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Engineering Geology Characteristics of Zarani Dam Site (South East of Iran) Emphasis Seepage from Foundation and Abutments

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Abstract

Embankment dam of Zarani in the Hormozgan province is located 35 km southeast of Minab. Studied area is located in the western end of the Makran subduction zone. The main regional faulting systems near the site, is Minab- Zandan-Palami right- handed thrust system. The purpose of this study was to identify the geology, engineering geology of reservoir area, and foundation and fulcrum of dam, scrutiny and analysis discontinuities of rock mass, to determine joints and fractures, determine the permeability of dam structure (foundation and fulcrum) based on the results lugeon test and finally, offer suggestions for cut off dam. The research method includes first gather basic information and general research, and then field investigations were done and finally were analyzed data by the Stereonet, Stereograph and Dips software. The result of lugeon test showed penetration depth in the right, middle and left side are 45, 45 and 50 respectively, the slope of shale - sandstone layers of site is near vertical and the dip direction is the east to northeast. This condition of site formation has cut off rule, but it cause to seepage on the right shore of reservoir. In the right shore of the reservoir, shale layers were dominant and have folded out by the Zendan faults and has changed trend of the layers, which caused cut off in this area. The left and right abutment of structure, three sets of discontinuities crosscut the rock mass, according to the layering in these categories are with discontinuities, make most of potentially space to escape water, but because of vertical layers, this space has not noticeable effect on seepage.

Keywords: Engineering Geology, Geotechnic, Zarani, Minab, Embankment dam.

1. Introduction

Iran is located in arid and semi-arid region (Alijani and Babai, 2009; Alijani, et al. 2008), has suffered from long water scarcity and droughts (Farajzadeh et al. 1994). Because of this, dam construction for water control and water storage and superficial flood during the precipitation and use it at dry season is essential and inevitable (Mahtabi et al. 2013). The objective of dam construction may be special-purpose or multi-purpose (Qaderi et al. 2007). To implement any dam construction project, subsurface geological survey and estimation of geomechanical parameters and hydrogeological of foundation and abutment of dam is necessary, so that we can properly evaluate the geotechnical characteristics of the rock bed in the structure area (Rahnamarad et al. 2013; Farhoudi et al. 2007 Kockbay and Kilic, 2006; Dadkhah, 2010; Ajalloeian and Moein, 2009; Ajalloeian et al. 2011,2012; Gurocak and Alemdag 2011; Lashkaripour and Ghafoori 2002; Ghafoori et al. 2011; Zeidabadinejad et al. 2012). Detailed survey in the detection phase can prevent problems in the construction and operation of dams (Adams and Akinwande 2014).

In this study, in addition to exploration drilling and borehole test conducted by the Hormozgan Regional Water Company and was performed laboratory tests on rock samples to obtain accurate data of geological dam, was prepared large-scale geologic map (1:2,000). Embankment dam of Zarani with a height of 5.27 meters on the Zarani River was suggested and is performed preliminary study. Embankment dam of Zarani in the Hormozgan province is located 40 km southeast of Minab at latitude 26° 50' 30" N and longitude 57° 15' 10" E. The access way is asphalt road of Minab to Bashagard (Fig. 1).

2. The geological site

The study area is located in the western end of the Makran zone. The dominant lithology of the area consists of Middle Miocene Ghushi marl, Middle - Upper Miocene Kheku sandstone unit, Upper Miocene Tiyab sandstone unit, Pliocene conglomerates of Minab and Quaternary deposits (Aghanabati 2004). The main regional faulting systems near the site, is Minab- Zandan- Palami right- handed thrust system (Peyret et al. 2009), it is formed western margin of the Makran zone that its strike is N160 and the slope is near to vertical and dip direction is northeast. Field studies show that dam site is formed the alternating with layers of thick shale and thin sandstone (Fig. 2). The bedrock consists of shale and sandstone that the shale bedrock is poor, green to dark gray, very fine, thin layers and with blade of gypsum- bearing sandstone, which is covered by thick debris material. Sandstone bedrock is weak, gray with gradual gradation, thin to moderate layer, slightly weathered with regular layered to intersect, with bands of shale and has a moderate to high permeability. Quaternary deposits consist of filler sediments of the riverbed and stream, the debris and slope wash, young sediments of terraces and alluvial deposite. The filler sediments of riverbed and stream with 1 to 2 m thick, is composed of a mixture of sand with angular rock fragments and semi-round to round. The rocks

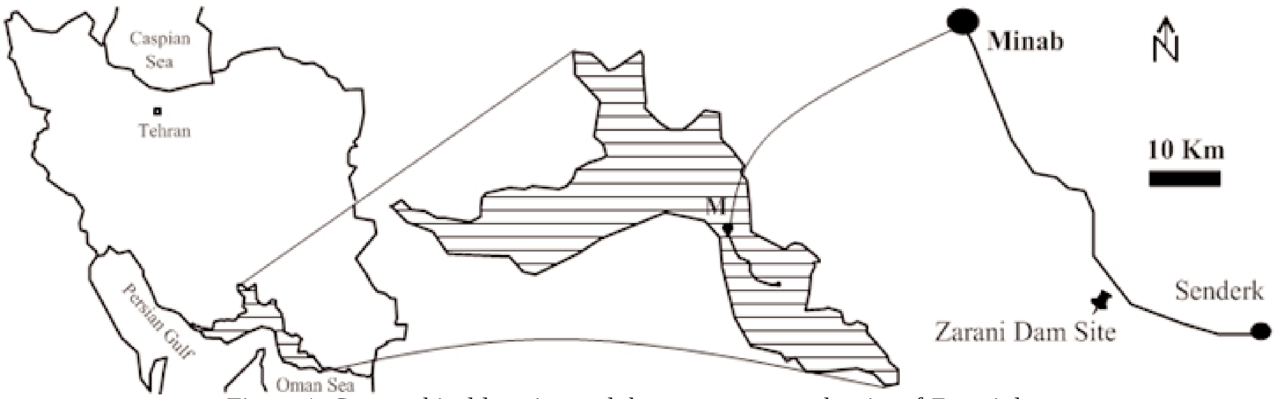

Figure 1. Geographical location and the access way to the site of Zarani dam

include limestone, sandstone and slightly igneous rocks. These materials are highly permeable. Debris substances and slope wash to maximum thickness of 3 m, consists of various pieces of rock (gravel to rubble size) in context of sand and silt. These materials are permeable. Young terraces extended on both sides of the river with a low permeability, thickness of about 3 to 4 meters and have formed mainly fine and uniform silty sand and sandy silt. At 5.0 meters above the terraces can be seen roots of plants. Alluvial fan deposits are formed on the some right shore of the stream. At these alluvial fans, materials gradually become fine from the apex of the cone to the base.

3. Geomorphology

Dissected Plateau is formed heights of the study area. Bashagard mount with 2158 and Mehrab mount with 2046 meters above sea level is formed the highest elevations (Fig. 3). Zarani River is created by Garou and Mazabi rivers that flow from east to west. Serni and Zarani rivers join together after crossing the Karyan plains near Joomahale and nearly perpendicular to the axis of the Koutak anticline, cut Goshi marl and it flows into the sea (Yamani 1378).

4. Field surveys

4.1. Structural Geology

4.1.1. discontinuities system

discontinuity field survey of include the amount and direction of dip, repeat interval, the length of opening, roughness and was performed at flanks of reservoir and was classified by Dips V.5.101 and Stereograph software.

4.1.1.1. Discontinuity on the left abutment

The rocks of this abutment including shale, sandstone, layering is inclined to the vertical, features of 80 discontinuities was measured in three joint sets.

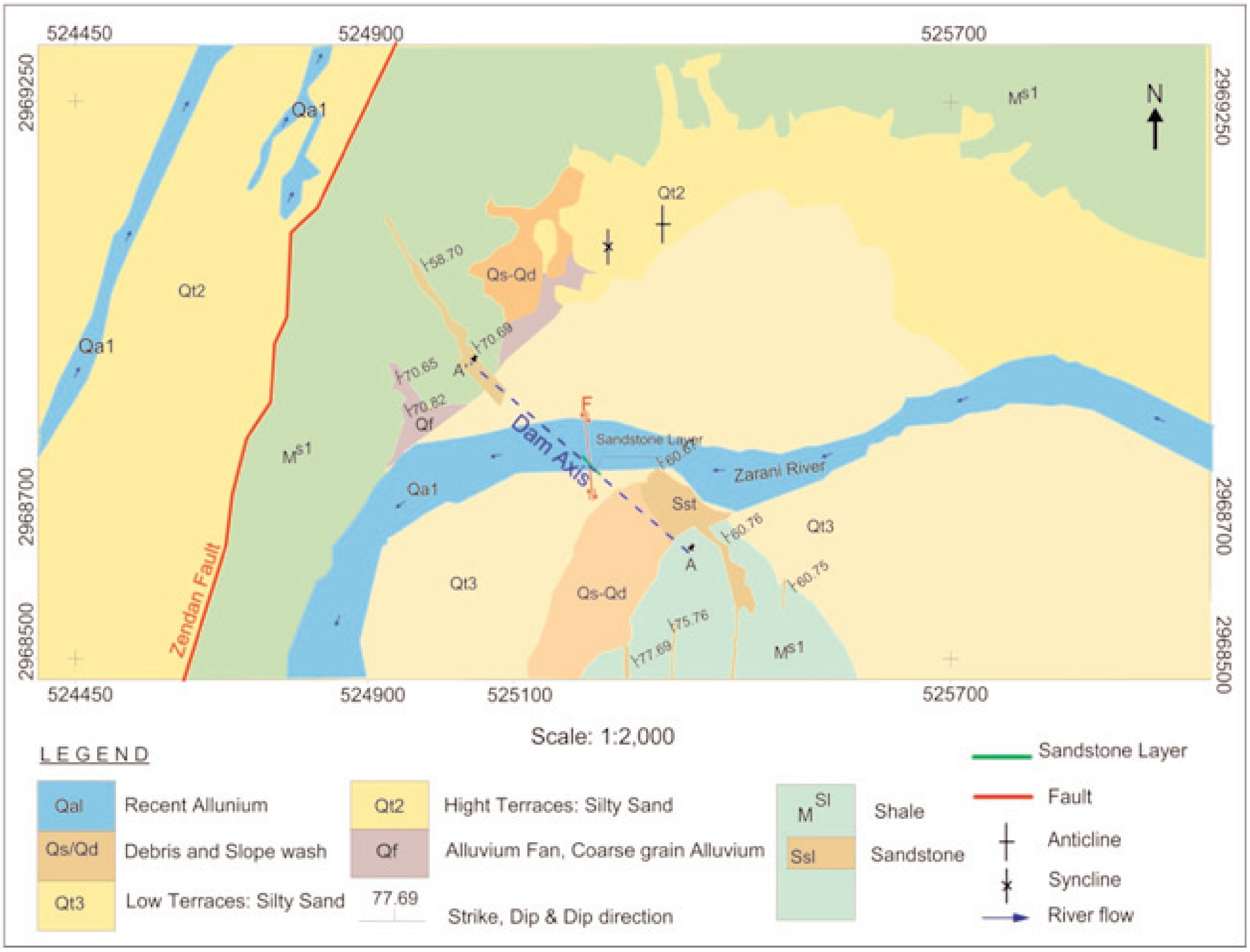

Figure 2. Geological map 1: 2,000 site of Zarani dam (adapted from geological map 1: 250,000 Taharoee, McCall 1985)

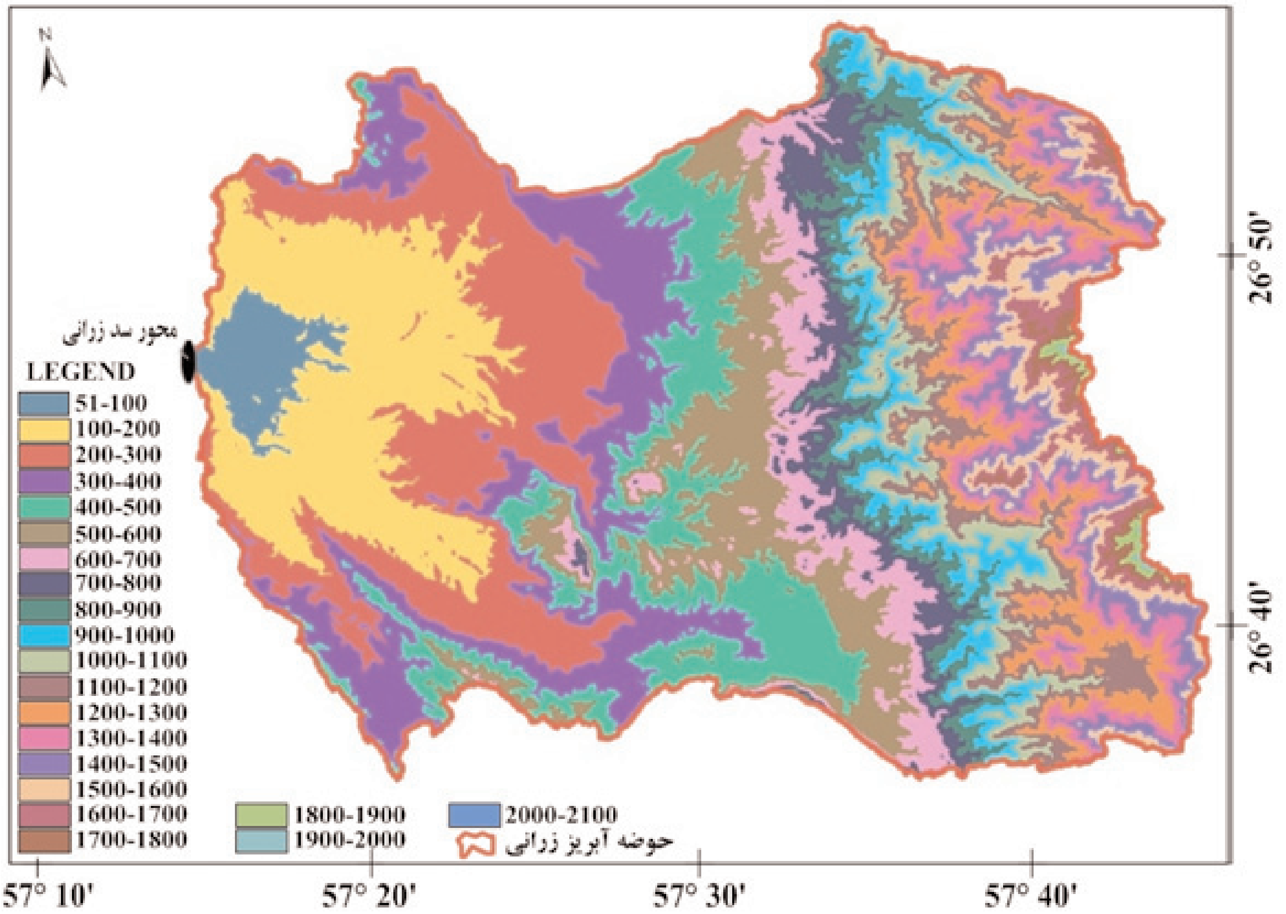

Figure 3. The elevation condition of the Zarani catchment

It should be noted that the second and third categories of discontinuity are perpendicular to the layers (the first category). The second and third discontinuities system has about 1 mm and first category of discontinuity has an opening about 2 mm and average repeated interval is 100 mm. The length of discontinuity of second and third category is less than 3 meters (Table 1).

Table 1. discontinuity features of the left fulcrum

Average opening	length of discontinuity	type	set
1-2 mm		Layering	1
1 mm	3m	joint	2
1 mm	3m	joint	3

Table 2. discontinuity features of the right fulcrum

Average opening	length of discontinuity	type	set
3 mm	> 30 m	Layering	1
1-2 mm	3m	joint	2
1-2 mm	3m	joint	3

4.1.1.2. Discontinuity on the right abutment

The rocks of this fulcrum are formed from sandstone with vertical layering. Features of 113 discontinuities were measured in three joint sets on layer of sandstone. According to (Fig. 7) and based on rose diagram (Fig. 8) and contour diagram (Figure. 9) and stereographic pages (Fig. 10), three categories of discontinuity, rock cut off right side. Also at this fulcrum, the second and third categories of discontinuity are perpendicular to the layers. The discontinuities system have opening about 1 to 3 mm and average repeated interval is 100 mm, the length of main discontinuity (layering) is more than 30 meters but other joint categories are less than 3 meters (Table 2).

4.1.1.3. Discontinuity on the right bank of the reservoir

Part of the right abutment of the dam reservoir called right shore of reservoir which consists of alternating thick layers of shale and thin interlayer of sandstone with high erodibility, these substances are formed boundary between rocks and soil that so-called loose stones (Bell 2007). In these scopes, is detected 85 joints in 5 categories of discontinuities (Fig. 10; Table 3). Discontinuity of these sides had 22 cm repeat interval, an average less than 3 mm and with a rough and uneven surface in sandstone and smooth and soft in shale. The extent of discontinuity of the first categories was more than 30 meters, the second and third categories were 1 to 3 meters and the fourth and fifth categories were between 1 and 2 meters.

Fault with a right-handed separation in the dam axis (Fig. 13) had slope of 60 degrees, and dip direction was 26 to 265 and passes the under right shore. Layers on both sides had slope of 62 to 73 degrees and dip direction was 33 to 45.

Table 3. discontinuity features of the right shore of reservoir

Average opening	length of discontinuity	type	set
3 mm	> 30 m	Layering	1
1-2 mm	1-3 m	joint	2
1-2 mm	1- 3 m	joint	3
1-2 mm	1 mm	joint	4
1-2 mm	1 mm	joint	5

5. Hydrogeology

In terms of Hydrogeology, the formations of reservoir area can be divided into two categories: solid formation and discontinuous. The solid formation composed of Pliocene conglomerate without cement, low to moderate permeability and capacity of storage and transferring underground water. But the other formation such as flysch- like facies of green unit and bottom unit with thick layers of shale, it can be generally considered impermeable and only within the layers of sandstone, limestone and conglomerate have low to high permeability because of smashing caused by located in the zone of Zendan and long

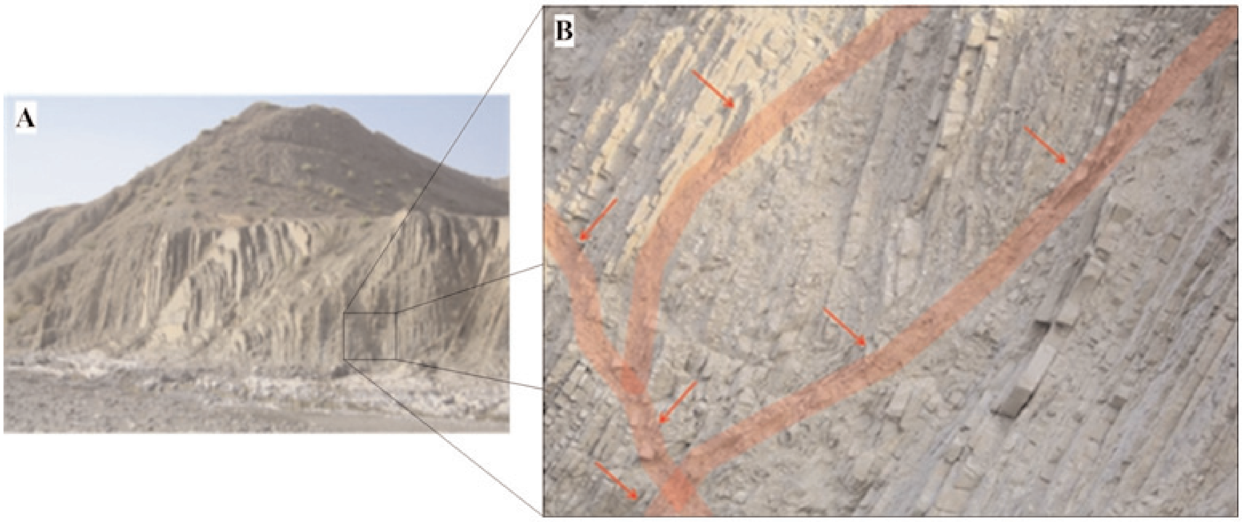

Figure 4. A) Condition of layering at alternating shale and sandstone (see to the west)
B) Magnifying of local fault on the left flank of site.

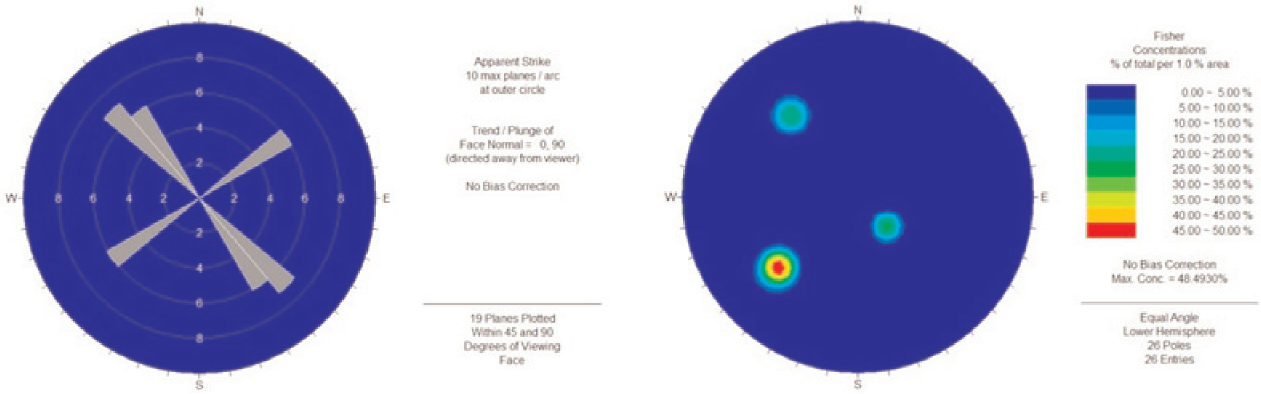

Figure 5. Rose diagram and Contour diagram of pole discontinuity strike of the left abutment.

faults. Due to locating at the impervious layers of thickness shale change cannot have effect on the hydrogeology.

6. Geological engineering and geotechnical characterization of dam site

Due to geology condition of the dam site, 34 bore-holes on exploration are drilled by Hormozgan Regional Water Company. In order to determine the physical and mechanical parameters of rock mass of

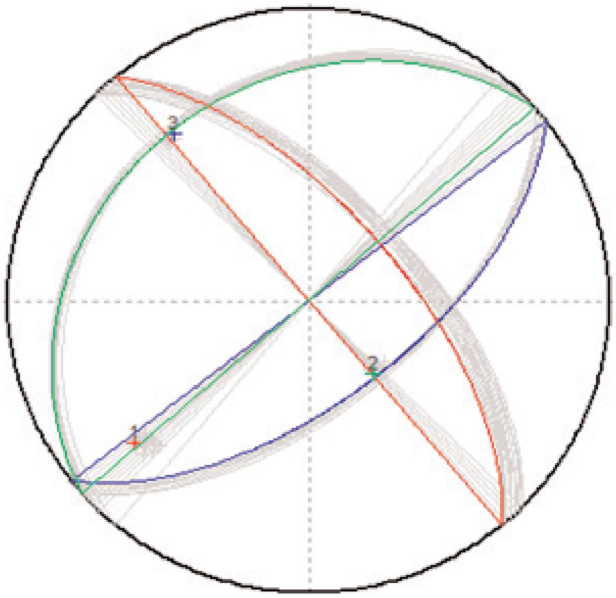

Figure 6. General Condition of main discontinuity sets of the left abutment on the southern hemisphere of Schmidt stereographic net.

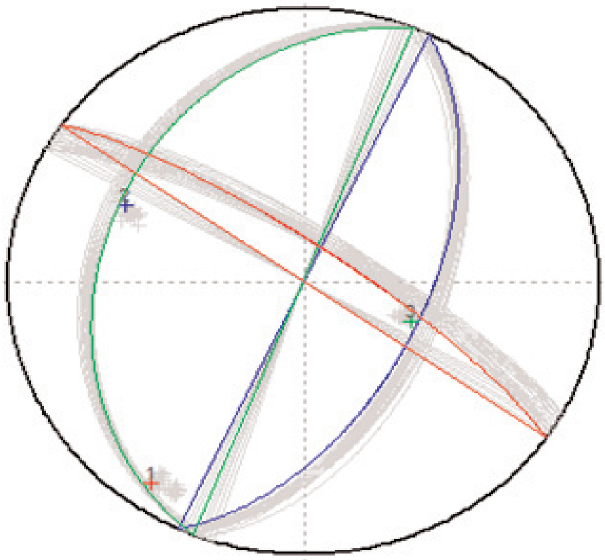

Figure 9. General condition of main discontinuity sets of the right abutment on the southern hemisphere of Schmidt stereographic net

Figure 7. Close up image and cross section of the layering condition on the right abutment

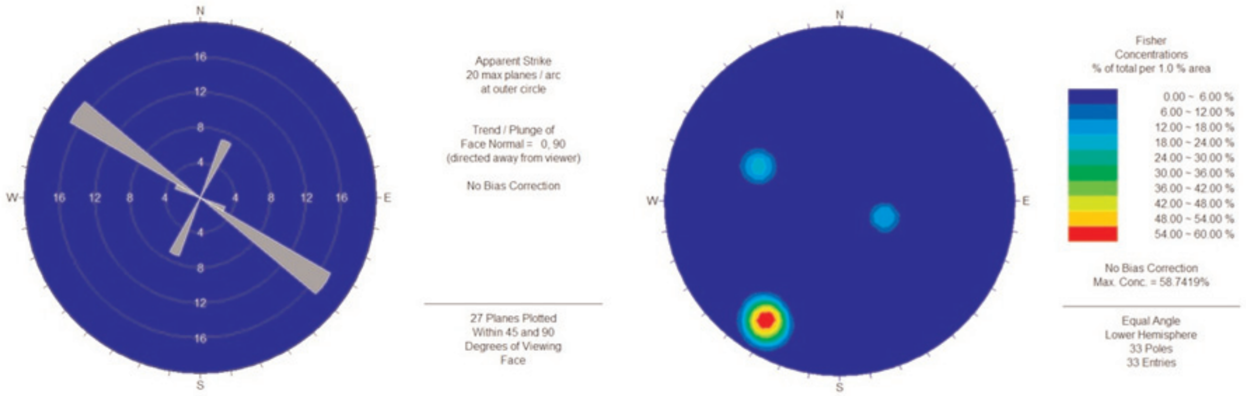

Figure 8. Rose diagram and Contour diagram of pole discontinuity strike of the right abutment

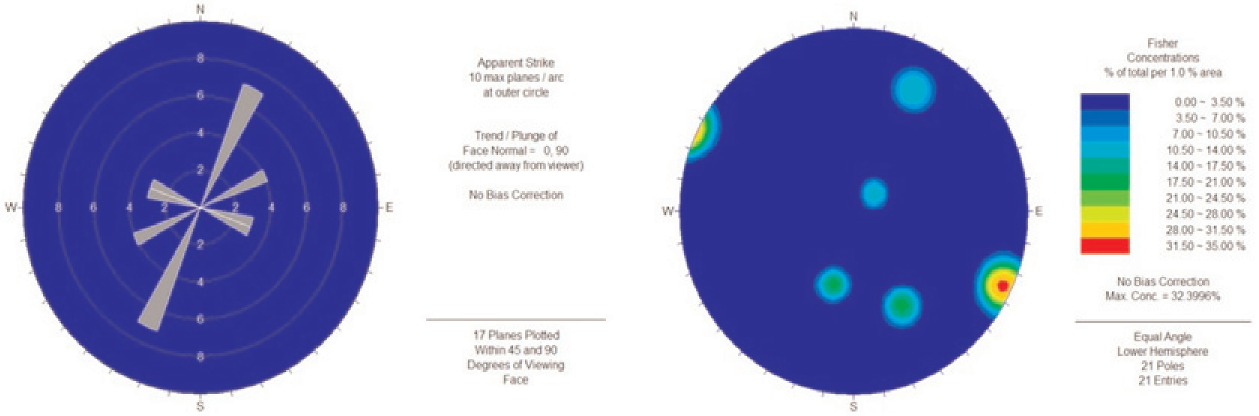

Figure 10. Rose diagram and Contour diagram of pole discontinuity strike of the right shore of reservoir

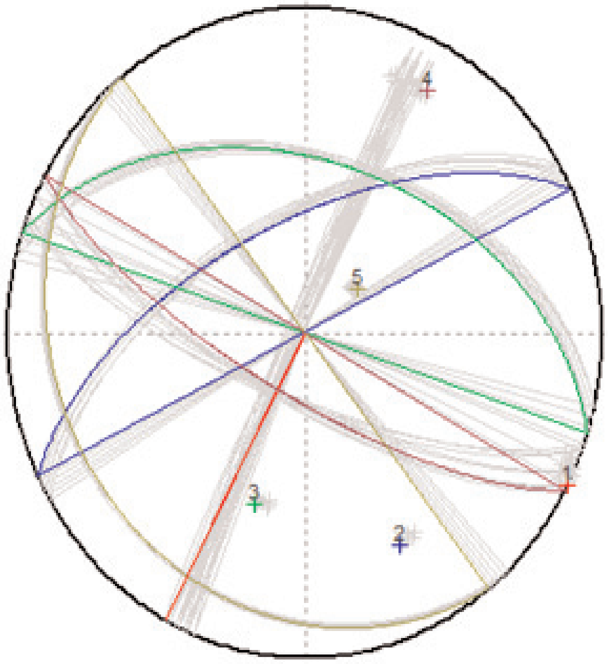

Figure 11. General condition of discontinuity category of the right reservoir on the southern hemisphere of Schmidt stereographic net

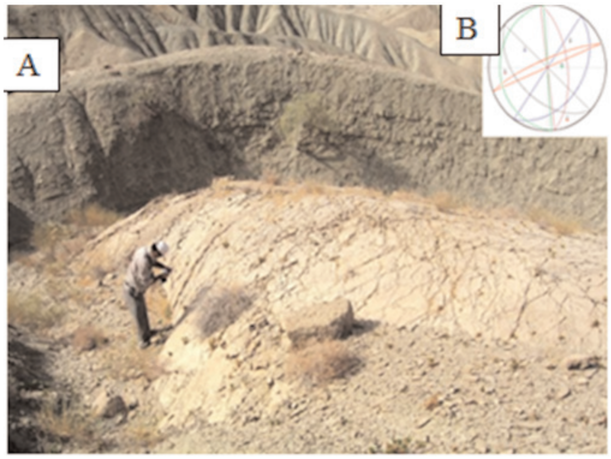

Figure 12. A) an anticline with the axis 22/160 on the right bank of the reservoir. B) The stereographic net of position of axial anticline

Figure 13. fault with right-hand separation at axis dam, a separation of about 2 m (see to the North East)

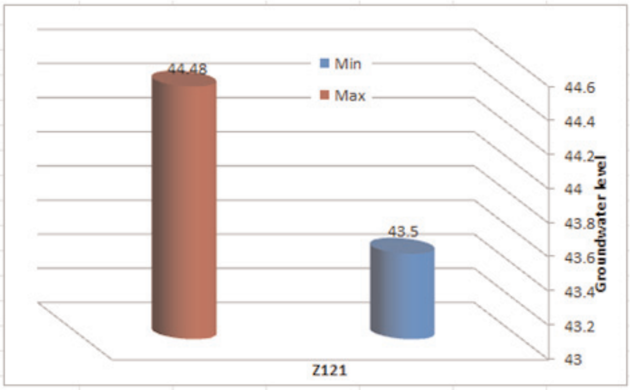

Figure 14. Diagram level of the water table at the right abutment

Zarani dam site, on samples obtained from the drilling of boreholes, the number of laboratory tests according to method proposed by the International Society for Rock Mechanics (ISRM 1981) was performed such as uniaxial compressive strength tests to determine the elastic modulus and Poisson's ratio, direct shear tests, density tests, water attraction, porosity, pressure waves, shear waves, Straight Shear and durability against water (It should be noted that the experiments was performed in dry and saturated condition).

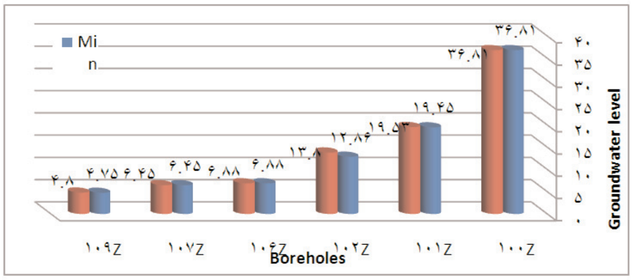

Figure 15. Diagram level of the water table at the left abutment

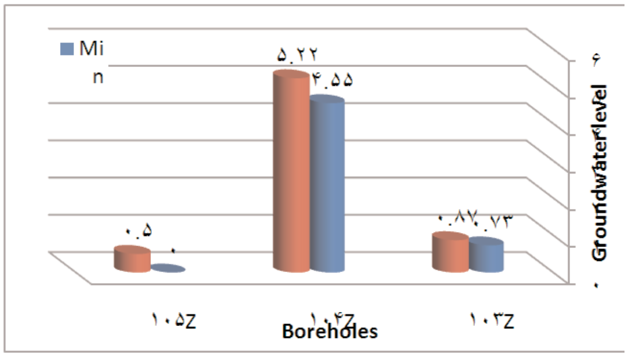

Figure 16. Diagram level of the water table at the middle valley

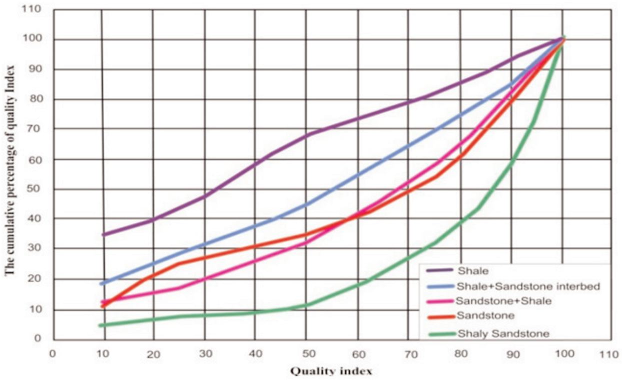

Figure 17. Quality index of bed rock mass of Zarani dam site based on classification (Deer 1989)

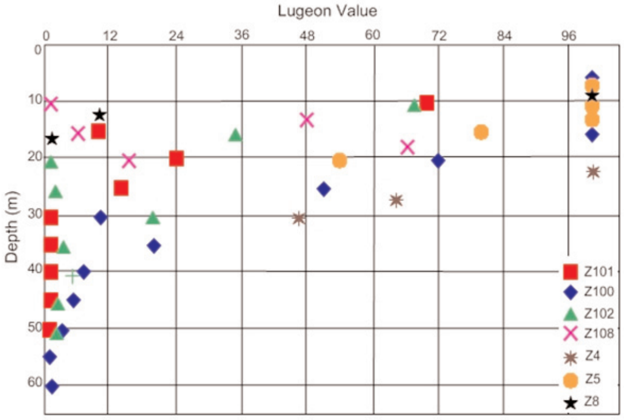

Figure 18. Lugeon values versus depth at the right abutment

6.1 The quality of the rock mass

The bed rock mass quality index, according to the diagram (Fig. 17), shaly sandstone and shale have highest and lowest quality index, respectively. According to quality index sandstone is placed at second category after shaly sandstone. Indeed sandstone and shale with interlayers of sandstone have same quality condition more or less. Quality weighted index, strong to weak, for mass bedrock of shaly sandstone, sandstone- shale, sandstone, shale with interlayers of sandstone and shale was 88, 67, 65, 55 and 32 percent, respectively.

6.2. Permeability of the rock mass

Results of water pressure test (Lugeon) of exploratory boreholes are shown in figures 18 to 20. The results show that at right shore of next reservoir, mass bedrock is more impenetrable. So that the permeability of 83% bedrock is below 5 units Lugeon and permeability of 17% bedrock is below

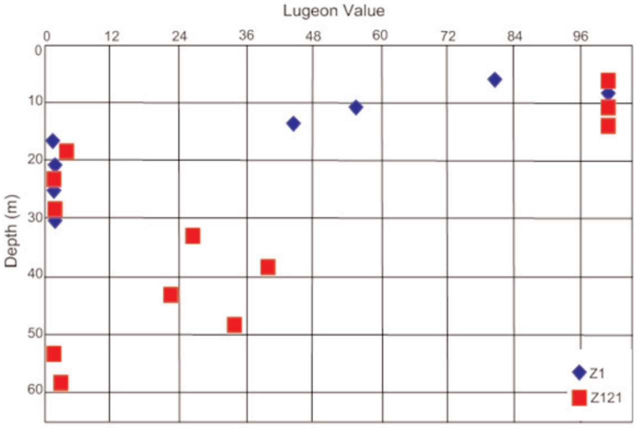

Figure 19. Lugeon values versus depth at the left abutment

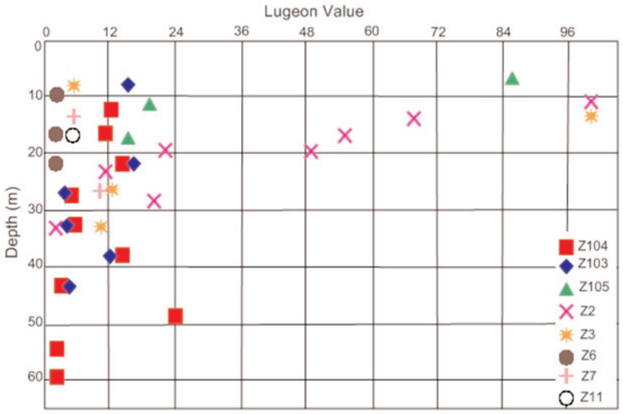

Figure 20. Lugeon values versus depth at the central valley (dam foundation)

Table 4. Engineering classification of rock mass of dam abutment based on compressive strength

	Left abutment		Right abutment			
	sandstone		**Shaly sandstone**		**shale**	
	Saturated	dry	Saturated	dry	Saturated	dry
compressive strength value(Mpa)	5.65	21.15	16.6	18	9.99	13.03
Strength	Very low		Very low		Very low	
Class	E		E		E	

Table 5. The scoring system of rock mass (Bienioweski, 1989)

Rock and abutment type Parameters	**Right abutment**		**Left abutment**
	shale	sandstone	Shaly sandstone
uniaxial compressive strength(MPa)	13.03	21.15	16.6
Score	2	2	2
index RQD%	32	63	88
Score	8	13	17
discontinuity distance(m)	0.1	0.1	0.1
Score	8	8	8
Condition of discontinuities surface	Smooth	Rough and uneven	Rough and uneven
Score	10	25	25
Underground water	air-dry	air-dry	air-dry
Score	15	15	15
Total score	33	63	67
Rock Class	IV	II	II
Description	Poor Rock	Good Rock	Good Rock

30 units Lugeon because of dominance of shale rock mass at right shore to site.

7. Laboratory tests

In order to access the geomechanical properties of the rock mass due to variation in lithology at the site, some of samples were sent to the laboratory for testing. The results of these experiments showed that shale of site has low density and high porosity, average compressive strength elasticity modulus and elastic wave velocity are low. Sandstone of site has low density and high porosity, average compressive strength elasticity modulus and elastic wave velocity are low. Soil of sites foundation in the United States classification is placed in CL rank and based on viewpoint of plasticity and viscosity is placed in high plastic and compressed plastic mud.

7.1. Classification of rock mass based on compressive strength

Uniaxial compressive strength of rocks has been considered as an important factor and common for recognizing geotechnical characteristics of the rock a long time ago. (Bell 2007). The results of these tests are presented in Table 4.

7.2. Geomechanical classification of rock mass of site

In order to evaluate the classification, the boreholes of foundation and abutments have been studied. The structural properties of the rock mass containing discontinuities, faults and joints were investigated.

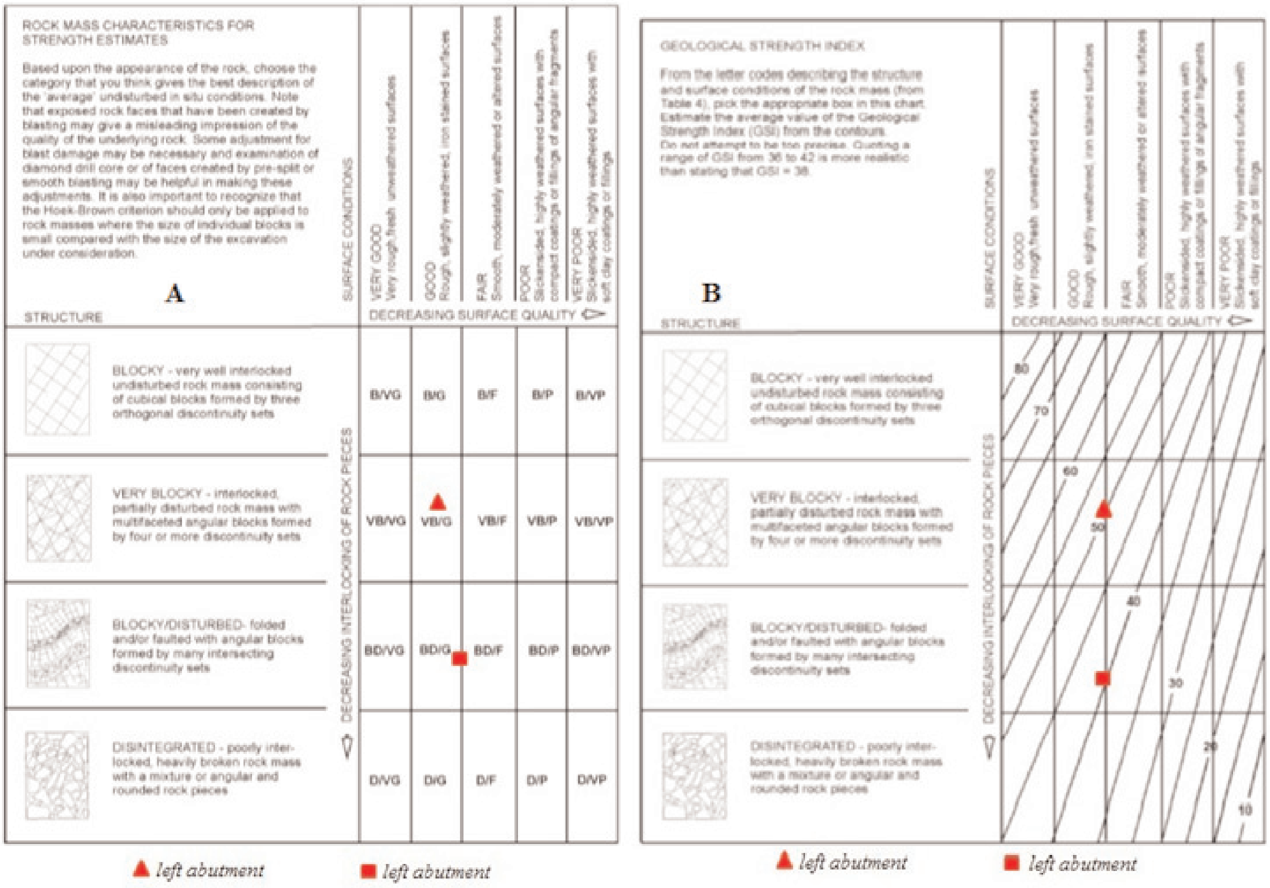

Figure 21. A. Rock mass characteristics based on interlocked and altered surface of joints (Hoek et al. 1998) B. Evaluation of the geological strength index based on descriptions of geological condition of the rock mass (Hoek, 1994)

Table 6. GSI classification for the rock mass of Zarani dam

Parameter	Right abutment	Left abutment
GSI value	5 ±40	5 ± 49
Description	BD/G - BD/F	VB/G

Table 7. Classification of rock mass of site based on Q system

Position Parameter	Right abutment		Left abutment	
	Description	score	Description	score
avrage %RQD	fair (32-88)	60	fair	63
Jn	Three categories of joints	9	Three categories joints+Random joints	12
Jw	drilling environment is quite dry or with extremely low water flow	1	drilling environment is quite dry or with extremely low water flow	1
Ja	Joint walls altered slightly and have been covered with thin layer of filler material like sand and crushed stone lack of clay	3	joint walls has sand-free clay particles	4
Jr	Soft and smooth to rough and wavy	2.5	Rough, irregular and wavy	3
SRF	A poor area with of clay or materials produced from chemical weathering (drilling depth is less than or equal to 50 m)	5	The presence of a shear zone in strong rock (without clay) drilling depth is less than or equal to 50 m.	0.5
Final score	1.33		7.875	
Q description	poor		average	

Based on the results of laboratory and field tests, such as uniaxial compressive strength, RQD, permeability, analysis of discontinuities systems, RMR classification for rock mass, were performed. The results are shown in Table 5.

7. 3. Geological Strength Index (GSI)

Strength of the rock mass depends on properties of virgin rock fragments and degrees of freedom of the fragments to slide and rotation under different conditions of stress. According to geological strength index rock mass of left and right side of dam site are placed at blocky to disturbed- folded and very blocky groups, respectively. It is used in abutment, but weathering and joints condition are not same on both of abutment. This system is presented in figure 21.

VB / G: very blocky rock has good quality at surface

BD / F: blocky/ disturbed- folded rock has fair quality at surface

BD/G: blocky rock has good quality

7.4. Rock mass classification based on Q system

This classification system of rock masses were presented for the first time by Barton in 1974 (Barton 1974). Generally, this classification is a quality classification and in this system, the evaluation of engineering behavior of rock masses is based on numbers or scores. The total number of Q is calculated from equation 1.

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF} \qquad \text{(Equation 1)}$$

8. The cut off and proposed grout curtain

Proposal and determine the depth of the injection curtain is done according to geological conditions, ground water level and permeability of the rock mass site. According to the results of the joint set, Lugeon testing, rock mass quality classification should first is removed site overburden (loose deposits and Quaternary detached) and then injected. The proposed depth of curtain injection in the site, from left abutment to the right side and the riverbed was varied between 30 and 45 meters and maximum depth would be 50 m under right abutment (Fig. 22). At the joints of abutments should is injected as parallel and also perpendicular to the layering.

9. Conclusions

1. Bedrock of Zarani dam site is formed the alternating with layers of thick shale and thin sandstone that weathered and surfacicial chopped zone at the right abutment, central part and left abutment is 8, 5 and 8 meters, respectively. Bedrock is buried under the 2.5 m thick of Quaternary sediments at right abutment and the riverbed. Therefore weathering percent at right, middle and left sides is 72, 53 and 56%, respectively, that bedrock mass placed at the moderate category of Deer (Deer 1989).

2. Average quality of rock mass especially at the middle and the left side can be caused by the Zendan fault that is located at about 500 meters far from the west of site.

3. Based on the results of lugeon tests, depth of penetration in the right, middle and left side is 45, 45 and

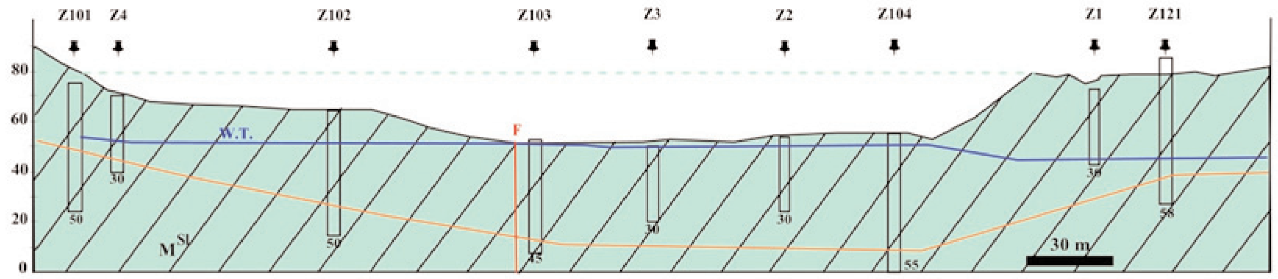

Figure 22. Geology, Geotechnical and hydrogeological section of site, A-A' axis (shown in Figure 2) with the proposed grout curtain, (Adapted from geological map 1: 250,000 by Taheroee, McCall, 1985 and the underground water level and borehole taken by the Hormozgan Regional Water company)

50 meters, respectively.

4. In terms of geology, total alternation of impermeable thick shale with layers of permeable sandstone acts as a dam, so if sandstone layers do not access to the open space, this set will act as a cut off.

5. In terms of structure, the slope of sandstone- shale layers of site is near to vertical and dip direction is east to northeast. This structure condition of site acts as a cut off but at the right shore of the reservoir cause seepage. The thick sandstone layer is located at the right abutment that surface outcrop is extended near of the Zendan fault but at Saddle area (topography surface of the right shore of the reservoir) shale layers was dominant and have folded affected by Prison faults and changed layer trend that it caused cut off at Saddle area.

6. In terms of permeability, depth of permeability of bedrock mass at left side, middle of the valley and right shore is 45, 50 and 10 meters, respectively.

7. In terms of morphology, on the left side of the valley of site, there isn't any river or stream deeper than the Zarani that reservoir water of future dam escapes it but in the right side there is area with the lower level than the reservoir that water can escape.

8. On the right shore of the reservoir of future dam, due to hilly area and its 300 meters length at approximately east-west direction (perpendicular to the dam axis), by constructing Zarani dam with height of 5.27 meters, can lead to escape water through Zinche and various streams at right shore of the lake.

9. Depth of grout curtain on the left side, middle valley, right side and maximum depth of Saddle part is proposed 45, 45, 50 and 10 meters, respectively.

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