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Analysis of rock burst in critical section of second part of Karaj-Tehran Water Supply Tunnel

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ABSTRACT: One of the geotechnical hazards in the tunnels under high overburden and high in situ stresses is the phenomenon of rock burst. Rock burst is a typical geologic phenomenon caused by excavation in rock masses. In this phenomenon, because of stress released and explosion in rock masses, they are broken as large and small pieces and are distributed, so that leads to damage of peoples or equipments. Therefore, familiar with this phenomenon and its mechanism of occurrence, is need to analyze this issue. The second part of water supply Karaj-Tehran tunnel with a length of 14 km and about 4.5 m diameter is located in Tehran province. Rock burst analysis has been carried out in the tunnel from kilometer 6 to 9.5 that is critical section because of high overburden (up to 800 m) and presence of faults and crushed zones. In this paper, for predicting rock burst in the critical section of second part of Karaj-Tehran tunnel, four criteria including, Strain energy, Rock brittleness, Seismic energy and Tangential stress criterion are used. Analysis results show that units with high overburden have high possibility of rock burst.

Keywords: Geotechnical Hazards; Tunnel; Rock burst; predict.

1 INTRODUCTION

When an excavation for a deep underground tunnel or chamber is undertaken in a strong and brittle rock, the change in stress results in dynamic damage to the adjacent rock, referred to as rockburst or break ways. Such rockbursts are a major hazard for the safety of engineers and engineering equipment as well as affecting the shape/size of the structure (Jiang et al., 2010).

The first recorded rockburst was in a British coal mine at Stafford in 1938(Jiang et al, 2010). Since that time there have been a number of reports of rock burst from all over the world. In recent years the importance of this geological hazard has become appreciated in infrastructure such as tunnelling and mining. Consequently rock burst has attracted a high degree of attention in engineering geology and rock mechanics. Cook et al. (1966), through experimental work, provided a theoretical method of predicting rockburst based on the opinion that violent damage of rock occurs when an excess of energy becomes available during the postpeak deformation stage. Brady and Leighton (1977) recorded a seismicity phenomenon before a moderate rock burst while Heunis (1980) introduced control strategies with regard to rockbursts in South African gold mines. At a seminar on 10 November 1983 E. T. Brown said, “It is difficult to reach an agreement on the definition of rock burst”.

Rock burst analysis has been carried out in critical section of second part of Karaj-Tehran tunnel because of high overburden and presence of brittle rock in tunnel route.

2 STUDY AREA

The second part of water supply Karaj-Tehran tunnel with a length of 14 km and about 4.5 m diameter is located in Tehran province which is located in the north of Iran (Fig. 1).

This tunnel is a part of water supply plan for the purpose of drinking water for Tehran. This tunnel is started from Amir Kabir Karaj dam and will continued to water softening (No: 6) of Tehran.

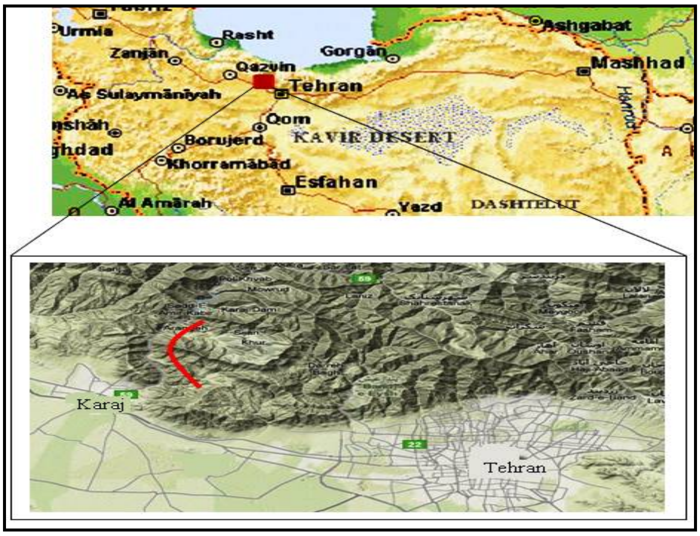

Figure 1. Location of study area in Iran (Alborz Mountain)

Rock burst analysis has been done in the tunnel from kilometer 6 to 9.5 as critical section because of high overburden (up to 800 m) and the presence of faults and crushed zones (Fig. 2). Engineering geological units in this section are formed with specific signs that are the initial letters of lithology of units.

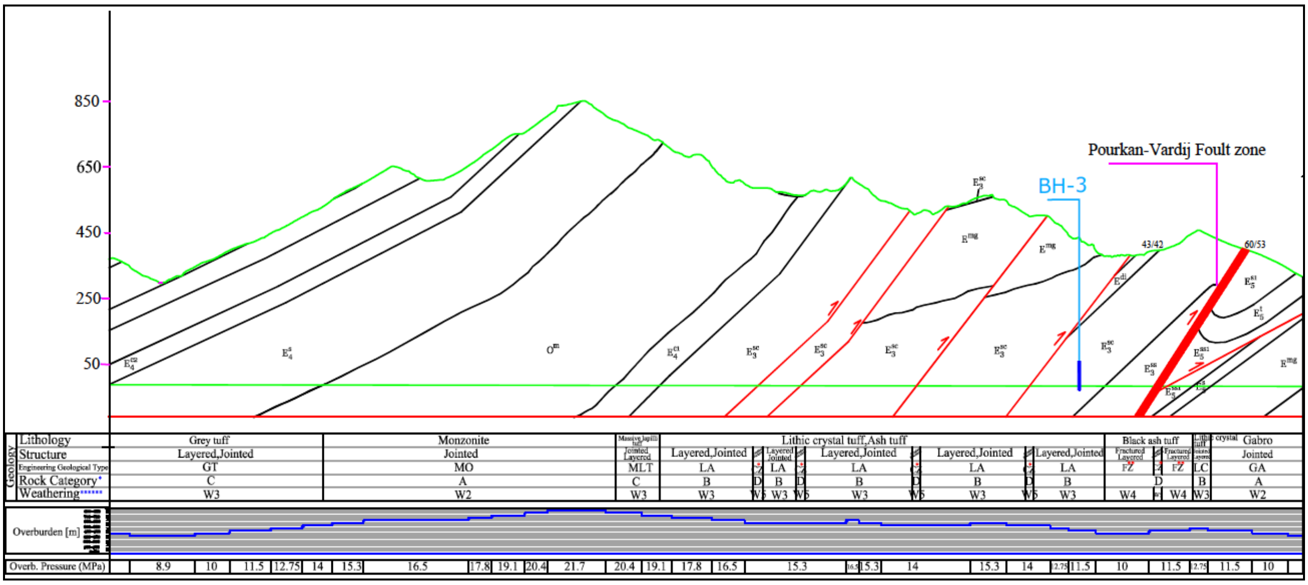

Figure 2. Critical section of Karaj-Tehran Tunnel route

3 ENGINEERING GEOLOGICAL STUDIES

Units of studied tunnel have been distinguished on the basis of some engineering geological characteristics such as lithology of layers, differences of structural features and geotechnical characteristics. In general, by considering the repeated units in different parts of the tunnel route, 20 engineering geological units were distiguished. Meanwhile, in the critical section, 8 units are located. Most units of critical sections have a pyroclastic source. This rock mass is including of many types of tuff such as MLT (Massive lapilli tuff), LA (Iithic crystal tuff, Ash tuff), LC (Lithic crystal tuff) and GT (Grey tuff). Igneous rocks of the studied section are Monzodiorite (MO) and Microgabro (GA).

There are several faults in the tunnel route. The main fault zone and crushed zone is Pourkan-Vardij fault zone that cuts the tunnel route in 6417 to 6442 meter from end of tunnel (Fig. 3). It should be noted, that CZ and FZ show crushed and fractured zone respectively due to fault activity.

Figure 3. A part of Pourkan-Vardij fault zone in tunnel route

For the study of strength and deformability properties of rock masses, a number of boreholes were drilled and needed core and block samples for laboratory studies have been selected. Some of geotechnical characteristics of intact rock that are essential for evaluation of rock burst problem are measured and are presented in Table 1.

Table 1. Some of geotechnical characteristic of intact rock of engineering geological units

Engineering geological units	saturated density (gr/cm^3)	Deformation modules (GPa)	Uniaxial compressive Strength (MPa)	Tensile strength (MPa)
GA	2.79-2.9	15-25	200-250	37.5
LC	2.3-2.7	20-40	100-150	4
LA	2.5-2.7	5-20	50-100	4
MLT	2.5-2.8	5-20	50-100	6
MO	2.55-2.8	15-25	100-200	32.5
GT	2.3-2.7	2.3-2.7	50-100	10
FZ	2.5-2.7	2.5-2.7	50-100	4
CZ	2.5-2.7	2.5-2.7	50-100	4

3.1 *Estimation of in situ stress*

The main origins of in situ stresses are geological conditions and geological history of the area. In general, estimating in situ stresses requires a detailed characterization of the site geology and considerable judgment (Amadei and Stephansson, 1997). Different expressions have been proposed in the literature for the coefficient K (ratio of horizontal to vertical stress).

Rummel (1986) presented an extensive literature review of stress variations with depth from deep hydraulic fracturing stress measurement conducted in various parts of the world and presented Eq. (2) for determining K_H and K_h at any depth. In this research, no field or laboratory test have been done for determination of stresses. Thus, they were calculated as:

$$\sigma_v = \gamma \times Z \quad (1)$$

Where:

σ_v = vertical stress (MPa), γ = unit weight of rock mass (MN/m^3), Z = tunnel depth below surface in m. And for K_H and K_h (Amadei and Stephansson, 1997):

$$KH = 0.98 + 250/Z; Kh = 0.65 + 150/Z \quad (2)$$

The results of equations are presented in Table 2. These empirical results are consistent with stress study at Amir Kabir dam site in the vicinity of Karaj-Tehran tunnel (Ahmadian et al.; 2007).

Table 2. Empirical results of stresses in Karaj-Tehran tunnel

Engineering units	Km from end of tunnel	Overburden (m)	σ_v (MPa)	K_H	K_h	σ_H (MPa)	σ_h (MPa)
GA	5971-6265	400	10.6	1.6	1.03	17.01	10.87
LC	6265-6322	500	13.25	1.4	0.95	19.61	12.59
FZ	6322-6417	450	11.925	1.5	0.98	18.31	11.73
CZ	6417-6442	450	11.925	1.5	0.98	18.31	11.73
FZ	6442-6559	400	10.6	1.6	1.03	17.01	10.87
LA	6595-6817	500	13.25	1.4	0.95	19.61	12.59
CZ	6818-6844	550	14.575	1.4	0.92	20.91	13.45
LA	6844-7171	550	14.575	1.4	0.92	20.91	13.45
CZ	7171-7197	550	14.575	1.4	0.92	20.91	13.45
LA	7197-7531	600	15.9	1.4	0.90	22.21	14.31
CZ	7531-7561	600	15.9	1.4	0.90	22.21	14.31
LA	7561-7663	600	15.9	1.4	0.90	22.21	14.31
CZ	7663-7693	600	15.9	1.4	0.90	22.21	14.31
LA	7693-7986	700	18.55	1.3	0.86	24.80	16.03
MLT	7985-8123	800	21.2	1.2	0.84	27.40	17.76
MO	8123-9037	700	18.55	1.3	0.86	24.80	16.03
GT	9037-9707	400	10.6	1.6	1	17	10.9

4 EVALUATION AND PREDICTION OF ROCKBURST

According to Zhang et al. (1994) rock burst is a type of brittle failure which occurs mainly in the rocks around tunnels and is associated with a sudden large release of latent pressures. Tao (1996) considered it occurs as a result of mechanical disturbance when the large quantity of strain energy accumulated within a rock mass is released suddenly, triggering a violent fracturing of the rock. Most authorities believe the main reason why rock bursts occur is related to the strain energy accumulated in a rock mass. However, the occurrence of rock burst depends not only on the accumulated strain energy but also on disturbance by external factors, e.g. Tao's "mechanical disturbance" (Tao, 1996). In tunnel constructions there are many such disturbances, e.g. explosion, vibration, stress impact from neighboring rock bursts, earthquakes, etc., all of which can be considered to involve dynamic loading (Blair, 1993).

Rockburst is one of the most complicated dynamic geological phenomena with intricate mechanism and numerous affecting factors, which accounts for the difficulty of predicting its characteristics. In the past few years, many methods of forecasting rockbursts, including rock mechanics assessment, stress detection and modern mathematical theories, have been proposed.

In this paper, for predicting rock burst in the critical section of second part of Karaj to Tehran tunnel, four criteria such as, Strain energy, Rock brittleness, Seismic energy and Tangential stress criterion have been used.

4.1 *Criterion of elastic strain energy*

Investigation (Kwasniewski et al., 1994) shows that the occurrence of shock and rockburst could be scaled by the so-called potential energy of elastic strain, PES i.e. the elastic strain energy in a unit volume of rock masses. Under uniaxial compression, the elastic strain energy stored in rock specimen prior to the peak strength is given by:

$$PES = \frac{\sigma_c^2}{2E_s} \tag{3}$$

Where, σ_c is the uniaxial compression strength (MPa), E_s is the unloading tangential modulus (MPa). In the opinion of Polish experts (Kwasniewski, 2000) if:

- PES<50 kJ/m^3, then the rockburst hazard is very low;
- 50<PES=100 kJ/m^3, then the rockburst hazard is low;
- 100<PES=150 kJ/m^3, then the rockburst hazard is moderate;
- 150<PES=200 kJ/m^3, then the rockburst hazard is high; and
- PES>200 kJ/m^3, then the rockburst hazard is very high.

4.2 *Criterion of rock brittleness*

Rock brittleness is defined by an index of the ratio of uniaxial compressive strength to tensile strength of rock, that is:

$$B = \frac{\sigma_C}{\sigma_T} \tag{4}$$

Where, σ_c is the uniaxial compression strength (MPa), σ_T is the tensile strength of the rock (MPa). Experimental study and in situ investigation of Qiao and Tian (1998) show that:

- B>40 then no rockburst;
- B=40-26.7, then weak rockburst;
- B=26.7-14.5, then strong rockburst; and
- B<14.5, then violent rockburst.

4.3 *Criterion of tangential stress*

This criterion considers both the state of in-situ stress in rockmass as well as the mechanical property of rock. The criterion of tangential stress is expressed by:

$$T_s = \frac{\sigma_\theta}{\sigma_c} \tag{5}$$

Where, σ_θ is the tangential stress in rockmass surrounding the openings or stopes (MPa) and σ_c is the uniaxial compressive strength of rock (MPa). The preliminary study (Wang et al., 1998) shows that:

- Ts<0.3, then no rockburst;
- Ts=0.3-0.5, then weak rockburst;
- Ts=0.5-0.7, then strong rockburst; and
- Ts>0.7, then violent rockburst.

To calculate the tangential stresses on the inner surface of the tunnel, Hook and Brown equations have been used (Palmstrom, 1996):

$$\sigma_{\theta r} = (A \times K - 1)P_v \tag{6}$$

Where, K is the ratio of horizontal to vertical stress, P_v is the vertical stress and K is 3 for circular tunnel. It should be noted that the tangential stress is calculated only on the roof of tunnel, because the amount of stress on roof is more and critical. The results of the three criteria described above with degree of rockburst are presented in Table 3.

Table 3. Determination of rockburst risk by using various criteria in the tunnel route

Engineering units	elastic strain energy criteria		rock brittleness criteria		tangential stress criteria		
	PES	Description	B	Description	tangential stress	Ts	Description
GA	1266.6	very high	6.0	violent	40.44	0.18	no
LC	260	very high	31.3	weak	45.58	0.36	weak
FZ	100	low	12.5	violent	43.01	0.86	violent
CZ	100	low	12.5	violent	43.01	0.86	violent
FZ	100	low	12.5	violent	40.44	0.81	violent
LA	225	very high	18.8	strong	45.58	0.61	strong
CZ	100	low	12.5	violent	48.15	0.96	violent
LA	225	very high	18.8	strong	48.15	0.64	strong
CZ	100	low	12.5	violent	48.15	0.96	violent
LA	225	very high	18.8	strong	50.72	0.68	strong
CZ	100	low	12.5	violent	50.72	1.01	violent
LA	225	very high	18.8	strong	50.72	0.68	strong
CZ	100	low	12.5	violent	50.72	1.01	violent
LA	225	very high	18.8	strong	55.86	0.74	violent
MLT	225	very high	12.5	violent	61.00	0.81	violent
MO	563	very high	4.6	violent	55.86	0.37	weak
GT	225	very high	7.5	violent	40.44	0.54	strong

4.4 *Criterion of seismic energy*

An event that sending a substantial kinetic energy about 104 joules has been introduced, as a seismic phenomenon. In all seismic phenomena, a kinetic energy released from a particular source. The actual seismic energy source that cause explosions in rock, include changes of induce stress resulting from drilling and sliding on the discontinuities e.g. geological faults.

Seismic energy values (E_S) is calculated by using Spoties and Gar equations (Bieniawski, 1987):

$$LogE_S = 1.5M_L - 1.2 \qquad \text{(Mj)} \qquad (7)$$

$$M_L = LogM_S - 1.16 \qquad \text{(Richter)} \qquad (8)$$

Where, M_S is the magnitude of shear wave, M_L is the magnitude of longitudinal wave. In this case, a classification scheme from Cook (1977) is presented in Table 4.

To determine the average of magnitude of possible earthquake on Richter scale, the engineering geological studies of second part of Karaj to Tehran tunnel has been used. According to studies conducted on studied area, the mean maximum of magnitude of possible earthquake, are in the ranges $6.5 \leq M_S \leq 7.7$.

By using equations (7) and (8), we get:

$$-3.5 \leq M_L \leq -0.27 \Rightarrow -1.72 \leq LogE_S \leq -1.6$$

$$19.05 \times 10^{-3} \leq E_S \leq 25.1 \times 10^{-3} (Mj)$$

$$19.05 \times 10^{3} \leq E_S \leq 25.1 \times 10^{3} (j)$$

Using Table (4), a level of damage has occurred by seismic energy is exfoliation of rocks. So by considering the situation, a serious threat for personals and equipments, will not be considered.

Table 4. Seismic event properties (Bieniawski, 1987)

Degree of damage	Monthly frequency	Richter scale	Seismic energy (j)	seismic event
Development of joints	2000	-3.5	0.4	Weak shake
	300	-2	63	
	80	-1	2×10^2	Weak earth-quake
Exfoliation	20	0	6.3×10^4	
	6	1	2×10^6	
Weak rockburst	1.5	2	6.3×10^7	
Strong rockburst	0.4	3	2×10^9	
Violent rockburst	0.02	4	6.3×10^{10}	

5 CONCLUSION

Critical section of second part of Karaj to Tehran tunnel, because of high overburden (up to 800 m) and the presence of faults and crushed zones, has been analyzed for rockburst risk. By using four criteria that including Strain energy, Rock brittleness, Seismic energy and Tangential stress, rockburst analysis has been carried out and results show, units with high overburden and weak rockmass because of high in situ stress and tangential stress have a high potential of rockburst. One of these areas can be found in Pourkan-Vardij fault zone.

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