Refurbishing and Upgrading Old Spillway Gate Installations

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SYNOPSIS Many old spillway gate systems are approaching the limit of operating life in their present form. The majority were designed and constructed robust, with little or no redundancy, and incorporate many single point and common cause failures. Design deficiencies, age and degradation present a reliability risk to the dam system and the downstream population. The paper sets out the requirements for safety and reliability, how these can be attained and to what extent, recognising the wide variations in installation design and condition. The degree of reliability obtained as a result of upgrade and refurbishment must be consistent with that required by the dam consequence category.

INTRODUCTION

Many old spillway gate installations, some dating back to early last century, are still in operation. Installations in service dating from the 1930s to 1960s are mainly of the vertical lift type. Radial gates, called Tainter gates in the USA, became more widely used later on because of advantages such as absence of overhead structure, gate guide channels and reduced hoisting forces. Although J.B. Tainter obtained a patent for a segment gate in 1886, the first installations (by M.A.N. of Germany) were not constructed until the 1930s. Radial gates have become dominant for spillways and vertical lift gates have remained the first choice for low level outlets or gates in tunnels.

There have been failures of spillway gate installations, resulting in extreme cases in dam collapse, such as Machhu II (India, 1979) when gate malfunction during a catastrophic flood caused overtopping and washout. It was estimated that 2000 people were killed. At Tous (Spain, 1982), which failed by overtopping during an extreme flood event, 16 were killed. Foster et al (2000) suggests that about 13% of dam failures are associated with a spillway gate.

Improvements in reservoir construction, operation and maintenance. Thomas Telford, London, 2006

IMPROVEMENTS IN RESERVOIRS

During the 1987 floods in southeastern Norway, 19% of dam owners experienced gate operating problems (Hinks & Charles, 2004). Other reported problems included communication (23%), damaged access roads (17%) and blockage of spillways (10%).

Some gate failure incidents outside Europe are documented in United States Society on Dams (2002).

In the last decades, dam safety has become more prominent and has been analytically examined. There has also been a greater realisation that spillway gate installations are part of the dam system, and need to be reliable so that the dam system can safely retain and effect controlled release of water. The analysis can become complex in the case of a river system comprising a number of gated dams, each one having different ownership and different reservoir storage capacity.

While old spillway gate installations may be robustly designed, they tend to reflect industrial practice which relied on timely repair of failed components, rather than on the availability of redundancy, diversity and independence. In a few instances it was recognised that some backup equipment was required, mainly in connection with electric motors.

Increased demands, greater complexity of operation, more stringent control systems and quantification of risks have shown that old spillway gate installations may not meet minimum reliability requirements. The operating mode of older facilities has been changed from local to remote automatic. Dam owners face increasing and more diverse demands on water use, both upstream and downstream of the dam. They can no longer assume sole proprietorship on the water, but have to exercise greater responsibility in properly controlling the release of water to satisfy society's expectations on safety and duty of care for the environment. This sometimes requires revision of the operating regime and relatively frequent updates to emergency response plans, e.g. for floods.

In recent years there have been considerable advances in seismic and flood design and data availability. In seismically active or flood prone areas, dam owners increasingly find that the initial design parameters may be too low to meet modern-day standards.

Additionally age, wear and design deficiencies may render it necessary to upgrade the installation as far as is practical. However, operational demands on spillway gate installations may be infrequent so the amount of effort spent on gate maintenance and testing may have diminished over the years, a situation often exacerbated by inadequate maintenance budgets, shortage of knowledgeable personnel due to staff turnover, and pressure from competing priorities. This means that dam safety is not only threatened by an extreme load event (probable maximum flood or maximum design earthquake), but also by a relatively small normal load event (say 1 in 200) which could have been avoided by the dam owner exercising proper duty of care.

STANDARDS OF RELIABILITY

Ballard & Lewin (2004) proposed a set of reliability principles. The authors suggest that for systems intended to provide some type of standby function, where the reliability measure is probability of failure on demand, a well designed and operated system should be able to achieve a reliability of approximately 10^{-3}. A high integrity system intended for a safety function should aim to achieve a standard of approximately 10^{-4}.

It requires careful design to achieve reliability of 10^{-4} for the mechanical and electrical aspects of spillway gate installations. Upgrading an old installation to that standard could be difficult or uneconomical. Nevertheless, a reliability assessment can identify the significant contributions to failure. Figures derived for reliability should be of an order of quantity since wear and degradation are difficult to assess.

ISSUES REQUIRING INVESTIGATION AND RESOLUTION

Provision of adequately reliable standby electrical power arrangements

Mains supply is vulnerable during a flood or storm. This is particularly the case where hurricanes are an annual event, but also applies wherever a tendency towards more extreme weather has been predicted as a consequence of global climate change. At sites where there is an earthquake risk, overhead mains supply is often the first casualty.

Standby generators are a requirement at spillway gate installations. Manual winding is not, in the majority of cases, a realistic alternative. Diesel engine driven standby supply has a high probability of failure on demand. For good reliability two units are required, or two portable diesel engine drive units which can be coupled to the hoist. Diesel engines which are not regularly tested on load have a very poor reliability record.

Installation of robust electrical power distribution with redundancy for gate operating equipment

Older installations – and even some recent ones – were designed on industrial lines with no redundancy and are subject to single point failure. The exception is equipment that can be repaired in the time between receipt of information of a flood event and when gates have to be raised, provided the gates are tested at the appropriate time to identify any failures.

Adequate segregation and protection of standby and operating equipment
Standby generators are frequently located in the same chamber as electrical switchgear and distribution. In the event of a fire, the whole installation becomes non-operational. Segregation should also be provided for electrical feeds to the gates. Cable runs to several gates in the same duct or cable tray can result in a common cause failure.

Improved protection against hazards such as lightning and fire
Lightning protection is not provided at most spillway gate installations, even at locations subject to electrical storms. Grounding grids may not meet contemporary standards. For vertical lift gates with steel overhead structures and high level hoist equipment, it should not be assumed that a conducting path is provided even if earthed. Stray high currents occur during a lightning strike. They can cause welding together of moving parts, cable insulation failure or control cubicle breakdown. Portable fire extinguishers should be provided at all spillway gate installations, particularly near generator enclosures.

Comprehensive assessment of seismic resistance
Where there is a seismic risk, the possible effects on gates and overhead structures are usually investigated. The assessment is not always extended to include the security of bolting of standby generators, or the possibility of overturning of transformers and control cabinets. Electrical switchgear fixed to the wall using wood screws has been observed, as well as fuel tanks supported by an inadequate base. Batteries for starting diesel alternators are frequently positioned so that they can slip off their support bank.

Maintenance of gate roller bushes at vertical lift gates
Lubrication facilities were provided for roller bushes at the guide wheels of lift gates. Self-lubricating bushes were fitted in North America from the 1940s onwards. However, in some cases the bearing pins were steel and were subject to corrosion. Even if bearings were originally sealed to prevent water ingress, seals could have degraded and may not have been replaced. Seizure of bearings is frequent. Replacement by self-lubricating bushes and fitting new roller axles machined from austenitic stainless steel is required at many vertical lift gates.

Maintenance of seals
At some old vertical lift gates where staunching bars seal the sides, flats have developed. Elastomeric seals may last 20 to 25 years, longer at bottom outlets where they are not subjected to sunlight. Delaying seal replacement

can cause local erosion where persistent leakage occurs, and at higher head gates vibration can occur. The potential to cause gate vibration can be recognised when side seal leakage becomes periodic. Discharge at sill seals is a cause of gate vibration (Lewin, 2001). Appreciable side seal flow discharge at staunching bars has also been observed.

Reliable reservoir water level instrumentation

Upstream water level is a key operation indicator. Two instruments are a minimum, arranged to compare output. Three instruments, controlled using PLC (programmable logic control) on a voting basis should ensure high reliability. Location should also be reviewed to ensure that instrument outputs are not affected by velocity head.

Formal staff training

Periodic tests give operating staff an understanding of and familiarity with the normal functioning of the flood discharge facilities and any alternative modes of operation. They also provide opportunities for fault diagnosis. All staff who may be required to operate gates should be rostered to take part in regular tests. A related issue which must be taken into account is the possibility of human error in gate operation (Hinks & Charles, 2004).

Planning of major maintenance and replacement operations

Elastomeric gate and machinery seals are subject to degradation and replacement should be pre-planned before serial failures are likely to occur. Couplings, brakes and limit switches without backup are sources of single point failures. Monitoring should provide data for planned replacement. Electric heaters to prevent freezing of seals, to maintain lubricating and hydraulic oil temperature and to avoid ice formation which can impede gate operation are subject to low reliability. Pre-planned replacement can reduce operational failures.

Analysis of operational and maintenance records

Operating and maintenance staff should be instructed to provide reasonably detailed reports of the wear of components, operational deficiencies and failures. The analysis of such information is a valuable tool for planning frequency of maintenance and forward replacement.

Spares availability

Spares for old installations are rarely available. In some cases this can necessitate early replacement of major components because sub-assemblies or components are no longer available. A review of spares holding can assist forward planning.

IMPROVEMENTS IN RESERVOIRS

Design problems

At old vertical lift spillway gates which were designed to overflow under some discharge conditions, flow breakers were not correctly designed to break up the nappe. Replacement based on published experience is required in these cases.

Another example of a design problem which needs to be rectified is where structural skin plate stiffener beams located close to the bottom of the gate cause flow re-attachment of the discharge under the gate lip. This can be responsible for serious gate vibration problems (Lewin, 2001; Naudascher & Rockwell, 1994).

PRIORITIES FOR IMPROVEMENT

A reliability assessment will identify a range of deficiencies in a spillway gate installation which have a detrimental effect on the reliability of flood discharge. Not all issues will have the same significance. The cost of improvements will vary appreciably and can be a limiting factor. The most important deficiency may be the one that has the largest single effect, however this may also be the most difficult and expensive to rectify. It may be preferable to address a group of individually smaller, but collectively significant, problems that can be put right reasonably quickly and simply. There is no single simple answer to questions of relative priority.

An evaluation of the relative importance (or the effect on reliability) of remedial works and improvements can act as a guide in the decision making process and form the basis of a programme of work. This can take the form of a simple reliability model of the dam flood discharge facilities, such as that constructed for BC Hydro after an extensive survey of spillway gate installations.

The fault tree model was quantified by generic data on failure rates of systems and components. Although relatively coarse, this model yielded useful information about the order of magnitude of reliability that can be achieved by components and systems. There is no analytical method of adjusting reliability data to reflect the degraded state of equipment due to age and wear.

As an example, a reliability assessment of three 50 year-old spillway gate installations identified the following significant contributors to potential failure:

- Failure of the gate electric motor or associated equipment~30%

- Failure to raise a gate because motors are overloaded due to seized rollers (bearings or debris) ~20%
- Failure of electric power supply to the gate ~15%
- Failure of gate mechanical drive ~15%
- Failure of gate control equipment ~10%

PLANNING CONSIDERATIONS

Unless regular refurbishment is carried out over the years, the scope of work and costs involved in upgrading an old spillway gate system to meet modern reliability standards can be very significant. As part of the asset management process, the dam owner may have to evaluate the need to invest money in gate refurbishment against other priorities, and consider the potential consequences of deferring or failing to take action.

<u>Factors for consideration when prioritising improvements</u>

Function of the gate system within the dam system
What is the role of the gate installation? Is it for flood routing, peak shaving (pre-spilling) or providing fish release? If for flood routing, what proportion of the flood does it discharge relative to other available discharge facilities, if any?

Consequence of gates failing to operate on demand
If a gate system fails to operate in demand, will it lead to dam failure (e.g. by overtopping) or an environmental incident (e.g. fish stranding)? Scenarios involving gates opening inadvertently due to faulty controls, flawed protocols or miscommunication should also be considered. The possible threats to river users, communities and environment, both downstream and upstream, need to be evaluated.

Reservoir and operational characteristics
A single gate system regulating frequent discharges from a reservoir situated upstream of a population centre but operated with minimal freeboard will, arguably, require higher reliability than a vast remotely located reservoir with multiple discharge outlets.

Interim control
If a gate fails to operate on demand or tends to operate without demand, is there a capability for effective intervention? Even in the case of a large reservoir with long lead time to spills, complacency must be avoided.

Maintenance personnel may assume that there is ample response time during which gate problems can be resolved, while operators – for economic or other reasons – may tend to wait until the last minute before implementing a spill, allowing no leeway for repairs.

When setting up a gate refurbishment program over a portfolio of dams, a prioritisation tool can be developed based on the above considerations (Hartford, 2005).

Improving the reliability of a gate installation is not a one-off investment. Dam owners must recognise that a recurrent investment of resources (both money and labour) will be required to upkeep an improved standard of reliability in the long term.

CONCLUSION

More stringent standards for design and greater demands from the public require a high level of reliability from gate installations, which are often critical parts of the dam system. Old installations which may have inherent design defects or may not have been properly commissioned, increasing challenges in allocating maintenance resources, and infrequent operation can lead to dam safety and environmental problems. Gate refurbishment is only the first stage in upgrading reliability. A continuous commitment to regularly maintain and test the gate system must ensue.

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