



A DETAILED SAFETY AND RISK ASSESSMENT OF PEQUENOS LIBOMBOS DAM

Melo, J. F.¹ LNEC	Sardinha, R.² COBA	Pimenta, L.³ COBA	Duarte, A.⁴ COBA	Freitas, R. M.⁵ COBA
Juízo, D.⁶ SALOMON	Martins, A.⁷ SALOMON	Sengo, D.⁸ ARA-Sul, IP	Timba, J.⁹ ARA-Sul, IP	Mabunda, L.¹⁰ DNGRH

ABSTRACT

At the request of the Mozambican National Directorate of Water Program (DNGRH) and as part of the National Climate Resilience Program, a study aimed to evaluate the current safety of the Pequenos Libombos dam and downstream valley was developed by the Consortium COBA/LNEC/SALOMON. The objectives encompassed a range of activities designed to ensure a thorough assessment and enhancement of dam safety, a critical issue to guaranty the integrity and reliability of this key water infrastructure in Mozambique. In this paper, structural and hydraulic-operational safety results are presented, as well as its adaptation to the new Mozambican dam regulations.

The Pequenos Libombos Dam, located on the Umbelúzi River, serves as the primary water supply for Maputo city. It features a 1,540-meter-long and 46-meter-high earthfill structure, with a 100-meter-long central gravity concrete dam where all the appurtenant structures are located.

The study involved a comprehensive evaluation of dam performance, including a review of operational procedures and detailed site inspections. It analyzed existing monitoring data and assessed current safety conditions. A thorough safety assessment identified both structural and non-structural mitigation measures.

The comprehensive assessment approach taken for the Pequenos Libombos dam revealed strengths and weaknesses in current dam safety practices. By implementing the recommended measures, the safety and functionality of these dams will be significantly enhanced.

Key lessons underscored the critical need for regular monitoring and robust risk assessment procedures. This will contribute to the overall resilience and security of the region's water infrastructure and ensure the safety of populations living downstream.

Keywords: Earth and concrete dam, safety assessment, safety regulation.

¹ jfmelo@lnec.pt, Portugal

² r.sardinha@cobagroup.com, Portugal

³ l.pimenta@cobagroup.com, Portugal

⁴ a.duarte@cobagroup.com, Portugal

⁵ r.m.freitas@cobagroup.com, Portugal

⁶ juizo@hotmail.com, Mozambique

⁷ amiromartins13@gmail.com, Mozambique

⁸ dsengo@yahoo.com, Mozambique

⁹ timbanetimba@gmail.com, Mozambique

¹⁰ luismabunda@gmail.com, Mozambique

1. INTRODUCTION

The Dam Safety Assessment of Pequenos Libombos dam was carried out by COBA-LNEC-SALOMON Joint Venture, in the scope of the contract established between the National Directorate of Water Resources Management (DNGRH). These services were developed within the scope of the National Climate Resilience Program (RCRP) of the Government of the Republic of Mozambique, funded by the International Development Association (IDA). These services were carried out between March/2024 and November/2024 and the main activities undertaken were the following:

- i. Compilation and analysis of existing documentation
- ii. Field inspections.
- iii. Dam safety assessment.
- iv. Recommendations of structural and non-structural measures needed to enhance dam safety.
- v. Training program.

The Pequenos Libombos Dam is a large structure, and as such, it falls under the provisions of the Mozambique Dam Safety Regulation (MDSR) [1]. It is classified as Risk Class I, with Medium Vulnerability and High Potential for Damage. This classification is subject to review every five years and outlines several responsibilities for the Project Owner. Among these, the following priorities will be addressed in the short term: i. Organization of the Technical Archive, ii. Development of the Safety Plan, iii. Organization of the monitoring data, iv. Providing the required information for the development of the External Emergency Plan, v. Identification and Development of structural and non-structural measures for safety improvement and rehabilitation.

This paper focuses on structural safety, hydraulic-operational safety, and the safety of electrical equipment and installations, as well as on the structural and non-structural measures aimed at mitigating the risks of failure and various malfunctions, improving safety conditions, and adapting the dam to the current safety regulations.

Downstream consequences of dam failure and operational flood releases are treated in the paper “Strengthening Key Water Infrastructure in Mozambique: A Risk Assessment of Downstream Valley of Pequenos Libombos Dam”.

2. PEQUENOS LIBOMBOS DAM MAIN CHARACTERISTICS

The Pequenos Libombos Dam, managed by ARA Sul, is situated on the Umbelúzi River in the Boane District of Maputo Province. Constructed between 1983 and 1986, the dam’s first filling occurred from 1986 to 1989. It is a multi-purpose dam primarily intended to provide water

supply to the cities of Maputo, Matola, and Boane, as well as to control flooding, support irrigation, and operate a small hydroelectric plant with an installed capacity of 1.7 MW. The hydroelectric plant operated from 2014 to 2016 but was subsequently suspended due to a drought that intensified water scarcity for other essential uses.

The Pequenos Libombos watershed spans 3,735 square kilometers, of which only 20% lies within Mozambique, with an average annual inflow volume of 350 hm³. The reservoir's maximum capacity is 393 hm³, with an operational capacity of 350 hm³, and it covers an area of 38 km² when the water level reaches the Normal Water Level (NWL) of 47 meters. The Maximum Flood Level (MFL) is 49.55 meters, and the minimum operational level is 25 meters.

The dam spans approximately 1,640 meters at the crest level, which sits at an elevation of 51.5 meters. The embankment cross-sections reach a maximum height of 46 meters and extend over 1,540 meters. In the central valley, where the appurtenant structures are located (**Figure 1**), the concrete section measures around 100 meters in length and has a maximum height of 48 meters.



Figure 1 – Appurtenant structures. Upstream and downstream views

The spillway consists of a middle-level outlet with seven spans, each equipped with radial gates (dimensions: width = 7.5 m, height = 5.3 m), positioned with a bottom sill at elevation 24 m and a discharge capacity of 5,600 m³/s. Additionally, an emergency spillway provides a discharge capacity of 1,200 m³/s, featuring six free spans at level 47 m and one central span with a 1-meter-high flap gate with the crest at level 46 m. The primary spillway includes a cofferdam gate measuring 7.5 x 11.175 m², operated by a gantry.

Two bottom outlets are installed along the left and right concrete walls that separate the earthfill dam from the concrete section, each 110 meters long with a diameter of 1.5 meters. These outlets are equipped with a fixed wheel safety gate upstream (1.3 m x 1.5 m) and a downstream slide gate (1.2 m x 1.3 m) for flow regulation. Each outlet has a maximum discharge capacity of 30 m³/s at the Normal Water Level (NWL).

The water intake has 4 intake levels, each equipped with 1.4m x 1.4m slide gates. The water is conveyed into a 700 mm diameter conduit. This conduit joins the bottom outlet conduit near its downstream extremity, sharing the same exit structure. The maximum discharge capacity is 1.2 m³/s.

Currently, 15-30% of the diverted water through the outlets is assigned to environmental purposes.

The occupation of the downstream valley has increased significantly in recent years. When the dam construction was completed, there were no dwellings in the floodplain downstream. Today, however, there is considerable development, including a new residential area that is flooded even with relatively small floods, around 200 m³/s, as well as a railway bridge crossing the downstream valley.

Figure 2 provides a Google Earth view showing the general layout of the dam, while **Figure 3** offers detailed views of the concrete dam and its associated structures. **Figure 4** and **Figure 5** present the dam's cross-sections.

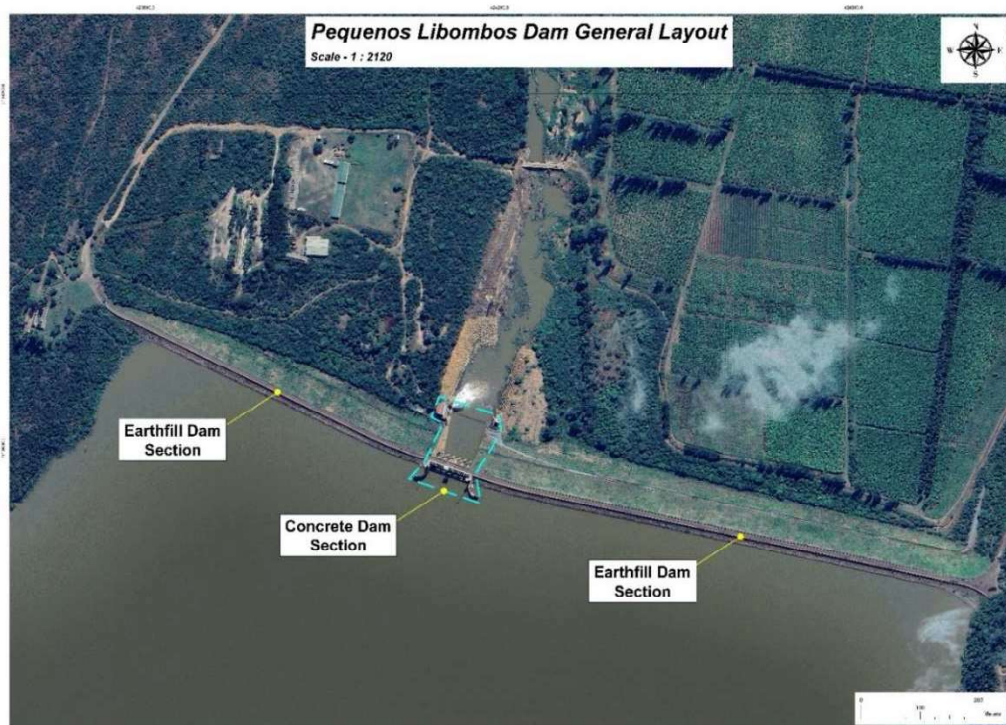


Figure 2 – Pequenos Libombos. View from Google Earth.

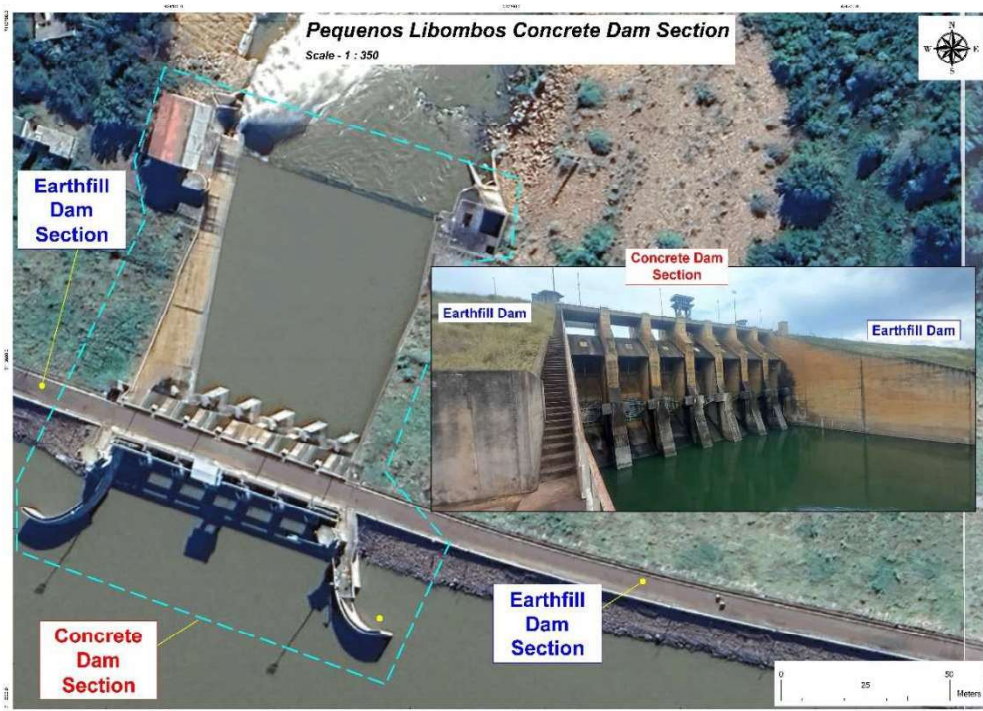


Figure 3 – Pequenos Libombos dam general layout of the appurtenant works.

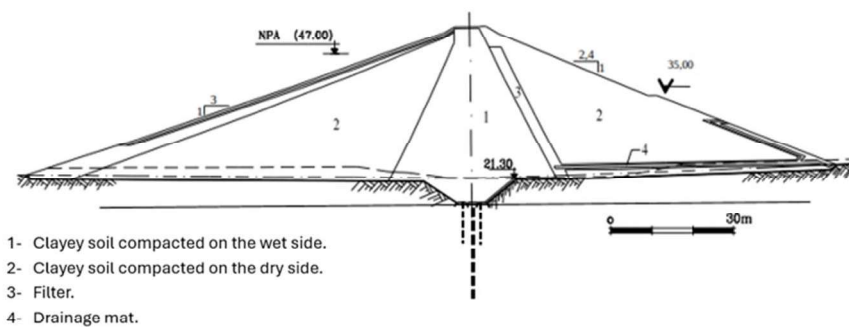
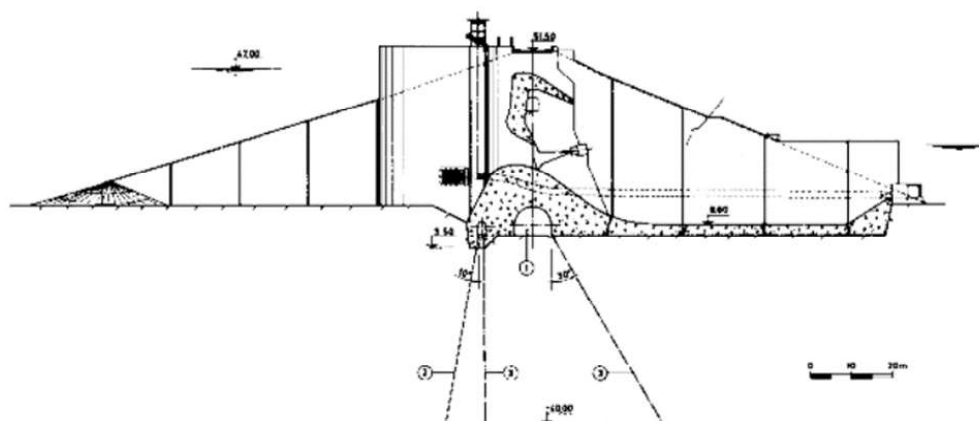


Figure 4 – Typical cross section of Pequenos Libombos dam
 (adapted from Portugal et al, 2012 [2], and Maranhã das Neves et al, 1985 [3])



1 – Gallery in the foundation; 2 – Impermeabilization curtain; 3 – drainage curtain

Figure 5 – Typical cross section of Pequenos Libombos spillway (Maranha das Neves et al, 1985)

3. FIELD INSPECTION

A field inspection was carried out following the agenda of the program previously agreed with DNGRH and ARA Sul. A dam Safety Inspection Form was prepared using the World Bank's Good Practice Note on Dam Safety (WB 2020) [4]. Also, a list of issues and aspects to be inspected and/or addressed during the inspection visits and meetings was previously shared with the Client. The following components were covered during the field inspection:

- i. Dam body and foundation,
- ii. Monitoring systems,
- iii. Appurtenant structures. Structural component,
- iv. Appurtenant Structures. Hydraulic and hydromechanical components,
- v. Electrical equipment and installations,
- vi. Downstream valley and environmental constraints.

During the inspection various meetings with the inspection team and the Owner's staff were held, to allow the gathering of information from the resident team and the engineers responsible for the operation and safety of the dam, as well as familiarizing the team with the facilities and the measurement equipment of the monitoring devices. At the end of the inspection visit the main conclusions and recommendations were conveyed, resulting from an initial safety assessment based on the information collected and the inspections carried out on the various components of the project [5].

4. DAM SAFETY ASSESSMENT

The performed dam safety assessment main conclusions [6] are presented on the following subsections.

4.1. Embankment dam body and foundation

Figure 6 and **Figure 7** presents general views of the earth dam and crest.



Figure 6 – Downstream slope. General view (view towards the right bank).

No indicators of abnormal behaviour in the dam body or its foundation that jeopardize the safety of the dam were identified. To assure longevity of the structure and to correct localised superficial landslides in the downstream face of the dam, it was recommended to improve the slope protection of the downstream slope of the embankment and to rehabilitate the asphalt road surface in certain sections of the crest. It was also recommended to assure periodic maintenance activities, mainly regarding the superficial drainage system and the irrigation system.

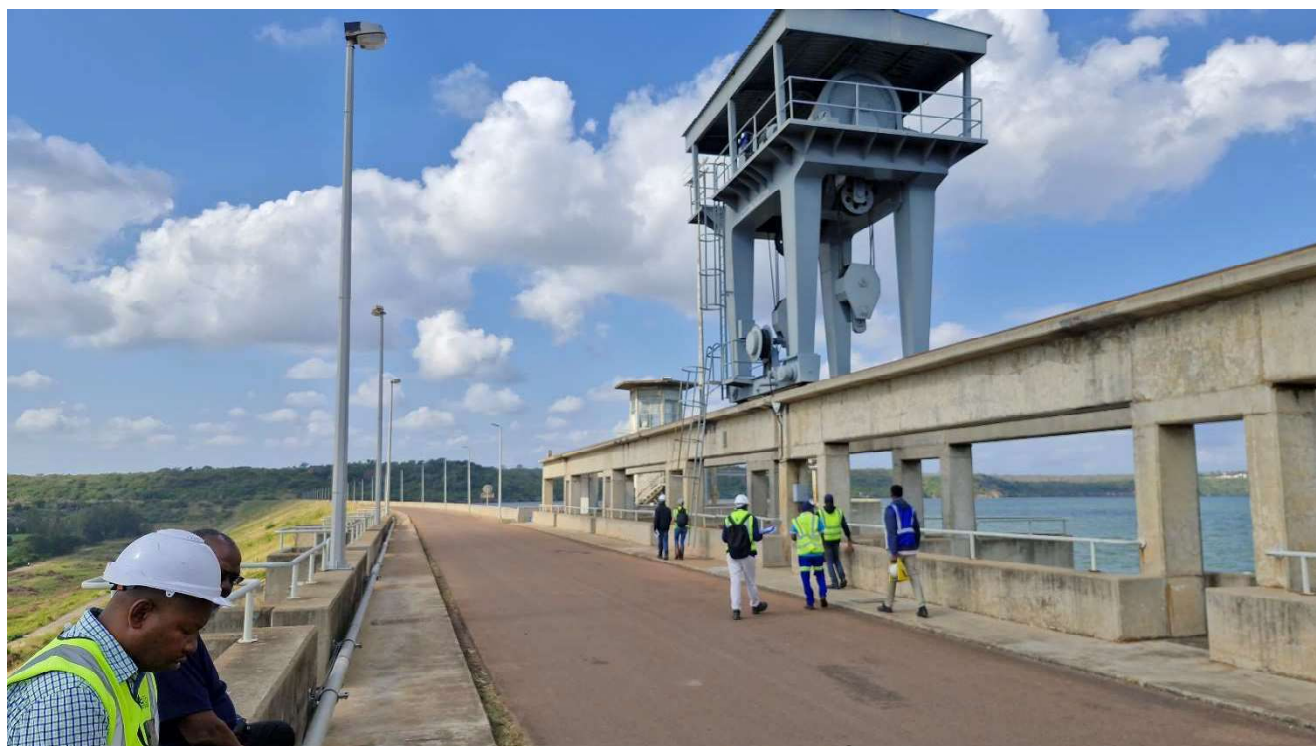


Figure 7 – Crest. General view. Section of the concrete dam (view towards the right bank).

The freeboard is constrained by the combination of factors related to the water level in the reservoir, estimated at the Maximum Water Level (MWL) of 49.55 m, which is assumed to be associated to a millennial flood. The current crest elevation of 51.5 m seems barely adequate to accommodate the wave run-up caused by a typical wind speed of 60 km/h (a modest value), a residual creep settlement estimated at 0.14 m, and an allowance of 0.4 m for unquantifiable factors, including seismic effects. However, for a design flood with a 2000-year return period, as specified by the MDSR for the Pequenos Libombos Dam, the current crest elevation can be insufficient.

4.2. Concrete Dam Body

No indicators of abnormal behaviour have been identified in the concrete dam body that houses the hydraulic structures. A routine maintenance plan for the reinforced concrete and metal structures was recommended, to ensure proper functioning and continuous monitoring of existing structural pathologies.

The observed reduction in the inflow rates to the large gallery between 2005-2014, for approximately constant reservoir levels, suggested a potential malfunction due to obstruction in the drainage system, raising the possibility of a concurrent increase in the uplift pressures. The latest monitoring data do not seem to confirm this hypothesis.

Given the importance of the stability of the reinforced concrete portico beam in the operation of the flood gates, an urgent need to repair the identified anomalies given the pattern of their occurrence along the spans was identified. This repair has been done afterwards.

Existing small cracks in the slab (specifically at the oil hydraulic units of the spillway radial gates) must be repaired and consistently monitored. The roof of the command of the regulating gate of the right-side bottom outlet gate needs to be repaired to prevent water accumulation inside. This water has corroded the perimeter of the DN700 bottom outlet pipe where it connects to the concrete base, and retained water must be evacuated to prevent further excessive corrosion.

As far as the metal structure is concerned, most elements need to be completely replaced, while others just need a protective coating. Additionally, the drainage gallery stairway and the stairs providing access to the spillway gates require rehabilitation, including the incorporation of resting platforms, particularly for the stairway leading to the control room of the right-side bottom outlet regulating gate.

4.3. Monitoring system, procedures and data

The observation procedures are centralized at the dam site and well-organized, allowing for the quick access and interpretation of the variables subject to periodic readings. There is no immediate transmission of observation data to either the Authority or the Mozambique Engineering Laboratory (MEL), as specified by the MDSR.

The operators are knowledgeable and familiar with the procedures for data reading and analysis, but the technical means at their disposal, namely hardware and software, urgently require improvements. Readings from the observation devices are performed by a team from ARA-Sul stationed at the dam site.

Regarding the surface marks in the embankment dam, the last known campaign dates from 1991. Maximum settlements were recorded in the central area of the valley where the embankment heights are greater, as expected. At that time, the maximum settlement on the downstream bench at elevation 35 was 64 mm. At the crest, the maximum settlement was 140 mm downstream (marks at elevation 50.5 m) and 112 mm upstream (marks at elevation 48 m).

A drone survey is recommended to obtain a quick assessment of the current elevations along the crest, allowing the reassessment of the dam's current freeboard. After this survey, it will be necessary to resume the readings of the superficial displacements of the dam.

In the concrete dam there are no devices to monitor movements, either in the dam body or in its foundation.

The hydraulic piezometers installed in the embankment body and its foundation generally show water levels consistent with the water level in the reservoir and their location. However, it is worth noting the limited number of piezometers installed and in operation. The water levels measured in the relief wells exhibit a similar behaviour (**Figure 8** and **Figure 9**).

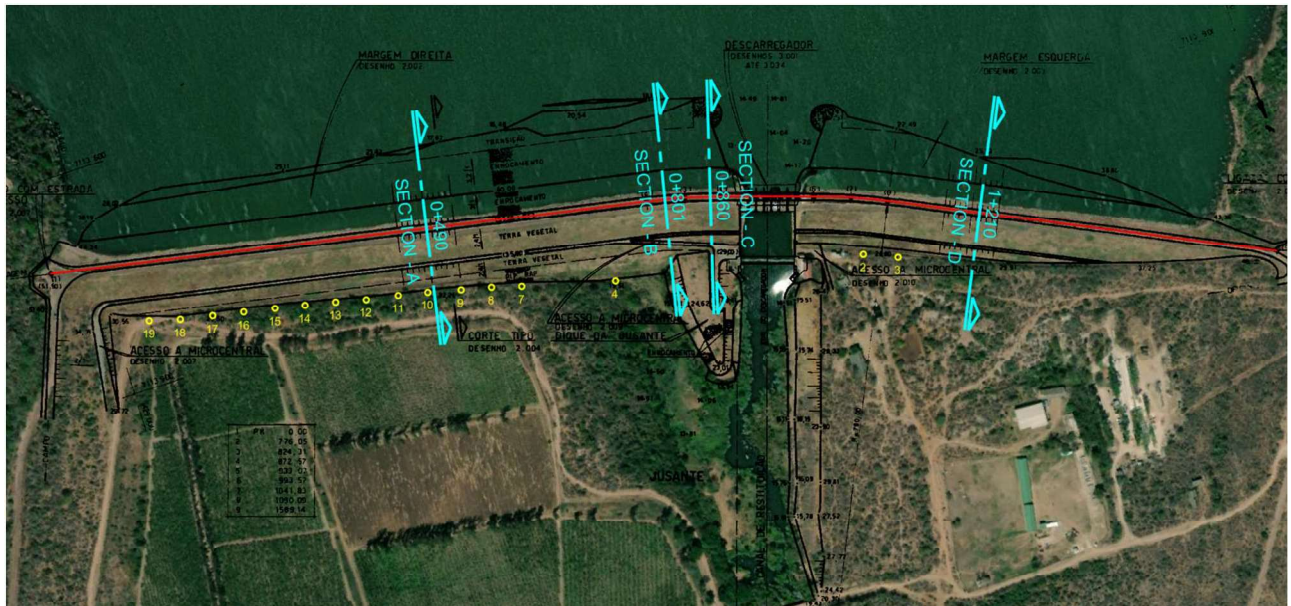


Figure 8 – Location plan of the monitoring cross-sections (A to D) and the relief wells situated downstream of the dam toe (yellow circles)

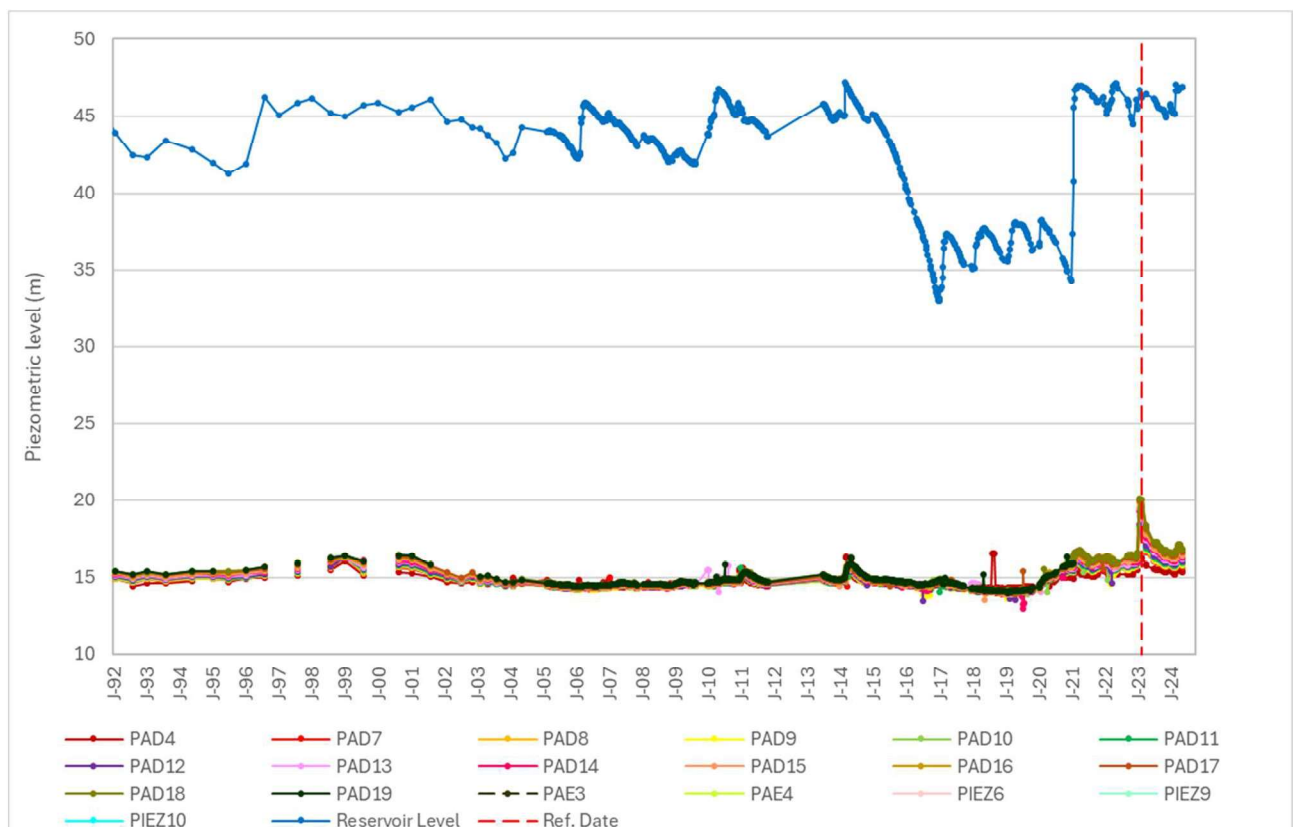


Figure 9 – Relief wells. Variation in piezometric levels from January 1992 to June 2024

Concerning the flows measured in the drains located in the longitudinal galleries of the concrete dam, the behaviour has fluctuated over time. Between 2005 and 2014, while total flows in the small gallery remained approximately constant, in the large gallery the trend was towards a decrease in total flows. From 2014 to 2017, total flows in both galleries decreased, following the drop in reservoir water levels, stabilizing between 4 and 7 l/min from 2017 to 2021, with relatively stable reservoir water levels, ranging from approximately 35 to 37.5 m. The sharp rise in reservoir water levels at the beginning of 2021, to around elevation 47 m, was accompanied by an increase in total flows in both galleries, though the values remained lower than those previously recorded for similar reservoir water levels. Finally, in March 2023, with the reservoir water near level 47, there was an exceptional increase (of unknown cause) in the total flows in both galleries (reaching values of around 39 l/min in the large gallery and around 34 l/min in the small gallery), followed by a sharp decrease for similar water levels in the reservoir, standing at around 25 l/min and 20 l/min, respectively, higher than the total flows recorded in the past for similar water levels (**Figure 10**).

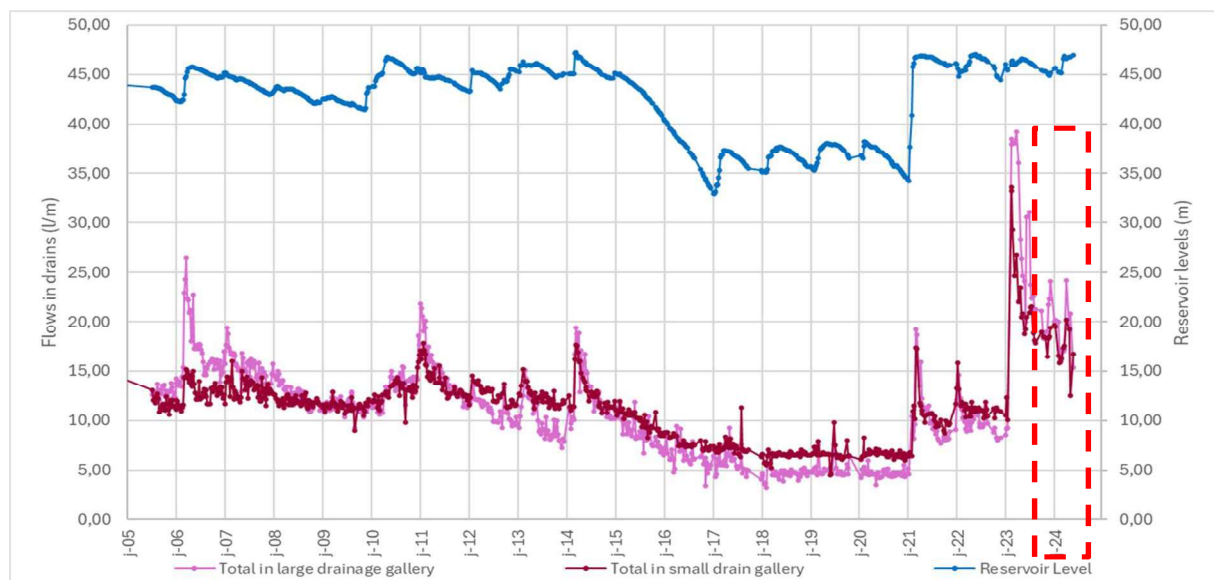


Figure 10 – Total flows in the small gallery and in the large gallery

Given that no significant variation was recorded in the readings from the piezometers with manometers installed in the gallery in March 2023 (**Figure 11**), it is possible that a drain cleaning intervention occurred, which could explain the sudden increase in the flows of the drains described above. These piezometers also did not register any pressure increases during the period when the trend in the drains showed a reduction in measured flow rates, with the reservoir levels remaining approximately constant. Therefore, the concern regarding a potential rise in uplift pressures in the foundation of the concrete dam does not appear to be supported by the integrated analysis of the monitoring devices' data, considering the readings up until 2023.

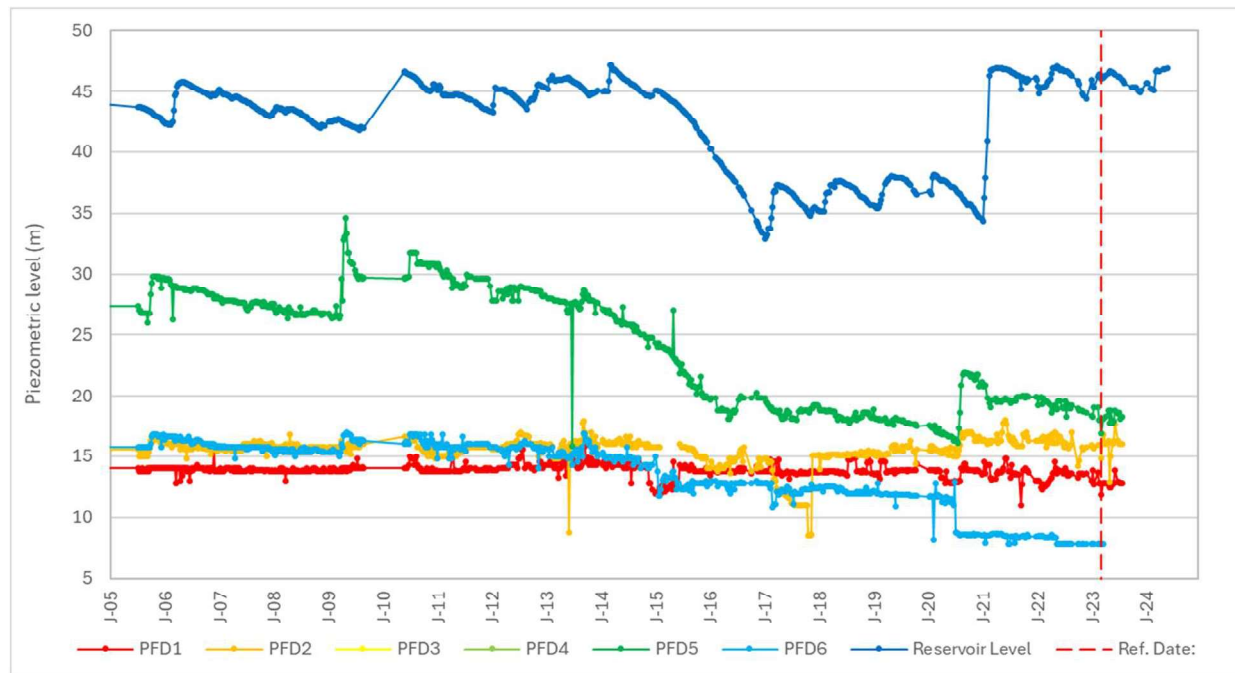


Figure 11 – Variation in piezometric levels in the spillway foundation

The monitoring data provided to the Consortium has been organized and compiled into an Excel file, which has been supplied to the Client and includes the respective analysis. This file can be used to upload and analyse the results of future reading campaigns.

4.4. Appurtenant structures. Spillway design and verification floods

The Pequenos Libombos Dam's spillway must comply with Mozambique's safety regulation (MDSR), which specifies a 2,000-year return period flood as the design flood and a 5,000-year return period flood for verification. Previous studies analysed extreme events such as the Probable Maximum Flood (PMF) and 10,000-year floods but did not address the MDSR's specific requirements for the 2,000-year and 5,000-year floods.

Those studies revealed, anyhow, that the PMF and 10,000-year floods could result in overtopping, highlighting the need for updated hydrological studies for 2,000-year and 5,000-year return period floods, as well as an assessment of the spillway system's functionality during scenarios of gate failure or power supply loss.

4.5. Appurtenant structures. Hydromechanical equipment

The following critical issues concerning the hydromechanical equipment were identified during the site inspections.

- **Gantry Crane Inoperability:** The crane, essential for maintenance and emergency operations of the radial gates, was non-functional during the visit, severely limiting the ability to address gate failures during floods.

- **Bottom Outlet System Corrosion:** Extensive corrosion was observed in the bottom outlet, embedded parts, penstock, and interconnecting gallery pipes, presenting a high rupture risk under operating pressures.
- **Outdated Equipment:** The dam's systems reflect 1986 technology without significant upgrades, leaving critical components vulnerable to wear and inefficiency. Remote gate operation is currently unavailable, demanding modernized control systems for safety and reliability.

4.6. Electrical equipment and installations

Since 1988/89, the dam had no major work done on the existing electrical installations. The only intervention known is the installation of new dataloggers equipment to record data, which is then sent by a radio communication system for data processing, exterior lighting installation in dam access and some maintenance repairs as usual are needed.

The technicians and engineers' dam team provided comprehensive support and information during the site inspection visit focused on dam safety. During the visit, it was possible to assess the state and condition of the electrical, control, and communications systems.

A significant set of safety issues has been identified and is listed in Chapter 5, along with the defined rehabilitation measures.

5. PROPOSED SAFETY MEASURES AND INTERVENTIONS

Under the scope of the assignment the following structural and non-structural safety measures and interventions were recommended. These arise, from dam safety assessment studies [7] and the requirements of the current dam safety legislation in Mozambique (MDSR).

Technical Archive of the Project

The Technical Archive of the Project should be organized and complemented to include: i) Dam's classification; ii) Dam's Safety Plan (Observation Plan, Operating Rules, Internal Emergency Plan and Environmental Safety Plan); iii) documents from operation; iv) documents from construction phases; v) rehabilitation design documents; vi) design studies; vii) preliminary studies.

Additionally, the technical record of the project should be prepared to be available at the dam site, paginated and sealed, for the purpose of recording inspection reports and significant events related to safety, observed during operations, and recorded by the Director of Operations.

Embankment dam body and foundation

It is necessary to improve the surface coating of the downstream slope of the embankment dam and to rehabilitate the asphalt road surface in certain sections of the crest, keep the drainage gutters unobstructed and repair the irrigation system.

The freeboard is presently constrained by the combination of factors related to the water level in the reservoir, estimated at the Maximum Water Level (MWL) of 49.55 m, which supposedly corresponds to a millennial flood. The current crest elevation of 51.5 m seems barely adequate to accommodate the wave run-up caused by a typical wind speed of 60 km/h (a modest value), a residual creep settlement estimated at 0.14 m, and an allowance of 0.4 m for unquantifiable factors, including seismic effects. However, for a design flood with a 2000-year return period, as specified by the MDSR for the Pequenos Libombos Dam, the current crest elevation can be insufficient.

Concrete Dam body

No significant indicators of anomalous behaviour have been identified in the concrete dam body housing the hydraulic structures. Nevertheless, it remains important to periodically undertake the unblocking and rehabilitation of the foundation drains in the concrete dam body and to install monitoring devices, such as plumb lines and extensometers, to assess the structure's behaviour over time.

It is important to establish a routine rehabilitation plan for the reinforced concrete and metal structures to ensure proper functioning and to ensure continuous monitoring of structural pathologies. Although not significant, the reported pathologies should be corrected to prevent further damages.

Monitoring system, procedures and data

It is recommended to review the monitoring plan considering the current dam safety regulations of Mozambique, the behaviour of the dam which has been in operation for 37 years, and the results of the inspection visit carried out. **Table 1** and **Table 2** below present the recommendations made for the monitoring plan review. The recommendations regarding the monitoring of the concrete dam (**Table 2**) follow the guidelines established by Hidroprojeto [8] and LNEC [9].

Table 1 – Monitoring plan review recommendations. Embankment dam cross-sections

Monitoring parameter	Device	Reading frequency	Instrumented profiles and location of the devices
Vertical and horizontal displacements	Surface Marks/High-precision geometric levelling	Annual	Upstream and downstream of the crest. Replacement or rehabilitation of existing ones.
Pore pressures	Hydraulic piezometers	Monthly	At the dam body and foundation. Rehabilitation of the existing ones and installation of new ones covering additional cross-sections both in right and left banks.
Seepage flows	Relief wells	Monthly	At the toe of the dam. Rehabilitation of existing ones.

Table 2 – Monitoring plan review recommendations. Concrete dam cross-section

Monitoring parameter	Device	Reading frequency	Instrumented profiles and location of the devices
Horizontal displacements	Reverse plumb line	Semestral	Left wing wall
Vertical displacements	Surface Marks/High-precision geometric levelling	Annual	Crest
Vertical displacements	Foundation Extensometers	Semestral	At the ends of the small gallery
Relative movements between blocks	Three-dimensional extensometer bases	Monthly	At all joints in the small gallery
Uplift pressures	Hydraulic piezometers with manometers	Monthly	Small gallery: one piezometer per block downstream of the drainage system and Rehabilitation of the existing ones or substitution
Uplift pressures	Hydraulic piezometers with manometers	Monthly	Large gallery: one piezometer per block upstream of the drainage system and Rehabilitation of the existing ones or substitution
Flow Rates	Drains	Monthly	Rehabilitation or Replacement of existing ones.

Appurtenant structures

The proposed safety measures and interventions resulting from the inspection and safety assessment include hydrological studies, infrastructure upgrades, and flood mitigation measures.

In terms of hydrological studies, the development of flood hydrographs for 2,000-year and 5,000-year return periods is recommended, along with the review and verification of compliance with flood capacity requirements designated by MDSR.

Regarding infrastructure upgrades, comprehensive inspections and refurbishments of the corroded bottom outlet system are necessary. Additionally, the gate operation and monitoring systems should be modernized to ensure remote control functionality. Restoring the operational status of the gantry is also imperative to facilitate emergency interventions, improving the dam's safety conditions.

For flood mitigation, risks associated with overtopping due to the probable maximum flood (PMF) or 10,000-year return period floods should be assessed, and mitigation measures must be developed. Furthermore, adjustments to the guide curves and recalculations of the dam's freeboard and crest elevation must be performed to comply with revised flood levels and safety requirements.

Electrical equipment and installations

The Pequenos Libombos dam is equipped with a range of electrical installations and equipment that have been in operation for several years, show signs of wear, and are in humid environments.

The difficulty of replacing protective equipment in the event of a breakdown or damage is a reality, compounded by long waiting times for the purchase and delivery of replacement materials. In some cases, the equipment is not even replaced because the market doesn't have similar equipment to offer.

During the site inspection, it was observed that the facilities critical to the electrical operation of the Pequenos Libombos dam, such as the HV/LV substation and the generator room, need intervention. In HV/LV substation, the switchgear and HV/LV transformer presents signs of corrosion and without any safety equipment. The generator room was poorly maintained or in deteriorating condition. As a result, we recommend replacing the equipment, fully renovating the buildings, and enhancing safety within these areas. Additionally, exterior periodic cleaning around these buildings is crucial for fire prevention, particularly due to their proximity to the HV/LV substation and generator room. The HV/LV substation and generator room should be restricted access to qualified technicians. The generators and switchboards need to be urgently replaced or repaired, and the technical room should be fully renovated.

The electrical panels are in working order and generally well-maintained inside. However, they are equipped with long-standing equipment that is difficult to replace, and the cabinets are showing signs of corrosion.

The power cables will have to be replaced as they have been in place since the dam began operating. New signal cables will have to be installed.

The lighting, sockets and fire safety installations should be renewed or installed.

The SCADA supervision system at the dam has not been installed. It is recommended to implement a Supervision System that enables technicians to remotely monitor (either locally or from a distance) a range of events and operations, as well as record critical events for planning repairs and inspections. Remote operation of the Pequenos Libombos dam should be conducted with caution and always with the presence and expertise of the Pequenos Libombos dam team.

The CCTV system should be implemented together with the control system.

It is also very important to carry out regular electrical checks, operations and inspections. The lack of records and the absence of an electrical project is commonplace. There should be a space dedicated to the technical archive with all the documents on the electrical activities carried out, from design, maintenance, inspections and equipment manufacturers' manuals.

Continuous training in the areas of electrical systems, instrumentation, automation, supervision, and IT should be prioritized. Additionally, the creation of a technical space for recording operations and a dedicated electrical workspace should be considered.

It is also recommended that the entire electrical installation be new, renovated in a phased manner to maintain the proper functionality of the Pequenos Libombos dam.

6. CONCLUSIONS

A Dam Safety Assessment of the Pequenos Libombos Dam, in operation since 1986, was carried out by the COBA-LNEC-SALOMON Joint Venture. Based on the findings of this assessment, the activities to be implemented for risk management of the dam are outlined below. As mentioned in the Introduction, this paper does not address aspects related to downstream consequences, environmental risks, or emergency planning.

Regarding the likelihood of failure, important key vulnerabilities related to hydromechanical equipment must be corrected, namely corroded bottom outlet systems and outdated control mechanisms.

For the dam risk prevention, the following measures are considered necessary:

- Development and implementation of up-to-date operation standards,
- Periodic staff training,
- Routine maintenance activities,
- Routine hydromechanical equipment tests,

- Routine electrical tests,
- Installation of two new generators with canopies.

The revision of the monitoring plan for the Pequenos Libombos Dam is mandatory, due to the requirements of the current regulatory framework in Mozambique, as well as the absence of displacement monitoring devices for the concrete dam body and its foundation, along with deficiencies and the inoperability of a significant set of instruments in both the foundation and the dam body of the earth dam.

Also, in accordance with the MDSR, the maximum flood level should be reviewed for both the design flood and the verification flood. This review must incorporate flood routing analyses to determine the dam's response under these conditions. Consequently, the freeboard calculations and the dam's minimum crest elevation must also be revised, and meanwhile, the guide curves may have to be adjusted so that safety requirements defined in the regulation are duly complied with.

A topographic survey of the dam using drone technology was recommended to obtain information in the short term that supports the evaluation of the dam's freeboard.

At hydromechanical level the following critical issues were identified and are to be refurbished as soon as possible:

- Bottom Outlet System,
- Outdated Equipment.

It is relevant to mention that the Gantry Crane was rehabilitated in December 2024 and so reducing the future priority refurbishment needs.

Finally, regarding the electrical equipment and installations, a significant set of rehabilitation and upgrade interventions must be implemented in the short term. This is an area often overlooked in dam risk and safety assessments, yet it plays a crucial role in preventing and mitigating various failure risks, particularly those related to the operation of the hydromechanical equipment.

REFERENCES

[1] MDSR (2017), "Mozambique Dam Safety Regulation"

[2] Portugal, J. C., Marcelino, J., Modelos de Comportamento da Barragem dos Pequenos Libombos em Moçambique, 2011, Proceedings do XI CNG, Sociedade Portuguesa de Geotecnia (2012), 18p.

[3] Maranha das Neves, E., Costa Pereira, A. S., Veiga Frade, J. T., Tratamento da Fundação da Barragem de Pequenos Libombos, Revista Geotecnia (1085), Vol 45, pág 59-74.

[4] The World Bank (2020) Good Practice Note on Dam Safety.

[5] COBA, LNEC and SALOMON (2024), “Inspection Report. Pequenos Libombos Dam”, Product 2 of the *Consulting Services for Dam Safety Assessment of Pequenos Libombos and Massingir Dams*

[6] COBA, LNEC and SALOMON (2024), “Technical Report. Pequenos Libombos Dam”, Product 2 of the *Consulting Services for Dam Safety Assessment of Pequenos Libombos and Massingir Dams*

[7] COBA, LNEC and SALOMON (2024), “Safety Assessment Report. Pequenos Libombos dam”, Product 3 of the *Consulting Services for Dam Safety Assessment of Pequenos Libombos and Massingir Dams*

[8] Hidroprojeto (1986), “Plano de Observação da Zona de Betão da Barragem dos Pequenos Libombos”

[9] LNEC (2005), “Barragem dos Pequenos Libombos. Avaliação da Segurança em Novembro de 2004 e Revisão do Plano de Observação”. Proc. 0403/001/14990.