Evaluation of engineering geological characteristics for the Kuhrang III dam site, Iran

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Abstract: Evaluation of engineering geological characteristics of a dam site is very necessary, because the dam foundation should be suitable for the construction of a concrete dam. In the current study, Kuhrang III dam site has been evaluated. In this site an arch dam of 95 meters height, 400 meters crest length and storage capacity of 440 million cubic meters is planned to be built on Cretaceous limestone. The dam site is located about 100 km west of Shahrekord city and is tectonically very complex and heavily fractured due to various faulting systems in the region. Since the stability and impermeability of the dam foundation is very important, the field investigations (including boreholes loges, field permeability test and field joint survey), as well as laboratory tests (including porosity, density, tension, compression and direct shear tests) have been rigorously conducted and evaluated. Finally, a suitable method and pattern of grouting to reduce water leakage has been recommended.

Résumé: Pour découvrir les caractères spécifiques de l'ingénierie géologique; a construction dun barrage est importantede sorte que sa fondation doit être convenable, Dans cette perspective, la construction de barrage de Kuhrang est mise à l'examen où un barrage en béton à deux arcs; hauteur de 95 m et largeur de 400 m et à une capacité de 440 million cube d'eau est planifié sur des calcaires de Cretaceous: Celui-ci est situé à environ 100 km à l'ouest de Shahrekord, considéré comme une région hautement fracturée. La fondation d'un barrage au niveau de la résistance et de la imperméabilité est aussi importante que les études désertiques (les rapports, le creusage, l'examen perméable désertique et l'analyse des crevasses). De plus, les examens de laboratoire (position, le poids de l'unité du volume, tension, pression et la coupe directe) sont également étudiés. En fin, dans notre recherche, nous avons proposé la méthode de rodage et de réduction perméable de la fondation du barrage.

Keywords: Engineering geology, Site investigation, In situ tests, Permeability, Laboratory tests, Limestone

INTRODUCTION

The proposed Kuhrang III Dam will be built on the Kuhrang River, 100 km southwestern of Shahrekord City, (Figure 1). It will be used for flood control and water storage transmission through the Kuhrang III tunnel to the Zayanderud catchment area. The tunnel intake is situated in the dam reservoir and is designed to transmit 300 million m^3 of water annually to Zayanderud River. The studied area is located in the over thrust or Crushed zone of Zagros. Birgan valley where the dam and its reservoir are located is part of the Karun River catchment area separated by Zarab Mountain from the Zayandehrud catchment area. This dam is a double-curvature arch concrete structure and it will be 95 meters high with a crest length of about 400 meters and storage capacity of 440 million m^3. The spillway has been designed in the middle of the dam body. The diversion system includes the upstream cofferdam, the downstream cofferdam and diversion tunnel. The elevation of the normal reservoir water level will be 2240 m above sea level.

The Kuhrang-III Dam site is located in a relatively narrow valley formed by tectonic activity and erosion of limestone. The valley width at this location and at the river elevation of 2155 m is about 40 m and increases to 220 m at the dam crest elevation (2240 m). The general slope of this river is about 2% in the Birgan Valley area and 10% at the dam site area.

GEOLOGY

The studied area is limited from northeast by the reverse fault and the rock foundation of Zarab mountain and Main Zagros Thrust and from southwest by Zardkuh Fault (High Zagros Fault). Between these mountains that have strike in the NW-SE direction, there are a number of reverse faults, with the same strike. The dip of the faulting planes is towards the northeast. The dynamic tectonics of the area, which is accompanied by strong earthquakes due to the movement of basement faults, has geological, morphological, stratigraphic and even hydrogeological consequences such as the disappearance of the southern flanks of the anticlines, outcropping of salt domes and of very old beds sliding from their original location, occurrence of strong earthquakes, formation of natural dams and fresh water lakes.

Structural geology

Despite the presence of a large volume of crushed rocks on the left dam abutment shows tectonic activity there is no fracture and discontinuity at the foundation of the dam. However, three probable fracture strikes have been found in the rock mass and designated as F1, F2 and F3 faults:

F1 probable fault: This probable fault is located 35 m downstream from the right side of the dam site with a strike of N282 and a sub vertical dip. Its length is estimated to be about 550 m and there is an observed mass of slopewash deposits at their foot with a thickness of more than 30 m.

F2 probable fault: This fault, which is not well defined, is about 450 m upstream of the dam axis. Due to the disturbance of bedding, the undisturbed rock mass surface is covered with colluviums and crushed rock masses upstream and downstream of the dam axis and the strike and fractures are not well defined.

F3 probable Fault: This fault cannot be traced clearly except from the topographic depression along the border between the in-situ limestone and the crushed rock masses on the left abutment of the dam. It is the most important fracture at the dam site. It seems to have a strike of N160° and a sub vertical fault plane dip. This fault lies under the crushed mass on the left abutment of the dam. This fault is apparently responsible for the rock mass.

Figure 1. Location of Kuhrang III Dam site

slide and formation of a large volume of crushed rock on the left abutment. The length of this fault is estimated to be about 3 km.

Stratigraphy of site

The Kuhrang-III Dam site is located on the northwest flank of the Dashtak Anticline and is in a valley formed by erosion and tectonic activities. The bedding dip is towards north and faulting in the river direction causing disturbance in the bedding dip and strike is not seen. The geology of the Kuhrang III Dam site is shown in Figure 2.

Based on surface studies and the data obtained from probe drillings as well as from microscopic and fossil studies, the rock units which form the dam foundation include dolomitic limestone and dolomite layers of cretaceous age. Geology of the dam axis and location of boreholes are shown in Figure 3.

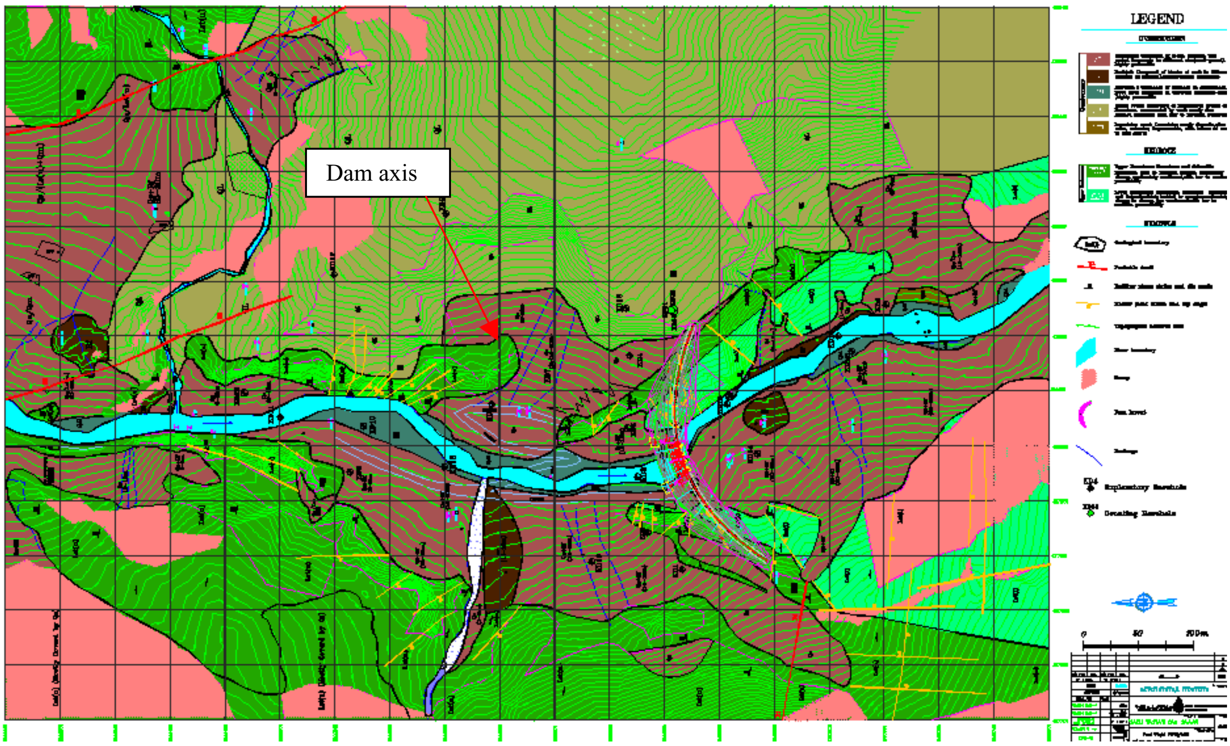

Figure 2. Geology of Kuhrang III Dam site

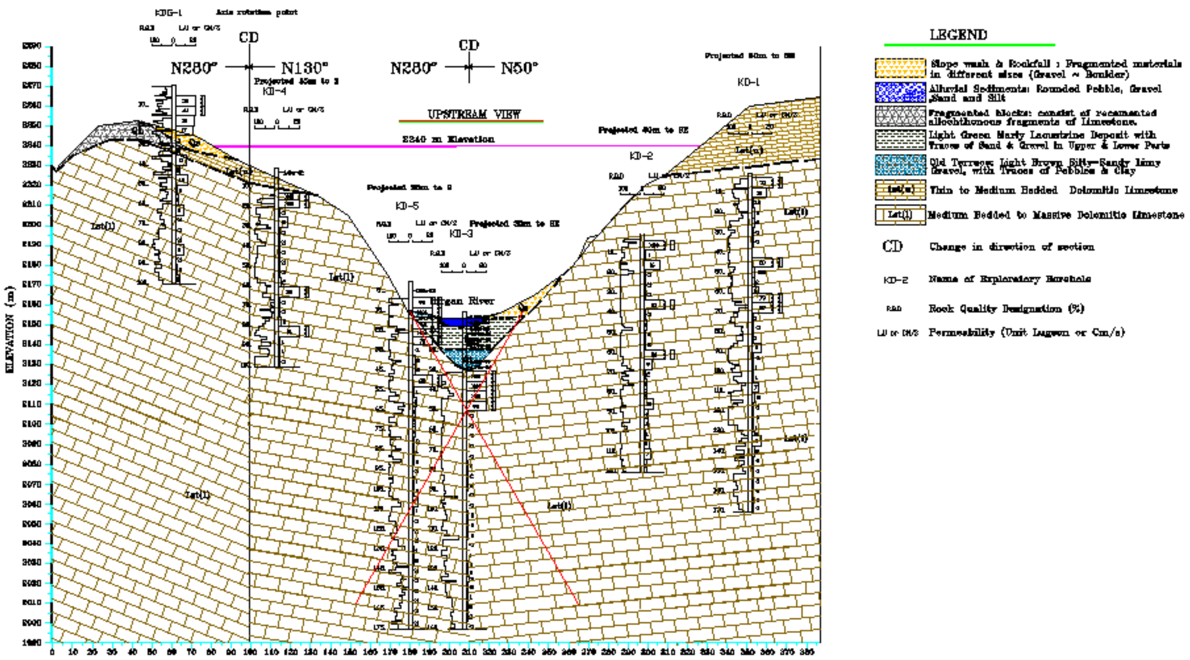

Figure 3. Geology of dam axis and location of boreholes

The Quaternary depositional sediments at the dam site consist of riverbed alluvium, lake deposits, slopewash deposits, alluvial terraces and residual soils. These deposits generally include river deposits-well rounded, of limestone nature and with different sizes ranging from sand to cobbles, lake deposits consisting of green marl with silt and sand interbeds of good cohesion. The thickness of this unit at the dam site is 15-17 m. Old terraces include well-rounded carbonate cobbles with silt and sandy cement. The maximum thickness of overburden around the dam axis is 30 m.

Karstification

The development of karstic phenomena (such as sink holes, karstic springs, karren and polges) in the foothills of the Zardkuh and Zarab Mountains is visible due to the large outcrop of limestone beds and the special conditions of this area from the viewpoint of snowfall. Permanent karstic springs in this valley (Kuhrang) are concentrated mainly along the Zarab Mountain foothills (northwestern foothills of the valley) while seasonal springs with very good quality water emerge during wet periods of the year at the southwestern slope.

Reservoir

The Kuhrang-III dam has a reservoir of about 18 km length and 90-1500 m width. At the reservoir area, the bedrock includes old to recent cretaceous dolomitic limestone and Miocene marl. The body of the reservoir consists of lake marls, river deposits, alluvial terraces and colluvial deposits.

From the viewpoint of structural geology, the reservoir is located within the asymmetrical anticline between the southwest slope of the Zarab Mountain and the northeast flank of the Zardkuh Mountain range. Considering the tectonic contact between Miocene marl layers in the middle of Kuhrang Valley with cretaceous limestones to the northeast and southwest, this valley is a structure that has been most probably formed due to the movement of a fault at its bottom. However, there is not any evidence to prove this. A number of tectonic lineaments have been identified as probable faults at the reservoir area.

ENGINEERING GEOLOGY INVESTIGETIONS

There are a number of studies concerning the dam site investigations, e.g. Ozsan and Karpus (1996). Engineering geological investigations mainly include discontinuity surveying, core drilling, borehole logs, and in-situ and laboratory tests.

Discontinuity survey

The quantitative description of discontinuities including orientation, spacing, persistence, roughness, aperture and filling were determined at the site by core logging in accordance to ISRM (1981). A total of 250 discontinuities, 138 on the right bank and 112 on the left bank, have been surveyed. The discontinuity orientations are presented using computer software based on equal-area stereographic projection namely DIPS 2.2 (Dietrich and Hoek (1989)). From this, the dominant discontinuity sets are distinguished on the left and right bank (Table 1).

Table 1. Dominant joint sets on left and right banks of Kuhrang III Dam site

Discontinuity	left bank		Right bank	
	Dip direction	Dip	Dip direction	Dip
Set 1	205	37	232	55
Set 2	221	75	181	66
Set 3	274	77	141	60
Set 4	358	45	085	79
Bedding	357	36	002	31

Table 2. Quantitative description and statistical distributions of discontiuities of rock masses at Kuhrang III Dam site

Parameter	Range	Distribution (%)	
		Left abutment	Right abutment
Spacing (cm)	< 30	18	29
	30-100	47	40
	> 100	35	31
Persistence(m)	< 1	26	25
	1-3	62	60
	3-10	12	15
Aperture(mm)	0.5-2.5	21	31
	2.5- 10	79	69
Roughness	Rough-undulating	33	32
	Rough-Planar	66	65
	Rough-Smooth	1	3

Table 2 gives a quantitative description and statistical distributions of discontinuities of rock masses at the Kuhrang III Dam site, according to ISRM (1981).

Drilling and borehole loges

Boreholes were drilled at the site to verify foundation conditions, bedrock depth, engineering properties of rock core samples, for karst investigation and to determine piezometric levels. 23 boreholes, with a total length of 2044 meters were drilled on the dam site. Rock quality designation (RQD) has been determined for the dam site and the RQD for the dam axis, shown in Table 3.

In-situ permeability tests

During core drilling, pumping tests were also carried out and the permeability of the rock mass was measured. A total of 302 pumping tests were performed at the limestone rock units in 23 boreholes. The relative frequency of Lugeon values for the dam site is shown in Table 4 and figure 5.

Table 3. RQD and lugeon value at dam axis

Borehole	Location	Depth (m)	RQD (%)	Lugeon value
KD1	Right bank	170	59	6.8
KD2	Right bank	120	78	8
KD3	River floor	160	74	15
KD4	Left bank	100	60	16
KD5	Left bank	175	60	15

The Rock masses at the site are slightly permeable to impermeable as shown in Table 4. The analysis of permeability test results shows that the permeability increases as the rock quality becomes weak and it reduces while the depth increases. Falling-head permeability tests were performed to determine the permeability of the Alluvium. According to the tests results, the alluvium is impermeable to permeable and permeability ranges from zero cm /s to 10^{-8} m/s

Table 4. Lugeon values and frequency of tests at Kuhrang III Dam site

Lugeon value	No. of tests	Percentage of tests (%)
60<	21	7
30-60	6	2
10-30	18	6
3-10	64	21
3 <	193	64
Total	302	100

Laboratory tests results

Laboratory experiments were carried out mainly on the limestone from the dam site to determine physical and mechanical properties of intact rocks including density, porosity, uniaxial compression, tensile strength and deformability parameters. Tests results are summarized and presented in Table 5.

Table 5. Laboratory tests results of intact rock at the Kuhrang III Dam site

Parameter	Density (gr/cm3)	Porosity (%)	UCS (MPa)	Tensile st. (MPa)	Modulus of elasticity (GPa)	Poisson ratio
Range	2.48-2.82	0.19-11.66	6.7-150	1.34-13.92	7.39-90	0.15 – 0.37
Average	2.72	2.54	72.5*	7.18	55.92	0.28

* Average UCS values are for zones II, III and IV, 60, 70 and 75 MPa respectively

ROCK MASS CLASSIFICATOIN FOR THE KUHRANG III DAM SITE

According to the results of field and laboratory tests and boreholes loggings, generally the rock masses could be divided into four zones. Zone I: Left abutment, disturbed rock masses with calcite and clay cementation in high levels. Zone II: Left abutment, rock masses with medium bedded limestone. Zone III: Left abutment, rock masses with medium bedded to massive limestone and dolomitic limestone. Zone IV: Right abutment and dam foundation: rock masses with medium bedded to massive limestone and dolomitic limestone.

According to Bieniawski (1989) and the above information and using geological and geotechnical data, the rock mass rating has been proposed for Kuhrang III Dam site (Table 6). Because of the disturbance to Zone I, its RMR is not valid and therefore it is not presented here.

Table 6. RMR for Kuhrang III Dam site

Rock mass	Range of RMR
Zone II	30-40
Zone III	40-50
Zone IV	50-60

Rock mass deformation modulus may be estimated from the final RMR rating. The following equation from Serafim and Pereira (1983) was used to determine the in-situ deformation modulus.

$$E_m = 10^{(RMR-10)/40} \qquad (1)$$

where E_m is the in-situ deformation modulus in GPa and RMR is the rock mass rating, Bieniawski (1989). The deformation moduli for the Kuhrang III Dam site are presented in Table 7.

Table 7. In-situ deformation modulus of rock masses

Rock mass	Uniaxial compressive strength (MPa)	In-situ deformation modulus (GPa)		
		Minimum	Maximum	Average
Zone II	60	2.40	4.33	3.25
Zone III	70	4.68	8.36	6.27
Zone IV	75	8.66	15.3	11.5

6. Strength of rock masses at the Kuhrang III Dam site

In this study strength of rock masses at the Kuhrang III Dam site was calculated using the Hoek-Brown empirical failure criteria, Hoek et al. (2002). The strength of a jointed rock mass depends on the properties of the intact rock pieces and also upon the freedom of these pieces to slide and rotate under different stress conditions. This freedom is controlled by the geometrical shape of the intact rock pieces as well as the condition of the surfaces separating the pieces. Angular rock pieces with clean, rough discontinuity surfaces will result in a much stronger rock mass than one which contains rounded particles surrounded by weathered and altered material.

Geological strength index (GSI) has been determined according to Hoek et al. (1997). The generalized empirical failure criterion is as follows, Hoek et al. (2002)

$$\sigma_1 = \sigma_3 + \sigma_c \left(m_b(\sigma_3 / \sigma_c) + s\right)^a \qquad (2)$$

where σ_1 is effective major principal stress, σ_3 is the effective minor principal stress and σ_c is the uniaxial compressive strength of intact rock, m_b is a reduced value of the material constant m_i and is given by

$$m_b = m_i \exp[(GSI-100)/(28-14D)] \qquad (3)$$

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

$$s = \exp[(GSI-100)/(9-3D)] \qquad (4)$$

$$a = 1/2 + 1/6(e^{-GSI/15} - e^{-20/3}) \qquad (5)$$

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.

When determining uniaxial compressive strength of a rock mass, $_3$ is accepted as 0. Also the in–situ deformation modulus of rock masses (E_m) can be obtained by using the GSI value in the formula below, Hoek et al. (2002).

$$E_m\,(GPa) = (1 - D/2) \times (\sigma_c/100)^{0.5} \times 10^{(GSI-10)/40} \qquad (6)$$

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

Table 8. The rock mass constants, GSI value, uniaxial comperssion strength and the in situ deformation modulus of each each rock mass

Parameter	Zone II	Zone III	Zone IV
Intact rock strength (MPa)	60	70	75
Geological strength index (GIS)	40	50	60
Disturbance factor (D)	0.7	0.7	0.7
Hoek-Browen intact rock constant (m_i)	10	10	9
Hoek-Browen rock mass constant (m_b)	0.37	0.641	0.999
Hoek-Browen rock mass constant (s)	0.0002	0.0007	0.003
Rock mass constant (a)	0.511	0.506	0.503
UCS of rock mass (MPa)	0.703	1.79	4.06
Deformation modulus (Gm) (GPa)	2.83	5.43	10.01

Experimental grouting in the Kuhrang III Dam site

Experimental grouting was carried out to determine rock mass groutability and to determine parameters such as effective radius of grout influence, maximum pressure and optimum mixture for a grout curtain.

The borehole depth is divided into a number of segments (5 m each), then the average depths for the center of the segments are determined. The surrounding rock mass density, permeability, and joint filling have been used, along with the average depth, to propose the optimum pressure for the experimental grouting (Table 9). The proposed grouting mixture includes cement, water, bentonite and sodium silicate. The weight ratio of cement / water changes from 1/3 to 2/1. Experimental grouting boreholes were drilled in the form of an equilateral triangle 3 m apart. Boreholes are vertical with 100 m depth. During core drilling, RQD is calculated and then the pumping tests were carried out. After compression of the triangular experimental grouting operation, one check hole was drilled in the center of the triangle for evaluation of the grouting influence area.

Table 9. The pressure proposed for the experimental grouting

Depth (m)	Pressure (bar)	Depth (m)	Pressure (units)
0 – 10	4	35 – 40	16
10 – 15	5	40 – 45	19
15 – 20	6	45 – 50	22
20 – 25	8	50 – 55	24
25 – 30	10	55<	25
30 – 35	13		

DISCUSSION AND CONCLUSOINS

Based on surface studies, probe drilling and microscopic and fossil studies, it was concluded that the rock unit constituting the dam site included dolomitic limestone and dolomite layers of cretaceous age. The Kuhrang-III Dam site is located in a relatively narrow valley formed by tectonic activity and erosion of limestone.

Based on the data obtained from the hydrogeological study at the dam site, groundwater flow is directed from the abutments to the river axis and its discharge is much higher on the left abutment than on the right. Groundwater level at both abutments and under the dam foundation is lower than the river water level. The groundwater level profile has a slope of 30^o-40^o under the left abutment which is steeper than that under the right abutment. The general direction of groundwater flow at the dam site is parallel with the Birgan river water flow in this area (north-south).

Surface and subsurface studies at the Kuhrang-III Dam site area have not revealed any indication of developed solution or karstic phenomena. Although the geological, tectonic and morphological data indicate that the dam is sited at a location where karstic phenomena are likely, such phenomena are not seen at the dam site area despite the outcropping limestone layers. The nearest place where there are indications of large solution cavities in limestone layers is about 1500 m upstream from the dam site.

Based on the permeability test results obtained at the dam site a thickness of 10 m below the foundation level on the right abutment and 8-28 m of rock on the left abutment is highly permeable. However, the permeability of rock decreases considerably with depth to only slightly permeable to permeable. This is because the number of joint sets decreases and are filled with secondary materials, and because there is a decrease in weathering. At the dam foundation area, the slightly permeable and impermeable rock starts from 2060 m elevation. The monitoring of rock mass at the dam site based on the analysis of Lugeon test results is shown in Table 10.

Table 10. The monitoring of rock mass at the dam site based on the analysis of Lugeon test results

Parameter	Percentage of tests (%)
Linear flow:	29
Turbulent flow	19
Impervious masses	33
Scour	7
Filling of cavities	8
Opening or dilatation of joints	4
Total	100

According to the Deere and Miller (1966) classification system the rock mass at the dam site is medium to good. At the dam site area the rock mass is evaluated as very poor to poor up to the depth of about 20 m and then it improves to medium to good (between the depths of 20 m and 60 m). Below a depth of 60 m, the rock quality decreases again to medium to poor.

The permeability of covering material and overburden is highly variable at the dam site, ranging from practically zero in the lake marlstones to very high ($k = 10^{-8}$ m/s) in the coarse-grained deposits.

Laboratory tests on core samples were carried out to find the physical and mechanical parameters.

Rock mass classification according to RMR system indicated that the left abutment is in poor to fair quality and the right abutment is in fair quality.

The in situ deformation modulus of rock masses at the Kuhrang-III Dam site was determined using RMR values from the formula by Serafim and Pereira (1983) and also using GSI values from the formula by Hoek et al. (2002).

The strength of rock masses at the Kuhrang III Dam site was expressed using Hoek–Brown empirical failure criteria, Hoek et al. (2002), Uniaxial compression strength of the rock for zones II, III and IV is 0.703, 1.79 and 4.06 MPa, respectively.

Grouting activities have been considered for the dam foundation for consolidation and to make it impermeable. Based on the test-grouting results, average cement grout take is about 82 kg/m. The grout is estimated to have penetrated up to 1.5 m round as traced from the check holes. This indicates that the grouting has been effective.

The grouting system design was based on the data obtained from probe drillings, permeability tests and test grouting. It consisted of a grout curtain at an elevation of 2060 m, extending 150 m into the right and the left abutments. Two galleries have been considered at each abutment to enable grouting. Also consolidation grouting by drilling boreholes with a maximum depth of 5 m arranged at 2 m intervals has been considered for improving the geomechanical quality of bedrock at foundation and abutments areas filling the cracks and joints developed by blasting.

For the final design, additional geotechnical investigations will be required for the study of supplementary structures such as the location and the design of the spillway.

Acknowledgement: The authors wish to thank the office of Graduate studies of the University of Isfahan for their support.

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