Hydro Review: Safer Spillway Gates

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A 12-m-wide by 4-m-high TOPS gate installed on the Runde River in Zimbabwe

By Bryan Leyland

I have always been concerned about the safety of spillway gates. Fifty years ago, I was horrified to discover that some of my civil engineering friends believed it was easy for mechanical and electrical engineers to provide highly reliable lifting gear. As an electrical engineer, I knew it wasn't true!

Since 1970, I have been involved with the design, fabrication and commissioning of many gated spillways, and my hydro consulting firm put a lot of effort into devising highly reliable gates and lifting gear.

One of the better examples was two 10 m by 10 m radial gates with backup operation from an emergency oil pump powered by a small turbine driven by water that overflowed when the water level was dangerously high. This has now been in successful operation for more than 30 years.

The best was a 5 m by 5 m gate that was counterweighted to open and held closed by another counterweight in a vertical shaft. If the water level became too high, the vertical shaft was flooded, reducing the force exerted by the counterweight and so allowing the gate to open. It has operated many times each year for more than 30 years. As far as I know, it has never failed.1

The worst was a backup system powered by cylinders of nitrogen gas. It had the major shortcoming that it opened the gate all the way. This was revealed during construction when a painter hung his paint can on the trip mechanism. The resultant flood could easily have put someone’s life in danger. This taught us that gates that open when they don’t need to can also be dangerous.

More recently, I have been working for the World Bank in developing countries as a member of dam safety panels on new and existing dams. On one new dam, the consultant proposed a large number of small radial gates each with winch operating gear but with a single backup power supply and a single control system. I was able to identify six separate failure modes (one was an invasion by Al Qaeda) that would disable all the gates. I also discovered that the briefing for the mechanical and electrical engineers did not even mention the need for extremely high reliability! Reliable they were not!

Based on this experience, I have concluded that the minimum requirement for reliability for a conventional radial gate with hydraulic lifting gear would be:

- Two independent automatically started diesel generators with air cooling and hydraulic starting for maximum reliability;
- A remote control system (if needed);
- A normal control system that would regulate the water level at any desired value; and
- A backup control system for each gate that would open the gate if the water level was dangerously high and prevent more than one gate from opening if the water level was normal. This would guard against hackers stopping the gates from opening in a flood or opening all of them under normal conditions.

I do not think there are many systems in the world that provide anywhere near this level of safety.

I have seen a dam in the U.S. where there were 24 vertical lift spillway gates lifted by a pair of gantry cranes that needed to drop a grabbing device into flowing water to remove the gates. Five operators were required for this operation. If the upstream dam failed, there was no chance that the gates could be removed in time to avoid the flood overtopping the dam.

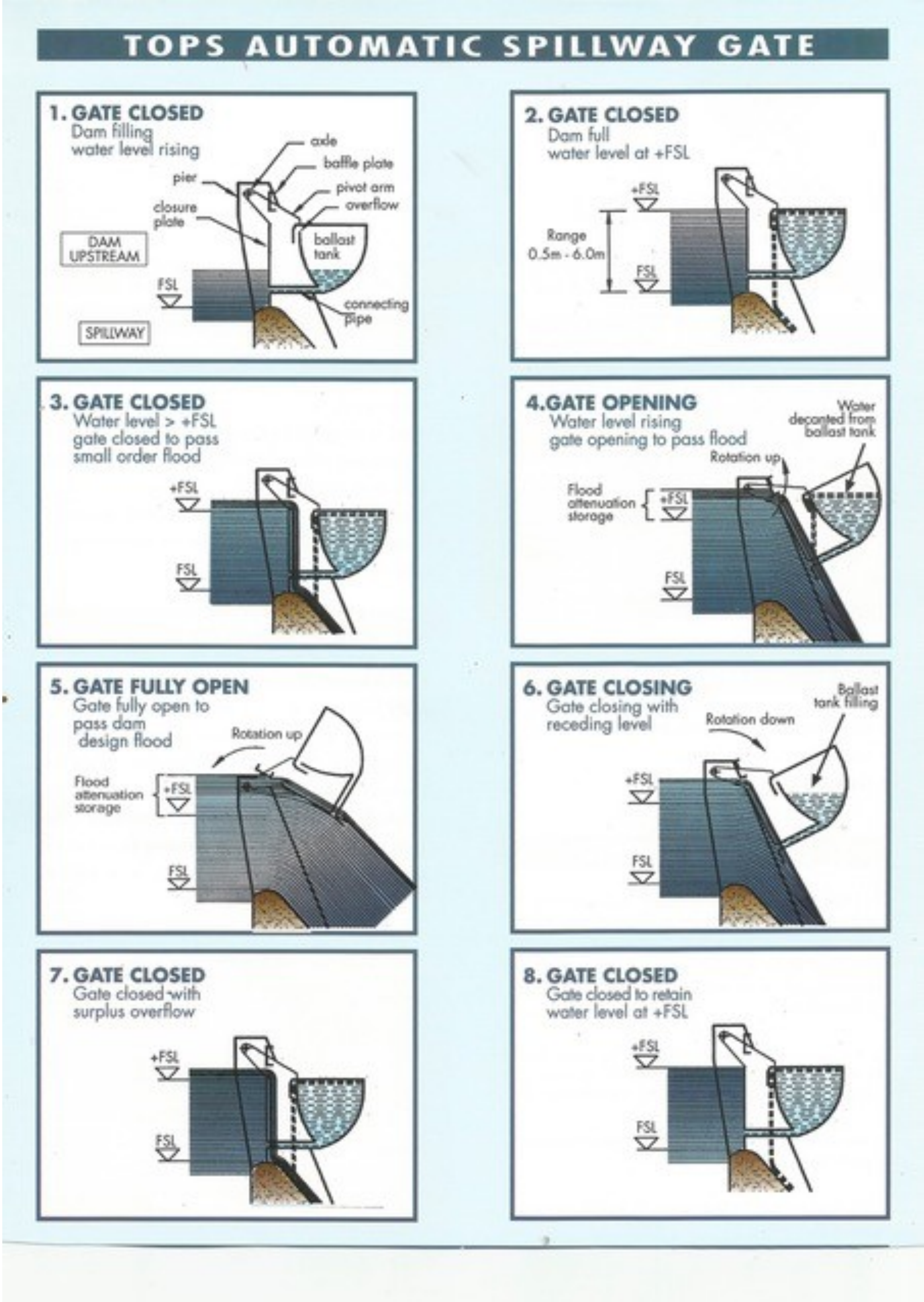
Another example is three irrigation dams in a developing country: one has gates that have never been commissioned and are stuck two-thirds open; another relies on a single diesel generator and, anyway, all three pumps on the hydraulic pumping unit have failed; and the third relies on a decrepit portable generating set sitting in the loading bay. All three dams are at serious risk.

Worldwide, many dams have failed because the spillway gates did not open and many more are at risk of gate failure. The hydropower industry must do better.

A unique approach

A few years ago, I became aware of the TOPS gate, developed and manufactured by Amanziflow Projects in South Africa.[2] The TOPS gate is ingenious and simple: It needs no external power supply, operates in response to water level, can be opened remotely, cannot be prevented from opening by a control malfunction and has no obvious mechanism that would cause it to fail to open. A dream come true!

The figure below illustrates operation of this gate.



The TOPS gate operates using a ballast tank that fills or empties in conjunction with the reservoir level.

The TOPS gate consists of a tank with a pivot above the lake level. Ducts connected to the upstream water keep the tank full of water at the level of the lake. When the water level is in the normal range, this gives the tank sufficient weight to hold it in the closed position. If the water level rises, water will spill over the top of the gate and, as the tank is already full, the force on the gate soon exceeds the weight of the water in the tank and the gate begins to open. As the gate opens, water drains out of the tank, which reduces its weight and allows it to open even more. In a major flood, all the water drains out of the tank and it floats on top of the nappe, providing only a very small restriction to the spillway flow.

When the flood abates, the tank descends and fills with more and more water, thus restricting the flow to maintain the upstream water level. As the flow continues to decrease, the tank continues to fill with water and finally the gate closes completely.

It is possible to open the gate at any time simply by opening a drain valve in the tank. This can be done locally or remotely.

It is difficult to envisage a situation where this gate would fail to open. If the friction in the pivot bearings increases, it will mean the lake level must be higher than normal to open the gate and this, in itself, should flag the problem. As the force on the gate will increase steadily as the head level rises above normal, it is hard to imagine that increased bearing friction would be able to stop the gate opening most of the way. It is also difficult to imagine how problems with the seals would prevent the gate opening. The gate moves away from seals rather than sliding, and there are very high forces available to overcome any seal sticking. Once it is overcome, the gate will open normally.

This photo shows a 12-m-wide by 1.5-m-high TOPS gate on the Mnjoli Dam in Swaziland. The gate is activated by a siphon and has opened automatically a few times already.

A number of TOPS gates have been installed on dams in southern Africa with, as far as I know, no problems at all. The biggest gate so far is 12 m by 4 m, but Amanziflow has done design studies on gates up to 30 m long and up to 10 m high. Other studies indicate that it is about 30% lighter than an equivalent radial gate and, when the savings from eliminating the lifting gear and power supply are factored in, it should be considerably cheaper than a conventional gate.

As a 20 m by 10 m gate would pass about 1,000 m3/s of flow, it would seem that TOPS gates are a simple, reliable and economic way of passing flows up to 5,000 m3/s or, in some circumstances, even more.

The civil works for the gate consists of two pillars to carry the pivots and sealing arrangements at the end of the gate and along the bottom. The loading on the pivot is carried in compression, rather than tension. The gate is relatively easy to retrofit on an existing dam because the pivot is above water level and relatively simple and installing the bottom and end seals is not difficult.

There must be hundreds of dams in North America and through the world that rely on flashboards or other decrepit and obsolete gate systems. If they were replaced by a TOPS gate, it would be much safer and much more reliable and would often provide an increased head.

To my mind, the TOPS gate is a quantum leap in gate safety, and it should be at the top of the list whenever a gated spillway is contemplated or obsolete gates need to be replaced.

Author bio
Bryan Leyland, MsC, DistFEngNZ, FIMechE, FIEE (rtd) has more than 50 years of experience in the hydropower industry. He had his own consulting company and is now semi-retired. He is the author of *Small Hydroelectric Engineering Practice*.

Notes

1http://www.bryanleyland.co.nz/hydropower.html
2https://www.amanziflow.com/file/596c5fe22510a/automatic-spillway-gates-to-remove-problems-with-electro-mechanical-gates.pdf