J. Basic. Appl. Sci. Res., 2(2)1696-1700, 2012
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ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Using Extensometer as a Monitoring System, Case Study: Taloun Pilot Tunnel in Tehran – North of Iran Freeway

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ABSTRACT

One of the important steps in the design and implementation of New Austrian Tunnels Method (NATM) is Monitoring and Instrumentation. Monitoring can help to evaluate the tunnel and to determine the properties of rock using measured displacement processing. Monitoring actually means caring rock structures with direct observation or using instrumentation. Monitoring is helping to examine the behavior of underground structure. In this paper, based on case study (Taloun pilot tunnel in Tehran – North of Iran Freeway) is shown that we can use instrumentation data to obtain geomechanical parameters and horizontal stresses with direct back analysis. FLAC software is used for back analysis. This method is based on comparison between displacements obtained from model and measured displacements obtained from Extensometer installed in the station 10. Thus at first the data obtained from instrumentation has been processed. After that, using the FLAC software, geomechanical parameters and horizontal stresses are obtained using sensitive analysis of Yong's modulus (E) and lateral earth pressure coefficient (K).

KEY WORDS: monitoring, Extensometer, back analysis, FLAC software.

1. INTRODUCTION

Because of quantitative assessment of earth parameters (such as geological structures, geomechanical properties of bed rock, the initial state of tension, ground water levels, groundwater conditions, permeability and etc) with sufficient accuracy is difficult, so the stability analysis of tunnels using numerical methods such as finite element, boundary element and finite deference method, behavioral properties of the rock mass cannot be understood as perfection. Due to the complexity of the geomechanical parameters, as the input data, predicting the mechanical behavior of rocks and stability evaluation of underground structures is difficult.

One of the ways that is useful to solve such problems is monitoring and instrumentation in tunneling. The purpose of instrumentation is to control displacement in order to evaluate the stability of underground structures and rock mass properties. Using the results of observations on the structural behavior to determine initial design parameters is called "Back Analysis." One of the systems used in monitoring is Extensometer. In this study, using monitoring data ,(reading of extensometer installed in the10th station), and processing of those data and their back analysis valuable information about in situ stress condition, geomechanical parameters of rock mass and support system performance can be determined.

2. Taloun Tunnel Position and Geological Conditions

Long Taloun tunnels in two numbers as two-lane road in the direction of Tehran - North of Iran between 21+ 336 to 26+ 232 km with a height of about 2300 meters above sea level ,40m distance between them and the length of 4896 meters are constructed. Taloun pilot tunnel between the main tunnels with a diameter of 6 meters with a smaller cross section of them (about 24 square meters) will be drilled. The first purpose of such a tunnel dug is survey of geological and geotechnical data required for design. It is also used to determine drilling and stability methods of the main tunnels. Another purpose is drainage and ventilation of the main tunnels and also can be used as tunnel emergency at the time of possible events. Also with installed instruments in the pilot tunnel and data processing and back analysis of them, stability analysis of the main tunnels can be examined.

Rock masses along Taloun tunnel are formed from tuffs (Eocene Karaj Formation rocks). Tuffs are igneous rocks that formed with low or high intensity during high explosion thrown out and have deposited in land and water. Due to this double feature (volcanic and sedimentary) it has different characteristics in terms of chemical composition, Mineralogy, physical and mechanical properties. Because of development of deep fractures in rocks, tuff rock mass shows various strength.

3. Extensometer Data in 10th station of Taloun pilot tunnel

Station 10 is a full station in which convergence meter, extensometer and load cell installed that useful information can be obtained from this station such as: determination of plastic zone radius, determination of

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effective drilling zone around tunnel, stability and evaluation of tunnel using direct strain control technique, drawing of characteristic curve of the earth and determination of appropriate support system for tunnel. In Fig. 1 and Fig. 2 the actual rock mass displacement charts around the tunnel in the left and right walls are shown. Table 1 shows actual displacements values in station 10 of Taloun pilot tunnel.

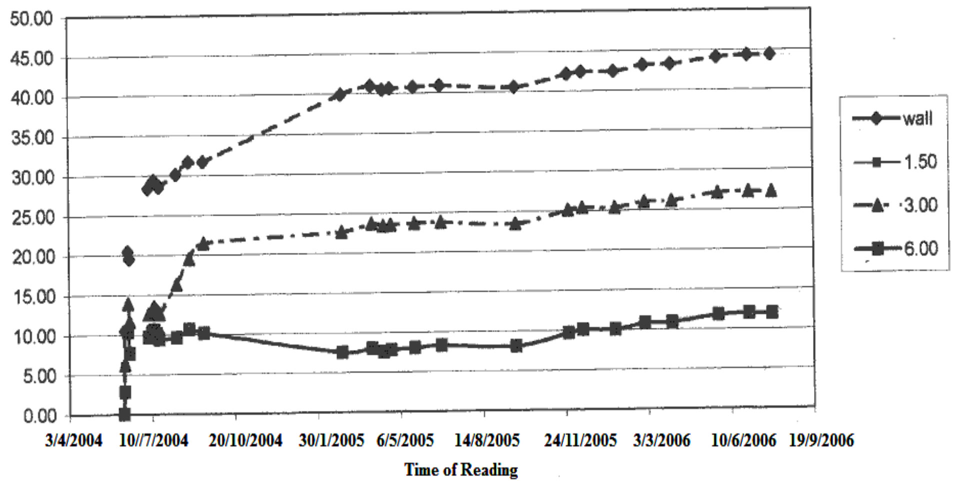

Fig.1 The actual displacement curve of the right rock mass in station 10 of Taloun pilot tunnel

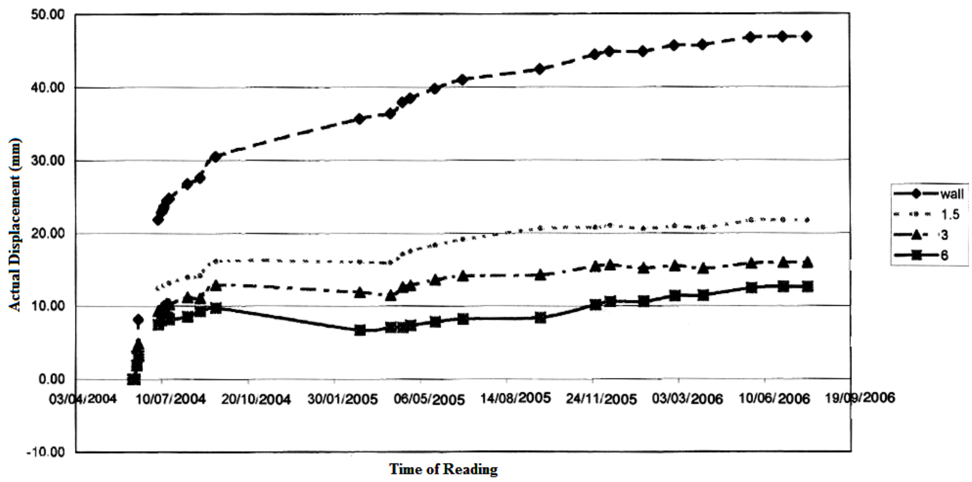

Fig.2 The actual displacement curve of the left rock mass in station 10 of Taloun pilot tunnel

Table.1 The actual displacement of the rock mass in 10th Station.

Area	Ceiling				Left corner			Left			Right corner			
Anchor Points	wall	1.5	3	6	wall	1.5	6	wall	3	6	wall	1.5	3	6
Displacement (mm)	4.4	1	1.7	3	24	12	10	44	27	12	47	22	16	13

3.1. Interpretation of the Extensometer Data in 10th station of Taloun pilot tunnel

Generally, according to the displacements, it can be concluded that the rate of displacements in the ceiling were not high and the rock mass on the ceiling was stable and the displacements are largely fixed. In the rock mass of the right wall after about 13 months in the wall, curves are not horizontal but the slope of the graph is very low and the trend has continued until the last reading taken. The anchor curves are horizontal, which indicates fixation of displacements and stability of the anchor points (Figure 1). The rock mass of the left wall after 10 months, the curve is almost horizontal but in the end of the chart it has ascending trend, so more readings are needed (Figure 2). In general, using the data obtained it can be indicated that the displacement of the tunnel walls is much higher than the tunnel ceiling; the wall is therefore needed for better support than ceiling.

4. Back Analyses

Back analysis is based on the instrumentation data that are used as part of the output results of numerical model and therefore the specifications of numerical model are determined. Thus by changing the parameters of rock and in situ stress and minimizing the difference between displacements obtained from model and instrumentation data, real parameters of rock will be obtained.

The instrumentation data here are the displacements measured in 10th extensometer station that are typically indicative of the displacement values of tunnel lining elements.

In this paper, the FLAC software is used that only provides the possibility of direct analysis. It is finite difference software capable of modeling the behavior of soil, rock or other material that may come to surrender or plastic flow. Back analysis Procedure using this software according to extensometer results are as follows:

- i- Selection of extensometer stations that the results obtained are accurate and complete.
- ii- Preparing numerical models in accordance with the conditions of the tunnel at selected stations in section *i*.
- iii- Analysis of model obtained in section ii and comparison of model results with extensometer data.
- iv- Change in initial conditions, boundary conditions and geological parameters of rock mass with the aim of closing displacement obtained from the model analysis to the measured values.

For back analysis of monitoring data of Taloun tunnel elastic model is used. In this model, Poisson ratio and density of rock mass is assumed constant. Effective parameters of this model are bulk modulus and the lateral earth pressure coefficient (K). To achieve solutions, due to large differences between displacement of ceiling and walls, area around the tunnel separated into three regions of the left (L) and right (R) side wall and ceiling (C) parts of the tunnel. For this purpose, combining more than 70 models of different conditions of geological parameters, rock mass and stress conditions, have been created and implemented with FLAC software. To find the best conformity between the results of models built and the results of instrumentation, error function is defined as follows:

$$Error = \sum_{i=0}^{n} \left(U_{mi} - U_{pi}\right)^2 \qquad (1)$$

In which U_{pi} is the rock displacement calculated by the model at point i, U_{mi} is the rock displacement measured at point i and n is the number of measurement points. The procedure is that a baseline value for the parameter E and K are considered first and the error function is computed. Change in the parameter E and K continues as far as the error function reaches minimum value. Initial values of geomechanical parameters of rock mass of 10th Station that is used in numerical modeling are given in table 2.

Table. 2 Initial values of geomechanical parameters of rock mass of station10.

Parameter		Value
Young's modulus E [Gpa]	E_L	2.5
	E_R	2.6
	E_C	4.7
Poisson ratio	0.27	
Density [Kg/m³]	2700	

4.1. Sensitivity analysis to Young's modulus (E)

In 10th Station four extensometers installed that only three of them are used (left, right, and the ceiling). The results of sensitivity analysis Young's modulus are given in Table 3.

Table.3 Results of sensitivity analysis to the change of parameter E

Model number		1	2	3	4	5	6	7	8	9	10	11	Actual displacement (mm)
E_L*		2.5	2.5	2.5	2.6	2.4	2.7	2.6	2.6	2.5	2.5	2.5	
E_R+		2.6	2.6	2.6	2.7	2.5	2.8	2.8	2.7	2.7	2.6	2.7	
E_C#		4.7	4	4.5	4.7	4.7	4	4.5	4.5	4.3	4.6	4.7	
Left wall displacement (mm)	wall	45	45	45	40	45	40	40	40	40	40	40	44
	3	25	25	25	24	25	24	24	25	25	25	25	27
	6	14	16	14	14	16	14	14	14	14	14	14	12
Right wall displacement (mm)	wall	45	45	45	40	45	40	40	40	40	40	40	47
	1.5	30	30	30	30	30	25	25	30	30	30	30	22
	3	25	25	25	24	25	24	24	25	25	25	25	16
	6	14	16	14	14	16	14	14	14	14	14	14	13
Ceiling wall displacement (mm)	wall	9	10	10	9	10	10	9	8	10	10	9	4.4
	1.5	10	10	10	10	10	10	10	10	10	10	10	1.0
	3	9	10	9	9	9	10	9	9	10	9	9	1.7
	6	6	10	7	6	7	7	6	7	7	7	7	3.0
Error value	-	324	385	341	372	361	349	317	383	416	341	374	-

* Young's modulus of the Left wall
\+ Young's modulus of the Right wall
\# Young's modulus of the Ceiling wall

As mentioned displacement calculated by the model is compared with actual measured displacement to get the best answer. According to table 2 and 3 displacement calculated in column 7 has the least error that the values of Young's modulus is 2.6, 2.8 and 4.5 for the right, left and ceiling wall respectively.

4.2. Sensitivity analysis of the K value

As regard the displacement of the tunnel walls is much higher than the tunnel ceiling, therefore it can be concluded that lateral earth pressure coefficient is higher tan 1.0. The reason is that the rock mass surrounding the tunnel is composed of tuff rock. Because the properties of rocks and minerals formed, tuff rocks influenced by weathering processes, especially the water penetrate to the deep (due to relatively good water absorption of about 1.2 to 3 percent) are dilating and scaling (that means residual stresses are released). Dilation occurs in the level of stratification, resulting increase in the displacement of the wall as the level of stratification has low slope and its direction is perpendicular to the tunnel alignment. Wall displacement is higher than ceiling displacement so in the numerical models, this can be modeled only by changing K value. Table 4 shows results of sensitivity analysis to changes of K value.

Table.4 Results of sensitivity analysis to changes in the value of K.

Model number		**12**	**13**	**14**	**15**	**Actual displacement (mm)**
K		4.5	5	5.25	5.5	
Left wall displacement (mm)	wall	32	35	35	40	44
	3	18	20	20	24	27
	6	10	12	14	14	12
Right wall displacement (mm)	wall	30	35	35	40	47
	1.5	20	25	25	25	22
	3	18	20	20	24	16
	6	12	12	14	14	13
Ceiling wall displacement (mm)	Wall	7	8	9	9	4.4
	1.5	8	9	-	10	1.0
	3	7	8	9	9	1.7
	6	5	8	6	7	3.0
Error amount		615	442	452	324	-

According to the table 4 it can be observed that the column 15 has the best answer. At this point E is 2.6, 2.8 and 4.5 for the right, left and ceiling wall respectively and K is 5.5.

4.3. Sensitivity analysis to the combination changes in of E and K

In order to achieve a better result, in this step the sensitivity analysis based on changes in the values of E and K is done to see the result of combination of these two parameters.

Table.5 Results of sensitivity analysis to combination changes of E and K.

Model number		**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**Actual displacement (mm)**
K		4	4.5	5	5.25	5.5	5	5.25	5.5	
E_L Gpa		2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.6	
E_R Gpa		2.6	2.6	2.6	2.6	2.6	2.7	2.7	2.8	
E_C Gpa		4.7	4.7	4.7	4.7	4.7	4.5	4.5	4.5	
Left wall displacement (mm)	wall	28	35	40	40	45	35	40	40	44
	3	18	20	25	24	25	20	20	24	27
	6	10	12	14	14	14	12	14	14	12
Right wall displacement (mm)	wall	28	35	40	40	45	35	40	40	47
	1.5	20	25	25	25	30	25	25	25	22
	3	18	20	20	24	25	20	20	24	16
	6	10	12	14	14	14	12	14	14	13
Ceiling wall displacement (mm)	wall	6	7	8	9	9	9	9	9	4.4
	1.5	7	8	9	9	10	9	9	10	1.0
	3	6	7	8	9	9	8	9	9	1.7
	6	4.5	5	6	6	6	6	6	6	3.0
Error value	-	779	388	225	300	324	434	292	317	-

Finally, according to the results of tables 3, 4 and 5 The values in column 18 has the least error that the values of Young's modulus is 2.5, 2.6 and 4.7 for the right, left and ceiling wall respectively and K is 5.0.

4.4. Final results

As mentioned before this station was divided into three parts with different modulus of elasticity that eventually, by sensitivity analysis of parameters E and K, the best answers that are close to the real displacements are determined. Table 6 shows output data of back analysis that actually are input data of FLAC software.

Table.6 Output parameters of back analysis obtained from extensometer data on 10th station.

Model of elasticity (Gpa)			Normal stress (Mpa)	Lateral stress (Mpa)	Height of model to the ground (m)	Poisson ratio	Density (kg/cm^3)
E_L	E_C	E_R					
2.5	4.7	2.6	4.715	23.575	178	0.27	2700

This analysis shows that the rock mass around the tunnel walls in the station, especially due to the fault and fractured has many fissure and discontinuities. As a result, because of development of fractures, especially in the walls, rock mechanical properties in these areas are reduced. Therefore modulus elasticity of the wall is lower than the ceiling.

5. Conclusions

According to the results, the data obtained from 10th station can be generalized to other rock mass surrounding behaviors that are similar to those in this section.

1. In Station 10 due to large displacement of the walls, it is needed to use better support than the ceiling.
2. According to back analysis of extensometer data with FLAC program and more than 70 models made, bulk modulus and lateral stress is achieved in 10th station. Bulk modulus obtained in the wall is lower than of ceiling rock mass which is due to the development of fractures in the wall that leads to increasing displacement in the direction of fractures and thus reducing mechanical properties of rocks and increasing lateral stress.
3. Study the behavior of rock masses along Taloun pilot tunnel shows that the behavior of rock mass at 10th station is not completely elastic and it shows plastic behavior , so it is suggested that elasto- Plastic back analysis performed.
4. Due to digging three tunnels together it is suggested that the effects caused by tunnel excavation on three tunnels on each other, such as changes in stresses and displacement occurred, must be examined.
5. Comparison of calculated strains of rock mass surrounding the tunnel and critical strain in station 10 shows instability in the walls of Taloun pilot tunnel.

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