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State assessment of rocks in foundation and boards of Shah-wa-Arus Dam using modern techniques

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Abstract

Shah-wa-Arus Dam is currently being built on Shakardara river, in northwest of Kabul province, 22 km from Kabul city, Afghanistan. The dam is erected using roller compacted concrete (RCC), its height is 77.5 m. The dam is multipurpose, designed for irrigation water storage, mitigation of floods and energy generation. The dam is located in active tectonic zone, and tectonic activity has a very significant effect on the state of its foundation and boards. The rocks are highly-fractured in this region. For such critical facility, detailed study of the state of rock masses is of great importance and a detailed survey was conducted for this purpose. This article presents a state assessment of dam site rocks according to DMR classification, based on the overview of complete geotechnical investigations and complementary field observations made by the authors.

Keywords: Shah-wa-Arus Dam, DMR, engineering geology, classification of rock massif.

1. Introduction

Geotechnical investigations play an essential role in the studies of dam foundations and boards. The quality of rock masses is one of the most important engineering-geological characteristics in design and construction of a dam. The main parameters to determine quality of rock mass are general geologic structure, ruptures and fracture density, strength and rate of decay (Bell 2007). Shah-wa-Arus Dam is one of the most important projects in Kabul province. Shah-wa-Arus Dam has a crest 303 m long, maximum height of 77.5 m and overall storage capacity of 9.38 mln cubic meters. Foundation and boards are made of amphibolite and granite-gneiss of the Proterozoic age. The state of dam rocks was assessed based on the DMR classification. This investigation was conducted based on previous investigations and laboratory tests, taking into account the fractures found by the authors on the left bank, downstream side of the dam.

2. Geological conditions

Shah-wa-Arus Dam is located in Shakardara river valley, northwest of Kabul province. Dam boards and foundation are made of amphibolite and granite-gneiss of the Proterozoic age. The dam is located 800 m away from a terrace of fault of Paghman in the active tectonic zone. Rocks are failed and fractured, with tectonic fissures in the region.

The slope of right-bank board of the dam is 50^0 - 70^0 and presented by banded rocks containing quartz, biotite, granite, and gneiss. The slope of left-bank board of the dam is 30^0 - 40^0 and the exposed outcrops are presented by several thin bands of solid gray quartz, biotite, and granite.

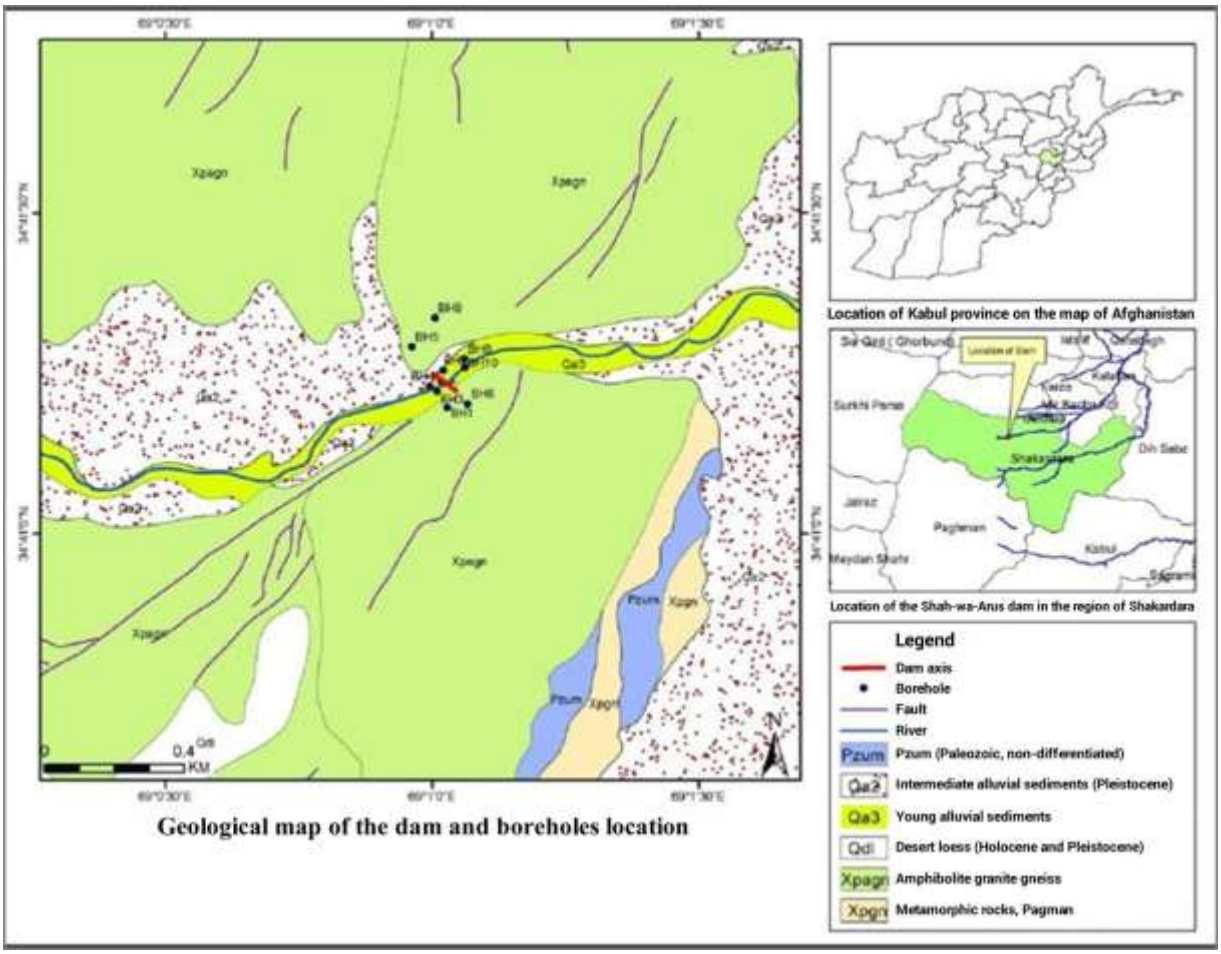

Figure 1. Geological map, sections of Shah-wa-Arus Dam.

Table I. Quantitative specification of rocks on Shah-wa-Arus Dam.

Parameter	Range	Distribution (%)	
		Right bank of the river	Left bank of the river
Fracture spacing (cm)	20 – 60	35	20
	60 – 200	65	80
Persistence (m)	<1	10	-
	1 – 3	30	45
	3 - 10	55	50
	10 - 20	5	5
Crack width (mm)	0.1 – 0.25	18	15
	0.25 – 0.5	30	20
	0.5 – 2.5	40	55
	10 – 100	12	10
	from very rough to smooth	65	60
	from rough to smooth	35	40
Crack filling	cracks are clean and with filling		
Weathering	little-weathered		

For quality assessment of rocks in the foundation and boards of Shah-wa-Arus Dam, some modern techniques were used:

Rock quality designation (RQD): This factor called Rock Quality Designation (or RQD) was proposed in 1964 by an American expert Donald Deer as a rock quality coefficient. RQD is defined by a percentage content of solid rock columns, each more than 10 cm long, in core.

Table II. Rock quality acc. to RQD.

RQD (%)	Quality of rock mass
<25	very poor
25 – 50	poor
50 – 75	satisfactory
75 – 90	good
90 – 100	very good

Table III. The results of rock quality assessment in wells drilled at the site of Shah-wa-Arus Dam.

Well	Location of well	Drilling depth (m)			Direction of dip	RQD	Rock permeability, Lu
		Total length (m)	overburden rock (m)	ock mass (m		Average RQD	Average Lugeon
Well 1	Right bank of the river	66.3	0.5	65.8	Vertical	52.358	38.00
Well 2	Dam axis/ river	23.3	11	12.3	Vertical	76.548	73.43
Well 3	Dam axis/ river	9.5	5.35	4.15	Vertical	25.00	25.00
Well 4	Dam axis/ river	15.8	9	6.8	30/310	81.875	74.75

Well 5	Left bank of the river	60	3.5	56.5	Vertical	62.358	29.00
Well 6	Right bank of the river	65	0	65	vertical	65.794	38.40
Well 7	Dam axis/ river	60.17	8.15	52.02	vertical	47.667	17.00
Well 8	Power plant /river	35	2.8	32.20	30/340	74.854	63.17
Well 9	Left bank of the river	65	4	61	vertical	50.471	27.38
Well 10	Dam axis/ river	20.25	1.9	18.35	30/140	63.80	18.40

*Lugeon test is a unit of rock permeability (water absorption) which is widely used to assess the average permeability of rocks. The test was named after Maurice Lugeon (1933), a Swiss geologist.

Bieniawski classification: Geomechanical classification of rock mass subsequently called as the Rock Mass Rating (RMR) was first developed by Z.T. Bieniawski in 1973, South African Council for Scientific and Industrial Research. In subsequent years, this classification was many times amended and modified. Below is a revision of 1984 (Bieniawski 1984).

Rock Mass Rating is based on the following six structural parameters:

- Uniaxial compression strength of sound rock sample;
- Rock quality designation (RQD);
- Fracture or contact spacing;
- Characteristics of fractures or contacts;
- Conditions of groundwaters;
- Fracture or contact orientation.

Each of the above mentioned parameters is independently assessed, giving an overall RMR ranging from 0 to 100.

Table IV. Classification of Rock Mass Rating (RMR) of Shah-wa-Arus Dam.

Parameters		Rating
Uniaxial compression strength (MPa)		108.5
Rating		12
Rock quality designation (RQD%)		60
Rating		13
Fracture or contact spacing (m)		0.2 – 2
Rating		15
Characteristics of fractures or contacts	persistence	1 – 15
	crack width (mm)	0.2 – 20
	roughness	from very rough to smooth
	crack filling	clean and filled with quartz and plagioclase
	weathering	little-weathered
Rating		2
Conditions of groundwaters		dry
Rating		15
Total of (independent) assessments		57
Rock Mass Rating (RMR)		III

DMR Classification: For assessment of rocks on the site of the dam, professor of Polytechnic University of Valencia (Spain), Manuel Romana proposed in 2004 the dam rock mass classification system that uses and supplements the Bieniawski classification.
DMR_{STA} (stability against sliding) is calculated as per the formula:

$$DMR_{STA} = RMR_{BD} + CF \times R_{STR} \quad (1)$$

DMR_{STR} – dam stability against sliding
RMR_{BD} – based on dry RMR
CF – geometrical correction factor
R_{STR} – dam stability adjustments – (defined acc. to Table V)

Table V. Adjustment factors, depending on dip orientation; DS (upstream) and US (downstream), A- or other direction of dip (Romana 2003).

Dam type	Very favorable	Favorable	Acceptable	Unfavorable	Very unfavorable
Earth	Other	10º – 30º downstream	0º – 10º upstream	-	-
Gravity	10º – 60º downstream	30º – 60º upstream 60 – 90 any	10º – 30º upstream	0º – 10º any	-
Arched	30º – 60º downstream	10º – 30º downstream	30º – 60º upstream 60º – 90º any	10º – 30º upstream	0º – 10º any
R_{STA}	0	-2	-7	-15	-25

Table VI. Degree of safety, regarding sliding (Romana 2004).

Rock mass rating	Degree of safety
$DMR_{STA} > 60º$	Low
$60º > DMR_{STA} > 30º$	Middle
$30º > DMR_{STA}$	High

$$CF = [1 - \text{Sin}(\alpha_d - \alpha_j)]^2 \ (\alpha_d > \alpha_j) \quad (2)$$

$$CF = [1 - \text{Sin}(\alpha_j - \alpha_d)]^2 \ (\alpha_d < \alpha_j) \quad (3)$$

where α_d – upstream and downstream azimuth in dam axis from northern direction, and α_j - dip azimuth, major main fractures.
CF = 0.48

Table VII. R_{STA} scoring.

Dam type	Favorable
Gravity	30º - 60º upstream
A_{STA}	-2

$DMR_{STA} = RMR_{BD} + CF \times R_{STR} = 56.04$

Based on the value of DMRSTR 56.04, safety of Shah-wa-Arus Dam acc. to Table VI is assessed as middle, closer to low.

Additional information: additional information on the state of the dam was obtained from local residents and subsequently confirmed by the authors upon its inspection. On the left bank of downstream side of the dam, a fracture was found. Thereafter the authors visited the sections of the dam body, the fracture from the left bank to downstream side was confirmed. Its overall length was approximately 20 m, but its depth and width are unknown, since the fracture was filled with cement.

3. Conclusions

Shah-wa-Arus Dam is located in Shakardara river valley, northwest of Kabul province. The dam is located in the active tectonic zone. The dam boards and foundation are composed of

amphibolite and granite-gneiss. According to field survey and observations, the rock mass near right-bank is unstable and requires investigation of slope stability. Moreover, field observations on the left bank downstream the dam body showed a fracture, which may become a serious problem for the dam. It is recommended to conduct special investigations by a group of experts (seismologist, engineer-geologists, geoscientists, dam architectural engineers and construction engineers).

Based on the DMR classification, the rocks of the dam section are assessed as middle (Table VI). However, this classification is new and requires additional studies.

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