AUTOMATIC SELF OPERATING SPILLWAY GATES: A NEW AND INNOVATIVE DEVELOPMENT IN DAM RAISING AND CONSTRUCTION

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ABSTRACT

Increasing the storage capacity of existing dams and reservoirs has become a necessity in many arid countries as new dams may not be possible. The change in climatic patterns, accumulation of sediment and the increased demand in domestic, industrial and agricultural sectors are the drivers for the need for increased storage. Dam owners need to consider raising the FSL of existing dams in order to secure sufficient storage to mitigate the risk of water shortages which adversely affect the potential for economic growth.

Various options are available to the dam engineer to find a suitable solution to this problem while complying with Dam Safety and Environmental requirements. This paper deals with the options available and evaluates the advantages and disadvantages of these options. Often the solution is a combination of gates rather than just one option.

Amanziflow Projects have developed a range of automatic self-actuating spillway gates which are not reliant on electro-mechanical mechanism to operate the gates. These gates provide a safe and reliable solution to raising dams especially at remote sites. The various design features of these gates are dealt with in this paper and reference made to past projects. Raising dams using automatic self-actuating gates makes economic sense and can be done in a shorter time than the conventional raising of dams.

1. INTRODUCTION

Spillways have the most important role to play in the safe operation of dams. The safest and most reliable form of spillway is an ungated spillway. However, in many countries in the world there is an increasing need for increased storage and gated spillways are an economical way of achieving this. Further, with the reassessment of design floods, a large number of spillways need to be upgraded to pass larger order floods. Sometimes, due to the topography of the dam site, the only option is to deepen the spillway in which case gates are sometimes required to maintain the full supply level (FSL).

When a spillway is gated, proper and reliable operation of the gates is critical to pass floods. This paper discusses the various options available to the designer in the choice of gates and specifically on automatic self-actuating water control equipment as they are the most suitable for developing countries.

2. THE DIFFERENT SPILLWAY OPTIONS

In the case of spillway upgrades the designer must make one of two decisions as shown in Figure 1.

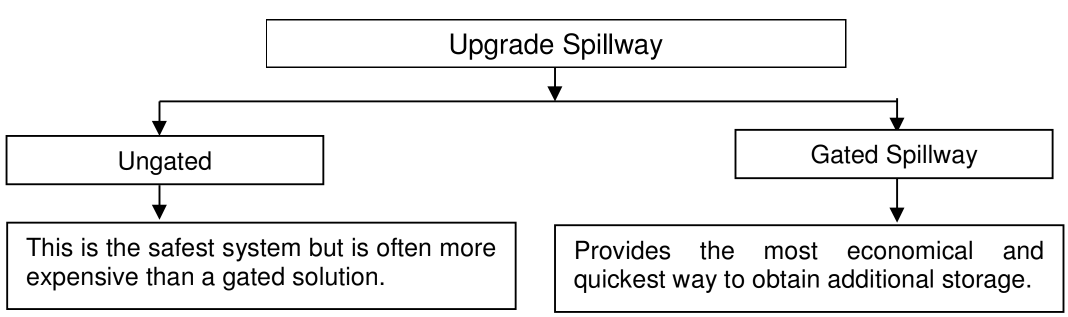


Figure 1. Spillway Options

2.1 Ungated Conventional Construction

This is done using conventional methods of quarrying for additional fill and or rock, placing and compaction to the existing embankment to provide additional strength required for the raising. The spillway and abutments are raised in mass or reinforced concrete and often are also anchored to the rock to provide additional stability.

There are reasonable adverse environmental impacts in providing the construction materials as well as the construction activity of traffic, noise and air pollution and it has a high carbon footprint. Further by providing a fixed raised spillway, the high flood level increases, leading to the purchase of more land above the previous high flood level which will be inundated by the raised high flood level.A fixed raising also does not provide a sufficiently large release of water for downstream environmental flows, nor does it allow for large releases for emergency drawdown.

Raising dams by conventional means is also generally more costly than the alternative as well as taking a longer time to construct and impound water.However, in South Africa, conventionalraising of dams is preferred, for good reasons, over some of the alternatives in raising dams.

With the increasing demand for water and the constraints on funding, conventional raisings should be carefully considered against the advantages of the alterative of an automatic gated system.

2.2 Gated Spillways

Figure 2.gives the various options available for gated spillways.

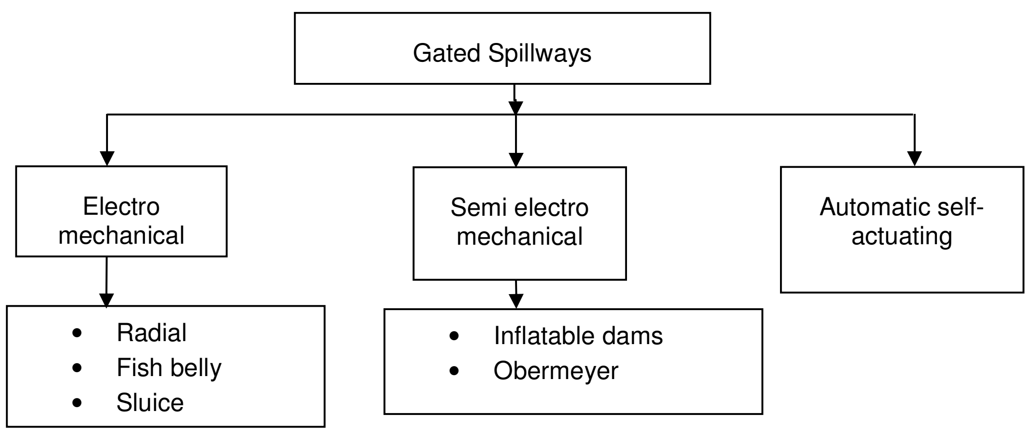


Figure 2. Gated Spillway Choices

The risks and failures associated with electro-mechanically driven spillway gates are clearly indicated in the paper, [1]B W Leyland, (2016) *Strategies for improving the safety of spillway gates*, ICOLD 2016, Johannesburg, South Africa, 16-19 May 2016.

The automatic self-actuating gates do not require any electro-mechanical mechanisms and are therefore more suitable to most sites in many developing countries. In this category of gates there is again a choice as shown in Figure 3.

2.3 Automatic, Self-Actuating Gates

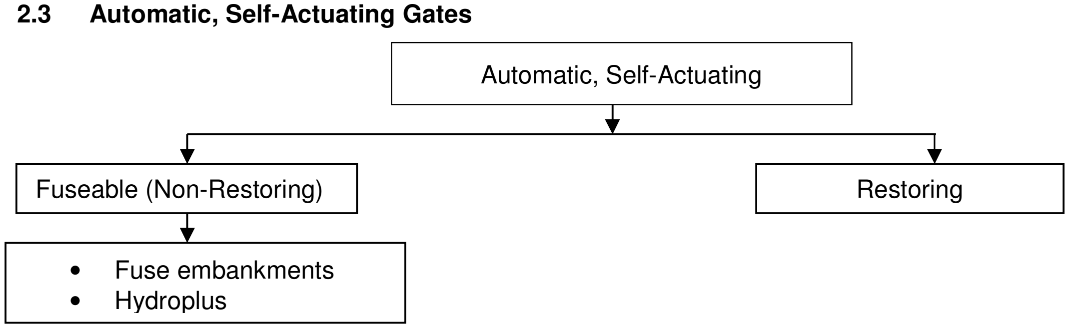


Figure 3. Choice of Automatic Gates

Fuse gates and earth embankments are fixed structures on the spillway which are designed to fail at a certain high recurrence flood event. Once the fuse gate or embankment fails, it passes the flood to ensure dam safety but the additional storage obtained by the raising is then lost. It can then also take some time to restore the fuse such that impounding of the dam cannot commence immediately. These fixed type structures also cannot release water for environmental purposes nor provide for emergency draw-down releases.

Their use is therefore limited for dam protection for extreme flood events only.

These fuse gates are covered comprehensively by [2]Lempiere F, Vigny J-P & Deroo L (2012), *New methods and criteria for designing spillways could reduce risks and costs significantly,* Hydropower and Dams, issue Three, 2012.

2.4 Automatic, Self-Actuating, Restoring

Figure 4 indicates the types of automatic, restoring gates available.

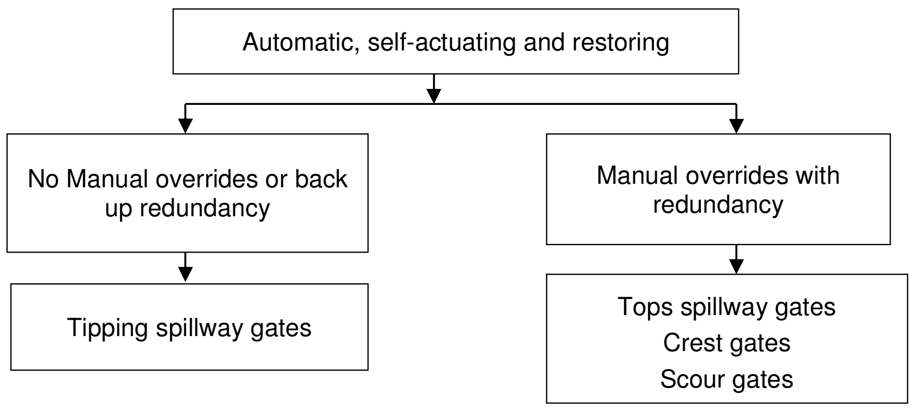


Figure 4. Choice of Restoring Gates

Counterbalanced gates consist of a heavy counterweight protruding into the water. This counterweight moves up and into the flow path as the gate opens thus providing an obstruction to flow, leading to instability and debris packing on the counter weights.

These gates cannot be easily opened or closed manually to release water for emergency draw down or other such need to discharge large flows, nor do they have back up redundancy features.

2.5 Fully Automatic Gates

These gates are developed in South Africa for extreme climates and flood events. The gates have been proven to be reliable and robust over some 30 years of installation. They are fully automatic to open to pass floods and to close automatically to retain the increased storage or FSL. These gates all have manual opening and closing devices for rapid draw down if required as well as having back up features for redundancy.

There are three types of gates, each with specific applications.

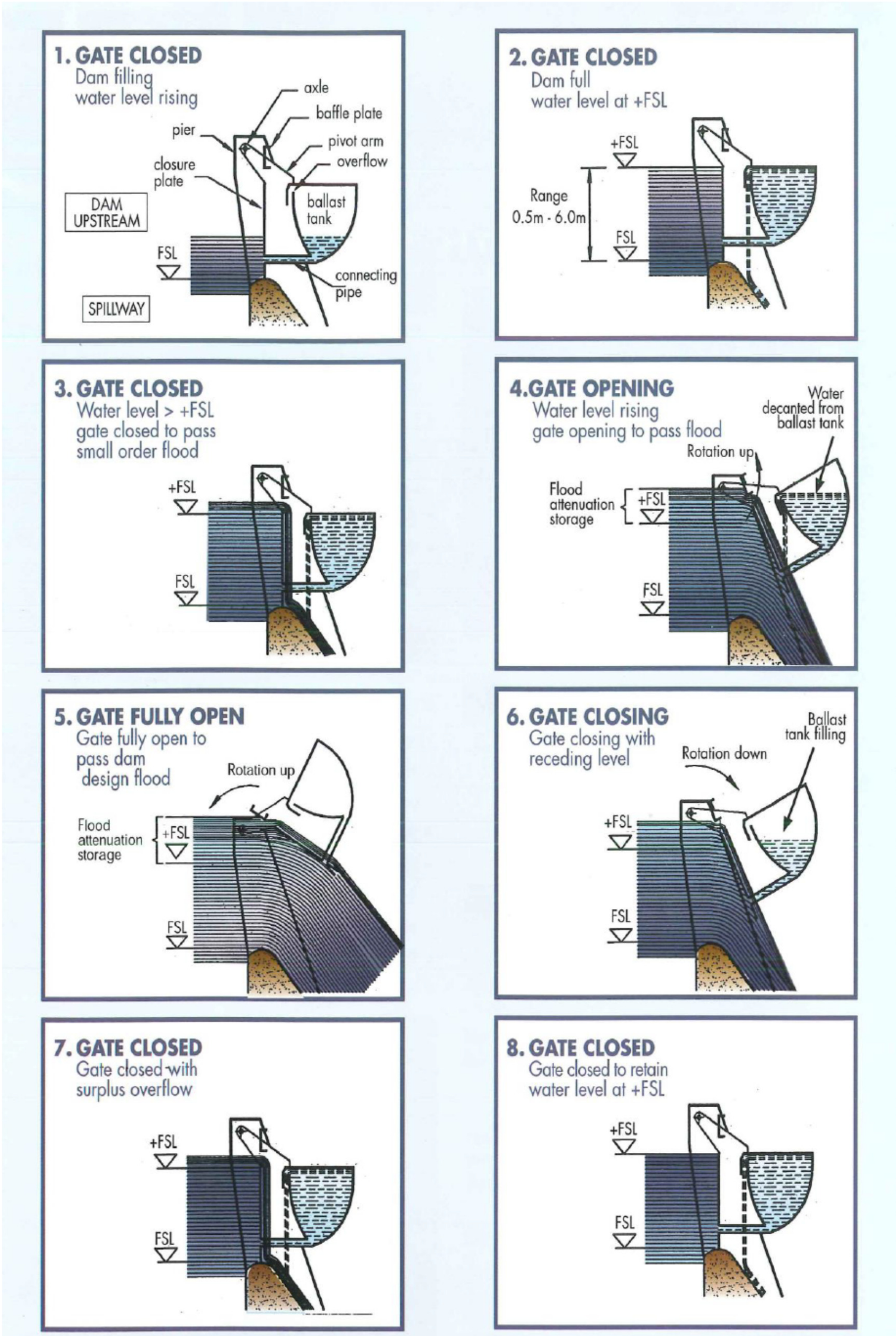
These types of gates can be found on website: www.amanziflow.co.za.

2.5.1 TOPS Spillway gates suitable for ogee and side channel spillways

These gates attach to an existing spillway to increase the water level in the dam. When a flood occurs and the water levels rise over the gates, the gates will open automatically and sequentially to release the flood waters in proportion to the inflowing flood hydrograph. These gates therefore safely pass floods through the dam.

When the water level recedes after the flood has passed, the gates will close automatically to retain the increased full supply level.

The working of the gate is shown diagrammatically in figure 5.



Therefore water forces alone will ensure that the gates open and close. There is therefore no requirement for an operator to open or close the gates.

Figure 6. TOPS gate open to pass flood water on Mnjoli dam, Swaziland

These gates were first installed on the Belfast dam, South Africa in 1997 and since then a number have been installed around Southern Africa. Two sets of gates, namely Avis dam in Namibia and the Rundu River weir in Zimbabwe, have already opened and closed automatically under flood conditions.

The Tops gate consists of a water ballasted tank attached by pivot arms to overhead axles supported on piers. As the water level in the dam increases, the gate will open automatically and as it rotates upwards, water is decanted from the ballast tank to make the gate lighter and so it opens easily in response to increasing water levels in the dam. The reverse applies when the water level in the dam recedes; the gate fills with water to eventually close automatically.

The Tops gate is also stable compared to radial gates because it has upstream pivots with the support arms in tension as opposed to radial gate arms which are in compression. The increased mass due to water in the ballast tank dampens out oscillations.

The largest Tops gate is 4m high, although gates up to10m high in concrete have been designed. For larger gates of greater than 3m high, they have an added advantage in providing an access way across the gates which can even be used by light vehicles.

The TOPS gate is used on ogee type spillways, but it is the only effective type of gate for side channel spillways with a flat sloping spillway channel as illustrated in Figure 7. below.

Figure 7. Avis Dam Namibia: 3m high TOPS gates on a side channel spillway

The TOPS gate has also been used as a scour gate to provide a large scour discharge for an 8m high river weir as illustrated in Figure 8. below.

Figure 8. 4m high TOPS gate, an effective scour gate on the Rundu river weir, Zimbabwe

The TOPS gate has also been modified for estuarine regions to act both ways to pass floods from inland into a tidal estuary, but will close automatically for high tides to prevent flooding inland by sea water as seen in Figure 9 below.

Figure 9. TOPS estuarine gate on the Karatara river at Sedgefield, South Africa

2.5.2 FDS Crest Gates

These gates have been installed on a number of dams and weirs in Southern Africa as illustrated in Figure 10. below.

Figure10. 2m high Crest Gates

The earliest crest gates are nearly 35 years old on the Little Fish River in the Eastern Cape. They have all withstood large floods and have worked well to automatically open to pass the floods and to close again once the water level has receded to its FSL. The largest gates to date are 3m high on the Umtata River hydro Scheme but larger gates can be designed.

These gates have a buoyancy tank which floats and seals against the upstream face of an ogee type weir to raise the water level. The gate is attached to pivots set in support piers protruding upstream of the spillway. As the water level rises, the buoyancy tank fills with water and sinks to submerge below the spillway crest thereby providing an unobstructed spillway to pass the flood. As the water level drops in the dam or weir, the tank is drained and the gate then floats to its fully closed position.

These gates are ideal for river weir and dams where there is a high debris load to discharge debris over the spillway**.**

The Crest gates work well in conjunction with Scour gates on river weirs to provide a relatively free weir for river storage and take offs to pump stations and canals. Refer to Figure 11. below.

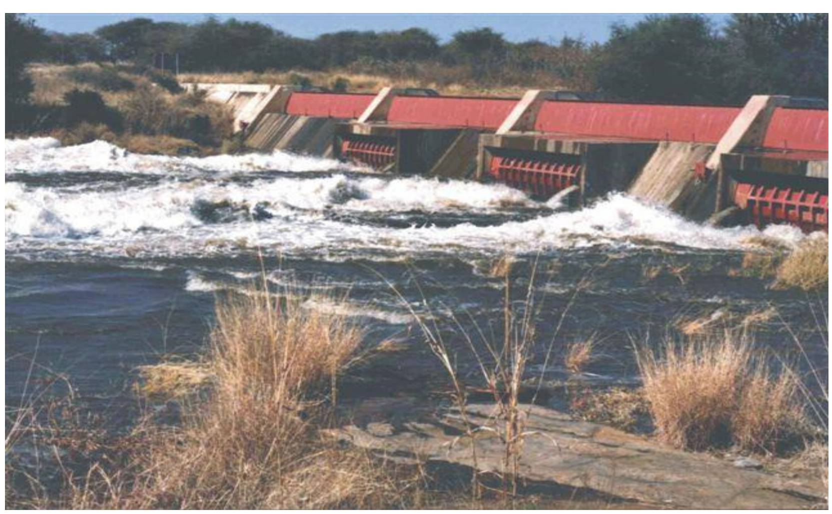


Figure 11. Crest and scour gates on the Tswasa weir on the Groot Marico River, South Africa

2.5.3 FDS Scour Gates

These gates have been in service for more than 35 years at various sites around Southern Africa. Figure 11 illustrates the largest scour gates situated on the Matsoku River; Lesotho Highlands Water Scheme. It opens during floods to keep the forebay to a tunnel free of sediment.

The gate is situated in a concrete chamber in a river weir or small dam. It is a fixed buoyancy gate with a closure leaf closing a scour tunnel through the weir. As the water level rises, water flows into the gate chamber to cause the gate to float and open the scour tunnel. As the water level recedes, the gate chamber is drained and the scour gate closes off the scour tunnel.

The Scour gate is very effective in keeping weirs relatively free of sediments because they open automatically in response to rising water levels when the sediment load is still mobile and passes through the scour tunnel.

Manually operated sluice gates are not effective to desilt weirs as they are often not opened when a flood is running and sediment then settles behind the weir. Once sediment settles and consolidates, it is difficult to remove,especially if reeds have established in the sediment bed.

Figure 12. Large Scour Gate at Matsoku River weir, Lesotho highland Water Scheme

It is possible to recover a substantial volume of storage lost to sedimentation behind weirs and small dams by retro fitting an automatic scour gate. This can be done by a series of successive flushes but only during periods of higher than normal flow in order to recharge to the dam or weir after each flush.

An automatic scour gate can be retrofitted to an existing concrete weir or dam spillway. It requires careful design of the existing structure to accommodate the scour tunnel and float chamber. This work will be constructed against a full head of water and therefore requires careful construction.

However, once the gate is installed, the weir can be flushed a number of times and once most of the sediment is removed, the scour gate will minimize the sediment build up in the weir or dam.

The operation of the scour gate is covered in more detail in the paper [3]P D Townshend, (2011) *The Removal of Sediment using automatic self operating scour gates*, International Conference on Sedimentation, Stellenbosch, South Africa.

3. RELIABILITY OF AUTOMATIC SELF ACTUATING GATES

These types of gates do not require any external source of power, either electrical or mechanical, to activate them. The activation to open and close is automatic and is determined by water levels only.

These gates do not require regular maintenance or control systems and consequently are suitable for dams in remote locations.

They have the following added advantages:

- There is no requirement for operator involvement to actuate the gates.
- The high flood levels are lowered and therefore land compensation costs are minimized.
- They open manually to release large flows for environmental purposes when required.
- They close automatically to retain the increased full supply level.
- The gates have built in redundancy, and have been proven at a number of installations over a period exceeding 35 years.
- They are generally more cost effective and quicker to install than fixed type of spillways.

  These aspects of the automatic, self actuating gates are adequately explained in the paper [4]P D Townshend, (2012) *Safety and maintenance issues associated with automatic, self-regulating gates,* SANCOLD Conference, South Africa.

4. SUMMARY

The matrix of features in Table 1 below will give the designer an overview of the relative merits of each type of hydraulic structure for dam raisings. Ideally one would require a gate to be as flexible in operation as a mechanically driven radial gate but which would not be reliant on mechanical or electrical power to operate it, which poses the possibility of dam safety being compromised.

However, a series of fully automatic, self-actuating gates exist to open and close when required. They have been tested and proven reliable under flood conditions. They can be used with confidence without compromising dam safety and are particularly useful and applicable to dams in developing countries. They provide the required flexibility required to safely operate dams.

However, for large dams, a combination of flexible fully automatic and non-flexible fusible gates should be considered for total dam safety.

Table 1.Spillway Gates Alternatives

Type Spillway	Ungated	Gated			
Features	Conventional Raising	Mechanical	Semi-Mechanical	Fuseable	Fully Automatic
Cost	X	X	√	√	√
Environmental	X	0	√	√	√
Maintenance	√	X	X	√	√
Retain storage after large floods	√	0	0	X	√
Time to construct	X	0	0	√	√
Reliability	√	X	0	√	√
No operator or external power required	√	X	X	√	√
Emergency draw-down / large releases	X	√	√	X	√

X = Disadvantages **0 = Possible Disadvantages** **√ = Advantage**

5. ACKNOWLEDGEMENTS

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5.1 Amanziflow Projects (Pty) Ltd, Johannesburg, South Africa

5.2 Royal Swaziland Sugar Corporation for Mnjoli dam raising Swaziland, Figure 6.

5.3 Windhoek City Council, Namibia for Avis Dam Namibia raising, Figure 7.

5.4 Murowa Diamond Mining, Zimbabwe for scour gate on the Rundu River, Figure 8.

5.5 Knysna Municipality, South Africa, for the estuarine gate on the Karatara River at Sedgefield, Figure 9.

5.6 Department of Water and Sanitation, South Africa for gates at the Tswasa weir, Figure 11.

5.7 Lesotho Highlands Water Authority, Lesotho for large scour gate on Matsoku River, Figure 12.

6. REFERENCES

1 B W Leyland, (2016) *Strategies for improving the safety of spillway gates*, ICOLD 2016, Johannesburg, South Africa, 16-19 May 2016.

2 Lempiere F, Vigny J-P & Deroo L (2012), *New methods and criteria for designing spillways could reduce risks and costs significantly,* Hydropower and Dams, issue Three, 2012.

3 P D Townshend, (2012) *Safety and maintenance issues associated with automatic, self regulating gates,* SANCOLD Conference, South Africa.

4 P D Townshend, (2011) *The Removal of Sediment using automatic self operating scour gates*, International Conference on Sedimentation, Stellenbosch, South Africa.