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Potential Cause of Dam and Bridge Failures due to Clogging by Drifting Floating Islands of Aquatic Vegetation

A Research Paper based on an attempted dam failure of St Marys dam

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***Abstract*— Masses of drifting floating islands of aquatic vegetation are known to block waterways and cause havoc in the water transport industry. In this paper such islands have been addressed with regard to how they would cause a failure of a dams or bridge with reference to an incident that occurred on St Marys dam.**

The objective of this paper is to give an in-depth outline and analysis of how floating islands of vegetation were generated in a dam reservoir and what danger they posed on it.

Methods used in collecting data included; physical observations, interviews, written reports and application of satellite technologies namely Google earth and Digital Elevation Model of Global mapper.

The study's results indicate that the emanations of the floating islands were as a result of the inundation conducted on a Typha infiltrated area ear marked for a dam reservoir that was previously left drained for over two decades. It was mainly the flooding that caused masses of aquatic plants to be uprooted, made to float in clusters and then suddenly drifted towards the outlet facility until the dam's spillway was clogged. The clogging of the spillway led to a build-up of water in the reservoir to a level where the dam's embankment was almost overtopped. Eventually, the impounded floating islands managed to escape at the expense of damaging the footbridge that spanned over the spillway.

The main recommendations are that before commissioning or during the operation of dams and bridges, the dam reservoirs and upstream areas should be dredged. Secondly, bridges and spillways should be designed with pillars that are placed with a maximum possible distance from each other in order to reduce the likelihood of clogging.

Keywords*— *Dam failure, Overtopping, Satellite technology, Floating islands.

I. INTRODUCTION

Today the world still needs more extensive and specific studies because oversights still exists on some unexpected but very catastrophic natural phenomena that lead to dam failures. An example of such a phenomenon is a dam failure that would be caused by a sudden drifting of a cluster of aquatic plants.

The aquatic plant managers refer to such debris of islands as tussocks, floating islands or forests, an occurrence witnessed globally in lakes and marshes [8]. Tussocks have been known to cause havoc in the shipping industries in that, whenever they occur in larger dimensions they block waterways and take several days to be cleared [6].

It was therefore very imperative to conduct a detailed study on how floating islands emanated and surprisingly damaged a footbridge, spillway and almost led to overtopping of St Marys dam in Lufwanyama district of the Republic of Zambia.

The justification to this study is that it creates awareness on an overlooked phenomenon that would lead to failure of dams and bridges. The study further outlines precautions that should be considered in designing, construction, commissioning and operation of such infrastructure. The paper also give a demonstration of how certain technologies such as Global mapper and Google earth can be applied in surveying, mapping or help defining hydrological parameters for dams and bridges.

A. Methodology

The methods of obtaining data involved extracting data from eye witnesses to the damage and attempted failure of the dam. Other sources were past written reports as well as from physical observations including the application of satellite data. Details are as follows;

i. Primary Sources of data

Gathering of primary data involved obtaining data by the use of survey equipment and physical observations.

The survey equipment's utilised was a dumpy level and measuring tape which were used in determining the dam design specifications namely the dam height, spillway width and freeboards. Part of the said parameters where then used to generate the reservoir capacities.

Interviews with eye witnesses to the failure attempt were conducted and extended to persons that had information on the historical operation of the dam in order to gather past records of dam failures.

ii. Secondary Sources of data

Collection of secondary data involved obtaining data from different documents on the background and past rehabilitation works of the dam.

iii. Satellite data

Part of the survey was conducted by using a combination of Google earth and Global Mapper (Digital Elevation Models) software. The combination of two was used in generating contours, delineating catchment and dam reservoir in order to ascertain their respective areas. The two technologies were also used in determining parameters such as the span of the embankment, throwback and perimeters.

II. RESULTS

St Marys dam is found on Ng'wena stream a tributary of Luswishi River also a tributary of Kafue River. The dam is made of an earthen embankment and spillway made of concrete and masonry. Uses of the dam include crop irrigation, river crossing and fishing. Table 1 displays the additional design specification and location of the dam.

Table: 1a Locations and design specifications

GPS reading	Spillway width (m)	Free-board (m)	Crest height (m)
-12.8898 E 27.3669 S	10	1.2	5.3

Source; Field measurements

Table: 1b Additional design specifications

Span for reservoir (m)	Throw back (m)	Area of reservoir (m^2)	Volume of reservoir (m^3)	Catchment area (m^2)
70	406	15630	19420.33	115770000

Source; Satellite data and field measurements

Note that the span for the reservoir, throwback, area of reservoir and catchment were generated by the earlier mentioned technologies that utilises satellite data. The volume of reservoir was on the other hand computed by using data obtained from field measurements and the same technology as stated in equation (1)

$$Q = \frac{LTH}{6} \quad (1)$$

Where:

Q = Reservoir storage capacity in m^3
L = length of the dam wall at full supply level (FSL) in m.
T = throwback in m
H= is the maximum height of the dam, in m, at FSL.

In February, 2012 a recently rehabilitated and re-commissioned St Marys dam encountered an attempted dam failure owing to the clogging of its spillway by vegetation [1]. This incident was surprising among dam experts and therefore called for an in-depth study.

The following are details of how the events unfolded based on written statements, field observations, interviews and application of advanced technology in water resources modeling;

A. Observed physical damage to the spillway and footbridge

Physical observations reviewed that the concrete footbridge had its right hand side end dragged in the downstream direction for a distance of about 1m. To prevent the worst from happening, the footbridge end in question was not dragged that much to come off the headwall. However, all the four (4) footbridge pillars were displaced and fractured with two (2) of them at the far right completely collapsed and washed away within and beyond the stilling basin. Implying that the footbridge was found suspended by the headwalls and two but seriously fractured and partially displaced pillars.

Further damage was noted on the reinforced slab of the stilling basin which had about 1/3 of its surface area ripped off and washed away.

At the time of observation, the footbridge was still being used by the locals and school children due to the fact that there was no alternative route between the main settlement area i.e. St Mary's Mission and the farming area.

B. An account of event during the attempted failure

With no doubt it can be stated that the primary cause of the attested failure was attributed by the malfunctioning of a combination of spillways and a footbridge to let water flow through when a collection of floating islands clogged it during a series of heavy downpours. During the study, eye witnesses and care takers of the dam reviewed that, the attempted failure incident commenced when a collection of clusters of floating islands of hydrophytes were sported drifting towards the spillway outlet. The said floating islands subsequently got trapped just above the main cascade of the spillway after being impounded by the pillars of the footbridge. The likelihood of the impoundment could be attributed by the fact that the average distances that separated pillars was about 1.7m and this was obviously to minimal to allow the mentioned clusters of floating islands of the weeds to bypass.

Eye witnesses further stated that during the attempted failure incident, a number of prompt efforts were made to fragment the impounded floating islands so that they pass through the spillway. Nevertheless, the rescue efforts were hampered by the massive volumes of the debris, hydraulic dynamics of the river current and heavy rains that accompanied the event. The unsuccessful rescue of the dam from floating islands cannot be deemed as a surprise since they are well known to be difficult to clear. In the end the water in the reservoir built up to a level that was just less than 0.15m from overtopping the embankment's crest level. Although the force exerted on the pillars became too much for them to withstand, consequently the impounded floating islands forced themselves through the spillway at the expense of displacing and fracturing all the pillars of the footbridge, and completely collapsing and washing away two (2) of them.

In addition, other recorded damage during the incident was the ripping off of part of a reinforced slab to the stilling basin by the impact of the failing pillars.

Last but not the least, it should be acknowledged that had the building up of water in the reservoir continued, the dam would have undergone overtopping of the embankment a phenomenon known to be the major cause of dam failures in the world as reviewed by [5],[7] and [3]. A report by [4] indicates that overtopping accounts of 1/3 of the recorded dam failures in the world [7]. Such revelations gives an impression of the danger that the dam was exposed to as overtopping is known to be the most lethal cause of dam failures. For more illustrations and verification refer to figures 1& 2.

Fig 1a; A recently rehabilitated spillway of St Mary's dam before being clogged and damaged. Note that initially the dam had four pillars. December 2011. *(Photo: Mumba Kolala).*

Fig 1b; Traces of debris left behind hanging on one of the pillars of St Marys dam in the aftermath of the attempted dam failure. Note that only two (but fractured) pillars were left standing. February 2012. *(Photo: Mumba Kolala).*

C. Establishing the factors that generated floating islands

In establishing the factors that produced floating islands one needs to be aware that in 1964 i.e. upon the commissioning of the dam, the entire area (of about 15630m^2 or 1.56ha) that was marked for the reservoir became flooded and it is obvious the vegetation in the mentioned area became transformed after being submerged. It is therefore probable that the inundated area could favorably support plants that were submarine in nature and that reduced the density of the flora population within the submerged area.

In 1997 the dam breached and the ecological territory that was inundated by the reservoir for the past 27 years of existence became susceptible to being occupied by aquatic to semi aquatic plants. The semi aquatic conditions persisted for more than the two (2) decades that the dam reservoir remained empty. In the process, the formerly inundated territory became infiltrated with semi aquatic/ terrestrial plants of which Typha were among the dominant spices.

In December, 2010 the dam reservoir was refilled after the first phase of rehabilitation works but was drained in October, 2011 to pave way for a second phase of rehabilitation and then filled for a second operation test in December, 2011 [2].

One thing that needs to be noted is that during the two events that saw the filling and draining of the dam, the reservoir's ecological territory was still predominantly occupied by Typha weeds. We also need to understand that these plants are amphibious in nature i.e. they have a hydrophytic in their substructure region (roots) and mesophytic in their superstructure region (leaves). Implying that their roots normally grow in marshy water logged region, whist their buoyancy elongated leaves are adapted to occupying water free aerial region above and are able to float on waters.

Consequently, during the mentioned period between 1997 and December 2011 i.e. a period that saw a prolonged draining (for over two decades) and then followed by occasions of filling and draining of the reservoir during the rehabilitation works, the roots of Typha plants got detached from the bottom of reservoir and turned into floating tussocks owing to the fact that their largely buoyancy biological tissue could no longer anchor them at the bottom of deep waters. Additionally, by February, 2012 i.e. when heavy rains and flush floods dominated, the reservoir was subjected to sharp rising and falling water level coupled with sharp changes in surges of water towards the dam's outlet systems (the Spillway). These fluctuation must have caused the already detached huge masses of floating islands of Typha plants to disintegrate and drift into deeper water in the centre of the reservoir where they were easily caught up by the strong river surges hence they were driven towards the spillway and were eventually impounded then led to the attempted failure of the dam but left behind a damaged spillway and a footbridge.

D. How floating islands would endanger ordinary bridges

It should be appreciated that what transpired at St Marys dam can also unfold for bridges if at all the area upstream to the bridge allow the generation of floating islands of vegetation. As earlier stated, conditions that induces the generation of floating islands includes rises in pool waters as well as strong surges of water in areas infiltrated by the aquatic plant. Similarly if any bridge is put up and for some reason there is ponding of water upstream then that can cause generation of floating islands. For a common bridge, floating islands can clog the culverts and lead to overtopping and eventual washing away, more especially for bridges on non-paved roads.

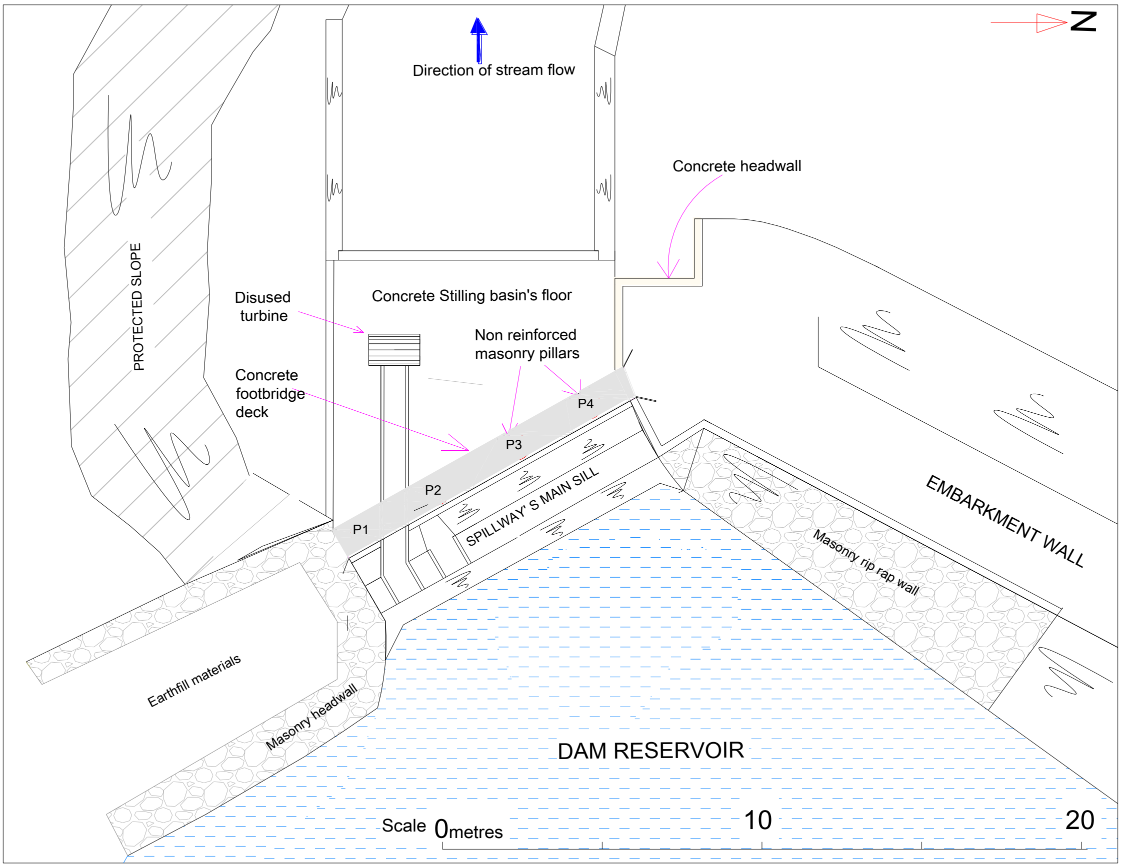

Fig 2a: Diagrammatic arial view of spillway & adjacent area assuming that the reservoir is partially filled

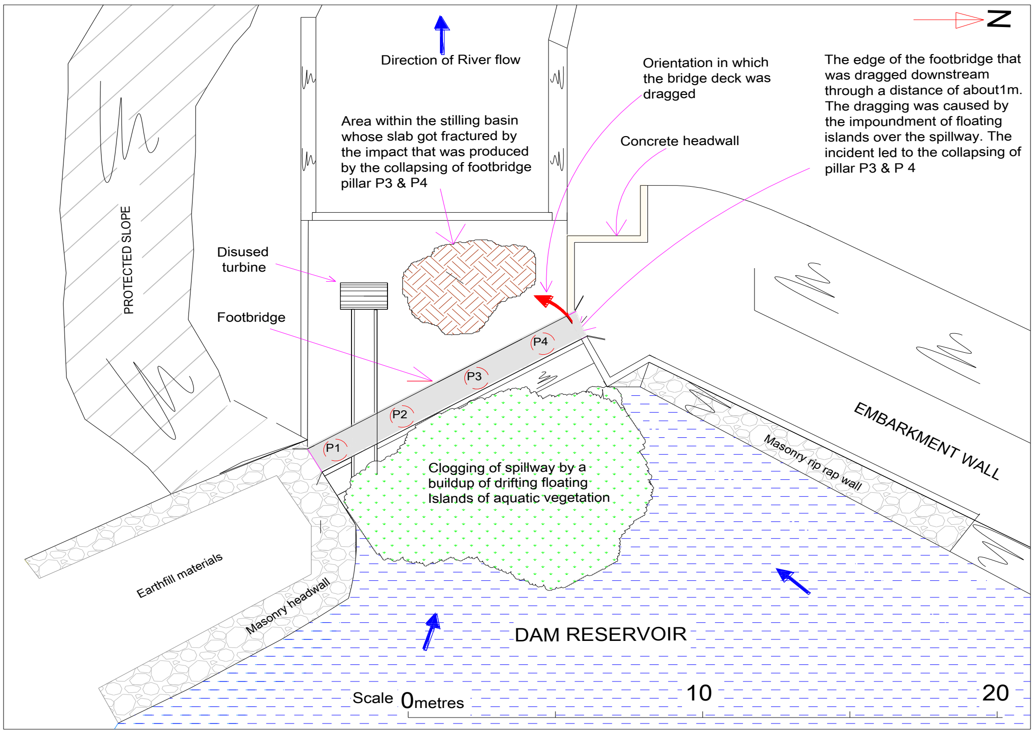

Fig 2b: Diagrammatic expression of events that characterized the damage and attempted dam failure

Fig 3a: Satelite picture of St Marys dam and surrondong areas

Fig 3b: Satellite image superimposed by contours and a shaded area of the dam reservoir

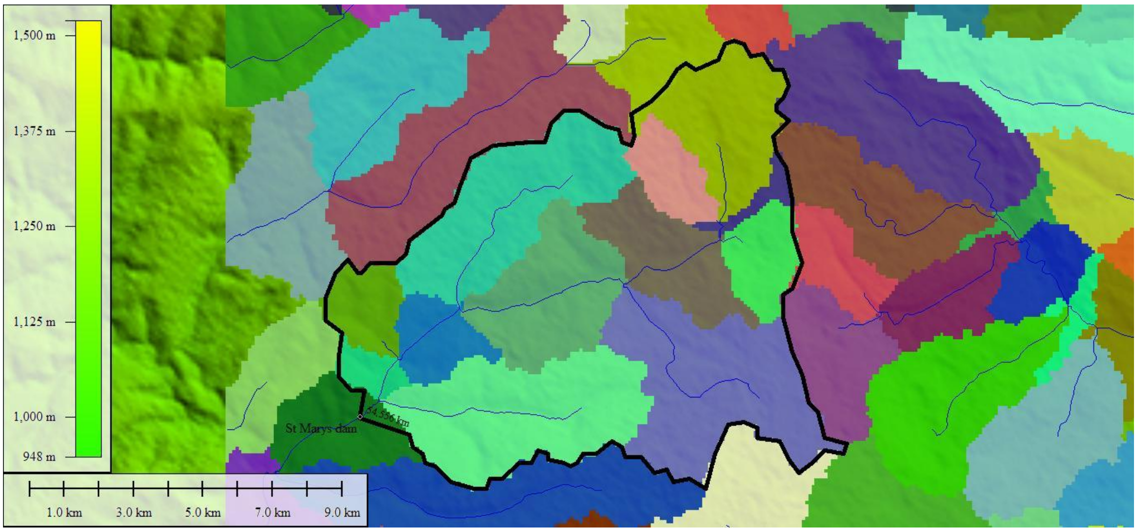

Fig 3c: Digital elevation satellite image superimposed by a boundary of the catchment are

Wrapping up the segment of the findings is a display of satellite imagery that was generated and then utilised in the survey. Note that fig 3a is a Google earth image and was used in determining parameters such as span of the dam wall and throwback, whilst fig 3b is a fusion of Google earth and Global mapper and was used to determine the area of the dam reservoir. Fig 3c is a Global mapper image used in delineated catchment boundary and determining its areas.

III. CONCLUSION

The obvious conclusion is that eventual flooding coupled occasions of draining and filling of a Typha occupied dam reservoir caused masses of aquatic plant to be uprooted and then float towards the spillway until it was clogged. The sudden drifting of the floating islands was also propelled by surges of river flows as a result of heavy down pours. During the incident, the clogging of the spillway led to a buildup of water in the reservoir to a level that the dam's embankment was almost overtopped and this was a very great danger to the dam as overtopping is known to be the most lethal cause of dam failures. Ultimately the impounded floating islands managed to escape at the expense of damaging the spillway by dragging down the pillars of a footbridge that spanned over the main sill of the spillway. Otherwise if the dam had undergoing overtopping, more especially for a prolonged period, then it would have encountered a catastrophic failure.

IV. RECOMMENDATIONS

- Dredging of dam reservoirs or upstream areas to dams that are heavily infiltrated with aquatic plants such as Typha;
- Dredging of upstream areas to bridges that are heavily infiltrated with aquatic plants such as Typha and are prone to flooding and surges of water.
- Design dams with bridges that have largest possible sizes of culverts or with pillars that are spaced with maximum possible spans. The same applies to ordinary bridges;
- To designing and construct bridges in a manner that does not allow ponding of immediate upstream areas.

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APPENDIX

Spillway before the initial rehabilitation works July 2010. *(Photo: Mumba Kolala).*

Pieces of collapsed pillars & ripped off the concrete slab of the stilling basin. February 2012. *(Photo: Mumba Kolala).*

One of the two (2) severely fractured pillars that were left standing. February 2012. *(Photo: Mumba Kolala).*

Traces of Typha debris left behind hanging on one of the pillars. February 2012.*(Photo: Mumba Kolala).*

Stilling basin with deposited debris of some of the masses of Typha Plants that bypassed the spillway after the attempted failure February 2012 *(Photo: Mumba Kolala).*

A floating island of Typha plants about to drift after others had moved & caused damage. February 2012. *(Photo: Mumba Kolala).*

Note that all photo by Mumba Kolala