



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

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This article is the translation of the article “Оценка состояния горных пород основания и бортов плотины Шах-и-Арус современными методами [Оценка состояния горных пород основания и бортов плотины Шах-и-Арус современными методами]” published on July 22, 2018.

IRSTI 70.17.29

doi: 10.29258/CAJWR/2018-RI.v4-1/41-47.eng

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

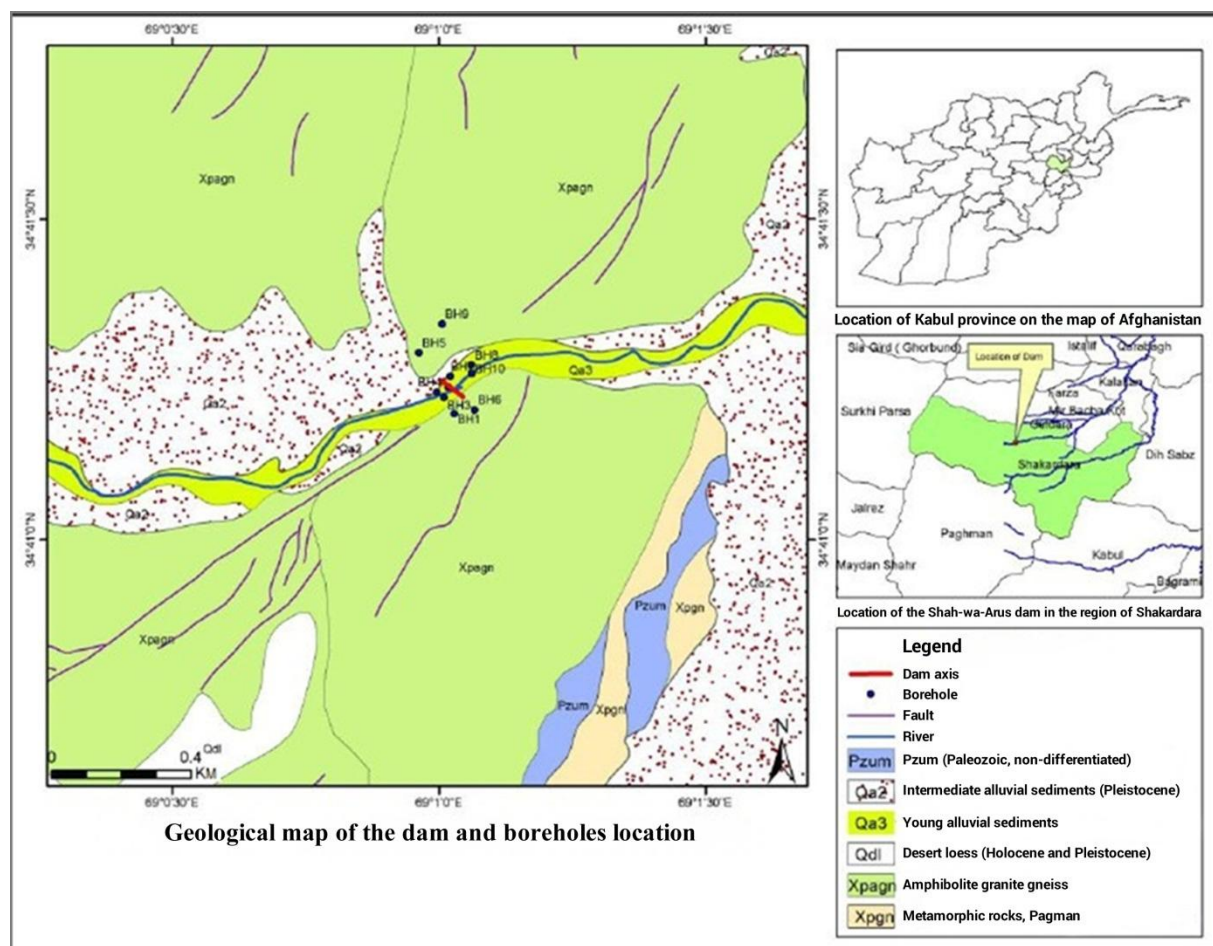


Figure 1. Geological map, sections of Shah-wa-Arus Dam.

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) | rock 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 | 10° – 30° downstream | 0° – 10° upstream | - | - |
| Gravity | 10° – 60° downstream | 30° – 60° upstream 60 – 90 any | 10° – 30° upstream | 0° – 10° any | - |
| Arched | 30° – 60° downstream | 10° – 30° downstream | 30° – 60° upstream 60° – 90° any | 10° – 30° upstream | 0° – 10° any |
| R_{STA} | 0 | -2 | -7 | -15 | -25 |

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

| Rock mass rating | Degree of safety |
|-----------------------------------|------------------|
| $DMR_{STA} > 60^\circ$ | Low |
| $60^\circ > DMR_{STA} > 30^\circ$ | Middle |
| $30^\circ > DMR_{STA}$ | High |

$$CF = [1 - \sin(\alpha_d - \alpha_j)]^2 (\alpha_d > \alpha_j) \quad (2)$$

$$CF = [1 - \sin(\alpha_j - \alpha_d)]^2 (\alpha_d < \alpha_j) \quad (3)$$

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 | 30° - 60° upstream |
| A_{STA} | -2 |

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

Based on the value of DMR_{STR} 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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