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ABSTRACT

The purpose of this research is the determination of maximum rate of advance in one stage of blasting in middle zone of Kaka-Reza water conveyance tunnel. In this zone of tunnel with average 700 meters of overburden, based on geological and geo-mechanical conditions, the supporting system will install immediately after excavation. The methodology of this research is combined of direct strain evaluation technique (DSET), numerical modeling (FLAC 2D) and convergence analysis. The research is done in three stages. At the first stage, the allowable strain in surrounding rock mass of tunnel is calculated based on DSET. At the second stage, allowable convergence is determined by using the value of allowable strain and numerical modeling (FLAC 2D) together. At the third stage of research, with using of convergence analysis and value of allowable convergence, the maximum rate of advance in one stage of blasting is determined and equal to one meter.

INTRODUCTION

Kaka-Reza conveyance tunnel has 3107.5 meters long and is located in north of Khoramabad city, Lorestan province in Iran. The shape of tunnel is modified horseshoe and the width of excavation is about 4.3 meters. The excavation method of tunnel is blasting because of the economical conditions and accessories. The length of tunnel is divided to five separate zones based on structural geology and stratigraphy. The middle zone of tunnel with average 700 meters of overburden needs more accuracy for design and execution. One of the most important factors in blasting is estimation of maximum rate of advance in each stage of construction. The speed of construction is related to advance in each stage of blasting. There are different factors for determination of maximum rate of advance. In addition to executive limitation related to blasting, there are some effective factors. The concentration of stress in rock mass around the tunnel is increasing in deep tunnel. This is caused by high gravity stress in it. The rock mass is collapsed because of applying of these stresses. The surrounding rock mass of tunnel may be collapsed because of strain increasing due to convergence of the tunnel boundaries to inside. The supporting system of tunnel installed immediately after excavation in middle zone of tunnel related to geological condition and geo-mechanical parameters of rock mass and highest gravity stress. In this paper, the strain in different distances from face of drilling is studied using DSET (Direct Strain Evaluation Technique), which is proposed by Sakurai and convergence analysis by Panet and Guenot (1982) and Chang (1984). The combination of results from numerical two-dimensional modeling in FLAC program and above methods is used for estimation of maximum rate of advance in each run of blasting.

ENGINEERING GEOLOGY OF TUNNEL

The position of Kaka-Reza tunnel with N14E orientation is located in limestone of Servak formation. Structural geological studies are shown that there are three discontinuity systems in limestone rock mass. The characteristics of discontinuity and their orientation are indicated in table (1) and Fig. (1) respectively. Based on the laboratories test results and analysis, the geomechnical parameters of intact rock and rock mass are calculated and shown in table (2). The tectonical studies of site and insitu stress measurement are proposed for the desired area. Therefore, the ratio of horizontal to vertical stress is equal to 1.4. The geological longitudinal profile of tunnel path is shown in Fig. (2).

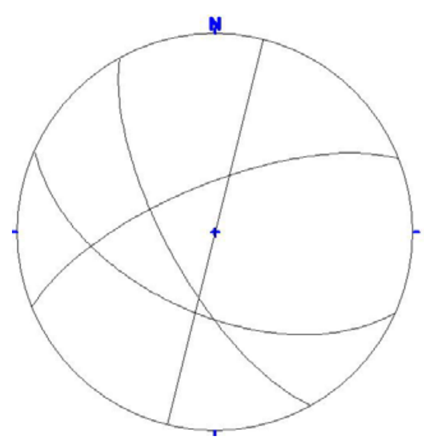

Fig. 1. Orientation of discontinuity and tunnel path

Table 1. Discontinues characteristics in rock mass

Discontinuity Type	Dip Direction (Deg.)	Dip (Deg.)
Bedding Plane	204	56
Joint Set I	241	70
Joint Set II	338	70

Table 2. Geomechnical Parameters in intact rock and rock mass

Geomechnical Parameter	Rock Mass	Intact Rock
E (GPa)	4	9
ν	0.25	0.22
C (MPa)	1.80	13 - 15
ϕ (deg.)	32	40

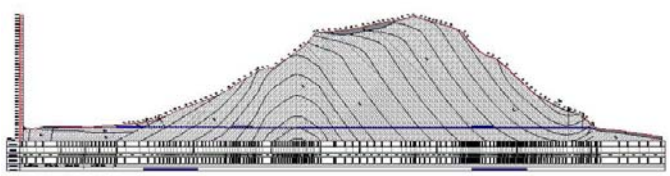

Fig. 2. Longitudinal profile of tunnel path

CONVERGENCE AND STRAIN IN SURROUNDING ROCK MASS OF TUNNEL

The determination of convergence amount and resulted strain from it in any distance from drilling face in tunnel is very important. As a matter of fact, the productive convergence is increasing based on the distance of drilling face in the desired tunnel section. The amount of strain is increasing in rock mass with increasing of convergence. Due to the increasing process, the rock mass is failed. Failure in rock mass is lead to collapsing and explosion in tunnel. The amount of maximum rate of advance in each stage of blasting is estimated with determination of allowable strain and convergence in rock mass. This convergence causes the desired allowable strain.

Allowable Strain

The Direct Strain Evaluation Technique (DSET) is proposed by Sakurai. This method is based on critical strain parameter and has three counters of strain warning for rock. This limitation of strain is based on modules of elasticity for rock. The limitation of strain warning is determined through the following equations:

$$Log\varepsilon_c = -0.25 LogE - 1.59 \quad (1)$$

$$Log\varepsilon_c = -0.25 LogE - 1.22 \quad (2)$$

$$Log\varepsilon_c = -0.25 LogE - 0.85 \quad (3)$$

The equations (1) and (3) indicate the lower and upper limit of strain respectively. The equation (2) is the logarithmic average of the previous equations. The Figure (3) is presented for DSET method by Sakurai and Adachi (1988). Based on this method, if the existence amount of resulted strain in rock mass was plotted below the line which is related to equation (2), the rock mass would be stable. But the instability condition in rock mass is created with increasing of strain from desired limitation in equation (2). The three strain limitations are calculated as 0.18, 0.43 and 1 percent with considering of rock modules of elasticity. These limitations are used as warning strain for rock mass around the tunnel. Based on DSET method, the 0.43 percent of strain is selected as maximum allowable strain before supporting system installation. The maximum length of tunnel without supporting system is equal to maximum rate of advance of blasting.

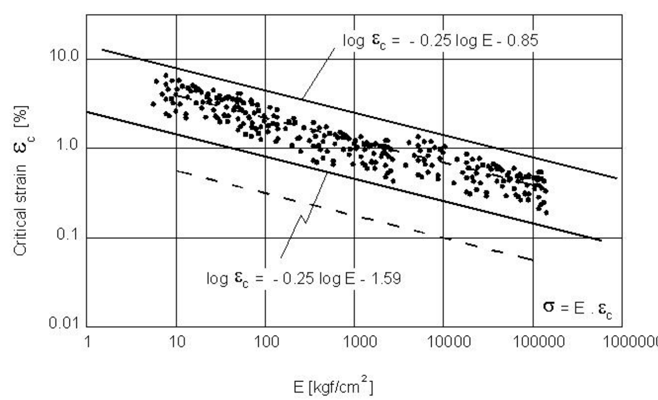

Fig. 3. Relationship between critical strain and the modulus of elasticity

Determination of Allowable Convergence

The allowable strain of rock mass surrounding the tunnel is determined as 0.43 percent. The amount of convergence, which is lead to this strain in rock mass, is called “allowable convergence”. The allowable convergence determination is done with numerical modeling. This modeling is proposed by FLAC program. The FLAC is a geomechanical software, which could be able to analyze the geomechanical continues areas. The Figure (4) shows the grid meshing in numerical modeling. The numerical modeling of tunnel section is created by using geomechanical characteristics of rock mass and geometry of model which is shown in Fig. (4). The method is calculated the amount of average strain in plastic zone near the tunnel and convergence in small step determination. The analysis of model is continued without supporting system installation. The result is the summation of convergences and adjacent to strain of them. The calculation of strain is done in two sensitive areas in roof and wall of tunnel. The figures (5) and (6) show the strain-convergence curvature of rock mass including tunnel in roof and walls. Considering these figures, the maximum allowable convergence is determined in roof and wall of tunnel 22 mm and 23.7 mm respectively. Finally, the convergence of 22 mm is determined as critical convergence or maximum convergence before the supporting system installation.

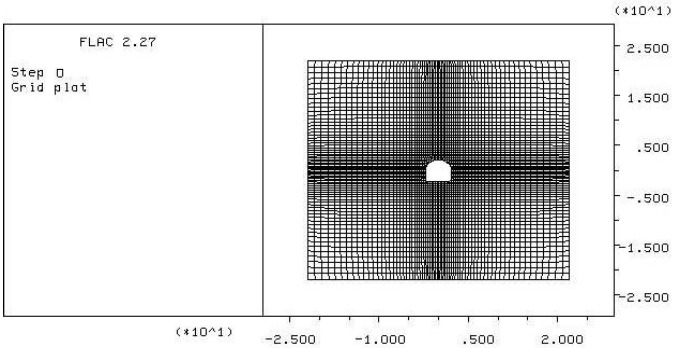

Fig. 4. Mesh generation for numerical model of tunnel

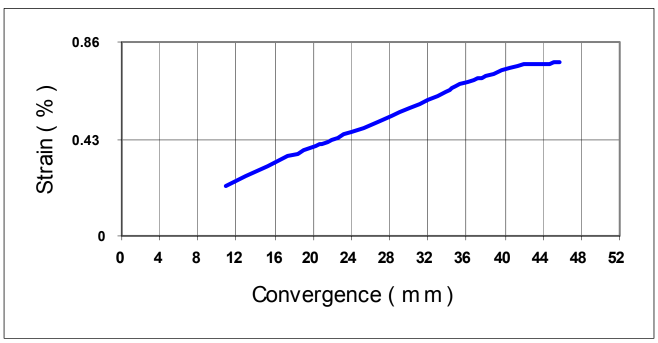

Fig. 5. Strain-Convergence curve of tunnel roof

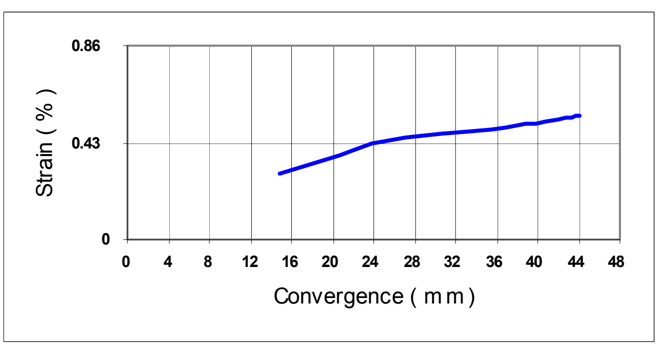

Fig. 6. Strain-Convergence curve of tunnel wall

Determination of Allowable Convergence Distance from Face of Drilling

Convergence in underground areas gradually increases and the reason of this process is related to redistribution of stress in tunnel around, and is increasing. The amount of convergence depends on two factors. The first factor is the distance from face of tunnel and the second one is time depended behavior of rock mass. The time depended behavior of rock mass against the effect of distance from face of tunnel is less effective and is neglectable. Panet and Guenot proposed an equation for estimation of convergence at tunnel in 1982, which is based on distance from face of tunnel using finite element method. Based on this equation, in each section of tunnel which has $X(m)$ distance from face of tunnel and in elasto-plastic material, the amount of convergence of tunnel is determined from the below equation:

$$U(x) = \lambda(x) \cdot U_{total} \quad (4)$$

$$\lambda(x) = 0.28 + 0.72\left[1 + \left(\frac{X}{x+X}\right)^2\right] \quad (5)$$

$$X = 0.84 R_P \quad (6)$$

In which

$U(x)$: The amount of convergence in distance X (m) from face of tunnel

U_{total} : The amount of convergence in long distance from face of tunnel

R_P : The radius of plastic zone around the tunnel

According to the above equations, Chang (1994) is presented a new equation as following:

$$U(x) = U_{total}\left[1 - (1 - \frac{U_0}{U_{total}})(1 + 1.19\frac{x}{R_p})^2\right] \quad (7)$$

In this equation, U_0 is the amount of convergence in face of tunnel that is generated immediately after excavation operations. In equation, which is performed by Panet and Guenot, the ratio $\frac{U_0}{U_{total}}$ is equal to 0.28. Chang is proposed an independent equation for determination of $\frac{U_0}{U_{total}}$ ratio. This equation could show as following:

$$\frac{U_0}{U_{total}} = 0.279\left(\frac{R_p}{R_i}\right)^{0.203} \quad (8)$$

In which

R_i : The tunnel radius or half width of tunnel

Hoek in 1997 presented an equation for determination of plastic zone around the tunnel, which is shown in equation (9).

$$R_p = R_i \left[\frac{2(P_0(M-1)+\sigma_c)}{(M+1)(M-1)P_i+\sigma_c} \right] \quad (9)$$

$$\sigma_c = \frac{2c.\cos\varphi}{1-\sin\varphi} \quad (10)$$

$$M = \frac{1+\sin\varphi}{1-\sin\varphi} \quad (11)$$

In which

P_0 : The hydrostatic stress

σ_c : The unconfined strength of rock mass

c : The cohesion coefficient of rock mass

φ : The initial friction angle of rock mass

The presented convergence equations are determined based on tunnel behavior with circular cross section and hydrostatic stress condition. However, the above equations are a suitable estimation of rock mass convergence in wall of tunnel. The Panet, Guenot and Chang equations are proposed a very close result in middle zone of Kaka-Reza water conveyance tunnel. The Figure (7) indicates the convergence curve in middle zone of tunnel against distance in face of advance, which is based on average of two sets of equations.

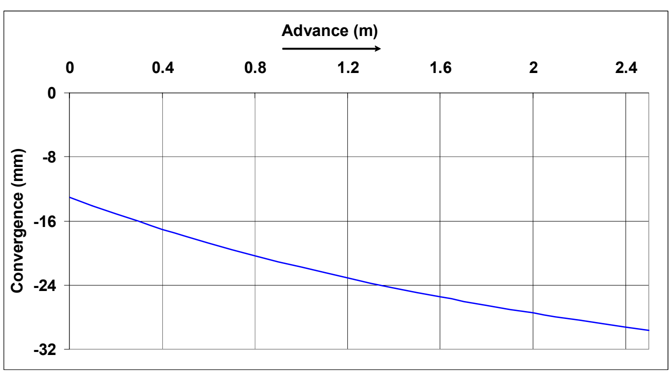

Fig. 7. Convergence graph related to distance from drilling face

CONCLUSION

The process of concluding for determination of maximum rate of advance of tunnel in each stage of blasting is based on the following steps:

1. Determination of allowable strain based on DSET method. In this step, the allowable strain is determined and is equal to 0.43 percent.
2. By using the results from step (1) and numerical modeling, allowable convergence is equal to 22 millimeters.
3. Based on obtained results from step (2) and convergence analysis using Panet and Guenot and Chang equations, the allowable convergence distance to face of drilling is determined. The amount of distance is equal to 1 meter.
4. The maximum rate of advance in each stage of blasting is equal to distance from drilling face where the occurred convergence is lower than allowable convergence.
5. The final result leads to that the maximum rate of advance in each stage of blasting in middle zone of Kaka-Reza tunnel is equal to one meter.

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