IMPROVING DAM SURVEILLANCE AND MONITORING IN COUNTRIES WITH NON-EXISTENT LEGAL AND REGULATORY DAM SAFETY FRAMEWORKS – A CASE OF ISIMBA HYDROPOWER PLANT (UGANDA)

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ABSTRACT

According to world statistics; the highest percentage of dam failures happen at impounding and then in the first 5years of operation hence a critical phase for the less developed countries. These countries are currently or in the near future will be dealing with the newly constructed dam risks. Given the non- existence on the Dam Safety Legal and Regulatory Framework in a country like Uganda, a dam owner may be reluctant to undertake dam surveillance. But this exposes the downstream communities to potential risks of loss of life, property and serious damage to the environment if a dam fails. The failure of the dam also comes with loss of the asset and revenue for the dam owner.

This paper thus discusses how improved dam surveillance does not only help protect the potentially affected communities but also benefits the dam owner. It also discusses how dam owners in countries with no regulatory framework can establish and implement an improved dam surveillance. Just like Isimba Hydro Power Plant in Uganda, which was commissioned in March 2019 and is currently under Defects Liability Period. The paper discusses ways of customizing dam surveillance based on benchmarked international best practices with reference to international guidelines and use of a strategy-based approach dam Safety review toolkit.

Keywords*: Dam Surveillance, Dam Safety, legal and regulatory frameworks, Isimba HPP, Uganda.*

1. INTRODUCTION

Dam Surveillance is a core of Operation & Maintenance and doubles as one of the Dam safety cornerstones and in turn, dam monitoring represents one of the key pillars of dam surveillance which are all key elements of risk mitigation. It is a control action that involves measuring physical parameters to assess their development, periodic checks, responsibilities and notification. A blend of instrumentation monitoring, visual inspections and testing activities has been implemented at Isimba Hydropower Plant.

Isimba HPP was commissioned, on March 21, 2019 with (4) Kaplan turbines each with 45.75 MW capacity generating up to a total of 183.2 MW that is evacuated onto the national grid. This was a remarkable milestone for the country as it works towards increasing generation capacity and an addition onto the country assets with the last dam having been commissioned in 2012. Uganda has a population of about 40 million people (UBOS 2018) with only 22% of the people connected to electricity. This means that Isimba HPP asset is of great importance and has to be jealously guarded, safely and sustainably Operated and Maintained to Generate for Generations.

The Isimba HPP is located about 50km downstream of the source of Victoria Nile River. It comprises of a 1.6 km long earth rockfill dam with a maximum height of 26.5m the details are in Table 1 below and the Aerial view of Isimba HPP complex is shown in Figure 1.

Table 1 : Main features of Isimba HPP

Description		Unit	Parameters
Dam type			Composite
Maximum Probable flood (10,000 year)		m³/s	4,500
Spillway design Discharge (1000-year flood)		m³/s	3,500
Reservoir storage		Mm³	170
Total length of dam axis		m	1,625.0
Dam height (Max.)		m	26.5
Dam crest level		masl	1057.50
Headwater flood level		masl	1055.00
Headwater normal level		masl	1054.5
Upper spillway sill level		masl	1044.50
Number of units			4
Rated head		m	15.1
Rated discharge	1 turbine	m³/s	344
	All turbine	m³/s	1,375
Installed capacity	1 unit	MW	45.75
	All unit	MW	183
Commencement date			April 30, 2015
Completion date			March 31, 2019
Project cost		USD	567 Million

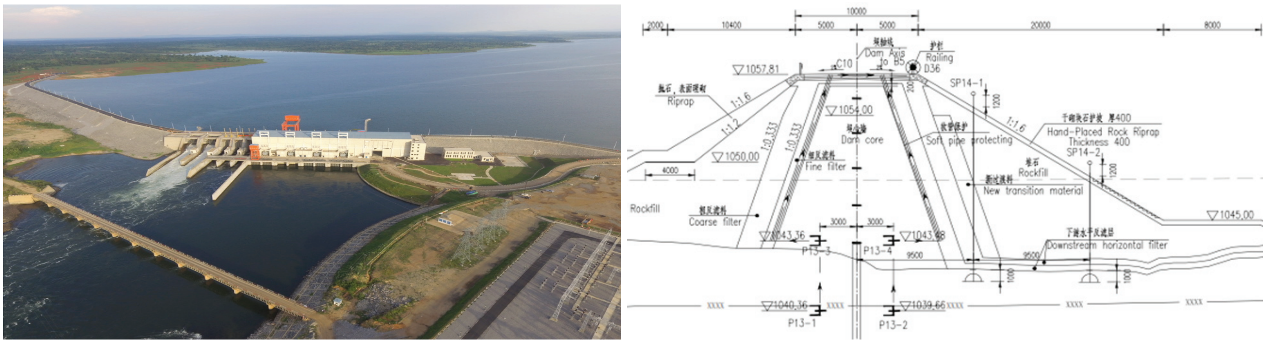

Figure 1 : An aerial view of Isimba Hydro Power Plant; Cross section view of Embankment Dam with installed instruments

Just like any dam, Isimba may suffer a delayed-related incident at any age, therefore; dam failure prevention must be efficient during the whole life cycle of the dam; i.e from impoundment to decommissioning. Improving Dam surveillance and monitoring is therefore the best strategy for risk attenuation (ICOLD, 2009). Continuous reviewing of the existing operational structures allows identification of weaknesses at both managerial and organisational arrangements.

In the knowledge of a non-technical dam owner, it could be expected that for a new power plant the dam would behave smoothly. However, according to world statistics, the highest percentage of Dam failures happen at impounding and then in the first 5years of operation hence a critical phase for the country. Large international Database of historic dam failures and safety related incidents worldwide is illustrated in Figure 2 (Regan, 2010).

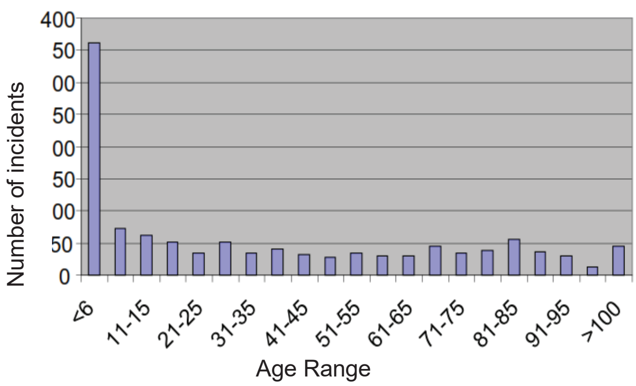

Figure 2 : A graph of number of incidents against age range of 1158 dams in the world (Regan, 2010)

The International Committee on Large Dams (ICOLD- Bulletin 1987) has determined that the major categories of dam failure are overtopping by flood, foundation defects and piping. For earth dams, the major reason for failure was piping or seepage, while overtopping remains a significant cause of dam failure primarily in cases of inadequate spillway. (Dam Safety: An owner's guidance manual, 1987).

Dams may actually suffer a delayed safety-related incident at any stage. Serious problems may occur at any time after many years of trouble-free operation. This means that dam failure prevention must be efficient during the whole life cycle of the dam, from impoundment to decommissioning.

The safety of a dam and the population downstream of it depends not only on the quality of its design and construction but it also depends significantly on proper maintenance during operation as well as appropriate surveillance to monitor the condition of the dam. The safety of water retaining facilities is principally based on three (3) elements –

(i) structural safety,

(ii) surveillance and maintenance,

(iii) emergency concept.

Currently, the structural safety was/is catered for by the EPC Contractor together with his Designer, and the Owners Engineer up to the end of the Defect Liability Period (2021) while the Dam owner/operator (UEGCL) on behalf of government is doing monitoring, surveillance and maintenance as well as emergency preparedness. At this stage, inspection, monitoring, data analysis and interpretation plays a critical role in Dam safety. The preventative actions have been built into dam surveillance tracking tool, a routine organisational arrangement of dam safety activities.

2. REGULATORY FRAMEWORK

The frequency of the routine, regular, periodic and formal inspections is normally set by the prevailing legal and regulatory framework which is non-existent in Uganda. Under normal practice, a National Dam Safety Policy is expected to establish a National Dam Safety Office responsible for regulating the dam safety practices of Operators of different dams in the country. Due to the absence of such a framework in Uganda, UEGCL opted to implement a DSMS based on best practices referenced in Swiss Federal Office of Energy (SFOE) Safety Guidelines and International Commission on Large Dams (ICOLD) Guidelines. This is one of the reasons why UEGCL and Directorate of Water Resources Management thought it necessary for Uganda to join ICOLD, the World's leading community in Dam Engineering.

In this case, countries without a regulatory framework like Uganda should not wait for it to be established in order to comply. An improved dam surveillance practice can be benchmarked and customized from the already existing international best practices. In the due course, the countries can establish the framework. In Uganda so far, Dam Safety Guidelines have been developed while development of Dam Safety Regulation is ongoing pending the revision of the Water Act.

3. MONITORING AND SURVEILLANCE

The monitoring and surveillance plan for Isimba was developed benchmarking on international best practices referenced from the Swiss Federal Office of Energy (SFOE) Safety Guidelines and ICOLD Guidelines. The topic of dam surveillance has been extensively described in the literature, addressing both structural and non-structural aspects as detailed No.118, ICOLD, 2009 in Figure 3 below.

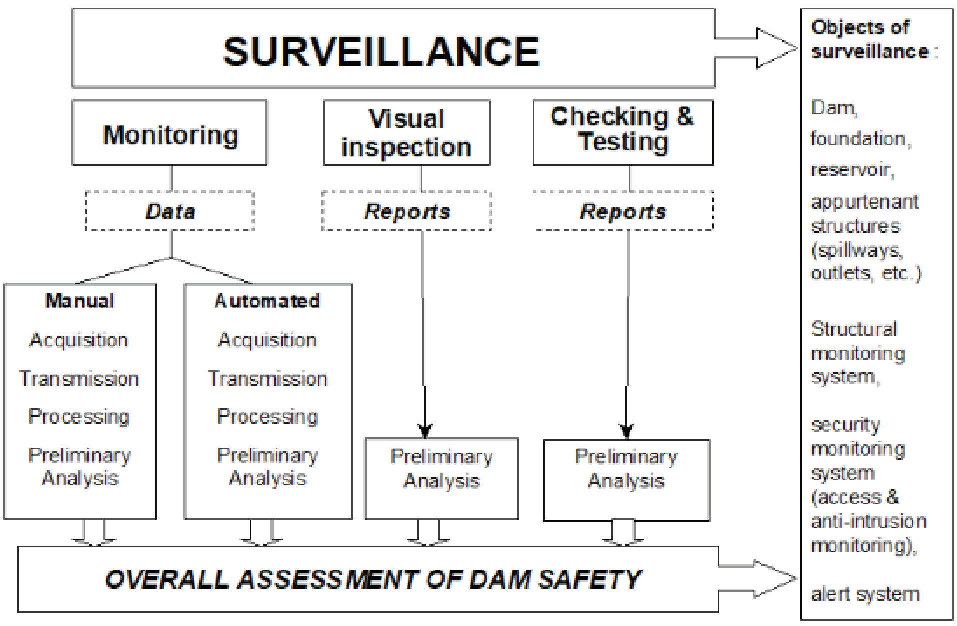

Figure 3 : Surveillance framework as adopted from ICOLD Bulletin 118 and 158

The local monitoring of the dam includes; routine inspections, instrumentation and functionality tests. A team of Dam Safety Engineers have been trained to enhance capacity development; Dam Wardens (level 1) have been equipped with sufficient knowledge to undertake visual inspection, data collection, processing and preliminary analysis. The activities done are double checked by the Operations Manager to ensure compliance with the pre-set guidelines in the Monitoring and Surveillance Manual. A plan to have a qualified person perform annual inspection and provide technical support is under way, and he or she shall there after provide recommendation (this shall be done in March 2020). The four-level surveillance organisation provides a detailed defence system with four independent layers of protection. It takes into account the individual's level of competence, and need for early detection of an anomaly and for rapid evaluation of its severity.

3.1 Why dam surveillance and monitoring:

- Identify key physical change on integral components of the dam to enable early detection of anomalies for example on 23/07/2019 a timber piece was observed between lower radial gate seal and the spillway concrete frame, control room was notified immediately and the timber was removed. This was a potential hazard to the gate in case the opening operations were initiated.
- Detect possible initiation and/ or progression of a potential failure mode (PFM) such as seepage, malfunctional spillway gates, unusual depression, sinkholes and turbid water so that timely action can be taken to prevent failure.
- On 20/08/2019 functional checks for the mobile hydraulic manual pump revealed that only one of the two pumps had fuel, hence putting the spillway opening at a potential risk and the entire dam in case of a blackout and failure of the diesel generator
- Conduct and analyse the trends especially instrumentation data to predict any possible change and therefore identify preventative and protection measures against potential dangers.
- Improvement or repair measures aimed at reducing an identified and quantified risk and potential damages downstream
- With the latest technology, large increase in automation may lead to more sophisticated computer and work process which can introduce more opportunities for human error, monitoring is therefore important to minimise possibility for human error and enhancing effectiveness of human work.
- Significant changes in plant control, protection or monitoring systems necessitate corresponding changes to the human -system interface in the main control room therefore it's crucial that such data is kept for future reference.

3.2 How Surveillance and Monitoring is Done

3.2.1 *Visual inspection*

Inspections are crucial party of dam safety surveillance and monitoring. Unlike instrumentation which is measurement at a single point, visual inspection comprises of targeted observation at the entire section of the dam. Since impounding, daily, weekly and monthly visual inspections have been incorporated in system with the goal of obtaining qualitative appraisal of dam state changes and deviation levels and comparing with expected results.

A team of level1 rolled out daily and regular inspection of the dam. This was in line with the Dam Surveillance Manual, which stipulates daily surveillance for the first one year of operation. The team is comprised of civil/dam safety, electrical, control and instrumentation as well as mechanical engineers.

The daily inspections have included the following;

- Downstream of Left and Right embankment with focus on damp spots, settlement, rip rap movements and deformation at contact with gravity dams
- Spillway gates (during operation and termination) where the focus is on proper closing of gates, leaking seals.
- Compare water level in control room of powerhouse with staff gauges

Weekly inspection; on additional of the above include;

- power house and grouting gallery
- gravity dams
- concrete structures,
- hydro-mechanical and electrical components of the dam.
- Reservoir area and downstream area

A joint inspection involving different Dam Safety Engineers and managers has been initiated and carried out every month to have a second look at procedures and review records. This serves as the second defence barrier assessing current integrity of the dam, by comparing current dam state and behaviour with past information Defects observed are identified by describing the exact location and marked where necessary on a drawing/sketch. Photos are taken and archived to follow development with time.

Assumption on cause of the defect observed is documented to detail and may include but not limited to; heavy rainfall, long dry spell, inappropriate material and change in properties etc. Daily and periodic visual inspections especially to a new facility are of great importance and if well conducted can prevent a catastrophe, reduce the would-be maintenance budget, interrupt production hence loss of revenue, enhance the integrity of the dam, prevent a dam overtopping and eliminate possible hazards of uncontrolled release of flood to downstream communities. It is important to note that the importance of a comprehensive checklist is a great yardstick towards achieving the intended purpose and covers all the parameters

A Crack monitoring tool has been developed to map new cracks and assess the existing ones. The tool contains a Crack Identification Matrix (CIM) to categorise cracks i.e. leaking, dry, humid and intact. Photographs are stored on the corresponding crack, and if needed, decisions are made on the treatment methodology and thereafter implemented. The CIM also tracks effectiveness of crack seals from previous repairs and incorporates recommendations/comments on the method used and prognosis of the crack.

According to studies, for the case of embankment dams, it has been proven that vegetation trees and vegetation growth is unacceptable (ICOLD, 2009). A team therefore has intensified schedules for uprooting vegetation growth both on upstream and downstream face of the dam.

3.2.2 *Functionality checks/tests of Spillways and Auxiliary Systems*

3.2.2.1 *Spillways*

The purpose of the spillway is to control and regulate the reservoir water level during flood events. The spillway of Isimba Dam is designed to pass a Probable Maximum Flood (PMF) 10,000 year of 4500m^3/s. The spillway system comprises of a total of 5 radial gates, 2 surface radial gates with flap with capacity of 1650m^3/s and 3 submerged radial gates with 3600m^3/s capacity. Therefore; the total installed capacity of the spillway is 5250m^3/s which is greater than the PMF. The gates are controlled by any of the three power options; remote, manual and local at all times as stipulated in the (O&M Manual – Isimba HPP). It is against this background that periodic checks were instituted to constantly check the operation of the gates.

Monthly functional checks and tests are conducted on all spillway gates to ascertain their current status. The checks include opening and closing to at least 10 cm and then determining the time and hydraulic pressure required to open and close. During the process, priority is given to remote control by coordinating with an operator in the control room using SCADA and in case of failure, the operation is switched to local mode operated as well. From our experience, it has been proven that one or more gates is faulty during testing, hence a need for continued functional checks to prevent complacence or a catastrophe in case of a flood. Anomalies in time taken to open or close and hydraulic reading are noted for further recommendations, leakages and water seals as well as vibrations are monitored for any abnormality and consequent repair. These tests are conducted in the presence of the Operations Manager or his assistant and periodically a qualified person is notified to have their input.

3.2.2.2 *Auxiliary Systems*

In the aftermath of Belci Dam, Romania failure in 1991, an inventory found that the failure was caused by non-operational floodgates during a high flood event (Vogel, 2009). This was due to bad hydrological forecast and failure of electric power including the backup generator. The Tous Dam, Spain failure by overtopping in 1982 was attributed to inadequate spillway design but also power loss to electrical grid during the early stages of the storm hence gates inoperable and phone lines damaged. Reports after the incident indicated that the back-up generator was not available (reason not known) and attempts to manually open were unsuccessful. The Tous dam experience illustrates the precautions necessary for the electrical supply of the flood gates: normal supply, backed by a regularly controlled generator (Mullet *et al , 2007)*. Two emergency diesel generators are installed at Isimba; One emergency diesel generator is intended to operate the spillway gates while the other for powerhouse. Monthly tests are carried out on the diesel generator to ensure that it is fit for purpose in case of a blackout and as such its operated for 30 minutes per month.

Spillway gates are operated once a year using a mobile hydraulic pump unit as a test to ascertain their suitability in case of an emergency. The mobile unit is the last resort in case of power outage and failure of diesel generator to start. Isimba Dam has two mobile hydraulic pump units used to open the two (2) upper radial gates.

3.2.3 *Instrumentation*

Like any other engineering facility, it’s important to take measurement for the dam with the aid of instruments especially for geotechnical and structural properties owing to the past history of seepage and piping in embankment dam, uplift on concrete structures etc. and the importance for early detection measures. Importance of instrumentation includes but not limited to the following:

- Give support and confirmation on presumption in planning, redesign, operation and maintenance.
- Confirm that the structure is behaving in a manner expected during operation
- Give a good background for comparing dam behaviour as the dam is ageing and provide a qualitative link between physical observations and measured results.
- Provide quantitative data on possibility of changes in instability of dam slopes, adjacent landslide areas, high uplift pressures, leakage and seepage, problems with cut off walls, deformations, settlements, cracking and temperature distribution in dams.
- Trouble shooting
- Research and development

Unlike dams built in the previous years, Isimba dam was able to tap into the latest technological advancement and technical developments in design and construction. With 293 installed monitoring points, Isimba Dam ranks number one as the most monitored dam facility in operation within Uganda. The installed instruments include: piezometers, monuments, inclinometers, strain gauges, etc. Figure 1 shows cross section of Right Embankment and instruments installed at chainage D1+ 275.

To monitor the dam settlement, geodetic measurements are carried out to find precise position of over 63 survey monuments by calculating their horizontal and vertical displacement of the sections. A closed loop survey is adopted for the calculation of vertical and horizontal displacement where each shot in a loop is systematically adjusted to minimise effects of the error hence distributing the error throughout the survey. Vibrating wire piezometer and load cells (cable instruments) are used to measure pore water pressures and uplift at different location of the embankment. V- Notch weir to measure seepage in the grouting gallery. The physical instruments (inclinometers, magnetic settlement gauge) to measure the horizontal and vertical displacement of embankment layers, the details of instruments is shown in Table 2.

Impounding was completed of 31st November 2018 and therefore a schedule for instrumentation data collection rolled out as per the international best practices. As stipulated in the requirements and standard guidelines Table 2 below shows the frequency adopted for data collection for the 1st year of operation which ended on 31st November 2019.

Table 2 : Summary of instrumentation at Isimba HPP at 31st November 2019 and the frequency for data collection

Type	Parameter	Frequency	Number
Physical instruments			
Inclinometer	Horizontal displacement	Weekly	12
Magnetic settlement Gauge	Vertical displacement	Weekly	12
Stand pipe piezometer	Uplift	weekly	102
Survey Monuments	Horizontal and vertical displacement	Monthly	63
V- Notch weir	Seepage water	Weekly	1
Water level gauges	Water level[2]	as and when	4
Automatic instruments			
Automatic weather station	All weather features	Daily/Hourly	1
3D and 1 D joint meters	Displacement between blocks	weekly	14
Dynamometers	Stress loss of anchor cables	Weekly	6
Vibrating wire piezometer	uplift	weekly	70
Temperature sensors	Thermal condition in concrete	weekly	12
Strain gauges	Stress and strain in concrete	Weekly	8
Automatic Water levels	Water level	Hourly	4

[2]Water level is critical in determining production as well as affecting piezometric readings.

4. DAM SAFETY INTERNAL AUDIT

A dam safety review on surveillance usually relies on a verification of compliance to prevailing laws and regulations. Although perfectly sound for developed countries, this approach may in practice encounter impediments in less developed countries with weak or non-existent legal and regulatory dam safety frameworks (Mean, *et al, 2012)*

In Uganda, there are ongoing developments in Dam safety regulations which are pending the finalization on the ongoing revision of the Water Act by Ministry of Water and Environment. The Ministry has designed an online Dam Safety Database Management System that has been incorporated into the online Water Information System (WIS) tool. Concurrently, UEGCL implemented the in-house Dam Safety Management System that fits into the Dam Safety regulations under development. This system was developed by AF-Consult Switzerland (AFC) with its Sub-contractor

WSS Services (U) Ltd. (WSS) as the Dam Safety Consultant (DSC). The Dam Safety Management System for Isimba Hydropower Plants (HPP) includes: Instrumentation Plan, Dam Monitoring and Surveillance Plan, Dam Operation and Maintenance (O&M) Manual, Emergency Preparedness and Response Plan, Dam Security and Protection Plan and Flood Forecasting System. This study scope was limited to the implementation of the Dam Monitoring and Surveillance Plan and the Dam Operation and Maintenance (O&M) Manual.

Periodic audits are conducted inhouse with the main objective of reviewing the adequacy of the Dam Surveillance system and confirm that the Dam Safety Management System of Isimba HPP is operating as designed and effectively. The Audits include: application of instrumentation data collected and processed, review of non-structural and managing systems, quality of reports prepared by the dam safety team and any other creative idea in line with the Management and improvement of the Dam Safety Management System.

5. PANEL OF EXPERTS

In countries where the dam safety is still young, there is need not to only rely on written experience in manuals but involve experts with rich experience in dam construction and operation as well. The main duty of the experts is to ensure that criteria and international best practices on Dam engineering are consistently applied from design stage, bid tendering, construction, operation, and maintenance of the dam and associated works. Amidst inexistence of national laws and standards as well as regulatory guidelines the construction, operation and maintenance partly relies on the guidance and advice of the panel of experts who majorly have the following expertise;

- Hydraulic structures and hydropower specialist
- Geotechnical and Foundation specialist
- Embankment /Rockfill dam expert
- Hydro-mechanical and electrical equipment
- Dam safety/dam engineering

In April 2016 a panel of 7 members, also referred to as PoEs, with combined total professional experience of over 300 years in dam engineering was instituted by the client (UEGCL) to oversee construction of Isimba HPP, operation and maintenance as well as provide their professional experience. With their continued interface with the client, contractor and owner's engineer several recommendations have been put into consideration by the EPC contractor. Figure 4 shows pictorial evidence of PoEs at the dam during one of their site visits.

Figure 4 : Dam Engineering expert (POE) together with contractor and UEGCL staff inspecting a weir downstream of the dam (left),; hydraulic structures expert (POE) members at 1025 elevation gallery (right).

6. CONCLUSIONS

Countries with non-existing laws and regulations can sustainably operate hydropower plants safely while mitigating the possible risks of losing revenue and affecting downstream communities by implementing dam safety best practices that include improving surveillance and monitoring from impounding to decommissioning as well as use of the surveillance self-assessment toolkit. The dam owner should invest resources in establishing Standard Operating Procedures, design and implement capacity building and training programmes according to needs and priorities throughout the life time of the dam. This is economically viable rather than wait for a catastrophe to happen due to reluctance given non-existing regulations.

By implementing best practices from countries with strong regulations and customising them to suit a particular country needs, such as a comprehensive surveillance and monitoring guideline that includes; instrumentation, regular visual inspections, functional tests throughout the life cycle of the plant, dam owners are able to ensure safety and sustainability of their facility. The safety of the dam facility and downstream communities relies on the efficiency of the systems implemented by the dam owner; both structural and non-structural, it is therefore important that even in the absentia of regulatory frameworks, plans should be designed and implemented as per the existing international guidelines.

This paper discusses the general internal monitoring systems by the dam owner, however external regulation is still important to ensure safety of the dams. The presence of laws and regulations cannot be downplayed either way therefore, it's important that such countries, even with a smaller number of dams, both large and small should priorities enaction of laws and regulations governing dam cascades, enforce collaboration of different plant operators within the country. This could include but not limited to joining ICOLD, benchmarking from other countries, implementing recommendations from experts etc.

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