Groundwater Seepage Estimation into Amirkabir Tunnel Using Analytical Methods and DEM and SGR Method

Hadi Farhadian, Homayoon Katibeh

Abstract**—**In this paper, groundwater seepage into Amirkabir tunnel has been estimated using analytical and numerical methods for 14 different sections of the tunnel. Site Groundwater Rating (SGR) method also has been performed for qualitative and quantitative classification of the tunnel sections. The obtained results of above mentioned methods were compared together. The study shows reasonable accordance with results of the all methods unless for two sections of tunnel. In these two sections there are some significant discrepancies between numerical and analytical results mainly originated from model geometry and high overburden. SGR and the analytical and numerical calculations, confirm high concentration of seepage inflow in fault zones. Maximum seepage flow into tunnel has been estimated 0.425 lit/sec/m using analytical method and 0.628 lit/sec/m using numerical method occured in crashed zone. Based on SGR method, six sections of 14 sections in Amirkabir tunnel axis are found to be in "No Risk" class that is supported by the analytical and numerical seepage value of less than 0.04 lit/sec/m.

Keywords**—**Water Seepage, Amirkabir Tunnel, Analytical Method, DEM, SGR.

I. Introduction

WATER inflow into tunnels is one of the most important problems in tunneling in rock media which flows through initial discontinuities and or which is created in tunnel walls. This causes some matters in progress of tunneling such as decrease in rock mass stability; make extra pressure on permanent and temporary stability system, destructive effects on geomechanical condition of rock and finally physical and economical dangers happen.

Due to impossibility of identifying and determining the whole factors which are affecting water inflow into tunnels especially during drilling, anticipating the exact amount of seepage into tunnels in rock media is difficult. Therefore, analytical methods, due to application of some simplification and assumptions, mostly used to calculate seepage amount into tunnels. Some of the important investigations carried out in order to calculate water inflow into tunnels include [1]-[8].

In spite of analytical methods, which are a total estimation of seepage, with attention to basic equations of seepage flow and site characteristics, with applications of numerical methods such as FEM, DFM, DEM, FVM water inflow into tunnel van be modeled and then seepage into tunnel in various situations in site can be calculated. These methods in opponent to analytical methods are difficult in calculation. Also, they require comprehensive data about the site. Moreover, there are less simplifications and assumptions in these methods. Though, numerical methods are very complex and application of them is time consuming, however, the results are more precision in comparison to Analytical methods [9].

In this paper, water inflow into tunnel in some sections of Amirkabir Tunnel is anticipated. First, analytical methods are used in seepage calculation. After that, according to boundary conditions and site characteristics, seepage in rock media around the tunnel is calculated in UDEC software which depends on the Different Element Method. Then, these sections quantitatively and qualitatively in point of underground water inflow danger with SGR method are rated. Katibeh and Aalianvari (2009) provided SGR method to rate tunnel length qualitatively and quantitatively in point of underground water seepage danger depends on initial site investigations [10]. According to the mentioned calculations in addition to seepage estimation into tunnel, accuracy and precision of results in comparison to the results of SGR method are evaluated.

II. Introduction to Analytical Equations of Seepage Inflow into Tunnels and Their Validation Range Review Stage

Analytical methods based on the equations of water inflow into tunnels with respect to parameters such as rock mass permeability, water table, tunnel radius, etc. estimate water infiltration into tunnels. Table I shows the analytical equations. In these equations H_0, distance between tunnel center and water table, Z, overburden, r, tunnel radius, K, equivalent permeability coefficient of rock media along seepage flow, Q_L, infiltration amount per unit.

Fig. 1 shows an overview in relation to parameters used in the equations presented in Table I. Analytical equations under the following conditions are invalid [9]:

1. Water inflow around the tunnel is vertical.
2. Bedding in the rock mass around the tunnel is very variable.
3. Rock mass permeability cannot be exactly identified.

H. Farhadian is with the Mining and Metallurgical Engineering Department, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran (e-mail: Farhadian@aut.ac.ir).

H. Katibeh is with the assistant professor of Mining and Metallurgical Engineering Department, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran (corresponding author to provide phone: 0098 2164542926; e-mail: Katibeh@aut.ac.ir).

TABLE I
ANALYTICAL EQUATIONS OF GROUNDWATER SEEPAGE FLOW INTO TUNNELS

Reference	Equation Number	Equation	Description
Goodman (1965) [1]	(1)	$Q = 2\pi K \frac{H}{2.3 log\,(\frac{2h}{r})}$	This equation has three basic defaults; radius flow, no significant changes in bedding, accurate application of media equivalent permeability. H is the hydraulic head, h the depth of the tunnel with H ≥ h.
Freeze and Cherry (1979) [2]	(2)	$Q = \frac{2\pi K H_o}{\ln(\frac{2H_o}{r})}$	These researchers have revised equation 1 by substituiting Z instead of H.
Heuer (1995) [3]	(3)	$Q_L = \frac{2\pi K H_o}{\ln(\frac{2z}{r})} \times \frac{1}{8}$	Heuer reduction coefficient (1/8) and some changes in denominator applied in order to revise equation 2.
Lei (1999) [4]	(4)	$Q = 2\pi K \frac{h}{\ln(\frac{h}{r} + \sqrt{(\frac{h}{r})^2 - 1})}$	In this equation, Goodman method has been corrected with application of exact real conditions.
El-Tani (1999) [5]	(5)	$Q = 2\pi K \frac{1-3(\frac{r}{2h})^2}{[1-(\frac{r}{2h})^2]\ln(\frac{2h}{r} - (\frac{r}{2h})^2}$	El-Tani has defined equation 5 as an optimum equation by considering above mentioned equations.
Karlsrud (2001) [6]	(6)	$Q = 2\pi K \frac{h}{\ln(\frac{2h}{r} - 1)}$	A combination of equation 1 and 3, according to field observations, is edited for reducing error in deep and shallow tunnels (under water table).
Lombardi (2002) [7]	(7)	$Q = 2\pi k \frac{h}{\ln \frac{2h}{r}\left(1 + 0.4\left(\frac{r}{h}\right)^2\right)}$	In this equation, Karlsrud method has been corrected with application of exact conditions.
El-Tani (2003) [8]	(8)	$Q = 2\pi k \frac{\lambda^2 - 1}{\lambda^2 + 1} \frac{h}{\ln \lambda}$	In this equation El-Tani has applied Mobius transformation method and fourier series and presented a new analytical solution for flow calculation, in which $\lambda = (h/r) - ((h^2/r^2) - 1)^{1/2}$

Primarily, in analytical methods a tunnel is compared with a vertical water pumping well under a steady state regime and the mentioned equations are inferred based on the simulation of conditions of pumping a well under a steady state regime or a tunnel which is located in a considerable depth towards water table. Under these conditions seepage into tunnel wells are assumed equal and symmetric (or to be more precise isotropic) in all directions. On the other hand, the most important factor in analytical methods is to determine the equivalent permeability of the media around the tunnel and due to inaccurate estimation of this parameter, most of these methods encounter with problems during water inflow estimation. Permeability coefficient (K) is inferred from lugeon test done in boreholes in various depth and it is generalized into intervals between boreholes. In places where lugeon tests are not performed, with attention to geological characteristics and borehole conditions, equivalent permeability is estimated but it has many problems [1]:

1. In lugeon test, a small volume of rock mass is tested and the calculated permeability is assumed as an equivalent permeability of huge volume of rock masses.
2. Individual geological structures such as faults, breccia and crushed zones control fluid flow. However, it is possible that none of these structures are test in lugeon test. Though the results will be differ from what is fact.

A huge volume of flow happens when a rock mass with high permeability exists around the tunnel. Although, it is known that they form only a few percent of rock media surrounding tunnel. In this case, high permeability values interfere with low permeability values. Therefore permeability value in a region will be affected by high and low values. On the other hand, analytical methods by means of hydraulic analysis and regardless of existing discontinuities encounter with problems in estimating the accurate groundwater inflow. In analytical analysis, interaction between flow and stress is avoided, however, in nature the interaction between flow and stress affected.

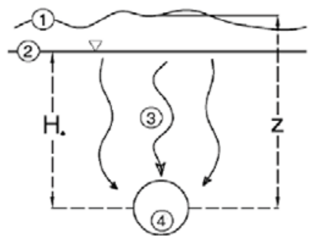

Fig. 1 Tunnel condition in Goodman equation and introduction of parameters Tunnel is in the saturated zone. (1) ground surface, (2) groundwater table which is possible to be upper than burden, (3) water motion zone with equivalent permeability coefficient, K, (4) inner zone of tunnel [9]

III. DISCRETE ELEMENT METHOD

Discrete element method based on block theory is developed in order to analysis discontinuous media. In this method, the mass of the object is intended as a collection of separate blocks. Also deformations and behavior of ingredients of the blocks are assumed negligible. Joints and cracks in the media are act as discontinuities between blocks or boundary conditions or assumed as a special element in the model. This technique depends entirely on making rock mass discontinuities ideal and makes simulation of complex relationships of joints, cutting and separation, plus a lot of movements and turning blocks possible. Blocks can be rigid or flexible. Blocks are assumed impermeable in point of hydraulic view and flow passes through the joints.

In numerical methods, conditions are assumed closer to reality in which the upper boundary of the model only has flow and lower and lateral boundaries have no flow. Accordingly, leakage into the tunnel from roof will be more than floor and side walls. This condition, according to relative proximity of tunnel roof to groundwater table (shortness of leakage path) than side walls and floor is more reasonable in terms of adaptation to natural condition. The main difference between DEM and analytical values lies in this fact [11]. In fact, due to difference between leakage condition into tunnel in isotropic analytical method and anisotropic numerical method, calculated values have significant differences. On the other hand, in numerical methods interaction between flow and stress and simultaneous hydromechanics process are taken into account which in turn affects the flow within the rock mass [11].

UDEC, a 2-D numerical analysis software based on discrete element method used for modeling discontinuous media. This software is planned and produced in 1971 by Dr. Cundall accompanied by Itasca company in Pennsylvania, USA. UDEC model the response of discontinuous media (jointed rock mass) toward various static and dynamic pressures. The model created in this application consists of separate blocks in which discontinuities are considered as boundary conditions between blocks.

UDEC works based on algorithm calculation. UDEC software has capability of analysis fluid flow in fractures existing in a system of permeable blocks. The analysis of this relationship is hydraulic-mechanical. This means that hydraulic conductivity of joints depends on the mechanical deformation and vice versa joints water pressure affect mechanical calculations [12].

IV. Tunnels Site Rating in Point of Groundwater Seepage Hazard View Based On SGR Coefficient

Katibeh and Aalianvari proposed SGR rating system based on initial site investigations for the first time in 2009 in order to classify tunnel length qualitatively and quantitatively in point of groundwater seepage hazard view [10]. In this rating system, with taking into account parameters like frequency and aperture of joints, Schistosity, crashed zones, karstification, soil permeability, water head above tunnel, annual raining and score them, tunnel length divide into 6 classes from groundwater leakage hazard point of view: No Danger, Low Danger, Relatively Dangerous, Dangerous, Highly Dangerous and Critical. According to this method, total score of site compute from:

$$SGR = [(S_1 + S_2 + S_3 + S_4) + S_5] S_6 \; S_7 \tag{9}$$

where: S_1, score of frequency and aperture of joints, S_2, schistosity, S_3, crashed zone, S_4, karstification, S_5, soil permeability, S_6, water head above tunnel, S_7, annual raining. It is obvious that in rocky site parameters like crashed zone, joint frequency and karstification is more of importance in opposed to earthen site. Vice versa, in earthen site permeability coefficient is more important, while, in rocky media this factor is lies within frequency and aperture of joints and etc. Though, in rocky site S_5 and in earthen site S_1 to S_4 are assumed zero. Annual raining becomes important when a tunnel is drilled in an unsaturated zone. While, a tunnel is drilled in a saturated area, it is assumed as unit.

After computing SGR coefficient for a considered section of a tunnel, there must be a criterion to evaluate magnitude of the coefficient, so that the hazard of groundwater seepage into a tunnel (with a qualitative and quantitative point of view) could be evaluated. This is proposed based on the values in Table II. Anticipating groundwater inflow into a tunnel leads to design a suitable drainage system and also selecting the most appropriate drilling method, so that necessary arrangements are made to prevent probable dangers. The larger the SGR coefficient is, the volume of infiltrated water will be high (at least in short term), so that drainage systems must be stronger and highly cost. Even, sometimes revision in drilling method must be done in order to reduce probability of dangers.

TABLE II
Qualitatively and Quantitatively Rating of Tunnel Site from Groundwater Seepage Point of View Based On SGR Coefficient [10]

SGR	Tunnel Rating	Class	Probable conditions for groundwater inflow into tunnel (lit/s/m)
0-100	No danger	I	0-0.04
100-300	Low danger	II	0.04-0.1
300-500	Relatively Dangerous	III	0.1-0.16
500-700	Dangerous	IV	0.16-0.28
700-1000	Highly Dangerous	V	Q>0.28
1000<	Critical	VI	-

V. Case Study; Amirkabir Tunnel

Amirkabir tunnel located in northwest of Tehran is designed and performing to transfer water from Amirkabir dam to Tehran. One of the problems will be occurred in this project is the probability of water in rush into tunnel during drilling operation. In this paper, the results of analytical, numerical methods and groundwater seepage rating (SGR) in 14 sections of Amirkabir tunnel (3.1-14.1 km) are investigated.

A. Geology of the Area

In geological studies which have been performed, tunnel divided into 14 geological units which is generally encompasses various sedimentary-volcanic sets of Karaj formation. Its petrology contains layers of tuff, sandstone, fine-grained conglomerate, siltstones, lava and agglomerate. In this study, the possibility of leakage from +3.1 km to +14.1 km of the tunnel length is considered which is divided into 9 geological parts: Gta2, sandstone layers, tuff, Gta3, sandstone layers, tuff, fine-grained conglomerate, Gta4-1, sandstone, tuff, Gta4-2, tuff, in some parts sandstone and conglomerate, Sts1, tuff, siltstone, sandstone layers and micro-conglomerate, Sts2-1, tuff, limestone, Sts2-2, tuff, limestone, siltstone, sandstone layers and conglomerate, Tsh-1, sandstone, shale, siltstone, Cr, tuff, sandstone, micro-conglomerate [13].

B. Results of Analytical Methods

As noted above, in analytical methods with taking into account parameters such as equivalent permeability of rock mass, water table height and tunnel radius, the rate of seepage into tunnel is estimated. Some conditions and assumptions should be considered to apply these equations [9]:

1. 2-D flow and circular tunnel section.
2. Homogenous and isotropic permeability
3. Tunnel section is located under water table (in saturated zone).

Basically, water ingress rate into tunnel is presented in the form of discharge rate or more precisely, water inflow volume per time per unit length of the tunnel. Due to slight geological variations of media around boreholes and in the distance between two adjacent holes, the effective length around each hole is defined in which water table and permeability coefficient is assumed equal to the data of the hole. Seepage rate into tunnel in the mentioned length is determined from multiple of length to discharge rate. Water leakage rate into tunnel is computed based of the data of each borehole by taking the above conditions and assumptions into consideration and provided in Table III.

C. Results of DEM Method (UDEC Software)

In UDEC software, by importing boundary conditions (stable head, steady state flow and or no flow boundaries), rock mass and joints characteristics as well as their geometry coordinate, as well as the situation of tunnel and its section, permeability and groundwater head is computed in different points of a aqueous layer. Then, therefore seepage rate into tunnel can be calculated. It is obvious that the accuracy of calculations by software is totally depends on the accuracy of input parameters [13].

In order to anticipate leakage rate in some parts of the tunnel, DEM method is applied. Because of that discontinuous media is modeled with UDEC software pack which is based on discrete element method and has the capability of modeling fluid flow in a system of impermeable blocks and investigates hydro-mechanical behavior of media. The model is formed of a block with 30 meters length, 30 meters height, two continuous joint set and a tunnel with 4.7 diameter which is located approximately in the center of the block. Fig. 2 shows model geometry as well as boundary conditions. Required data for modeling sections are gathered from field information and investigations in initial investigations of Amirkabir tunnel. Water inflow rate into tunnel in 14 sections of tunnel lengths are provided in Table III. Fig. 3 shows water pressure in one of the modeled sections after tunneling and seepage.

TABLE III
RESULTS OF ANALYTICAL AND NUMERICAL METHODS; SEEPAGE RATE INTO TUNNEL IN 14 SECTIONS OF AMIRKABIR TUNNEL

Section number	Section situation (meter)	Water discharge (lit/sec/m), Numerical method, UDEC	Water discharge (lit/sec/m), mean of analytical methods	Relative difference (%)
1	3100	0.111	0.113	1.5
2	3250	0.175	0.16	9.6
3	3800	0.686	0.425	61.4
4	4200	0.181	0.184	2
5	4650	0.147	0.164	10.5
6	5250	0.042	0.047	11.7
7	6700	0.032	0.029	8.8
8	7500	0.022	0.02	8.1
9	7900	0.487	0.456	6.9
10	8350	0.066	0.068	1.9
11	9250	0.018	0.018	1.6
12	10800	0.031	0.025	20.3
13	12150	0.036	0.035	3.4
14	13550	0.011	0.038	72

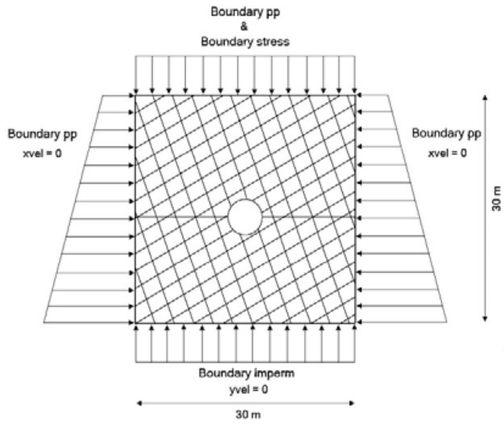

Fig. 2 Model geometry with boundary conditions

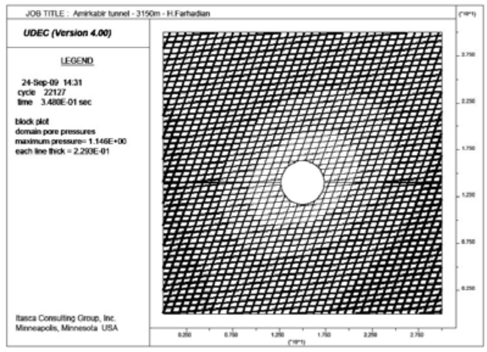

Fig. 3 Water pressure in a section of Amirkabir tunnel after tunneling and seepage

D. Groundwater Seepage Hazard Rating and Inflow Anticipating with SGR Method

By taking into account parameters such as joints aperture, depth of tunneling, width of crashed zone, height of groundwater table above tunnel axis, SGR coefficient in 14 sections of tunnel length is computed. The results are shown in Table IV. It is obvious that because the site of Amirkabir tunnel is rocky, parameters like Fracture and joints, joints frequency and karstification have more of importance. Though, permeability coefficient is considered as zero and S_7 coefficient (related to annual raining score) is assumed as unit because the tunnel from 3.1 km to 14.1 km is drilled in saturated zone. The results show that 6 sections from 14 sections is in No Danger class, 2 sections in Low Danger, 2 sections in Relatively Dangerous, 2 sections in Dangerous and 2 sections is in Highly dangerous and critical class. With respect to geological structure and rock types which are mainly low permeable rocks, it can be claimed that the major danger in tunneling is related to crashed zones which in SGR rating system, they have been rated as highly dangerous and critical class. As can be seen in Table IV, sections of crashed zones, 3800 meters and 7900 meters, have 10028 and 8984.2 SGR coefficient, respectively which are rated in highly dangerous and critical class. Therefore, these zones should be highly considered in tunneling.

E. Result Analysis

Because Amirkabir tunnel is drilled in jointed rocky media and Discrete element Numerical method has capability of application in discontinuous media as well as simultaneous hydromechanics analysis, the results of water inflow estimation into tunnel in mentioned sections is more reliable in numerical methods than analytical methods.

Fig. 4 shows the results of analytical and numerical water inflow into Amirkabir tunnel calculations in 14 different sections. As can be seen, both of the result sets have similar pattern. With respect to Table III, the maximum seepage which is computed by numerical method is 0.686 lit/sec/m in section 3. Also in analytical methods, it is computed 0.425 lit/sec/m in the same section which is occurred in crashed zone. In other words, both analytical and numerical methods have a similar variation pattern. But, relative difference of results in more than 70 percent of sections is less than 10 percent and in the other ones, it is more than that. The maximum relative difference of numerical and analytical results is in sections 3 and 14 which are 72% and 61.4%, respectively. In section 14 in 13550 meters of the tunnel, the overburden and water head is 625 and 490 meters, respectively. Stress of overburden and water pressure lead to a fine aperture of joint sets. So, due to simultaneous hydraulic process in discontinuities and interaction between flow and stresses of too overburden above tunnel, the amount of seepage modeled with UDEC is negligible and relative difference between analytical and numerical method is high, approximately 72%. Also, in Section III in 3800 meters of tunnel length, the results of analytical and numerical methods show a relative difference about 69% which is due to geometry of the model. Because this section is located in Gta2 crashed zone, in order to compute groundwater seepage rate with numerical method and assuming highly dangerous seepage condition, the size of the smallest block in the section (lowest distance between discontinuities) is considered. So that, the amount of groundwater ingressing into tunnel is estimated 0.686 lit/sec/m by means of numerical method.

Also, By SGR method, these sections are investigated in point of groundwater seepage hazard view (with qualitative and quantitative view). Fig. 5 compares the amount of seepage in 14 sections mentioned by numerical and analytical methods with SGR proposed class for the flow rate. As it is said, each class of SGR is quantitatively located in a special range of flow and in Amirkabir tunnel, proposed seepage ranges of SGR are in accordance with the results of analytical and numerical methods.

Based on SGR, Analytical and Numerical methods groundwater seepage into tunnel is concentrated in crashed zones. Based on SGR, 6 sections of 14 sections in Amirkabir tunnel length is in No Danger class which is in accordance with the results of analytical and numerical methods which show a flow less than 0.04 lit/sec/m.

As can be seen in Fig. 5, all groundwater inflow amounts computed with analytical and numerical methods are in the SGR proposed range. Also, seepage rate and SGR coefficient have a similar pattern.

TABLE IV
RATING AMIRKABIR TUNNEL SITE IN POINT OF GROUNDWATER SEEPAGE HAZARD VIEW BASED ON SGR COEFFICIENT IN 14 VARIOUS ENGINEERING GEOLOGICAL SECTIONS

Section (meter)	S_1	S_2	S_3	S_4	S_5	S_6	S_7	SGR	SGR rating
3100	18.88	0	0	0	0	21.71	1	410	Relatively Dangerous
3250	16.60	0	0	0	0	30.73	1	510	Dangerous
3800	29.00	0	200	0	0	43.79	1	10028	Highly Dangerous and critical
4200	14.50	0	0	0	0	47.49	1	689	Dangerous
4650	11.64	0	0	0	0	42.29	1	492	Relatively Dangerous
5250	9.58	0	0	0	0	24.24	1	232	Low Danger
6700	0.02	0	0	0	0	45.28	1	1	No Danger
7500	0.00	0	0	0	0	15.57	1	0.004	No Danger
7900	0.11	0	300	0	0	29.94	1	8984.173	Highly Dangerous and critical
8350	0.04	0	5.40	0	0	34.66	1	188.646	Low Danger
9250	0.00	0	0	0	0	27.52	1	0.038	No Danger
10800	0.01	0	0	0	0	39.27	1	0.301	No Danger
12150	0.03	0	0	0	0	72.29	1	2.071	No Danger
13550	0.06	0	0	0	0	79.1	1	4.450	No Danger

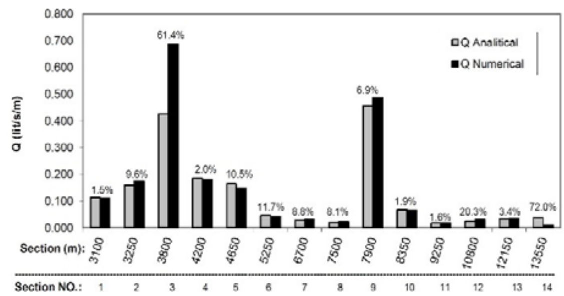

Fig. 4 Results of analytical and numerical groundwater seepage calculations into Amirkabir tunnel in 14 different sections. Values in the above of the columns show the relative difference between the seepage results of analytical and numerical methods

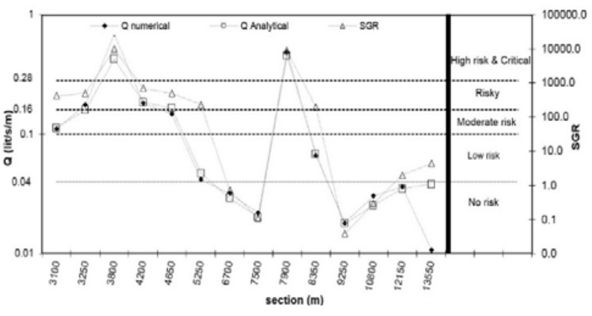

Fig. 5 Analytical, Numerical results and SGR coefficient in 14 sections of Amirkabir tunnel length

VI. CONCLUSION

1. The changes of groundwater seepage computed by analytical and numerical methods are the same in an acceptable limit. Just in two sections, Analytical and Numerical seepage values have significant differences which are due to model geometry and high overburden.

2. Tunnel site rating by SGR method has a reasonable accordance with values of analytical and numerical methods. Based on SGR method and Analytical and Numerical calculations, seepage into tunnel is concentrated in crashed zone. Maximum groundwater seepage by means of analytical methods is approximately 0.425 lit/sec/m and by application of DEM numerical method, it is calculated about 0.628 lit/sec/m which is occurred in crashed zone of tunnel. Based on SGR method, 6 sections from 14 sections of Amirkabir tunnel length is in No Danger class with a flow less than 0.04 lit/sec/m which have an accordance with results of analytical and numerical equations.

References

[1] Goodman, RE, Moye, DG, Schalkwyk, AV, Javandel, I, (1965) Groundwater inflows during tunnel driving. Bull. Ass. Eng. Geologists 2, pp. 35–56.
[2] Freeze RA, Cherry JA, (1979) Groundwater: Prentice-Hall, Englewood Cliffs, New Jersey.
[3] Heuer RE (1995) Estimating rock-tunnel water inflow. In Proceeding of the Rapid Excavation and Tunneling Conference. Ed. G. E. Williamson and I. M. Growring; pp. 41-60.
[4] Lei S (1999) An analytical solution for steady flow into a tunnel. Ground Water 37, pp. 23–26.
[5] El Tani M (1999) Water inflow into tunnels. Proceedings of the World Tunnel Congress ITA- ITES 1999, Oslo, pp. 61–70, Balkema.
[6] Karlsrud K (2001) Water control when tunneling under urban areas in the Olso region. NFF publication, 2001. 12(4): pp. 27-33
[7] Lombardi G (2002) Private communication.
[8] El Tani M (2003) Circular tunnel in a semi-infinite aquifer. Tunn. Undergr. Space Technol. 18 (1), pp. 49-55.
[9] Farhadian H, Aalianvari A, Katibeh H, (2012) Optimization of Analytical Equations of Groundwater Seepage into Tunnels: A Case Study of Amirkabir Tunnel. J. Geo. Soc. India 80, pp. 96-100.
[10] Katibeh H, Aalianvari A (2009) Development of a new method for tunnel site rating from groundwater hazard point of view. J. App. Sci. 9, pp. 1496-1502.
[11] Jing I, Hudson JA (2002) Numerical methods in Roch Mechanics. International journal of rock mechanincs and mining science, vol. 39, pp. 409-427.
[12] Itasca (2004) UDEC manuals, Minneapolis: Itasca Consulting group Inc.
[13] SCE Company (2006) Geological and Engineering Geological Report for Amirkabir Water Conveyance Tunnel Project (Lot1), unpublished report.