Measured and computed movements of Gavoshan Tunnel

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ABSTRACT
In this paper, the measured and computed movements of Gavoshan Tunnel located in the west of Iran are presented and discussed. This tunnel with a length of about 20.2km is the longest tunnel excavated in Iran. Several instruments are used for the monitoring the behaviour of the tunnel including tape extensometers, rod extensometers, total pressure cells, piezometers and load cells. The convergence of the tunnel is measured using tape extensometers in several stations. The results obtained from the convergence measurements are compared for various sections along the tunnel. The measured values are also compared with the results obtained from the numerical modeling.

RÉSUMÉ
En cet article, les mouvements mesurés et calculés du tunnel de Gavoshan situés dans à l'ouest de l'Iran sont présentés et discutés. Ce tunnel avec une longueur environ de 20.2km est le plus long tunnel excavé en Iran. Plusieurs instruments sont utilisés pour la surveillance du comportement du tunnel comprenant des extensomètres de bande, des extensomètres de tige, des cellules totales de pression, des piezometers et des cellules de charge. La convergence du tunnel est mesurée à l'aide des extensomètres de bande dans plusieurs stations. Les résultats obtenus à partir des mesures de convergence sont comparés pour différentes sections le long du tunnel. Les valeurs mesurées sont également comparées aux résultats obtenus à partir de modeler numérique.

1 INTRODUCTION

Monitoring the behaviour of underground structures by instrumentation is one of the most reliable methods for the evaluation of their stability. Several instruments are used for the monitoring of tunnels and underground structures including tape extensometers, rod extensometers, total pressure cells and piezometers. Convergence measurement using tape extensometers is among the most common and simple methods for the monitoring of the displacements and stability of the tunnels.

In this article, using the data obtained from the convergence measurements of Gavoshan Tunnel, the real displacements of the tunnel are calculated and are compared with the results obtained from the numerical analysis.

Gavoshan Tunnel with a length of 20.18km is a water conveyance tunnel and is located in the west of Iran close to Sanandaj-Kermanshah main road. The aim of the construction of this tunnel is to transfer water from Sirvan River basin to the head branches of Karkheh River and to supply water for 31000 Hectares of agricultural lands of Miandarband and Bilehvar and also to supply drinking water (60 millions m^3 per year) for the city of Kermanshah (Mahab Ghods, 1997).

Four access tunnels comprising Tavankesh, Haltooshan, Kachaleh and Sarbenav, have been excavated in the length of the main tunnel. The tunnel and its access tunnels have been excavated by different methods including excavation by TBM, roadheader and drilling and blasting method.

2 GEOLOGY OF THE REGION

The route of Gavoshan water conveyance tunnel is divided by Morvarid Fault (in 8+389 km) into northern and southern parts with different characteristics. The northern part consists mainly of slightly weathered sedimentary rocks. The southern part consists of igneous rocks such as diabase, gabbro, andesite, ultrabasics (mainly serpentinized), spilite and basalts. Therefore, weak, loose and laminated rocks are located the in northern part and strong and good quality rocks (except in the fault regions and crushed zones) are located in the southern part of the tunnel. Geological diversity and various discontinuity and lithological contacts are the main features of the Gavoshan Tunnel.

3 ANALYSIS OF THE CONVERGENCE DATA

Analysing the results of the convergence measurements in the tunnel are dealt with in this section. The main purposes of these analyses are to compare the values of convergence in the different sections of the tunnel and to compare the values of convergence obtained from the measurements with the results computed from the numerical methods.

The first step in the analysing the data obtained from instrumentation is to eliminate abnormal data and to modify the results to account for the installation conditions. In this respect, the following corrections have been made in convergence data: (1) Elimination of abnormal data, (2) correction of convergence results based on the time period of the first reading.

As shown in Table 1, because of executive problems and interference with the excavation operations, the first readings of convergence have been made with lag and in some distances from the tunnel face. For correcting the effect of tunnel face distance from the measuring section during the first reading, the convergence measurement curve in each section has been modified based on the distance of the measurement station to the tunnel face.

The important point in the convergence measurement is the installation of convergence measurement pins immediately after the advance of the tunnel face and as close as possible to the tunnel face. This makes it possible to obtain the convergence as a function of time and distance to the tunnel face. Convergence function can be written as:

$$C_t = F(X) + G(T) \qquad [1]$$

In the above equation, C_t is total convergence function, $F(X)$ is a function of tunnel face distance and $G(T)$ is a function dependent on time elapse (Panet et al. 1982).

Table 1. Convergence measurement stations in the downstream of Haltooshan access tunnel.

Station region	Region of amphibolite and gabbro		
Station name	CHD2	CHD3	CHD4
Kilometer	10+625	11+010	11+045
Reading duration (day)	430	210	170
Distance from tunnel face (m)	10	3.5	5

Figure 1 shows the location of convergence measurement stations of Haltooshan access tunnel downstream in CHD2, CHD3 and CHD4 stations. As can be seen, all three sections are located at the same depth and within amphibolite and Loco gabbro regions. CHD3 and CHD4 stations are close to the Bovaneh Fault.

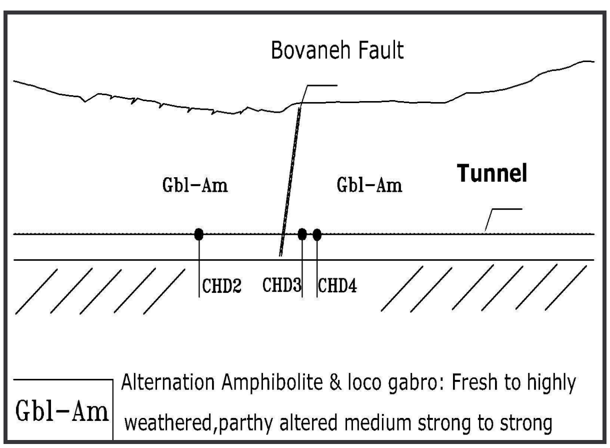

Figure 1. Gavoshan Tunnel longitudinal profile in the downstream of Haltooshan access tunnel

Figures 2 to 4 show the convergence of CHD2, CHD3 and CHD4 stations, respectively. From these figures, it can be noted that the convergence has reached a constant value after a specific period of time. This indicates that the support system used for the stabilization of the tunnel is sufficient.

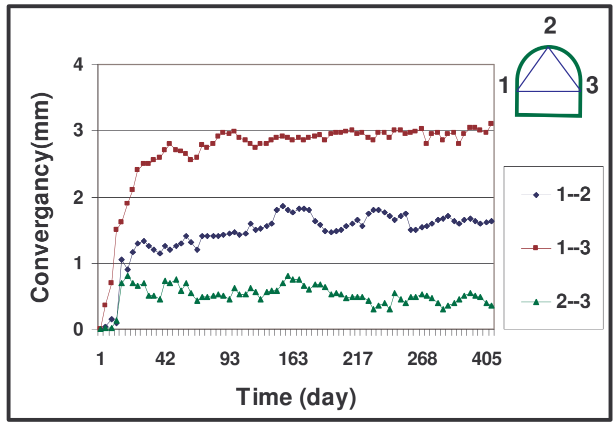

Figure 2. Convergence curves for CHD2 station

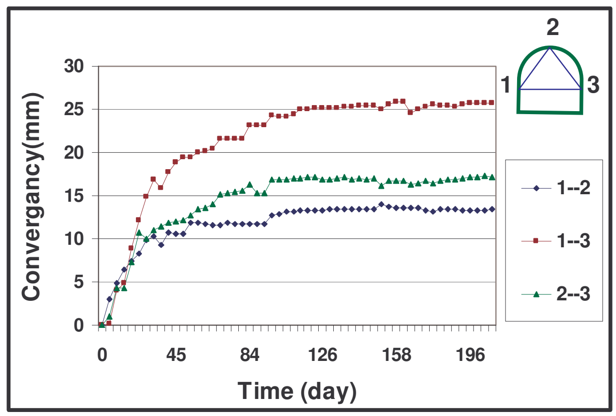

Figure 3. Convergence curves for CHD3 station

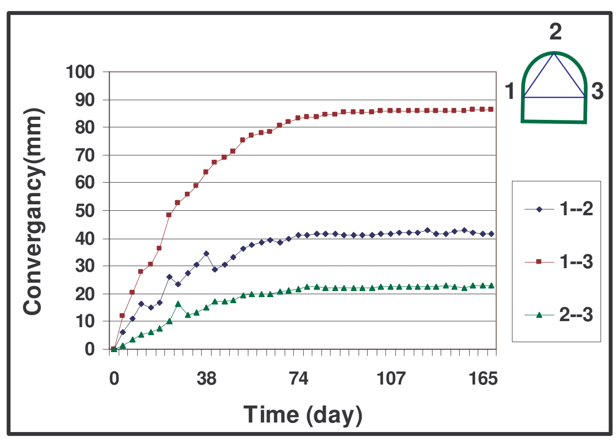

Figure 4. Convergence curves for CHD4 station

Another point that can be concluded from the convergence measurement curves is the importance of lateral stress which is shown by the value of convergence obtained from 1-3 side of convergence measurement stations. The convergence measurement curves in CHD2, CHD3 and CHD4 stations all show that the horizontal stress is greater than the vertical stress.

The plan view of the tunnel is shown in Figure 5. It can be seen that all of these stations are located in one direction, approximately in the direction of the tunnel outlet axis. The angle between the tunnel inlet axis and outlet axis is 130° which can cause changes in the stresses in the tunnel inlet area.

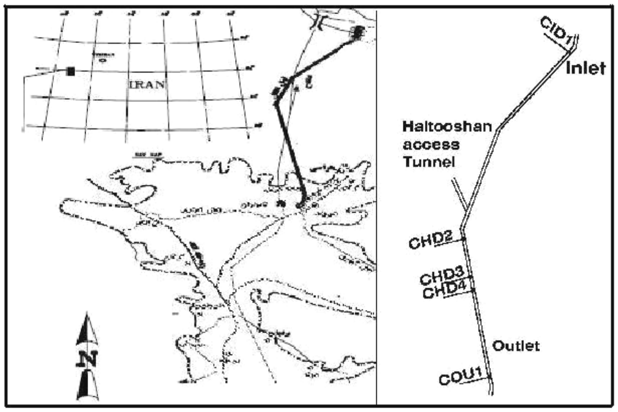

Figure 5. Plan view of Gavoshan Tunnel

4 ESTIMATION OF TOTAL CONVERGENCE

Total convergence can be estimated using the following relation (Panet et al., 1982):

$$T = \frac{measured\ convergence}{2} + R(0.3T) \quad [2]$$

For calculation of R, a longitudinal model which length is twice the distance of the first station from the tunnel face and its height is equal to the tunnel height, is made. After model equilibration, the ratio of the displacement of a point in a specified distance to the tunnel face to the displacement of the crown of the tunnel face is obtained.

Table 2. The values of total convergence

Station name	CHD2	CHD3	CHD4
Distance from tunnel face in the first reading (m)	10	3.5	5
Measured convergence (mm)	3.10	25.90	86.44
R	1.92	1.81	1.87
Total convergence (mm)	3.65	28.33	98.45
Error resulting from delayed reading from tunnel face	18 %	9 %	14 %

The values of total convergence for CHD2, CHD3, CHD4 stations, calculated using the above mentioned method are presented in Table 2. It can be seen that the total convergence error is increased by the increase of distance from the tunnel face in the first reading.

5 PANET CURVE

In this research, the numerical modeling has been made using 2D software, while tunnel excavation and support are 3D issues and the effect of the third dimension along the tunnel length should be taken into account when using 2D analyses. Panet (1979) has proposed a solution for this problem which relates the distance from the tunnel face to the percentage of the stress relief at that point (Figure 6).

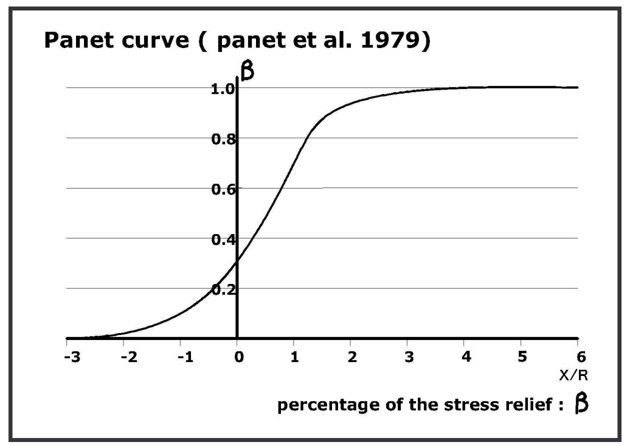

Figure 6. Panet curve (1979)

According to Panet relations, radial displacement (Ur) is related to the distance from tunnel face (Y) as (Panet et al., 1982):

$$Ur = C_0 + C_1^{\{1-\exp(-\frac{Y}{0.7R})\}} \qquad Y \geq 0 \quad [4]$$

$$Ur = C_0 - C_1^{\{1-\exp(-\frac{Y}{0.7R})\}} \qquad Y \leq 0 \quad [5]$$

$$C_0 = -\frac{\sigma_0 R}{2G} h_0 \quad [6]$$

$$C_1 = -\frac{\sigma_0 R}{2G}(1-h_0) \quad [7]$$

In the above relations, R is the radius of the excavation section (m), σ_0 is in situ stress (MPa), G is shear modulus (MPa), Y is the distance from the tunnel face (m) and h_0 = 1/3.

Panet curve for CHD2 station obtained from the relationships provided by Panet and using the parameters presented in Table 3 is shown in Figure 7.

Table 3. Parameters used for obtaining Panet curve

Station name	CHD2
R (m)	3.1
σ_0 (MPa)	9.94
G (MPa)	833
h_0	0.33

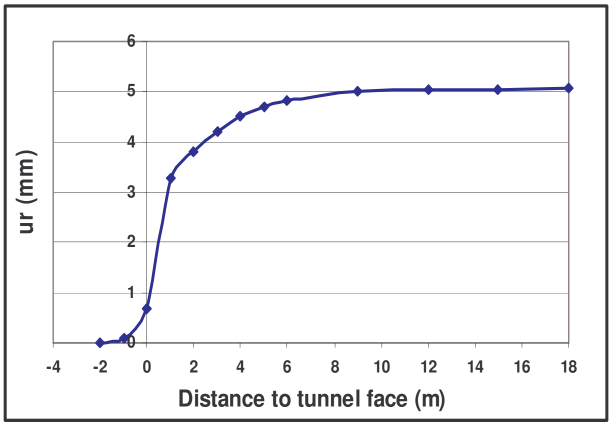

Figure 7. Panet curve based on mathematical relations for CHD2 station

6 NUMERICAL MODELING

For numerical modeling, PLAXIS software with jointed rock calculation model (JR) and 6 nodes triangular elements in plane strain condition have been used (Plaxis user's manual, 2007).

Parameters used for modeling of CHD2 station are shown in Table 4.

Table 4. Parameters used for modeling the tunnel

Station name	CHD2
Overburden (m)	340
k_m	1.30-1.80
C_m (MPa)	0.25
ϕ_m	32
γ (t/m^3)	2.84
ν	0.20
E_m (GPa)	7.10

To model the downstream of Haltooshan tunnel in CHD2 station, a finite element mesh with dimensions of 100m×70m is used (Figure 8). So, the boundaries are not influenced by tunnel excavation.

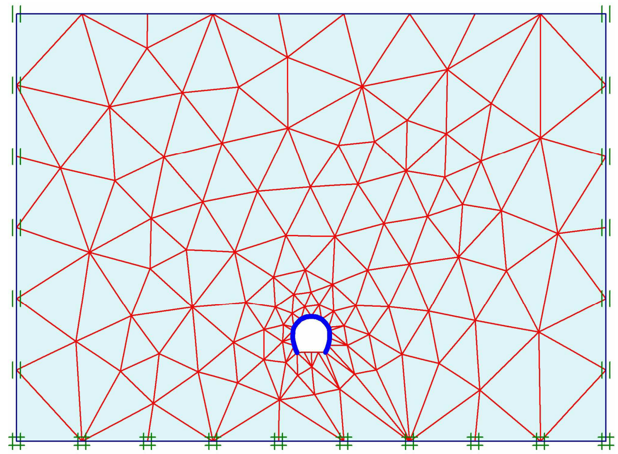

Figure 8. Geometry of the model used in CHD2 station

As mentioned earlier, the effect of tunnel face advance is considered in the model as stress relief percentage with distance from the tunnel face.

After equilibrium of the model (primary equilibrium), k values from 1.3 to 1.8 are applied to the model and the results of each stage are saved in separate files.

Then, the results obtained for the displacement are compared with the convergence measurement results and the value of k is estimated for the region. The results of numerical model for the CHD2 station are shown in Figure 9 along with Panet curve. By comparing Figure 9 and the corrected convergence curve in Figure 10 for the CHD2 station, it can be seen that k=1.6 is acceptable.

The modeling for other stations of Haltooshan access tunnel down stream has been made and the results have been compared with Panet and convergence curves (Table 5).

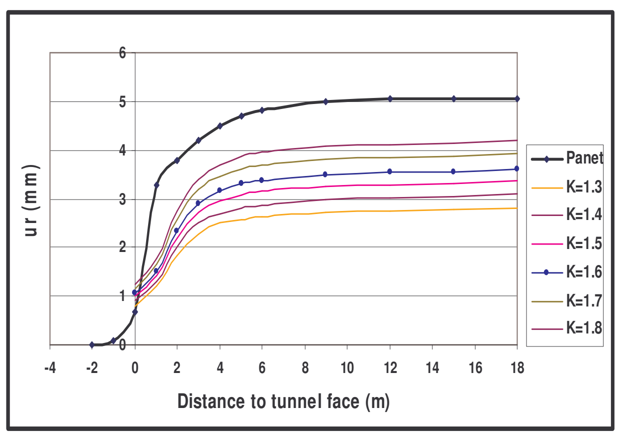

Figure 9. Convergence curves for CHD2 station obtained from Panet relations and numerical modeling

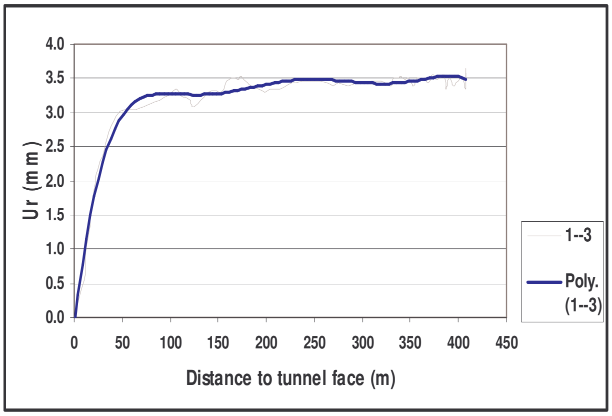

Figure 10. Convergence measurement curve for CHD2 station after correction

Table 5. Comparison of total convergence of stations

Station name		CHD2	CHD3	CHD4
Results of numerical modeling (k=1.6)		3.60	18.34	18.34
Instrument Results	Before correction	3.10	25.90	86.44
	After correction	3.65	28.33	98.45
Panet		5.06	18.46	18.46

As can be seen from Table 5, instrument results, Panet relations and numerical modeling in CHD2 station all are at the same range. But in CHD3 & CHD4 stations, convergence results after correction are greater than numerical modeling results. This can be attributed to the vicinity of these stations to the Bovaneh fault.

7 CONCLUSIONS

The measured and computed displacements of Gavoshan Tunnel located in the west of Iran were presented and discussed. Several instruments were used for the monitoring the behaviour of the tunnel including tape extensometers, rod extensometers, total pressure cells, piezometers and load cells. The convergence of the tunnel was measured using tape extensometers and was corrected to account for the distance of stations from the excavation face. The results obtained from the convergence measurements were compared for various sections along the tunnel. The measured values were also compared with the results obtained from the numerical modeling.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the support of the University of Tehran and JTMA Construction Company.

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