	K	24.02	19.64	-4.38
	k'	-26.37	23.67	50.04
	Y	9.02	-4.41	-13.43
BM4	K	23.72	53.57	29.85
	k'	-26.85	26.53	53.38
	Y	8.95	36.61	27.66
BM5	K	24.02	36.96	12.94
	k'	-26.37	8.98	35.35
	Y	9.02	31.19	22.17
BM6	K	28.64	10.71	-17.93
	k'	-25.07	-1.22	23.85
	Y	10.09	12.54	2.45
BM7	K	27.95	17.14	-10.81
	k'	-24.6	2.04	26.64
	Y	9.93	15.93	6
BM8	K	28	23.57	-4.43
	k'	-25.62	0	25.62
	Y	9.94	24.07	14.13
BM9	K	26.71	22.32	-4.39
	k'	-25.11	8.16	33.27
	Y	9.64	15.93	6.29
BM10	K	27.35	34.28	6.93
	k'	-26.18	28.57	54.75
	Y	9.79	8.47	-1.32

Table 3: Coefficient K_f in different conditions (Birön and Arioglu 1983).

K_f	Type of rock in ceiling
1	Sandstone
2	Sandy shale
3	Shale
4	Extremely deformed rocks
5	Coal
6	Coal + shale + deformed rocks

Table 4: Coefficient K_t in different conditions(Birön and Arioglu 1983).

K_t	Support system of stope adjacent to gallery
1	Consolidated matters like Anhydride and or concrete
2	Wooden pillar
3	Handed filling

5) Mining time (t)

Because survey was done at a time when the stopes close to gallery had been completely mined, it was assumed that the time step between the completion of mining of stopes near gallery and the survey time influenced convergence value. This parameter was not considered in Equation 2 either.

6) Destruction conditions (s)

Figure 4: Comparison of calculated (k_a) and measured (k_b) values

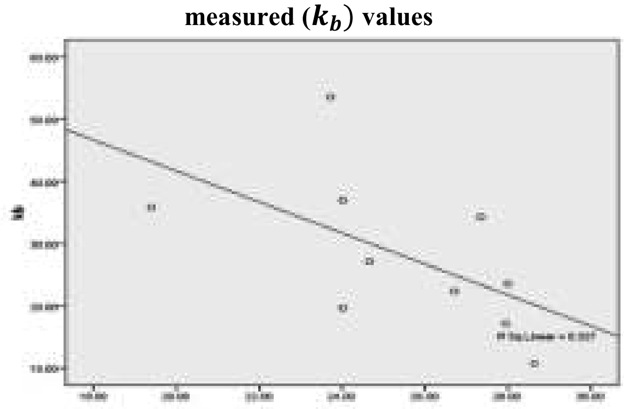


Figure 5: Comparison of calculated (k_{c1}) and measured (k_{b1}) values

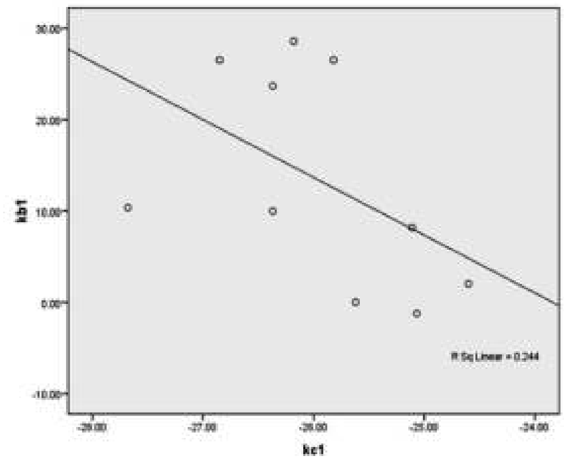
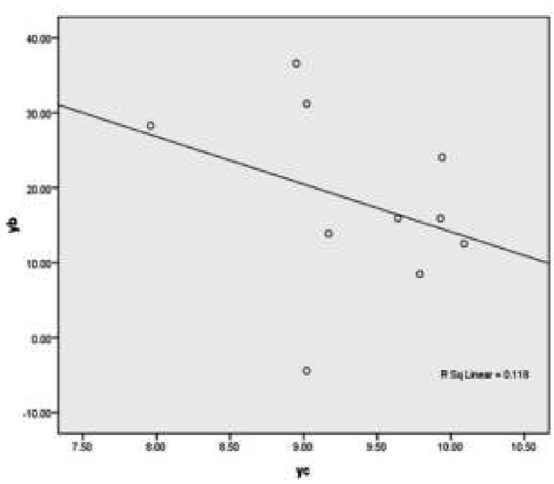


Figure 6: Comparison of calculated (y_c) and measured (y_b) values



To prevent uncontrolled destruction, after taking coals from the mine, the stopeshad to be destructed completelyand bein the control mode.Destruction conditions also influenced the convergence. The stopes close to gallery were destructed and so conditions related to support system in Equation 2 (K_t) were not valid. Thus, a new parameter, according to Table 5,was proposed so that the destruction condition would be presented.Sometimes, to restrain layers movement and roof control, the excavated location had to be filled with waste materials existing nearby. In manual filling, operation wasperformed with workers and in mechanical filling, process wasdone with machines. If filling process were performed without water, dry materials would be used. Also, to compress filling, water could be added to other materials (Materials used in this method were called wet materials). Table 5suggests authors'experiences in the study field**.**

Table 5: Support system conditions of stops next to the gallery

S	support conditions of stops near gallery
7	Complete destruction
6	Incomplete destruction with accumulation lower than %50
5	Incomplete destruction with accumulation from %50 to %70
4	Incomplete destruction with accumulation more than %70
3	Filling by dry material with handed method
2	Filling by dry material with mechanical method
1	Filling with wet material

According to figure 8 and errors found in the calculated results from equation 6, it can be seen that wall convergence value is related to both ceiling heave and the final convergence of the gallery. However, according to the relations of German mines (Equation 6), ceiling heave only relates to the final convergence of the gallery, so these relations should be corrected.In Table 6, values of factors have been given for the surveyed sections from BM1 to BM10. The final convergence, ceiling heave and wall convergence of gallery can be calculated by parameter values effective in parameters given in Table 6 and also, by a form of multiple linear regression Equations shown in Equations 7, 8, 9, 10, 11 and 12. Multiple linear regressions Equation is a relation applied for the calculation of convergence as given in Equation 4.

Table 6: Support system conditions of stopes next to the gallery

T (year)	H (m)	m (cm)	a (deg)	kf	s	Station
17	100	50	40	1	5	BM1
16	105	65	37	1	4	BM2
16	105	65	43	1	6	BM3
14	107	55	47	1	5	BM4
13	105	60	50	1	5	BM5
11	110	70	40	1	6	BM6
10	108	75	42	1	5	BM7
11	110	65	37	1	5	BM8
12	109	70	44	1	5	BM9
13	110	60	38	1	5	BM10

$$k_b = f(H, m, cos\alpha, s, t) \quad (7)$$

$$k_b = cte + B_1H + B_2m + B_3cos\,(a) + B_4K_f + B_5s + B_6t \quad (8)$$

$$k_{b1} = g(H, m, cos\,(a), s, t) \quad (9)$$

$$k_{b1} = cte + A_1H + A_2m + A_3\cos\,(a) + A_4K_f + A_5s + A_6t \quad (10)$$

$$y_b = h(k_b, k_{b1}) \quad (11)$$

$$y_b = cte + C_1k_b + C_2k_{b1} \quad (12)$$

Multiple linear regressions Equation has a constant value and 6 regression coefficients in equations 8 and10, and 2 regression coefficients for equation 12 belong to independent variables, instead of an offset and a regression coefficient. These coefficients are called "partial regression coefficients". The detailed regression coefficients in sample are the estimation of society uncertain coefficients. To estimate the coefficients, the squares minimum method is used, and coefficients that have squares sum the minimum of the difference between observed and predicted values of dependent variable.In multiple linear regressions, data must be a random sample of society. The Necessary hypothesis is that therelationship between dependent variable and independent variables must be linear; also, for each compound of independent variable values, the distribution of dependent variable values is normal and its variance must be constant.Before coefficients estimation, it should be ensured that dependent and independent variables have a linear relationship with each other. Otherwise, data should be changed in order to satisfy a linear relation. Figure 7 shows a matrix of transmittal plots between relevant and independent variables related to the collected data of Tazareh Mine gallery K21. In this matrix, transmittal of pair wise relation of variables has been presented; as can be seen, k_b and k_{b1} have an unidentified relationship withk_f, H, s, t and m variables.

In Figure 8, the transmittal plot matrix has been given as attained after changing the measurement scale of k_f, H, s, t and m variables. Data conversion was relatively effective, showing that $k_b$and k_{b1} had an acceptable linear relation in their columns with m, s, cos (a), in t and $k_f.\sqrt{H}$.

Figure 7: Data transmittal plot matrix

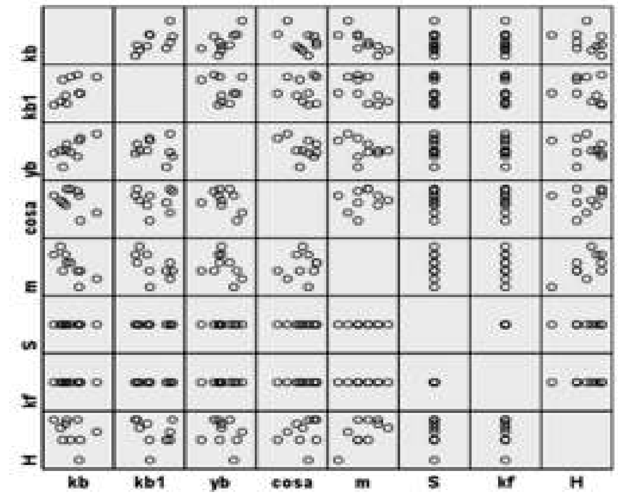
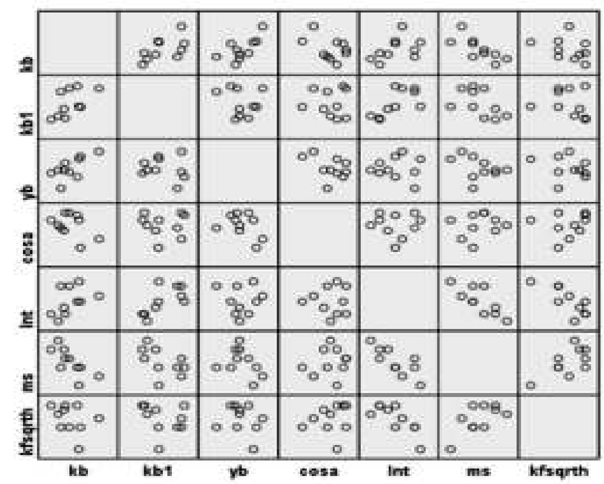


Figure 8: Data transmittal plot matrix after conversion



Presentation of the convergence model

The results of the analysis of multiple linear regressions have been shown in Table 7. The parameter RS in Table 7 is representative of correlation coefficient of the observed value of relevant variable and its predicted value from the regression model. If this parameter equals 1, it shows that the relevant variable value can be completely predicted by independent variables. Zero value means that the independent variables do not have a linear relation with dependent variable. 0.923 value for the first model shows that %92.3 of the observed scattering of wall convergence (y_b) is by gallery final convergence(k_b and ceiling heave(k_{b1}). 0.71 value of this parameter for the second model shows that %71 of the observed scattering of the final convergence of Tazareh gallery K21 is by four independent variables,cos (a), Ln(t), m.s and $k_f.\sqrt{H}$, and 0.753 value of this parameter for tunnel ceiling heave indicates that %75.3 by four independent variables,cos (a), Ln(t), m.s and $k_f.\sqrt{H}$, is justified. Nail convergence is justified by four independent variables. This shows that the present linear regression model can well predict the final convergence, gallery ceiling heave and wall convergence of coal mine.

Table 7: Results of multiple linear regression analysis for the three models

Parameter	Coefficient value			Tolerance		
	Model 1(y_b)	Model 2(k_b)	Model 3(k_{b1})	Model 1	Model 2	Model 3
Constant value	-1.820	-54.22	-900	-	-	-
k_b	1.121	-	-	0.677	-	-
k_{b1}	-0.850	-	-	0.677	-	-
$k_f.\sqrt{H}$	-	23.16	68.311	-	0.35	0.346
m.s	-	-29.83	0.789	-	0.37	0.369
Ln(t)	-	-1.94	92.321	-	0.23	0.862
Cos(α)	-	-78.15	-44.847	-	0.86	0.235
RS	0.923	0.71	0.753	-	-	-
Standard estimation error	3.7	8.94	7.8	-	-	-

The linear relation between independent variables is measured by an index called "tolerance". Tolerance lower than 0.1 represents a linear compound between one variable and other independent variables and theinaccuracy of the linear regression model. In Table 7, this value for the first model is 0.677, 0.23 to 0.86 for the second model, and0.235 to 0.862 for the third presented model.Models 1, 2 and 3are related to equations13,14 and 15, respectively.

Regression Equation is estimated by independent variables coefficients as follows:

$$y_b = 1.12k_b - 0.85kb_1 - 1.82 \quad (13)$$

$$k_b = 23.158k_f\sqrt{H} - 29.832m.s - 1.941Lnt - 78.152cosa - 54.215 \quad (14)$$

$$k_{b1} = 68.311k_f\sqrt{H} + 0.789m.s - 44.847cos\alpha + 92.321Lnt - 900 \quad (15)$$

where y_b is convergence value of tunnel wall (%),k_b is gallery final convergence (percent), k_{b1} is ceiling heave value (%), H is gallery depth (meter), m is coal layer thickness (meter), t is time distance between extraction completion of stopes close to gallery and survey time (year), "a" is coal layer slope (degree) and "s" is the parameter related to destruction condition and the type of support system of stopes close to gallery as given in Table 5. Our resultsshow that hypothesis holding that ceiling heave coefficients and tunnel final convergence equal to zero can be refused. All of the variables except the tunnel final convergence(k_b) are negative, showing that by reduction in the ceiling heave and the increase in tunnel final convergence, the convergence value of tunnel walls will increase. Based on these findings, it is expected that walls convergence canbe obtained by the difference of tunnel final convergence and ceiling heave values.

The predicted convergence by the new presented model (Equation 14), measured value and their remaining values(the difference between the measured and predicted value) for each station have been shown in Table 8. It should be noted that in station BM1, the measured value (k_b) equals 35.8 and the predicted value by regression model (PRE) equals 37.41; thus its remaining value is -1.61 (residuals are seen in RES column). Since this value is negative, it shows that the measured value is lower than the predicted value of model convergence (these conditions for equations 13 and 15 are observed in Tables 9 and 10, respectively). If residuals are standardized such that their average equals zero and standard deviation equals 1, then their relative magnitude can be debated.

To calculate the standardized residual (ZRE in Table 8), the measured residual is divided into estimated standard deviation of residuals (standard estimation error value in Table 7 is 8.94 for the second model). If distribution of reminders were almost normal, approximately, %95 of the standardized residuals would be between -2 and +2 and %99 of them would be between -2.58 and +2.58. Samples whose standard residuals do not occur in this range are unusual. As can be seen in ZRE column in Table 8, the stated condition is satisfied for the presented model and in this respect, the model fits well.

Table 8: Predicted convergence by the new model, measured convergence and the residuals of the linear regression for the second model (Equation 14)

Station		PRE_2	RES_2	ZRE_2	SRE_2	SDR_2	k_b	p2
BM1		37.41385	-1.61385	-0.18055	-0.49052	-0.44969	35.80	0.64
BM 2		18.32893	8.81107	0.98573	1.62185	2.10717	27.14	0.17
BM 3		31.04513	-11.40513	-1.27593	-1.57713	-1.98989	19.64	0.18
BM 4		44.86864	8.70136	0.97345	1.34419	1.50446	53.57	0.24
BM 5		38.36948	-1.40948	-0.15768	-0.23627	-.21252	36.96	0.82
BM 6		19.72909	-9.01909	-1.00900	-1.15166	-1.20173	10.71	0.30
BM 7		12.02750	5.11250	0.57195	0.95081	0.93961	17.14	0.39
BM 8		24.63984	-1.06984	-0.11969	-0.16361	-0.14673	23.57	0.88
BM 9		0.10344	0.21656	0.02423	0.02907	0.02600	22.32	0.98
BM 10		32.60408	1.67592	0.18749	0.26215	0.23610	34.28	0.80
Total	N	10	10	10	10	10	10	10

In the calculation of standardized residual, all measured residuals are divided in to a constant number. However, the predicted scattering is notconstant for the entire points; it also depends on the independent variable value. Samples whose value of independent variable is close to the average of samples have thelower scattering of predicted values, in comparison with samples that have the distance from the average. Studentized residuals also include the difference between scatterings of points. Standardized residual results from the division of the observed residual by the estimation of standard deviation of that in the respective point (Standardized residuals have been shown by SRE in Table 8). This residual facilitates the observation of incorrectness of assumptions, so it is preferred to the standardized residual.Tables 8, 9 and 10 are related to equations 14, 13 and 15.

If regression assumptions were right, for the calculation of standardized residual observation probability (P symbol in Table 8),whose absolute value equals at least the measured value, it would utilize "t" distribution so that its degree of freedom would be equal to the number of samples minus the number of coefficients (including offset). If the probability were lower than 0.05, it could be assured that this residual would be improbable. This probability, with respect to the Table, does not exist in the model.

Table 9: Predicted wall convergence by the new model, measured convergence and the residuals of the linear regression for the first model (Equation 13)

station		PRE_1	RES_1	sdR_1	ZRE_1	SRE_1	y_b	P
BM1		29.49646	-1.18646	-0.32747	-0.31255	-0.35059	28.31	0.74
BM 2		6.06187	7.82813	7.0340	2.06217	2.49859	13.89	0.04
BM 3		0.08515	-4.49515	-1.7581	-1.18416	-1.54273	-4.41	0.17
BM 4		35.68575	0.92425	0.3481	0.24348	0.37234	36.61	0.72
BM 5		31.12794	0.06206	0.01733	0.01635	0.01873	31.19	0.99
BM 6		11.22033	1.31967	0.40557	0.34764	0.43219	12.54	0.68
BM 7		15.65794	0.27206	0.07530	0.07167	0.08131	15.93	0.94
BM 8		24.59797	-0.52797	-0.14974	-0.13908	-0.16144	24.07	0.88
BM 9		16.26491	-0.33491	-0.08762	-.08823	-0.09458	15.93	0.93
BM 10		12.33169	-3.86169	-1.2572	-1.01729	-1.20816	8.47	0.27
Total	N	10	10	10	10	10	10	10

CONCLUSION

By the calculation of gallery convergence caused by the displacement of floor, ceiling and walls, the pressure applied on support system can be predicted using an appropriate design of support system. Yet, the variety of analytical and numerical models used to determine the convergence of mine galleries has been presented. Nonetheless, the presentation of a simple and empirical model that can predict the convergence of galleries of coal mines, far from the complexities of numerical Equations, can be addressed by miners. In this paper, by studies and field measurements, it was concluded that the present numerical relations for the prediction of final convergence, ceiling heave and wall convergence of galleries of coal mines were not applicable for convergence determination of galleries of Tazareh Mine. Thus, a relation for more accurate estimation of galleries of Tazareh Mine by concentration on its gallery K21 of Tazareh Mine (because of data accessibility of this gallery and the similarity of geometrical-mechanicalproperties of this gallery to other galleries) was presented

Table 10: Predicted wall convergence by the new model, measured convergence and the residuals of the linear regression for the third model (Equation 15)

station		PRE_3	RES_3	ZRE_3	SRE_3	SDR_3	p3	k_{b1}
BM1		12.85979	-2.48979	-0.31679	-0.86069	-0.83408	0.43	10.37
BM 2		23.26228	3.26772	0.41578	0.68409	0.64268	0.52	26.53
BM 3		26.08241	-2.41241	-0.30695	-0.37941	-0.34434	0.72	23.67
BM 4		22.40572	4.12428	0.52476	0.72462	0.68508	0.50	26.53
BM 5		10.88468	-0.90468	-0.11511	-0.17248	-0.15473	0.87	9.98
BM 6		6.80117	-8.02117	-1.02059	-1.16490	-1.22064	0.30	-1.22
BM 7		-7.31685	9.35685	1.19054	1.97914	3.80360	0.10	2.04
BM 8		5.14217	-5.14217	-0.65427	-0.89435	-0.87278	0.41	0.00
BM 9		13.66453	-5.50453	-0.70038	-0.84036	-0.81110	0.44	8.16
BM 10		20.84409	7.72591	0.98302	1.37445	1.55854	0.23	28.57
Total	N	10	10	10	10	10	10	10

For this purpose, at first, effective parameters in convergence such as depth, coal layer thickness and slope, conditions of gallery floor rocks, mining time and destruction conditions were determined. Then, multiple linear regression Equations by the application of all influential parameters in convergence were used to define the convergence relation so that there would be a linear relationship between independent variables and the relevant variable.The comparison of predicted convergence values by the presented model in this paper and real measured values in survey stations showed that the presented model could well determine convergence of the gallery. By this empirical relation, it was possible to determine the convergence of coal galleries whose coal layer had different slopes.

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