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Stability and safety assessment of the arch dam Foum Gleita in Mauritania

Etude sur la stabilité et la sécurité du barrage voûte de Foum Gleita en Mauritanie

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ABSTRACT
The 20 years old arch dam Foum Gleita lies in the southern part of Mauritania on the river Gorgol Noir. The height of the dam is 45 m. Concerns of the Ministry for Rural Development and Environment of the Islamic Republic of Mauritania represented by the National Society for Rural Development (SONADER) on the safety of the habitants downstream and the long term provision of irrigation water from the reservoir led to a stability and safety assessment study. Results of the study are presented in this paper.

RÉSUMÉ
Le barrage voûte de Foum Gleita construit il y a 20 ans se situ dans la partie méridionale de la Mauritanie sur le fleuve Gorgol Noir. La hauteur du barrage est de 45 m. Des craintes du Ministère pour le Développement Rural et de l'Environnement de la République Islamique de Mauritanie représentée par la Société Nationale pour le Développement Rural (SONADER) sur la sûreté des habitants en aval et la provision à long terme en eau ont mené à une étude d'évaluation de la stabilité et de la sûreté du barrage. Les résultats de l'étude sont présentés dans cette publication.

1 INTRODUCTION

The dam Foum Gleita (Figure 1) lies in the southern part of Mauritania on the river Gorgol Noir upstream of the confluence with the river Sénégal. The area has a dry climate with 380 mm of average annual precipitation.

The height of the arch dam is 45 m. Its crest length is 117 m. The dam closes a narrow gorge through a mountain ridge, providing a most favourable location for the dam (see Figure 2). The dam is equipped with a central spillway of a maximum capacity of 300 m³/s. The left side of the dam contains the bottom outlet and a small powerhouse with an 18 PS Francis turbine. The water intake on the left abutment has a diameter of 3.70 m. A tunnel brings the water to the diversion intake. According to irrigation water requirements the water is either redirected into the irrigation channel or back into the Gorgol Noir.

Figure 1. Foum Gleita arch dam

Due to favourable topographical conditions the reservoir has a volume of more than $400 \cdot 10^6$ m³ (Figure 2). The storage area is 160 km² in size and has a capacity of 1.2 times the average annual runoff of 340 million m³. The main purpose of the dam is to provide water for 3,600 ha land irrigation.

Lahmeyer International GmbH provided parts of the design and the construction supervision from 1981 to 1984.

20 years later, concerns of the Ministry for Rural Development and Environment of the Islamic Republic of Mauritania represented by the National Society for Rural Development (SONADER) on the safety of the habitants downstream and the long term provision of irrigation water from the reservoir led to a stability and safety assessment study. The World Banks International Development Association (IDA) financed the study. In 2003, the SONADER and the IDA commissioned a joint venture of the consulting engineers Lahmeyer International GmbH and SCET-Rim from Mauritania to conduct the study on the dam.

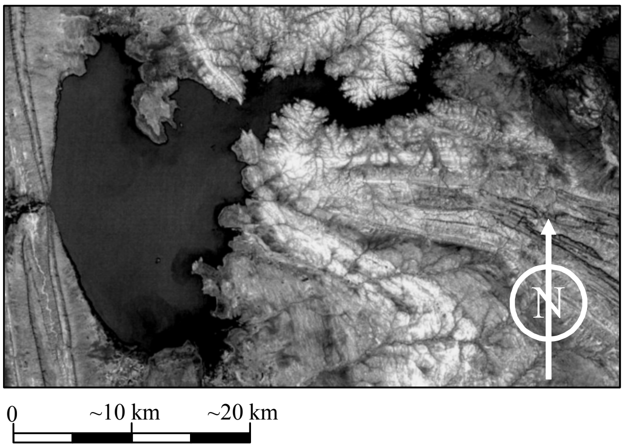

Figure 2. Satellite picture of the reservoir

According to the project necessities to ensure safe and efficient operability of the dam the Consultants provided the subsequent services:

- Inspection of general dam conditions
- Inspection of hydromechanical equipment
- Sedimentation analysis
- Analysis of existing survey data

- Analysis of operational capacities of local dam personnel
- Proposal for an improved monitoring programme
- Proposal for operation and maintenance programme
- Proposal and cost estimate for rehabilitation measures

The authors conducted a stability and safety assessment programme and the evaluation of its results. Digitally recorded survey data exist since the construction of the dam. They allow an interpretation of the given data and to point out the demands on the rehabilitation and maintenance programme for the dam and its side structures.

The Consultant further conducted a bathymetric survey to provide sedimentation data for the reservoir. The results may not be addressed in detail in the present paper. It can be summarized that the sedimentation processes of the past years was very low and had no major impact on the reservoir.

2 DAM STABILITY AND SAFETY ASSESSMENT

Previous to the inspection the Consultants established a programme for the dam stability and safety assessment. During this initial project phase they studied existing documents and reports on the dam and the recent hydrological data of the region. Lahmeyer International GmbH had run a similar inspection programme in 1994.

The Consultants established a checklist for the visual inspection based on ICOLD Guidelines (ICOLD, 1987, 1988a, 1988b and 1998). The checklist gave previous general information on the dam. Subsequently, it took consideration of the stability and safety assessment information collected during the site investigation. The Consultants identified nineteen relevant safety assessment issues (Table 1).

Table 1. Dam stability and safety issues

Number	Section
1	Dam Crest
2	Dam Foundation
3	Dam toe
4	Concrete
5	Spillway
6	Powerhouse
7	Bottom outlet
8	Water intake
9	Diversion intake
10	Derivation channel
11	Restitution channel
12	Turbine
13	Survey instruments
14	Survey programme and data registration
15	Maintenance programme
16	Sedimentation
17	Reservoir water
18	Irrigation channel
19	Previous rehabilitation measures

For most of the Sections the investigation team described the characteristics and appearances of the analysed element. Then they evaluated the general conditions, suggested measures to be undertaken and prepared cost estimates. The filled checklist formed the foundation for subsequent studies on the dam.

According to the conducted safety assessment programme the dam itself is in generally satisfying conditions for all concrete parts. Only some minor superficial cracks have to be treated.

A major crack in between the left abutment and the rock should be monitored.

The inspection of the hydromechanical parts showed deficiencies. The gates of the bottom outlet are in good conditions but show leakages at some places. Cracked cables restrict the removing of the intake for maintenance measures. The diversion intake can not be used. Therefore no restitution of water to the river is possible.

The turbine works satisfyingly. Missing air condition in the powerhouse reduces the working time due to heating.

Large parts of the dam monitoring instruments are defective. The authors give a more detailed approach in Section 3 of this paper. An engineer from SONADER collects digitally the data from the survey instruments. Therefore, continuous amount of data is available for running instruments.

The checklist gave only a brief overview on the sedimentation of the dam.

The irrigation channel is largely deteriorated due to different reasons. A Wadi (spate water) repeatedly destroyed the side dike. The executed rehabilitation measures did not satisfy the geotechnical demands and did not consider prevention for the future. Some adjacent farmers drilled holes in the dike to irrigate their land and weakened it. Locally some slope failures occurred. Also their rehabilitation did not meet the geotechnical necessities.

3 DAM MONITORING PROGRAMME

SONADER recorded digital survey data from January 1986 onward. The Consultant evaluated the data in February 2004 subsequent to the field investigation.

A TELEMAC data logger registers the data sent from:

- Capsule tensiometers with vibrant cord
- Inclinometers with vibrant cord
- Piezometers with vibrant cord

Due to time and climate influence a large amount of instrument does not give valuable data anymore. Today 29 out of 64 initially installed instruments are defect. Unfortunately, all 3 inclinometers do not give anymore reasonable data. 5 out of 16 tensiometers do not work correctly but still 4 of 5 piezometers give data. 20 of 40 thermometers are defect. According to the presented distribution of defective instruments, the thermometers are mostly affected by deterioration. From the geotechnical point of view their data is of minor importance.

The local agent of SONADER records manually hydrological data as follows:

- Upstream and downstream water level
- Amount of water provided to the irrigation channel
- Upstream and downstream water- and ambient temperature
- Thermometers

The instruments used for the topographic survey were in poor conditions. Therefore, the Consultant did not consider their data in the dam safety survey analysis.

Figure 3 shows selected monitoring instruments in the arch dam installed during construction. An explanation of the shown instruments follows in Section 4.

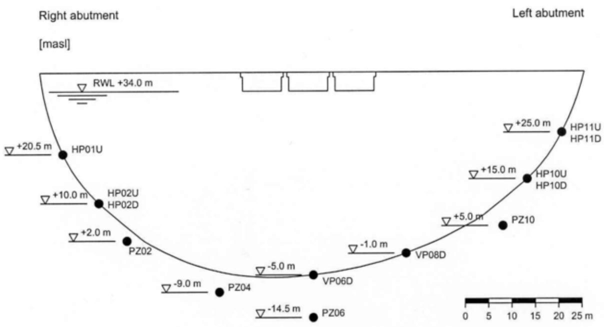

Figure 3. Selected monitoring instruments in the Foum Gleita dam

The Consultants were concerned on scour below the foundation that could not be seen by visual inspection. Therefore, they guided a detailed interpretation on the survey data. The subsequent study focuses on the stresses in the dam recorded by piezometers and tensiometers as described in the following Sections.

4 WATER PRESSURE IN THE FOUNDATION

A significant concern on the safety of arch dams is the uplifting force of water pressure below the foundation. Scour processes in joints below the dam may change the flow behaviour. The issue can easily be assessed by the evaluation of piezometer heads in the foundation.

It is most satisfying that four out of five installed piezometers are still operational. The piezometers read the water pressure below the dam foundation that is equivalent to the uplift.

Figure 3 shows the location of the piezometers PZ02, PZ04, PZ06 and PZ 10 below the dam foundation. The retention water level (rvl) of the dam is 34.0 masl.

PZ02 (+2.0 masl) is installed in the right abutment and 5 m below the dam foundation. This is equivalent to 32 m below retention water level. PZ10 (+10.0 masl) is installed in the left abutment 5 m below the dam foundation. The difference to the retention water level is 24 m. PZ04 (-9.0 masl) is installed in between the centre of the dam and the right abutment 5 m below the dam foundation. The difference to the retention water level is 43 m. PZ06 (-14.5 masl) is 10 m below the dam foundation installed in its centre. The difference to the retention water level is 48.5 m.

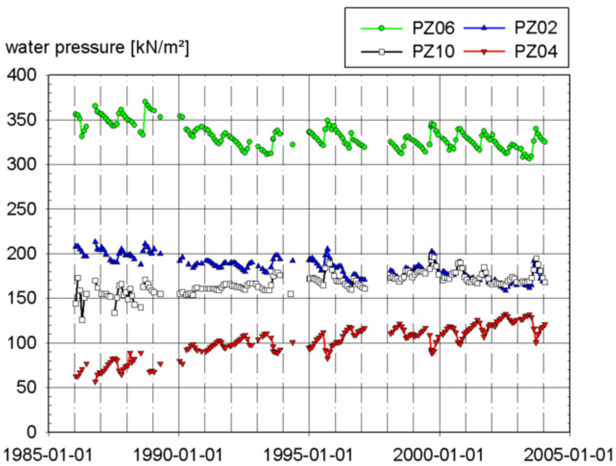

Figure 4. Piezometer readings since implementation

Figure 4 shows the readings of the four operational piezometers since implementation of the dam. Mostly, their pressure level agrees with their installation depth below water table. PZ06 shows highest values. Seasonal variations correspond to the variations in water table.

PZ04 shows the lowest pressures, were higher values were expected. It is supposed that the high potential decrease occurs upstream of PZ04. While the three other piezometers showed an almost constant or decreasing piezometer head, pressure in PZ04 increases slowly since implementation time. The historical peak value reached in June 2003 was 132 kN/m². The medium value doubled from 60 kN/m² to 120 kN/m². The increase is most probably due to transportation of fines in joints. However, a regression analysis by the Consultant confirmed that the gradient is decreasing. An extrapolation to 2008 showed that a constant value slightly above of 120 kN/m².

The Consultant conducted a safety analyses that proved that none of the piezometers has reached critical uplift values. Until today the dam foundation is safe and sound.

5 STRESS DISTRIBUTION IN THE DAM

Figure 3 shows the position of the vertical pressure gauges VP06D and VP08D in the downstream foundation of the dam. Both gauges indicated almost constant values since implementation of the dam. Seasonal differences are low. VP06D in the lowest point of the foundation shows a value of 400 kN/m², while VP08D, downstream in the left abutment, designates a value of 800 kN/m². This distribution of stresses is characteristic with arch dams that redistribute forces to the abutments (Boggs et al., 1988 & U.S. Army Corps of Engineers, 1994).

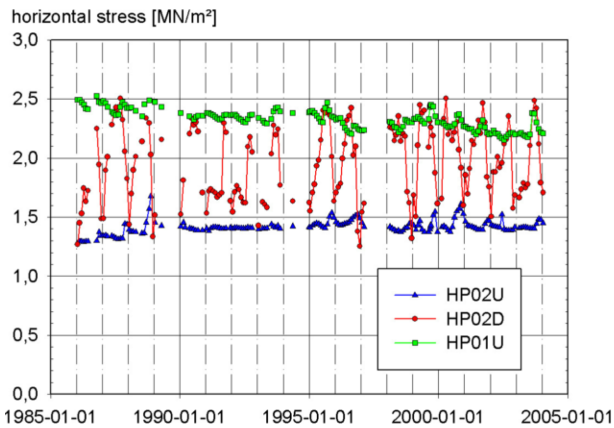

Figure 5. Horizontal normal stresses in the right abutment

Horizontal normal stresses in the upstream side of the right abutment are about 2.3 MN/m² at the level of +20.0 masl (HP01U) and 1.4 MN/m² at the level of +10.0 masl (HP02U) with only little seasonal variations (Figure 5). Downstream important seasonal variations were observed (HP02D). An explanation for this behaviour is that the seasonal deformation caused by varying reservoir tables has a higher impact on the downstream abutment. The maximum value in HP02D is reached after the hibernation, when the reservoir is full.

The stress distribution in the left abutment (Figure 6) shows different behaviour. Stresses are higher in the lower pressure gauges (HP10U and HP10D) and seasonal variations in the upstream and downstream gauges more important than in the right abutment.

This is due to higher deformations in the left abutment. An explanation therefore is that the joints in the left abutment are oriented parallel to the normal forces. In the right abutment their orientation is perpendicular.

The average horizontal pressure on the left abutment at the level of +15.0 masl is 2.8 MN/m² upstream and 2.3 MN/m² downstream respectively.

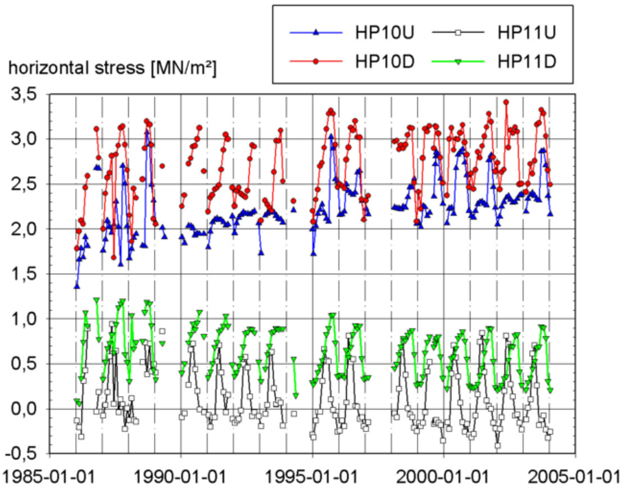

Figure 6. Horizontal normal stresses in the left abutment

Average horizontal pressure on the left abutment at the level of +25.0 masl is about 0 upstream and 0.5 MN/m² downstream respectively. The 0 at the upstream side at 25.0 masl could be interpreted as an alarming sign. Additionally, tension was measured seasonally. Nevertheless, since the filling of the reservoir this instrument indicated tension seasonally. The downstream instrument showed that contact was always assured.

These results are reassuring. Nevertheless, as mentioned, the Consultants identified a crack in the respective position. The proposed improved monitoring programme shall consider these findings.

6 IMPROVED MONITORING PROGRAMME

The results of the assessment and safety study lead the Consultants to the development of an improved dam monitoring programme. This programme shall provide reliability that is crucial with the 20 year old dam and unfortunately non-existing maintenance works.

The Consultant presented the programme in detail in his study to the Client. Basic aims of the programme are to provide reasonable certitude on the future stability of the dam at affordable costs.

The presented future monitoring programme shall include the:

- Continued recording of stresses, water pressures and water levels
- Periodical topographical survey of the dam to assess deformations
- Observation of the crack in the left abutment via installation of a fissure meter

The Consultant and the Client agreed on the necessity of executing the enhanced monitoring programme. SONADER actually raises funds to acquire instruments and implement the programme. The Consultant will provide the local personnel with the basic training on instruments. The Consultant shall also enhance existing software to apply with the extended monitoring programme.

The improved monitoring programme shall be part of an operation and maintenance programme that will ensure the replacement of defective hydromechanical parts and other necessities as described in Section 2.

7 SUMMARY AND OUTLOOK

This paper presented a case study on the investigation programme for existing dams as planned and executed. The programme is in accordance with ICOLD guidelines. It was adapted to the requirements for a dam in the Mauritanian province.

The authors described the existing monitoring programme that still gives valuable data after 20 years of operational time. In the Sections 4 and 5 the authors assessed the dam monitoring data and presented conclusions on the stability of the dam. The dam showed himself in overall stable conditions.

Nevertheless, due to the low maintenance level and the importance of the dam for irrigation and fishing the future safety of the dam shall be assessed by an enhanced monitoring programme. That programme shall be installed parallel to a future operation and maintenance programme by the SONADER.

The replacement and rehabilitation of defective hydromechanical parts and other elements of the dam shall be the operation and maintenance programme.

Finally, the rehabilitation of the irrigation channel is imperative. The dam was intended to provide with irrigation water. As the authors described before the irrigation canal is in very poor almost not operative conditions. A project for technical rehabilitation of the irrigation channel is urgently suggested. The technical rehabilitation programme shall review also population structures, demands and needs and the options for auto-administration and auto-financing of operation and maintenance of the irrigation canal.

ACKNOWLEDGMENTS

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