INFLATABLE GATES – CASE STUDIES AND EXPERIENCES IN THE UNITED STATES

by

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1. INTRODUCTION

Inflatable gates in the United States have been utilized for over 50 years. Case studies in PIANC WG 166 report include a discussion of operation and maintenance issues and detail some of the operation and maintenance concerns of inflatable gates (both rubber gates and steel-rubber gates). The case studies include sites where inflatable gates have worked well and other sites where they have not. A number of these case studies are from hydropower sites but several are flood control applications. There are also several recreational sites discussed. The case studies of Tempe Town Lake and Coon Rapids Dam are examples where failures pushed the operators to return to the "standard steel technology". At both dam sites, the rubber gates were operated under extreme conditions. A number of conditions were not preferable for this gate type and had a significant influence on the expected lifetime of the rubber membrane. Several hydropower sites, however, have had good experience with inflatable gates and they have been in service close to 30 years. The operating mode of inflatable gates greatly influences the lifespan. Rubber gates which are always fully inflated seem to have a longer lifespan including Highgate Falls, Palmer Dam and Curtis Dam. For gates which are seasonally deflated and thus more exposed to debris and sediments (Adam T. Bower, Coon Rapids), a shorter lifespan may be assumed. If the rubber gate is to be deflated, additional inspections may be warranted on a yearly basis and this must be accounted for in the design. In order to avoid vibrations and damage from ice and debris in the deflated position, it should be insured to have a stable position when both deflated and inflated.

Inflatable gates can be effective for water level control and flood control projects and there are several applications such as this in the United States. This is provided that the rubber material is properly reinforced to avoid or minimize air leakage in case of punching loads by floating debris. The attachment of the inflatable gates to piers and to the concrete weir sill is critical and can induce significant stresses on the rubber bladder. Many of the operators contacted for this report point out the cost benefit and the low amount of maintenance of inflatable gates. Regarding operation, most of the operators have comparable requirements regarding the upstream water level control, but it must be noted that the required tolerances are greater for hydropower purposes (Curtis, Palmer, Highgate Falls). Passing debris and ice was not an issue at Highgate Falls, Curtis Dam and Palmer Dam. The operators of Highgate Falls reported no operational issues under extreme cold conditions and ice passing the partly deflated gate.

High temperatures can have a detrimental effect on rubber gates. Since the carcass temperature and environmental conditions are the dominant factor in rubber gate lifespan, it is critical this be accounted for in the inflatable gate design for sites with extremely high temperatures (Tempe, Nine Mile Dam). Water overtopping the dam may help cool the membrane and can be option for increasing the life span. This may not be possible on hydropower dams however. Also, some dams may not have enough flow capacity to do this.

The restraining strap of the steel rubber (SR) gates has been an issue at some dam sites in particular Nine Mile Dam in Washington State. This is generally a problem with the older design and Obermeyer (the primary manufacturer) has improved the system. The restraining straps are an important feature in the design and the design loads must be accounted for. The maximum working pressure puts additional stresses on restraining straps. At hydropower sites, restraining straps could potentially be in tension all the time and this could be an issue and needs to be considered during design.

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2. RESERVATION HIGHWAY AND SAYLORVILLE LAKE DAMS

Reservation Highway is a dam site is located in western Minnesota, United States, and operated by the United States Army Corps of Engineers (USACE). It utilizes steel-rubber (SR) gates that operate in a cold climate and temperatures can drop to minus 34ºC in the winter. The SR gates are normally kept inflated throughout the winter to maintain pool levels of the adjacent lakes. Replacement of an old concrete control structure took place between 1999 and 2001 and a new control structure was installed. The new control structure consists of SR gates for control of lake and pool elevations. Overall, the SR gates have worked well for control of water levels. However, there are some operation and maintenance issues that were noted by the operators. Because of the cold climate, there were issues with ice floes freezing and expanding into the steel plates. The ice can also freeze solidly to the steel plate and the gate will not drop down as intended. However, the dam operators now utilize mixers and deicers to keep ice from freezing on the gate panels. This has worked well. During cold weather operation in the fall and spring, the rubber bladders sometimes cannot be fully lowered. The cold weather stiffens the rubber and prevents a gate setting at the lowest possible position.

At Saylorville Lake in Iowa, all the rubber bladders were replaced in 2011 because the rubber ply layers in the bladders separated. However, this was repaired by the manufacturer and the dam and SR gates now work satisfactorily and no further issues or problems have been reported. This was also one of the early installations for the gate manufacturer. The failure of the rubber bladders was due to delamination of the cured rubber layers and concerns the original design and the 1994 construction and installation. According to the manufacturer (Obermeyer) adhesion testing is now performed on samples of the rubber sheet rolls that are used to produce the bladder. This adhesion testing is now included in their quality procedures. The manufacturing process is now different.

3. COON RAPIDS DAM

Coon Rapids Dam is located on the Mississippi River within the Minnesota (United States) counties of Hennepin and Anoka. There have been many operation and maintenance issues with this dam site since the air inflated rubber gates were first installed in 1995.

Figure 1: Coon Rapids Dam Rubber Gates

Eventually the rubber gates were completely replaced with steel hinged crest (flap gates) in 2013 and 2014. The rubber gates installed in 1995 were replaced in 2001 after only 6 years of operation by the manufacturer. The rubber gates were replaced because of repeated failures and subsequent deflation. No formal independent testing was conducted on the original bladders. However, these failures were generally determined to be caused by deflating the structure in the winter and re-inflating in the spring. This stressed the material where the rubber sections are joined. Leakage and delamination was also observed in the corners where the rubber gates attached to the vertical piers. The rubber gates installed in 2001 shown in Fig. 1 were then completely removed in 2013 and 2014 and replaced with steel hinged crest gates (flap gates). These new steel gates are now operational. Testing and analysis was done on the rubber gates installed in 2001 as part of the PIANC 166 Working Group report.

4. TEMPE TOWN LAKE DAM

Tempe Town Lake is an 0.89 km² (220 ac) urban lake located in Tempe, Arizona, USA. The lake was formed by two air inflated rubber gates constructed across the Salt River bed at the upstream and downstream ends of the lake (upstream rubber gates and downstream rubber gates). The downstream dam consisted of four rubber gates anchored between the abutments and three reinforced concrete piers. The downstream gates were all temporarily replaced after a failure of one of the bladders in 2010. The downstream rubber gates at Tempe Town Lake were then replaced in 2014 and 2015 with steel hinged crest (flap) gates. The steel gates are now installed and operational in lieu of the rubber gates. An engineering investigation of the failure of the downstream gates was done by the City of Tempe and Bridgestone, the rubber dam manufacturer. The conclusion in the report was that the failure was the result of intra-carcass pressurization (ICP). The cause of the ICP was a combination of age of the dam and the environmental conditions (temperature) in which it existed. The age of the dam was over 11 years and the temperatures in the Tempe area are extremely high, often exceeding 37ºC (100°F).

5. ADAM BOYER DAM

Adam T. Boyer dam is located in Sunbury, Pennsylvania, USA. It is advertised as the longest inflatable dam in the world and spans the Susquehanna River at Sunbury, Pennsylvania. The dam is deflated in the fall and inflated in the spring. Between 1984 and 1988 Bridgestone, Ltd. replaced the membranes using a 13.5 mm thick rubber membrane (Fin-type) and switched the filling system to an air-filled type. Additionally spacers were applied inside the rubber membranes in order to allow a fully deflation of the gates. The new rubber gates showed a higher abrasion resistance and performed well during the first years. There are seven rubber gates total that make up the dam. The rubber gates are 2.44 m (8 ft) in height. The total length of the dam is 602 m (1975 ft). There are over 10.4 km (6.5 miles) of supply and return piping for the dam. The original Firestone rubber gates were pressurized with a mixture of both air and water typically half water and half air. When the Bridgestone gates were installed in 1986, only air was utilized for inflation. This is the current design for the dam.

Since the initial installation of the Adam Boyer dam, there have been minor problems with lightning strikes and mechanical problems with one computer and discharge valve. A new control system was recently installed. The rubber gates all had oscillation problems prior to replacement in 1986. Overall, the new control system has allowed for more control of the rubber gate sections especially during times of high water. The rubber gates are inspected in the spring and fall. The site addresses any problems immediately after that. Most of the problems are small cuts that are patched and then repaired. However, according to the site operator, this doesn't happen too often. The site has had problems with stone and rocks washing in and getting under the rubber gates which they try to remove. The dam is on a river that floods a lot so the stones and rocks are a constant problem. A major issue is the bladder replacement if that becomes necessary. It is very labor intensive and dictated by the fluctuating water levels of the river.

6. HIGHGATE FALLS

Highgate Falls is a dam located in Highgate Falls, Vermont, and is a single 4.6 m high by 67 m long (15 ft by 220 ft) rubber gate that regulates pool elevation at a 9.8-MW hydroelectric plant. The rubber gate shown in Fig. 2 was manufactured by Bridgestone. It was made in 1992 and installed at the facility in 1994. The rubber gate at the facility is one of the tallest in the world. Overall, this rubber gate has worked well and experienced few operation and maintenance problems. Access inside the rubber gate is provided at this site. This dam is one of the first in the world to have a pressurized hatchway allowing dam operators to walk inside. Annual inspections of the dam are conducted every August. The operators of the dam reported the rubber gate works well for passing ice.

Figure 2: Highgate Falls Rubber Gate

References

PIANC. (2018). Report of Working Group 166: Inflatable Structures in Hydraulic Engineering. PIANC, Brussels.