Investigation of Engineering Geology characterization of Khersan 3 dam site.

R. Dadkhah[1], R. Ajalloeian[2], Z. Hoseeinmizaei[3]

1 PhD. Student, Ferdowsi University of Mashhad, Mashhad, Iran

2 Asst. Prof., Dept. of Geology, Faculty of Science, Isfahan University, Isfahan, Iran,

3 M.Sc., Dept. of Geology, Faculty of Science, Hamedan University, Isfahan, Iran

Abstract

*This paper discusses the results of engineering geological investigation and geotechnical studies carry out at the propose Khersan3 dam site. The dam will be built on Khersan river, located in 50 km of west of Lordegan city in west of Iran. The Khersan dam has 370 m length crest, 175 m maximum height and 777.505*106 m^3 total storage capacity. The dam is mainly founded on sedimentary rocks of the Tertiary age and on Quaternary deposits. Geotechnical information obtains from both of field and laboratory study. Field study includes engineering geological mapping, surface discontinuity mapping, drilling borehole and sampling for laboratory testing. Samples obtain from drilling have been tested in the laboratory, included of uniaxial, triaxial and tensile strength tests and deformation parameters, unit weight and porosity. We can classification rock masses of dam according to RMR, Q and GSI system. Detailed of geological and geotechnical study (i.e. scan-line survey, discontinuity measurements, various laboratory, in-situ tests, kinematics analyses and etc.) was carrying out in the project area to determine the engineer in geological characteristics of the rock masses. In this study, using Geological Strength System (GSI) and the Hoek-Brown equation for rock mass classify properties to obtain rock mass strength parameters and elasticity modulus.*

1. Introduction

Rocks have been classified on the basis of their origin, mineralogical composition, void index, fracture/joint intensity, joint inclination, flow rate of water, velocity of propagation of shock wave, weathering, colour or grain size. When rocks and rock masses are classified for geotechnical purposes, they need to be classified on the basis of strength and/or modulus to give an indication of their stability and/or deformability. The purpose of this study is to investigate the Engineering geological characteristics of the rock Material and rock mass a khersan3 dam. The Khersan3 dam will be situated on the Khersan River, 50 km south-west of Lordegan in the east part Mountain Zakrose of Iran (Fig. 1).It will be used for flow control and water storage for product energy projects. The design of Khersan3 Dam is under the direction of General Directorate of the Ministry of Energy, Iran. This paper explains engineering geological assessment for safe design of the proposed khersan3 Dam. These geotechnical Investigations (scan-line survey, discontinuity measurements, various laboratory and in-situ tests, kinematical analyses, etc.) have been carried out at the project site and in the laboratory. Various laboratory and in-situ tests were performed to assess the characteristics of rock masses. Detailed discontinuity surveying was also carried out. In the study, rock mass properties were classified using RMR (Bieniawski, 1989), Q (Barton et al., 1974) and GSI (Hoek and Brown, 1997) was used to obtain rock mass strength parameters.

2. Geological setting

Geological factors play a major role in designing and constructing a dam. Of the various natural factors that influence the design of dams, none are more important than the geological ones. Not only do they control the character of formations, but they also govern the material available for construction. There exist numerous examples of projects where the conditions of the foundation were not sufficiently known and the cost of construction and treatment greatly exceeded the original budget (Ichikawa, 1999). The Khersan3 Dam is located on sedimentary rocks of the Tercier Age and on Quaternary deposits.

3-Engineering geological investigations or site investigation

The preliminary site investigations were carried out start on the 1996. Engineering geological investigations and rock mechanics studies mainly include discontinuity surveying, core drilling, in-situ is testing.

3-1-Mass properties

The engineering geological properties of the rock masses at the site have been assessed in accordance with the working partly and the International Society for Rock Mechanics (ISRM) Suggested method (ISRM, 1978).

3-2-Discontinuity surveying

Discontinuities surveys consisted of orientation, aperture, roughness, persistence, infilling and spacing was determined at the site by exposure logging in accordance to ISRM (1981).

A total of 558 discontinuities, 258on the right bank and 300 on the left bank, have been measured. The basic orientation data were analyzed using a computer program based on equal-area stereographic projection namely DIPS 5.0 (Diederichs and Hoek, 1989) in order to determine the number of dominant discontinuity sets. Three dominant discontinuity sets and bedding are distinguished on the right bank (Fig. 2) that including: (dip direction/dip) J1:65/275; J2:35/235; J3:45/180. Four dominant discontinuity sets and also are determined on the left bank (Fig. 3) that including: (dip direction/dip) J1:73/300; J2:80/030; J3:30/140; J4:45/260. Table 1 shows quantitative descriptions and statistical distributions of discontinuities of rock units at the dam site according to ISRM (1981).

3-3-Drilling

In order to verify foundation conditions and to obtain rock samples for laboratory testing, borings were made at this site in چند stages. Based on these studies, 47 boreholes, totaling 5303.7 m, were drilled on the dam site (Fig. 4). Tables 2 show the Rock Quality Designation (RQD) of the right abutment, left abutment, riverbed and boreholes, respectively.

4-Laboratory tests

Detailed laboratory studies were performed on the specimens prepared from blocks, samples and core specimens of NX-size; (54.7 mm) determine the geotechnical parameters of the intact rock. The tests on NX size specimens were carried out according to the procedures recommended by ISRM (1981) suggested methods

Mechanic tests, the Uniaxial Compressive Strength (UCS) test, density, absorption test, deformability and porosity tests were conducted according to ISRM (1981) standards. The deformability parameters, Poison's` ratio (m) and modulus of elasticity (Ei) were also obtained from deformability test. The results are given in Table 4.

5-Rock mass classifications of rock units

For the qualification of the rock mass the khersan3 dam, RMR and Q rock mass classification systems and GSI system were used. These systems have been used for a long time and evolved due to the requirement of modifications for the different case studies but there are still doubts and confusions on the applications. A brief explanation of RMR and Q systems and their evolutions is therefore necessary.

Bieniawski (1974) has initially developed rock mass rating (RMR) system. He has developed this system on the basis of experiences in tunnel projects from South Africa. Since then, this classification system has undergone significant changes. These changes are mostly on the ratings given to ground water, joint condition and joint spacing. In order to apply this system for the classification of rock mass, the uniaxial compressive strength of intact rock, rock quality designation, RQD, joint spacing, joint condition, joint orientation and ground water conditions have to be known. Barton et al. (1974) have developed Q rock mass quality system. Q system is also known as NGI rock mass classification (Norwegian Technical Institute). This system is defined by the function of joint sets, Jn, discontinuity roughness, Jr, joint alteration, Ja, water pressure, Jw, stress reduction factor, SRF and RQD. Recently, Barton (2002) has compiled the system again and has made some changes on the support recommendations. He has also included the strength factor of the rock material in the system.

Rock mass classifications can serve as a powerful design tool in Dams construction, showed how to estimate the compressive strength of a rock mass based on the (m) and (s) criteria. Hoek et al. (1995) have expressed the compressive strength of rock masses with an equivalent set of cohesion and friction parameters for given Hoek–Brown values.

The geotechnical properties of the rock units comprising the Dam site were assessed by using three empirical rock mass classification systems, namely RMR method, Q method and GSI (Geological Strength Index). The Geological Strength Index (GSI), introduced by Hoek (1994), Hoek et al. (1995) and Hoek et al. (1998) provides a system for estimating the reduction in rock mass strength for different geological conditions as identified by field observations.

5.1. Results of rock mass classification systems at dam site rock units

In order to overcome some uncertainties of these classification systems, a range of rock mass values was estimated rather than just a single value.The RMR (Bieniawski, 1989) classification of the Dam site rock units is shown in Table 5. As shown in this table, the rock units are classified as medium rock quality (class III). The *Asmary* unit at left bank is classified as medium rock masses (RMR=56). The *Asmary* unit at right bank and riverbed is classified as fair rock (RMR=59). The Q (Barton et al., 1974) classification of the dam site rock units is shown in Table 6. As shown in this table, the rock units are classified as medium rock quality (class III). The *Asmary* unit at left bank is classified as medium rock masses (Q=6.79). The *Asmary* unit at right bank is classified as fair rock (Q=7). In the study, furthermore RMR and Q methods, rock mass properties were classified using the GSI system. This system was evaluated by (Hoek et al., 1998). These groups are shown in Table 7. *Asmary* unit at right bank (crystalline to microcrystalline limestone) is classified as *Blocky* to *Very Blocky* (GSI=53-64). *Asmary* unit at left bank (crystalline limestone to marly limestone) is classified as *Blocky* to *Very Blocky* (GSI=49-58).

6. Rock mass strength estimation

Singh (1993) proposed the following relationship to be an approximate estimate to the value of the rock mass compressive strength based on the rock mass Q and rock density γ (kN/m^3), in Bhasin and Grimstad (1996).

$$\sigma m = 0.7\gamma Q^{1/3}\,(MPa)$$

Too the rock mass strength parameters such as, Hoek–Brown constants, modulus of elasticity and uniaxial compressive strength, are essential need in the preliminary stages of dam design. In this study, Hoek–Brown strength criterion was used for estimation of the rock mass strength parameters. To estimate, the parameters related to Hoek–Brown criterion, which represent the rock mass, the test results of the intact rock specimen were used in conjunction with GSI values. The generalized empirical failure criterion is as follows (Hoek et al., 2002)

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b\frac{\sigma_3'}{\sigma_{ci}} + s\right)^a$$

Where σ'_1 and σ'_3 are the major and minor effective principal stresses at failure σ_{ci} is the uniaxial compressive strength of the intact rock material and m_b is a reduced value of the material constant m_i and is given by

$$m_b = m_i \exp\left(\frac{GSI-100}{28-14D}\right)$$

Intact rock constant (m_i) was found from Table 8.3 of Hoek et al. (1995).

s and *a* are constants for the rock mass given by the following relationships:

$$s = \exp\left(\frac{GSI-100}{9-3D}\right) \qquad a = \frac{1}{2}+\frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right)$$

D is a factor which depends upon the degree of disturbance to which the rock mass has been subjected by blast damage and stress relaxation. It varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses (Hoek et al., 2002). Also the in-situ deformation modulus of rock masses (Em) can be obtained by using the GSI value in the formula below (Hoek et al., 2002).

$$E_m(GPa) = \left(1-\frac{D}{2}\right)\sqrt{\frac{\sigma_{ci}}{100}}.10^{\left((GSI-10)/40\right)}$$

The rock mass constants, uniaxial compression strength and the in-situ deformation modulus of each rock units are presented in Table 8.

7-Conclusions and recommendations

Based on the information collected at site and the analysis carried out, the Both theoretical and empirical solutions showed that limestone Asmary unit creates no problem since the rock mass strength greater than tangential stress concentration.

When the results from different methods based on parameters found by using GSI are examined, it is seen that GSI gives consistent results irrespective of the evaluation method. Khersan3 Dam will be built on sedimentary rocks which consist of microcrystalline limestone and marly limestone of the tercier Age. Quantitative description of discontinuities was performed at the site by exposure logging in accordance with ISRM (1981). This high permeability is one of main geological engineering problems of the Khersan3 Dam. Therefore, improving the rock units by injection of cement is recommended for reduction of seepage flow through the foundation and left bank of the dam.

Khersan3 Dam, concrete dam will be located on the sedimentary rocks. These rocks indicate fair rock mass quality. Engineering geological investigations, test results and computations indicate that Khersan3 concrete dam can be safely constructed on the proposed site. The regional and local engineering geology have played a major role in the planning, design, construction and preference of the Khersan3 Dam. This paper assesses the engineering geological characteristics of the rock units and rock mass and suggests appropriate recommendation and improving techniques at Khersan3 dam site. A detailed engineering geological study (scan-line survey, discontinuity measurements, core drilling, etc.) was carried out in the project. The dam site and reservoir will be situated in an area underlain by Upper Cretaceous sediments, and Quaternary deposits. The rock masses of the dam site were classified as fair quality rock mass. The results of the Permeability testing showed that permeability in the rock units of the dam foundation and left bank are medium to high. This high permeability is one of main geological engineering problems of the Khersan3 Dam. Therefore, improving the rock units by injection of cement is necessary for permeable zones to prevent leakage through the foundation and left bank of the dam.

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Table 1:Quantitative descriptions and statistical distributions of discontinuities of Right and Left bank at the Khersan3 Dam site.

	Range	Description	Distribution (%)						
			Right bank			Left bank			
			J1	J2	J3	J1	J2	J2	J3
Spacing (mm)	20>	Extremely close	-	-	-	-	-	-	-
	20-60	Very close	-	-	-	-	-	-	-
	60-200	Close	35	16	12	-	-	-	-
	200-600	Moderate	35	24	18	40	35	-	-
	600-2000	Widely	20	60	38	40	30	25	50
	2000<	Very widely	10	-	32	20	35	75	50
Aperture (mm)	0.25-0.5	Partly open	20	20	15	-	10	-	-
	0.5-2.5	Open	10	20	17	10	20	10	5
	2.5-10	Moderately wide	70	60	68	90	70	90	95
Persistence (m)	0.25-0.5	Partly open	10	10	10	10	30	50	5
	0.5-10	Moderately	90	90	90	90	70	50	

Description		Right bank			Left bank			
		J1	J2	J3	J1	J2	J3	J4
filling	Clay	*	-	-	*	*	-	*
	Calcite	-	-	*	-	-	-	-
	Hematite	*	*	*	*	-	*	*
	Limonite	*	*	*	*	-	*	*
Water Condition	Dry	*	*	*	-	*	*	*
	Wet	-	-	-	*	-	-	-
Roughness	Rough	*	*	*	*	*	*	*
	Smooth	-	-	-	-	-	-	-

Table 2: Rock Quality Designation (RQD) of the abutment site boreholes.

	Borehole NO.	**Upper Asmary (m)**	**RQD%**	**Lower Asmary (m)**	**RQD%**
Right Bank	KT-15	0-48.60	56	48.60-90	68
	KT-18	0-70	74	-	-
	KT-23	0-134.35	62	134.35-150	80
Ave			65		74
Dam axis	KT-33	-	-	6-210	63
	KT-35	-	-	6-100	58
Ave			-		60
Left Bank	KT-24	0-92	58	92-105	87
	KT-36	0-44.45	56	44.45-150	69
Ave			58		78

90-100	**75-90**	**50-75**	**25-50**	**0-25**	**R.Q.D%**
Very Good	Good	Medium	Bad	Very Bad	Rock Quality Designation

Table 4: Laboratory testing results of Asmary rocks at Khersan3 Dam

Rock unit	Borehole NO.	Density gr/cm^3	Absorption %	Porosity%	UniaxialCompressive Strength (Mpa)	Modulus of elasticity (GPa)	Poisson Ratio	Cohesion (MPa)	Internal friction angle (φ)
Upper Asmary	KT-15	2..66	0.94	2.18	67.99	40.17	0.20	49.98	53.19
	KT-18	2.61	2.01	4.92	73.18	43.25	0.19	50.49	57.75
	KT-23	2.63	1.57	4.03	118.26	37.51	0.21	39.20	60.20
	KT-24	2.51	4.31	11.30	68.78	23.35	0.17	24.20	55.30
	KT-36	2.48	5.02	12.41	62.73	19.81	0.20	21.80	49.99
Ave		2.57	2.77	7.52	78.02	32.81	0.19	37.13	55.28
Lower Asmary	KT-15	2.60	1.91	3.23	58.47	41.25	0.2	13.2	27
	KT-23	2.53	2.58	6.37	36.89	34.67	0.25	11.50	18.98
	KT-33	2.61	2.1	5.98	102.18	32.23	0.17	15.30	31.1
	KT-35	2.62	2.01	4.19	48.37	26.30	0.22	12.81	19.1
	KT-24	2.62	1.48	2.72	94.57	43.83	0.25	14.39	29.20
	KT-36	2.59	0.98	1.99	120.72	40.4	0.21	16.32	21.23
Ave		2.59	1.69	4.08	76.87	36.45	0.21	13.92	24.43

Table 5: The RMR classification of the dam site rock units

Parameters		**Location**			
		Right bank		Left bank	
		Value	Rating	Value	Rating
UCS (MPa)		78.02	7	76.87	7
RQD		70	13	68	13
Spacing (m)		0.6-2 and 2<	18	0.2-2	12
Condition of discontinuities	Persistence (m)	0.25-10	4	0.25-10	4
	Aperture (mm)	0.25-10	0	0.25-10	0
	Roughness	Rough	5	Rough	5
	Filling	Smooth filling < 5 mm	0	Smooth filling < 5 mm	0
	Weathering	Low weathered	5	Low weathered	5
Groundwater		dry	15	Dry and wet	12
Discontinuity orientation		Fair	-5	Fair	-5
RMR		59		56	

Table 6: The Q classification of the dam site rock units

Parameters	**Location**			
	Right bank		Left bank	
	Value	Rating	Value	Rating
RQD	70	70	68	68
Joint set number (Jn)	four joint sets plus random	15	four joint sets plus random	15
Joint roughness number (Jr)	Rough and irregular, undulating	3	Rough and irregular, undulating	3
Joint alteration number (Ja)	Slightly altered joint	2	Slightly altered joint	2
Joint water reduction factor (Jw)	Dry excavation or	1.0	Dry excavation or	1.0
Stress reduction factor (SRF)	Medium stress	1	Medium stress	1
Q	7		6.79	

Table 7: Field of GSI classification of distinct rock mass types encountered in the Khersan3 dam.

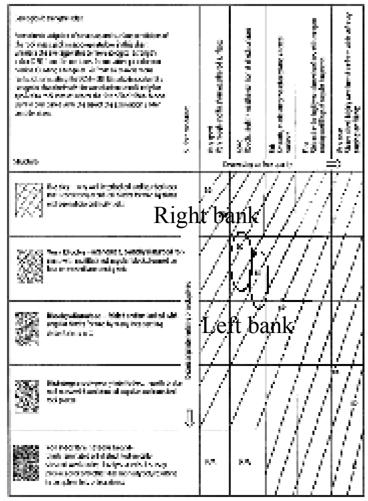

Table 8: Geotechnical parameter of the dam site rock units

Parameter		Location					
		Right bank			Left bank		
		Min	Max	Ave	Min	Max	Ave
Intact Uniaxial Compressive Strength (MPa)		62.73	118.26	78.02	36.89	120.72	70.87
mi		10	14	12	8	12	10
material constants	m_b	1.866	3.87	2.678	1.294	2.678	1.866
	s	0.0054	0.0183	0.0094	0.0035	0.0094	0.0054
	a	0.505	0.502	0.503	0.506	0.503	0.505
Upper Limit of Confining Stress (MPa)		4.027	4.419	4.179	3.772	4.347	4.071
Cohesion (MPa)		1.434	2.869	1.868	0.973	2.377	1.523
Friction Angle (Deg)		42.63	52.45	47.05	35.63	50.02	43.52
Rock Mass Parameter (MPa)	Tensile Strength	-0.1813	-0.5596	-0.274	-0.0986	-0.424	-0.205
	Uniaxial Compressive Strength	4.497	15.869	7.451	2.096	11.529	5.081
	Global Strength	11.684	32.857	17.662	5.661	27.328	13.2
	Modulus of Deformation	9413.21	22387.21	13999.19	5733.96	15848.9	10005.3
GSI		53	64	58	49	58	53

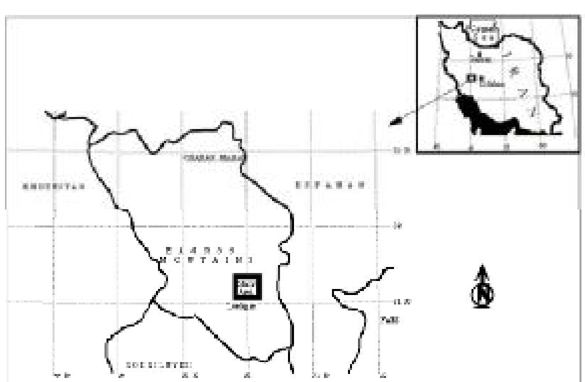

Fig. 1. Location map of the Khersan 3 Dam site.

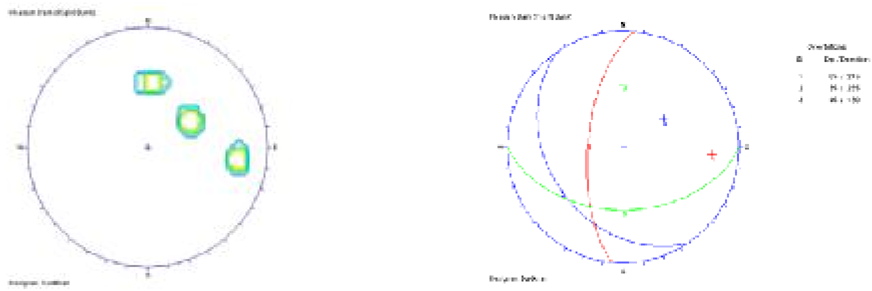

Fig.2: Dominant joint sets on right bank of the Kersan3 Dam site.

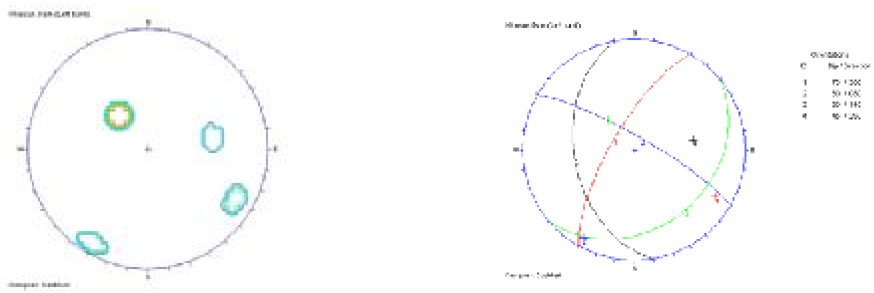

Fig.3: Dominant joint sets on Left bank of the Kersan3 Dam site.