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Effect of engineering geological properties on dam type selection of the Qadis Khordak Dam, Afghanistan

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Case Study

Keywords
Engineering geology
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Joint study

Abstract

This paper deals with engineering geological properties of Qadis Khordak dam site in Northwest Afghanistan. This study is based on on-site and laboratory tests, surface discontinuity surveying, drilled borehole and permeability test of dam foundation. The engineering geological properties at the dam site were studied in order to evaluate geotechnical characteristics of rock masses at dam foundation, geotechnical properties of alluvium at dam axis, reservoir and borrow materials. The structural geological studies also carried out due to stability and safety of dam on their abutments reservoir and seismicity. Existence of a fault, high permeable zone at dam foundation and the thickness of alluvium at dam axis, are the most engineering geological issues that cause change on dam type selection. In the feasibility phase, the dam type was chosen as the concrete face rock-fill dam, because of state of engineering geological properties of dam site. However, in the design phase dam type has been changed as a rock-fill with a clay core.

1. Introduction

Dams have been part of human efforts as a mechanism to harness the environment for over 6000 years. Since then, dam-engineering and technology have advanced to allow the safe operation of Gargantuan earth and rock structures such as the Tarbela dam in Pakistan (approximately 13.69 km^3) and enormous concrete and steel structures, such as the Three Gorges dam in China – approximately 39.3 km^3 (Stewart, 2016). Afghanistan is a country which is located on an arid to semi-arid climate with a wide distribution of precipitation as low as 75 mm per year in Farah province to 1100 mm per year in Parwan province (Favre & Kamal, 2004). In order for Afghanistan to overcome both the quick growth in population and the spatially and temporally irregular precipitation and irrigation losses, infrastructure development is fundamental (Brown & Lall, 2006; Bosshard, 2012; Tortajada & Biswas, 2014).

Qadis Khordak reservoir dam site is located at the Southeast Qadis district, Badqis province in the north western part of the country (Figure 1). Qadis Khordak dam is a 32 m in height and the capacity of reservoir is approximately 5,000,000 m^3. Geographical coordinates of dam site are 63° 34’ 49.4 E, 34° 42’ 39.8N. The selection of the type of dam requires collaboration among experts representing several disciplines-including planners, hydrologists, geo engineer, geotechnical, hydraulic, and structural engineers to ensure economical and appropriate designs for the physical elements, such as topography, geology and foundation conditions, borrow materials, hydrology, and seismicity. Engineering geology studies are an important parts of dam site investigation. In recent years, the analysis of the dam location characteristics was the main consideration for many investigators (Lashkaripour & Ghafoori, 2002; Romanov et al., 2003; Ghobadi et al., 2005; Kocbay & Kilic, 2006; Unal et al., 2007; Ghafoori et al., 2011; Uromeihy & Farrokhi, 2012). The importance of geological factors on the suitability of a dam site has been thoroughly discussed (Oliveira, 1979; Anderson & McNicol, 1989) and in some cases generally accepted criteria for chosen the type of dam have been challenged (Bell, 1993).

The safety of a dam can be estimated when the features of its foundation are measured accurately, and the design of the dam is proportional to the features of the foundation. This is why identifying engineering geological features controlling the stability of the foundation is necessary for safe and economical design. Many dams have failed during or after construction because of the weak foundation of the rock mass. This is the reason of the proficiency of designers and construction personnel without knowledge of geology studies and geological engineering could not guarantee the safety of the dam. The choice of the dam location in any

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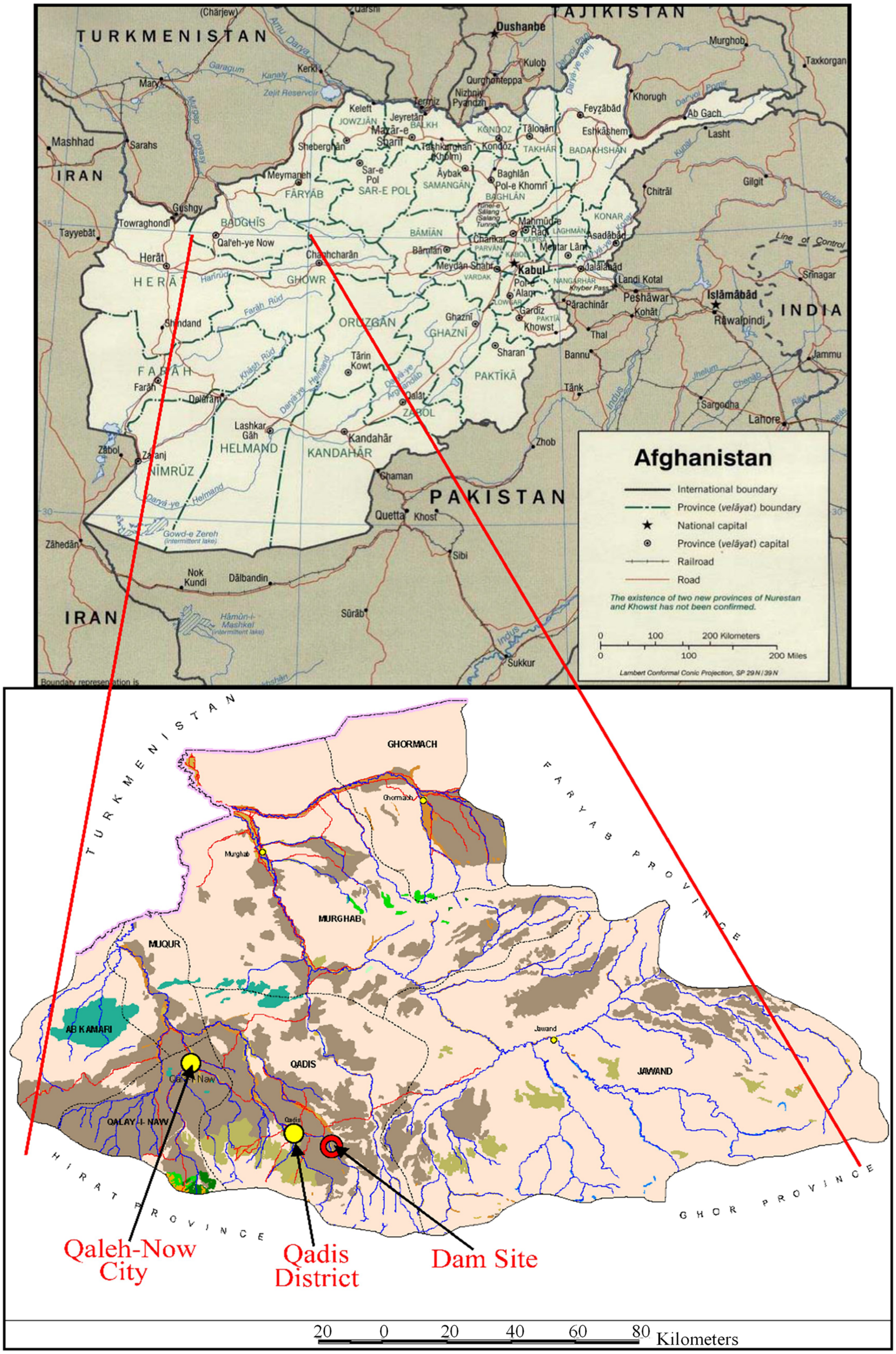


Figure 1. Geographical location of Qadis Khordak dam site.

area mainly depends on the situation of the dam area and the dam reservoir (El-Naqa, 1994). Suitable information on the geological condition, geotechnical parameters and hydrogeological conditions of dam area is vital to design and guarantee the safety of dam body. The importance of geotechnical studies becomes even more important as the dimensions of such structures are increased in height, depth and volume of reservoir (Haftani et al., 2014).

Apparently, there are not always proper conditions of the ground and rocks of the dam in a given site, so it is the engineer's responsibility to state the weakness of the ground, reservoir, and accessory structures of the dam. The most important responsibility is to study the geology, the geological engineering, and geotechnical condition of the area where the dam is to be constructed (Heidari, 2000).

2. Geological conditions of dam site

2.1 Regional geology

Afghanistan is composed of a complex collage of mostly Gondwanan derived terranes which were accreted onto the southern margin of Eurasia prior to, and during, the India-Eurasia collision (Celãl Sengör, 1984; Boulin, 1991). The study areas are comprised of intrusive igneous rock such as andesite, basaltic andesite, rhyolite, trachyte and conglomerate that are likely from the Eocene-Oligocene. The average study area height summit between 1600 and 1850 m above the sea level. Creeks of the all drain inlets to the Qadis Khordak river. The study area is a rugged mass with dendritic drainage pattern. The vegetation cover seen only in the river bed.

2.2 Specific geological conditions of dam site

At the proposed Qadis Khordak dam site, the river flows through a meandering course making a convex shape towards the left bank. rock units upper Eocene-Oligocene in terms of lithological and petrographic are highly variable, so that the lava Andesite, Basaltic Andesite, Trachyte with a combination of Ignimbrite and Tuffs and pyroclastic included with age of the primitive Eocene-Oligocene is formed. These rocks have been altered in different parts of the reservoir at different levels. Andesitic rocks, Basalt and Trachyte due to high resistance compared with pyroclastic rocks make up the crest prominent areas.

In the northern part of the study area, in abutments, bed and reservoir, light green-gray colored rocks of volcanic Breccia (pyroclastic rocks of Lithic Tuffs, Tuff, and Crystalline Tuff) with age of Oligocene has been seen. The field of these rocks are included mostly of tuff and crystalline tuff which can be seen mostly in the dam axis and reservoir. The results of drilling of the boreholes are indicative of high thickness of these rocks more than 60 m in abutments and reservoir.

The youngest sediments of the dam axis, including the recent sediments. Bed rock of reservoir in deeper depth and near the bed river are covered with alluvial deposit mostly coarse grains and flood sediment pertain to current bed or old terraces. Terrace normally can be seen in the boarders of the river bed with different thickness. In the present, nearly all of the alluvial terraces have been used as agriculture fields. Figure 2 shows the geological map of dam site.

2.2.1 Left abutment

The left abutment hill makes a steep hill slope, at about 55°-75° from the river bed level and consists of light brown Andesite. The height of the abutment is more than 30 m from the river bed and gets increased. The left abutment covered by a thin layer of residual soil. There are joints and normal separation at this abutment (Figure 3).

2.2.2 Right abutment

Right abutments consist of dark grey Basaltic Andesite. The natural slope of the right abutment is approximately 40°-50° and has about 26 m height. The joints in the right abutment strike approximately N-S and dips at 30^o-80^o towards upstream and downstream. The right abutment also intersected by another set of horizontal joints (Figure 3).

2.2.3 River bed

The river bed is about 46 m wide with the bed level at 1610 m above sea level and occupied by the present day riverine deposit in the form of clay, silt, sand, cobble, gravel and boulder located both upstream and downstream of the dam axis. The alluvial sediment almost has 20-25 m thickness in the dam axis.

2.2.4 Reservoir

The reservoir of Qadis Khordak dam will extend upstream to the full reservoir level of 1640 m above sea level and will come under its submergence. The reservoir spread is bounded by high mountains trending EES- WWN on either side of Qadis Khordak river. Geologically, these high mountains comprise the intrusive igneous rock formations belonging to Eocene-Oligocene age represented by varieties of porphyry andesite, basaltic andesite, trachyte andesite and volcanic tuff. The reservoir rim formed of hard and compact intrusive igneous rocks is expected to be tight. The chance of reservoir leakage through the right bank is more than the left bank and need to be considered during design and construction phases.

2.2.5 Structural geology

Tectonics studies of the dam axis including the description of the main faults and joints to serve as the main structures and tectonic rock mass, are affected site. Structurally, the

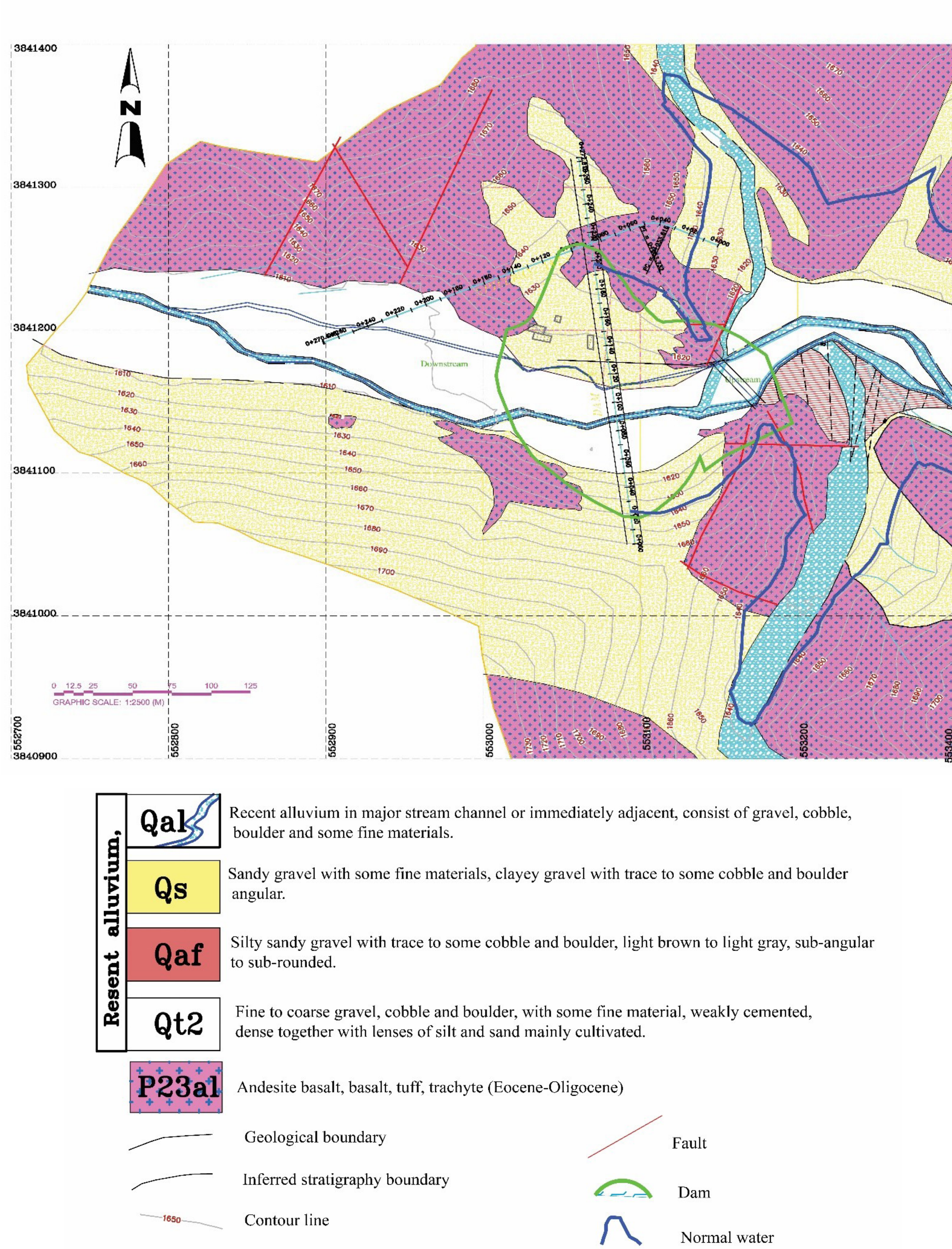
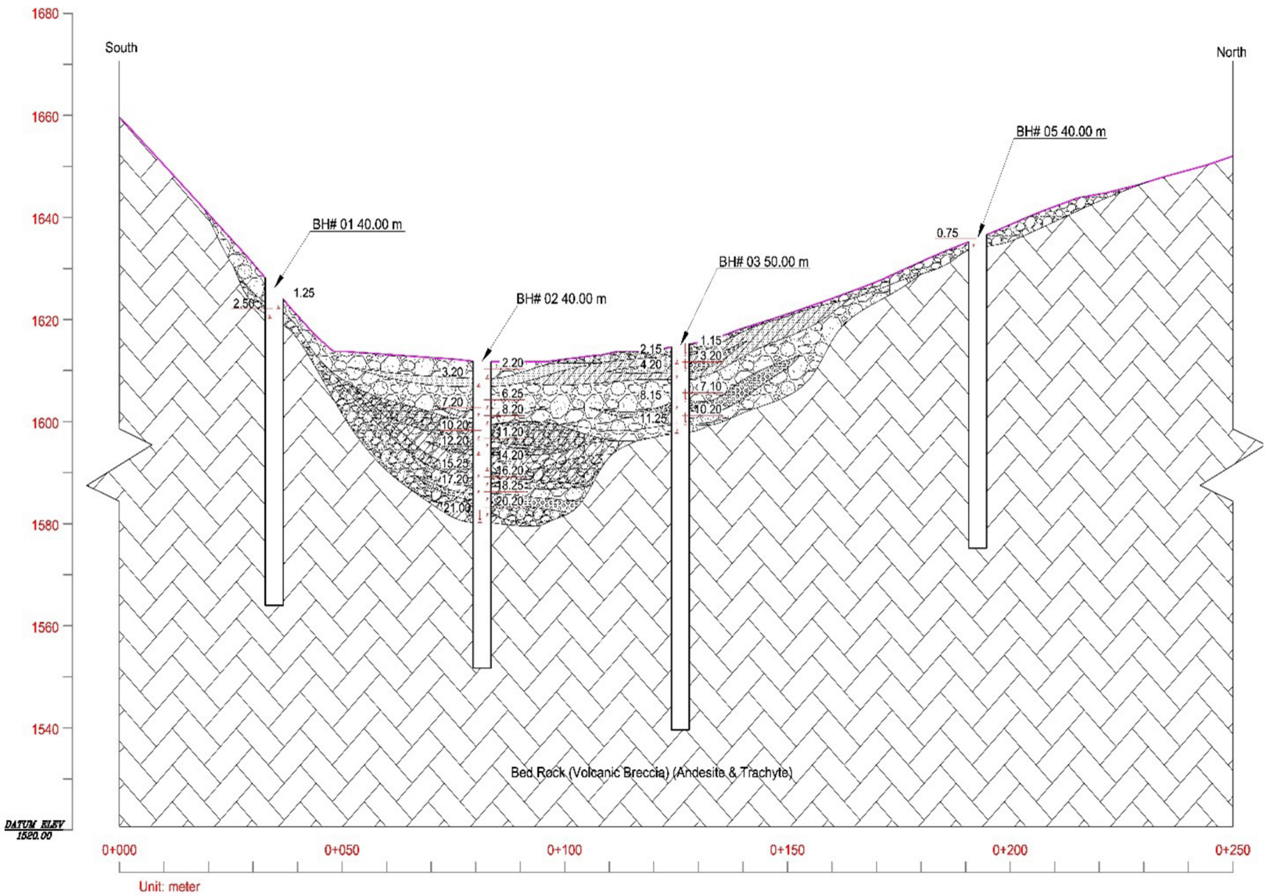


Figure 2. Geological map of the dam site.



Legend Material description (USCS Classification)	
Gravelly Silt with Sand	
Silt with Sand	
Gravelly Silt	
Silty Gravel with Sand	
Silty Gravel	
Clay Gravel with Sand	
Silty Sand with Gravel	
Poorly Graded Gravel	
Silty, Clayey Gravel with Sand	
Sandy Silty Clay	
Poorly Graded Gravel with Silt	
Well Graded Gravel with Silt and Sand	
Silty, Clayey sand with Gravel	

Figure 3. Geological cross section of dam axis.

intrusive rock has been gently fractured. The pillow lava unconformity is the main unconformity in the site project. The main and nearest fault in the dam area is the thrust fault. There is not any evidence of new structural activity such as quaternary fault and fold. The main trend of joints is WN-SE, EN-SW and E-W. Joints have not spread in the intrusive igneous rock because of inherent properties of intrusive igneous rock, but in the sedimentary rock these two joint sets clearly appear at the downstream of the study area. The local drainages, valleys and river appear to be controlled by these joints and fractures.

3. Engineering geological properties of the dam site

In the feasibility study, detailed design and construction phases of the dam, the regional and local engineering geology are very important (Lashkaripour & Ghafoori, 2002). Engineering geological and rock mechanics studies mainly include discontinuity surveying according to ISRM (Brown, 1981), core drilling according to ASTM D2113 (ASTM, 2008a), *in-situ* and laboratory tests according to ASTM Standards (ASTM, 1999, 2001, 2003).

During drilling, discontinuities (such as dip/dip direction, roughness, infilling, and spacing) in the rocks were investigated according to ISRM (Brown, 1981). The discontinuities systems properties rock is highly affected by the mechanical behavior of rock. Discontinuities can cause changes in value in some rock masses properties, increasing on amount of permeability and plasticity and decreasing on the value of strength (Bell, 2007; Goodman, 1989).

3.1. Joint study

To know the status of discontinuities permeated in the mechanical items of rock masses requires the information collected from the field. After this phase, data analysis was carried out using software Dips. In Figures 4 to 6, the polar graphs, rosette charts and discontinuities in dam system are provided, respectively.

Based on data from the study of the right and left abutment, discontinuity systems include the direction and amount of joint dip, presented in Table 1.

Based on the field studies it was observed that the reservoir area and the proposed axis is affected by the three major joints with two main fault systems. As it is indicated in Table 1, joint systems are mostly low and relatively high steep slopes (more than 30°). With regard to the general trend of the main faults in the region, it can be concluded that the joint system is created by the dominant tectonic forces.

Summing up the results of field investigations and geotechnical borehole data shows that joints dips are close to vertical but what is at ground level can be seen, the dominant slope of joint looks sharp. Generally, in the study area, we have low to moderate joint surface with weathering, a moderate joint surface without weathering, and flat and rough joint surface. The samples obtained from exploratory drilling indicates that the lower depths to the surface of the joint is almost no weathering. The space between the joints more by iron oxide, clay and rock material have been filled. Other parameters are spacing and persistence discontinuities. Based on field data, the continuity in the joints are mostly

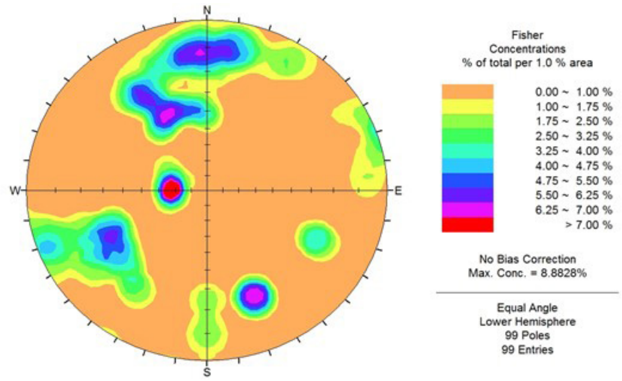


Figure 4. Polar discontinuities in Qadis Khordak dam site.

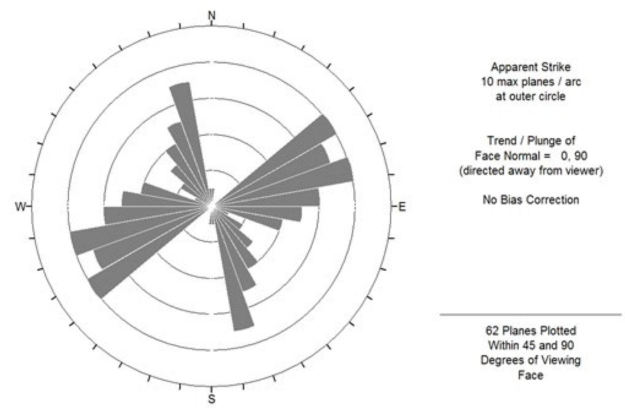


Figure 5. Rosette chart for discontinuities in the Qadis Khordak dam site.

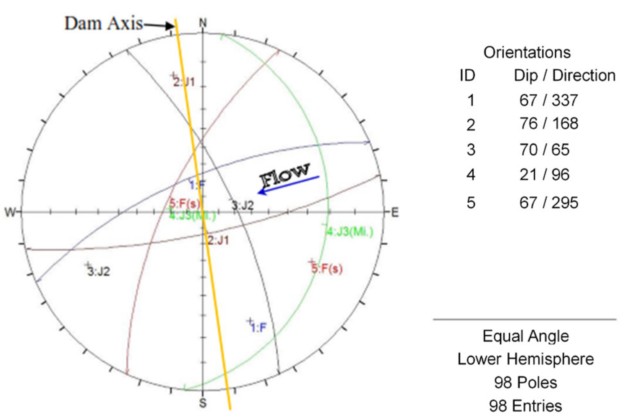


Figure 6. The main planes of discontinuities in the Qadis Khordak dam site.

Table 1. Discontinuity types in Qadis Khordak dam site.

Discontinuity type	Dip	Dip direction
Fault	67°	337°
Fault	67°	295°
Joint	76°	168°
Joint	70°	65°
Joint	21°	96°

in the range of 3-10 m and space are in the range of 0.6-2 m. Discontinuities mainly undulating surfaces and comes with a slickenside effects of the dominant features of the discontinuities. The opening of a joint dominant between 1 to 5 mm (towards closed joints), and the level of opening at the surface locally are more than 10 mm.

3.2. Strength of rock units

One of the most important aspects that should be considered during the design and construction of a dam is rock mass quality. The first stage of design of a dam is estimation of ground strength, permeability, and other factors with the required level of accuracy; these should be determined through a diversity of tests (Lashkaripour & Ghafoori, 2002). According to ISRM (Bieniawski & Bernede, 1979), several uniaxial compressive strength tests have been conducted on over 130 m of rock core samples to determine the strength of rock units that underlie the foundation of the dam. The results of compression tests on different rock units in dry and saturation conditions are shown in Table 2.

The compressive strength of the bedrock based on uniaxial compressive strength test performed on the core samples obtained within 20.3-154.6 MPa which classifies the strength of the bedrock as moderately hard rock to very hard rock medium strong to strong (Bieniawski & Bernede, 1979).

Table 2. Summary of laboratory testing results.

Parameters	Rock unit		
	Min	Max	Average
Uniaxial compressive strength (MPa)	20.3	154.6	59.5
Modulus of elasticity (GPa)	2.15	19.44	7.12
Internal friction angle, ϕ (°)	54	66.5	60.8
Cohesion (MPa)	0.13	3.54	1.1

3.3. Rock quality designation (RQD)

In geotechnical terms, degree of fracturing in drill cores is one of the simplest and easiest methods to describe the quality of the rock mass. Based on the results of geotechnical data, the average rock quality designation (RQD) is in the midrange, and varies from 54 to 94 according to the Deere classification (Deere & Deere, 1989). The rock mass quality (RQD) in many boreholes in both abutments are good and excellent (Deere & Deere, 1989). The jointing between the rock mass is in the range of low to medium and permeability of the rock mass is due to high hydraulic opening joints.

3.4. Permeability

During the core drilling, in-situ permeability tests were performed in the Qadis Khordak dam foundation directly in the vertical boreholes. The main reasons for carrying out of this test was to measure the permeability of each section of rock masses of the dam foundation and its banks (Vaskou et al., 2019). As shown in Table 3, permeability in boreholes is measured in the lugeon scale. Table 3 shows the results of lugeon and RQD values for dam site. The results reveal that permeability is in the range of impervious to very high permeability. High permeability is one of the main geological engineering problems of Qadis Khordak dam. The results of the permeability tests from boreholes which are located along the dam axis indicate very high permeability (LU > 100) to 20 m depth, with increasing depth from 20 to 40 m permeability of the rock mass decreases (30 < LU < 60). The results of lugeon tests in many sections including the left and right abutments show the permeability is in the range of medium, high to very high.

Table 3. Results of the rock quality designation and lugeon test for the boreholes in the dam site.

Boreholes	Location	Geotechnical parameters					
		Lugeon value, LU			RQD (%)		
		Average	Min	Max	Average	Min	Max
BH N5	Right abutment	94	28	>100	65	23	91
BH N2	River bed	30	5	69	91	70	100
BH N3	River bed	43	5	>100	90	65	100
BH N4	River bed	40	40	40	94	88	100
BH 1	Dam reservoir	41	9	>100	77	50	100
BH 2	Dam reservoir	19	2	65	80	39	100
BH 3	Dam reservoir	54	30	79	54	0	88
BH 4	Dam reservoir	34	1	93	78	0	100
BH 5	Dam reservoir	6	2	11	80	21	95
BH 6	Dam reservoir	>100	>100	>100	82	28	100
BH 7	Dam reservoir	98	76	>100	58	28	89
BH 8	Dam reservoir	1	1	1	89	69	100
BH 9	Dam reservoir	96	76	>100	77	44	100
BH N1	left abutment	27	6	96	92	80	100

4. Slope stability

In terms of morphology as well as the reservoir were, especially the left side of the reservoir walls, are generally steep slopes. According to various studies under the present conditions, the reservoir wall is stable and no major potential for instability domains overlooking the reservoir. However, at the present there are signs of local instability in left seaside heights can be seen which are outside of the reservoir. In this region, the instability in the surface material and small volume are product of alternation and weathering of bed rock. Slide in this area are mostly circular slides.

As mentioned before the slide regions are outside of the reservoir level. Therefore, it can be expected that with filling the reservoir nothing happens.

In parts of reservoir walls, especially the left seaside, which alluvial sediments located in the steep slope of the hillside, the probability of surface slide in the perimeter of the lake, can be expected. Certainly, with filling the lake and washing the loose alluvial sediments, it can be expected that there will be stable condition. Therefore, in the future, the wall of reservoir will be stable and there is no potential for major instability except local slides in surface weather zones and rock fall of the small and separate rock blocks.

5. Discussions

During the feasibility study and detailed design phases, selection of the site and the type of dam should be carefully considered. Generally, initial designs and estimates for several types of dams and appurtenant structures are required before one can be proved the most suitable and economical. It is, therefore, important to understand that the project is likely to be unduly expensive unless decisions regarding the site selection and the type of dam are based upon adequate study.

The availability of suitable rock and fine borrow materials for embankment dam is a factor favorable to the selection of an embankment dam. Every local resource that reduces the cost of the project without sacrificing the efficiency and quality of the final structure should be used. In Qadis Khordak site there are fine and coarse borrow materials in large quantity and accessible for construction of rock-fill dam with a clay core.

In this site some local faults were observed, therefore in active seismic location which rock-fill dam shows better resistance based on the flexibility to the movement and seismicity. In addition, there are three joints sets and local faults in left and right abutment of dam axis, which have made faulted and jointed blocks in the dam axis. The faulting and different joint systems also significantly affect the permeability of rock units in the dam foundation.

The thickness of alluvial sediments of river bed in dam site and reservoir is about 20-25 m. In similar situation, the rock-fill dam was recommended, because constructing concrete dam or other gravity structures may cause settlement in foundation of dam.

6. Conclusions

In the feasibility stage, the dam type was chosen as the concrete face rock-fill dam, depending on state engineering geological properties of dam site. In design stage, dam type has been changed as a rock-fill dam with a clay core. The thickness of alluvial sediments of river bed in dam site, three joints sets and local faults in left and right abutment of dam axis and necessary of using cutoff wall in alluvial foundation, availability of large quantity of borrow materials for rock-fill dam are the main engineering geological properties concern for changing dam type from concrete face rock-fill to a rock-fill dam with a clay core.

With regard to geological conditions in order to prevent water seepage under the dam foundation and seeking and maintaining dam safety, cutoff wall in alluvial foundation and grout curtain consisted of three parts, including the right abutment, the bed and left abutment is essential too.

Due to the characteristics of the foundation rock, excavation operations will be combined by blasting. Therefore, many fractures in rock surfaces will be created. For this reason, and in order to prevent water leakage and flushing of clay core, modifying treatment of trench is necessary. Consolidation grouting consists of filling opened joints, open layered surfaces, faults zones and cavities in the rock mass.

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Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' contributions

Sayed Mohammad Alipoori: Data curation, Writing-Original draft preparation. Gholam Reza Lashkaripour: Conceptualization, Methodology, Validation. Mohammad Ghafoori: Reviewing and Editing. Naser Hafezi Moghadas: Reviewing and Editing.

List of symbols

ASTM	American Society for Testing and Materials
BH	Borehole
E	East
ISRM	International Society for Rock Mechanics
LU	Lugeon

Max Maximum
Min Minimum
N North
RQD Rock Quality Designation
S South
W West
ϕ Internal friction angle

References

Anderson, J.G.C., & McNicol, R. (1989). The engineering geology of the Kielder Dam. *Quarterly Journal of Engineering Geology and Hydrogeology*, 22(2), 111-130. http://dx.doi.org/10.1144/GSL.QJEG.1989.022.02.03.

ASTM C88-99. (1999). *Test method for soundness of aggregates by use of sodium sulfate or magnesium sulfate*. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/C0088- 99A.

ASTM C127-01. (2001). *Test method for specific gravity and absorption of coarse aggregate*. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/C0127-01.

ASTM C131-03. (2003). *Test method for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine*. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/C0131-03.

ASTM D2113-08. (2008a). *Practice for rock core drilling and sampling of rock for site investigation*. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/D2213-08.

Bell, F.G. (1993). *Engineering geology*. Blackwell Scientific Publications.

Bell, F.G. (2007). *Engineering geology* (2nd ed.). Butterworth-Heinemann.

Bieniawski, Z.T., & Bernede, M.J. (1979). *ISRM Suggested methods for determining the uniaxial compressive strength and deformability of rock materials*. Pergamon Press.

Bosshard, P. (2012). *Infrastructure for Whom? A Critique of the Infrastructure Strategies of the Group of 20 and the World Bank*. International Rivers.

Boulin, J. (1991). Structures in Southwest Asia and evolution of the eastern Tethys. *Tectonophysics*, 196(3-4), 211-268. http://dx.doi.org/10.1016/0040-1951(91)90325-M.

Brown, C., & Lall, U. (2006). Water and economic development: the role of variability and a framework for resilience. *Natural Resources Forum*, 30(4), 306-317. http://dx.doi.org/10.1111/j.1477-8947.2006.00118.x.

Brown, E.T. (1981). *ISRM suggested methods for Rock characterization testing and monitoring*. Pergamon Press.

Celãl Sengör, A.M. (1984). The Cimmeride orogenic system and the tectonics of Eurasia. In A.M. Celãl Sengör, *The Cimmeride Orogenic System and the Tectonics of Eurasia* (vol. 195). Geological Society of America. https://doi.org/10.1130/SPE195-p1.

Deere, D.U., & Deere, D.W. (1989). *Rock quality designation (RQD) after twenty years* (Final report, No. Gl-89-1). U.S. Army Engineer Waterways Experiment Station.

El-Naqa, A. (1994). Rock mass characterization of Wadi Mujib dam site, Central Jordan. *Engineering Geology*, 38(1-2), 81-93. http://dx.doi.org/10.1016/0013-7952(94)90026-4.

Favre, R., & Kamal, G.M. (2004). *Watershed atlas of Afghanistan: working document for planners* (2 Vols.). Kabul: Afghanistan Information Management Services.

Ghafoori, M., Lashkaripour, G.R., & Azali, S.T. (2011). Investigation of the geological and geotechnical characteristics of Daroongar Dam Northeast Iran. *Geotechnical and Geological Engineering*, 29(6), 961-975. http://dx.doi.org/10.1007/s10706-011-9429-6.

Ghobadi, M.H., Khanlari, G.R., & Djalali, H. (2005). Seepage problems in the right abutment of the Shahid Abbaspour Dam, Southern Iran. *Engineering Geology*, 82(2), 119-126. http://dx.doi.org/10.1016/j.enggeo.2005.09.002.

Goodman, R.E. (1989). *Introduction to rock mechanics* (Vol. 2). Wiley.

Haftani, M., Gheshmipour, A.A., Mehinrad, A., & Binazadeh, K. (2014). Geotechnical characteristics of Bakhtiary dam site, SW Iran: the highest double-curvature dam in the world. *Bulletin of Engineering Geology and the Environment*, 73(2), 479-492. http://dx.doi.org/10.1007/s10064-013-0498-z.

Heidari, F. (2000). *Evaluation of engineering geology and geotechnical issues Karun 2, Axis A3* [Unpublished master's dissertation]. University of Isfahan (in Persian).

Kocbay, A., & Kilic, R. (2006). Engineering geological assessment of the Obruk dam site (Corum, Turkey). *Engineering Geology*, 87(3-4), 141-148. http://dx.doi.org/10.1016/j.enggeo.2006.04.005.

Lashkaripour, G.R., & Ghafoori, M. (2002). The engineering geology of the Tabarak Abad Dam. *Engineering Geology*, 66(3-4), 233-239. http://dx.doi.org/10.1016/S0013-7952(02)00044-3.

Oliveira, R. (1979). Engineering geological problems related to the study, design and construction of dam foundations. *Bulletin of the International Association of Engineering Geology*, 20(1), 4-7. http://dx.doi.org/10.1007/BF02591232.

Romanov, D., Gabrovšek, F., & Dreybrodt, W. (2003). Dam sites in soluble rocks: a model of increasing leakage by dissolutional widening of fractures beneath a dam. *Engineering Geology*, 70(1-2), 17-35. http://dx.doi.org/10.1016/S0013-7952(03)00073-5.

Stewart, A.K. (2016). Dams in Afghanistan. In J. Shroder & S. J. Ahmadzai, *Transboundary water resources in Afghanistan* (pp. 213-268). Elsevier. https://doi.org/10.1016/B978-0-12-801886-6.00009-4.

Tortajada, C., & Biswas, A.K. (2014). Infrastructure and development, an editorial. *International Journal of Water Resources Development*, 30(1), 3-7. http://doi.org/10.1080/07900627.2014.891927.

Unal, B., Eren, M., & Yalcin, M.G. (2007). Investigation of leakage at Ataturk dam and hydroelectric power plant by means of hydrometric measurements. *Engineering Geology*, 93(1-2), 45-63. http://doi.org/10.1016/j.enggeo.2007.02.006.

Uromeihy, A., & Farrokhi, R. (2012). Evaluating groutability at the Kamal-Saleh Dam based on Lugeon tests. *Bulletin of Engineering Geology and the Environment*, 71(2), 215-219. http://doi.org/10.1007/s10064-011-0382-7.

Vaskou, P., Quadros, E.F., Kanji, M.A., Johnson, T., & Ekmekci, M. (2019). ISRM suggested method for the lugeon test. *Rock Mechanics and Rock Engineering*, 52(10), 4155-4174. http://doi.org/10.1007/s00603-019-01954-x.