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Evaluation and rectification of concrete defects in hydraulic structures during DLP-case of Isimba Hydro Power Plant (183mw) in Uganda

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Abstract
The dam and concrete structures of Isimba Hydropower Plant were designed with 100-year service life with focus on structural reliability and operational integrity. Isimba Hydropower Plant (183MW) a run off river plant located in East Africa, Uganda was commissioned in March 2019 with a total defects liability period (DLP) of 4 years and has since been in operation for 3.5 Years. During the last 3.5 years of operation, numerous concrete defects manifested within the structure and these included; seepage through concrete in the galleries, leaking joints, washout and abrasion damage in the water ways, exposed reinforcement in water ways, and spalling. As a result, these defects were rectified by the Contractor in accordance with the contract as part of his obligation during DLP. The paper therefore, evaluates the genesis of the different categories of defects experienced within the hydraulic structures of Isimba HPP, the methodology used in rectification, challenges faced, the lessons learnt and recommendation for minimizing similar defects in new hydropower plants. The paper further discusses the roles of different professionals and stakeholders during DLP in ensuring delivery of a fit for purpose structure that is in line with the 100-year design service life.

Keywords: Isimba HPP, concrete, defects, DLP, rectification, hydraulic

1. INTRODUCTION

Hydraulic structures are structures that are fully or partially submerged in water. The essence of building hydraulic structures is to either divert, disrupt, store, or completely stop the natural flow of water bodies. Based on the work they are designed to perform on streamflow, hydraulic structures are categorized as water retaining structures (dams and barrages), water-conveying structures (artificial channels), and special-purpose structures (structures for hydropower generation or inland waterways) [1].

Like any other hydraulic structure, hydropower dams are susceptible to concrete defects given the harsh environment they are subjected to, while in operation. The sources include; hydrostatic pressure, abrasion, chemical attack, imposed loads, age-related deterioration and carbonation. Neglecting to perform periodic maintenance and repairs to concrete structures as they occur could result in failure [1]. Unlike conventional concrete for example in structures that only carry loads, concrete in hydropower dams is normally under extreme hydrostatic and hydrodynamic pressure. This pressure forms part of the critical load to withstand [2].

About Isimba HPP

Isimba Hydropower Plant (HPP) is located in East Africa, Southern part of Uganda, on the Nile River (Longest River in the world) 50km downstream of its source; Lake Victoria. With four Kaplan turbines, the installed Capacity is 183.2MW (Figure 1). The complex constructed and commissioned in March 2019 consists mainly of the water-retaining dam, spillway, power-house, and the switchyard. The dam includes an earth rock fill dam on the left bank (LED), two gravity dams (GD1 and GD2) and an earth rock fill dam on the right bank[3]. The total volume of concrete cast was 357,020m^3.

Figure 1. Arial view of Isimba HPP

2. DEFECTS LIABILITY PERIOD

According to FIDIC [4], the Defects Lability Period (DLP) is the period which commences at works completion or a stage signified by issue of a takeover certificate or equivalent by the contract administrator in accordance with the construction contract and continues for the period specified in the contract. Ficken [5] acknowledges that the contractor is required to perform construction fully in accordance with the contract documents, usually consisting of at least plans, specifications and the building code within required time.

According to the Isimba HPP contract, during the DLP any defect found in the design, engineering, materials and workmanship of the plant supplied or of the work executed by the contractor was the contractor’s obligation to be corrected to meet the specification.

During Isimba HPP’s first year of Operation and Maintenance (O&M) several concrete defects were identified by the client (UEGCL), notified to the Owner’s Engineer (OE) and consequently addressed by the Engineering Procurement and Construction (EPC) Contractor as part of his obligation during DLP. Therefore, this paper shall comprehensively evaluate the concrete defects encountered and rectification during the DLP of Isimba HPP.

3. CONCRETE DEFECTS AT ISIMBA HPP

Isimba Dam structures experienced numerous concrete related defects right from impoundment in November 2018 and they continued to manifest even after commissioning (March 2019). According to Obiora [6] concrete defects can either manifest at the beginning of the early stages following loading, or later during the service life of the structure. Concrete defects affect over 65% of all structures globally according to recent statistics [6]. These defect normally result from poor handling methods, placing, insufficient curing, poor workmanship and poor materials. The defects included the following;

3.1 Seepage Through Walls

The seepage was through the walls, floor and joints that were more evident in lower galleries that included EL1017 (drainage gallery) EL1024masl (grouting gallery) EL1025masl (spiral case floor) EL 1030masl (cooling water floor) and EL1037masl (turbine pit floor).

With the dam crest at EL 1057masl a hydrostatic pressure head of 20-40meters largely influenced the magnitude of the leakages in the galleries (see Figure 2).

Figure 2: Concrete leakages along staircase from EL1025 and at EL1017

3.2 Damp Spot and Leakages Along Lift Joints

These were distributed across all the elevations more evident in the lower galleries (Figure 3).

Figure 3: Damp spots and leakage along lift joints at EL1024 and EL1017

3.3 Cracks

Cracks are the most commonly seen kind of defects observed in concrete structures, and may be due to various causes, including; overloading, drying shrinkage, and thermal stress. Cracks are widely regarded as a long-term durability and maintenance problem because they increase the permeability of the concrete [7]. Hairline cracks manifested in areas especially the ones previously grouted using a wrong methodology. Cracks at EL1030 and EL1037 were hidden since these floors were plastered and painted.

3.4 Concrete Defects in Waterways (draft tube and spiral case)

These were the most critical concrete defects experienced at Isimba HPP having been observed just after 2 years of commercial operation. They included; severe washout (Figure 4) and abrasion damage, exposed reinforcement, concrete spalling, long transverse concrete cracks, concrete pop outs at some sections of the ceiling slab, joint leakages and damp spots along the spiral case wall, leakage through crack seals and cavities in 2nd stage concrete.

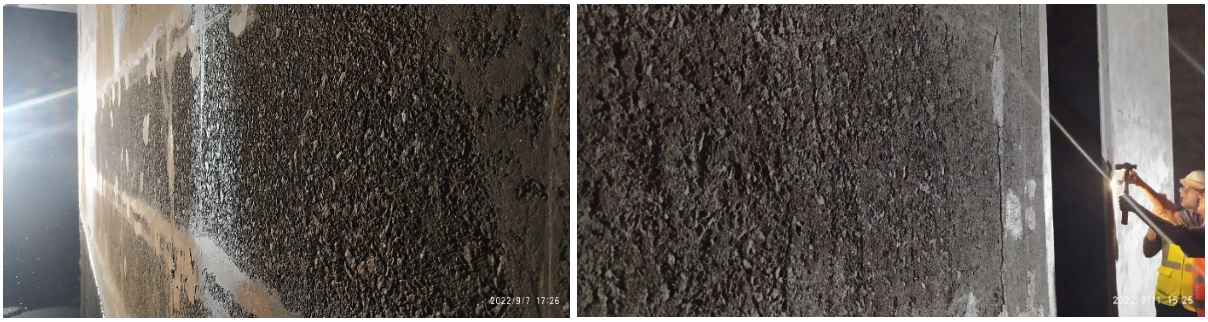

Figure 4: Severe abrasion in Unit 3 draft tube (left) and abrasion in Unit 3 spiral case(right)

3.5 Shrinkage Cracks on the Intake and Tailrace Platform

Concrete defects on tailrace and Intake platforms manifested in the form of alligator cracks that ran horizontally and transverse across the entire platform. These cracks were categorised as shrinkage cracks with no structural effects attributed to rapid evaporation due to insufficient curing of the slab.

The cracks were also partly attributed to poor design due to insufficient expansion joints provided within the slabs whose dimensions were spanning over 95metres in length and 5-8metres wide.

4. ROOT CAUSE ANALYSIS OF THE CONCRETE DEFECTS

Laboratory tests on porosity of the cored as-built concrete sample showed a variability in porosity values with a wide range (6.1%-17.1%) which indicated problems with quality control during construction and possible presence of numerous pores within the structure.

Soft water attack was suspected after the first inspection of the spiral case owing to the uniform abrasion on the walls. Whereas during the preliminary stage soft water attack was ruled out by calculating Lingerie index, the recent developed Basson Index carried out in September 2022 confirmed the soft water attack of River Nile water on concrete. All the total calculated corrosion values from the samples obtained were greater than 1100 indicating a very high aggressiveness of the water [8].

5. RECTIFICATION METHODOLOGY FOR CONCRETE DEFECTS

According to Kurt [9], the first step to increase the likelihood of a successful repair, is to use a consistent, systematic approach to concrete repair. The recommended concrete repair and maintenance system consists of seven basic steps:

i. Determine the cause(s) of damage
ii. Evaluate the extent of damage
iii. Evaluate the need to repair
iv. Select the repair method and material
v. Prepare the existing concrete for repair
vi. Apply the repair method
vii. Cure the repair properly

Therefore, the above criteria laid out in [9] was used as a guiding tool while addressing the different categories of defects.

5.1 Methodology for Leakages, Damp Spots and Wet Cracks

The methodology was onsite based, with different defects having different methodology. Leakages along construction joints were injected with Sika 201 (polyurethane based material) at a spacing of 300mm, 400mm depth with pressure in the pump at 8-10MPa and holes drilled at an angle of 45^0 to the wall.

5.1.1 Calculation of grouting pressure

The grouting pressure (P_{max}) was calculated using the as-built concrete class in the powerhouse galleries. The design concrete strength for Isimba was C20/25 for the galleries therefore, laboratory test results were reviewed to qualitatively obtain the strength to avoid damage that could possibly emanate from injecting the material at high pressure.

$$P_{max} = \frac{\text{Concrete Strength X10}}{3} = \frac{25\text{X}10}{3} = \boxed{83\text{ Bar}} \quad (1)$$

Therefore, 80Bar was adopted as the grouting pressure for all the Isimba structures.

5.1.2 Spacing of packers and depth

Along a dry or wet crack, packers were installed at an offset of 300mm from crack- packer and packer- packer which was equivalent to $^1/_2\,D$ as shown in Figure 5 where *D* is the thickness of the structure. A depth of 400mm was adopted which was within the acceptable range (200-600mm). The alternating pattern was used to ensure that the crack was intercepted, since the location of the crack underneath the surface is usually unknown.

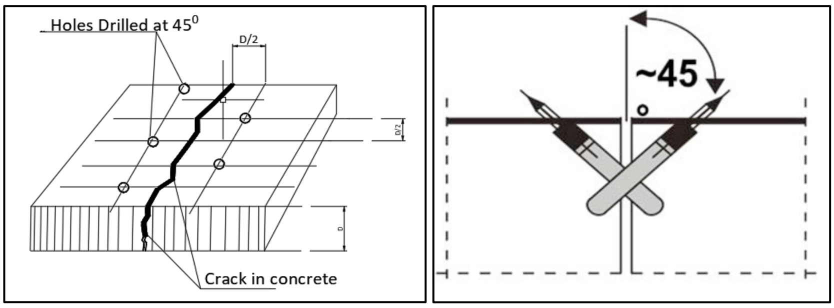

Figure 5: Schematic diagram showing spacing of grouting packers

5.1.3 Selection of polyurethane material

According to [9] cracks to be injected with polyurethane resin should not be less than 0.127mm. Sika Injection -201 CE an elastic polyurethane-based resin for permanent water tight sealing was used throughout the grouting process, Sika injection 101Rc for temporary water stoppage was used in few occasions in areas with high water flow. Hydrophilic based polyurethane resin (Sika201 and 101) were specifically selected due to their rapid reaction with water to form a permanent flexible foam that stops flow of water. This was necessary since over 95% of the defects at Isimba HPP had damp spots.

In other areas under hydrostatic pressure with numerous leaking points, curtain grouting was recommended that involved use of Sika 201 Injection while drilling grouting holes perpendicular to the wall at a spacing of 300mm from each other as shown in Figure 6.

Figure 6: Curtain grouting at EL1037 and stairs to EL1017

5.2 Methodology for Areas Under Intense Hydrostatic Pressure

These were areas in which grouting was first used however, intense leakages resurfaced within a very short time. It should be noted that polyurethane material is effective along thin lines of water passage. In such areas channels were instead adopted to act as pressure relief and the residue water directed to the nearby drainage channel. Since the leaking water normally contains calcium salt deposits, regular inspection and cleaning has been included in the maintenance routines to keep the leakage water flowing and prevent blockage.

5.3 Methodology for Concrete Defects in Units' Spiral Cases

Concrete repair for damaged surfaces, and lift joints in unit #1 #2, #3, and #4 spiral cases was undertaken using;

i. Sika Monotop 412S; a fiber reinforced low shrinkage repair mortar, then
ii. Sikagard 720 Epocem; an epoxy modified mortar to act as a moisture barrier and
iii. Sikagard PW; an epoxy coating with outstanding mechanical and chemical properties as a final sealing protective coating.

These products were applied independently or combined depending on the concrete defect as guided by the Sika technical personnel. Therefore, the coatings applied were designed to provide an improved concrete surface, for increased resistance or performance against specific external influences both mechanically and chemically. With only defective areas repaired instead of the whole area (Figure 7). Recommendations have been made to line the entire spiral case walls with the same material in future. The same defects were observed in the draft tubes hence a similar procedure shall be adopted before expiry of the DLP.

Figure 7: Final coating of Sikagard PW in Unit 3 spiral case

5.4 Leaking Expansion and Construction Joints

Leakages were observed on several expansion joints right after commissioning with water through sides of the joint tapes. Old dilapidated joint tapes were removed and replaced with Sikadur - combiflex a high performance joint sealing system that allows variable and high levels of movement. This was bonded with sikadur epoxy to maintain the water tightness properties.

5.5 Methodology for Shrinkage Cracks on the Intake and Tailrace Platforms

A top concrete layer of 80mm depth was removed by hacking and re-works undertaken using Y-6 reinforcement mesh, fiber reinforced concrete of C40 grade cast and sufficiently cured for 14 days. The additional of cellulose fiber was intended to minimize possible shrinkage cracks. Expansion joints were also introduced at an interval of 3metres to eliminate possible cracks due to expansion and contraction.

6. ROLES OF EXPERTS AND INDEPENDENT CONSULTANTS

In countries where the Hydropower Dam Construction has not attained sufficient experience, there is need not to only rely of written experience in manuals, it was thus recommended to involve a panel of experts (PoE) with rich experience in dam construction and operation. For the case of Isimba HPP in April 2016 PoE comprised of 7 members with combined total professional experience of 300 years in dam engineering was instituted by the client (UEGCL) to ensure international best practices on dam engineering was applied from design to construction, operation and maintenance.

Other independent specialists included; NDT specialists independent laboratories (determining properties of the as-built concrete properties), MIRA image experts Level 2 experts and researchers. The contribution of all the above specialists/experts in additional to PoE was key in aiding the facility owner to make informed decisions.

7. CHALLENGES FACED AND LESSONS LEARNT

i. Re-occurrence of defects in treated areas. Whereas chemical grouting is acceptable, continuous grouting in the same area using polyurethane material could weaken the concrete structure and impact on its service life.
ii. With the right methodology employed by trained professionals in concrete grouting and repair techniques it is possible to eliminate most of the leakages.
iii. Most of the concrete related defects at Isimba emanated from deficiency in either design or construction procedures or methodologies. This could have been eliminated by in-depth peer review of the designs as well as following the right procedures during the entire construction phase by all teams. For example determining aggressiveness of water using Basson index instead of Langelier Saturation index.
iv. Periodic reviews and inspection by experts, should be maintained even during DLP to enable comprehensive assessment of the as-built structures and provide technical guidance to ensure delivery of a fit for purpose facility.

8. CONCLUSION

Concrete defects in a sophisticated construction like for Isimba hydro power plant can be effectively minimised right from the design stage, following proper construction procedures and practices, robust quality control system and use of proper methodologies for repairs throughout the construction phase to commissioning. In practice, whereas minor damp spots are acceptable in any hydraulic structure given concrete is not 100% water tight, it is critical that continuous evaluation of the defects' status is periodically ascertained to mitigate culmination into structural deficiency and consequently failure.

Therefore, developing a long-term monitoring system for hydraulic structures that is able to provide information for evaluating structural integrity, durability and reliability throughout the plant's life cycle is the most critical activity of any maintenance team to ensure optimal maintenance planning and timely intervention.

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