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General considerations on the use of inflatable gates on waterways. A review of PIANC WG166

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General considerations on the use of inflatable gates on waterways. A review of PIANC WG166

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1 Introduction

Inflatable gates are relatively new gate types, and are considered to be innovative hydraulic structures. A rubber gate consists of a multi-ply rubber membrane, which is fixed to the weir sill using clamp plates and anchor bolts. The rubber gate is inflated by pumping air or water inside the rubber body until the design height or pressure is reached. It is deflated by allowing the air or water inside the rubber body to escape. A steel-rubber gate is a row of steel gate panels supported on their downstream side by inflatable air bladders. By controlling the pressure in the bladders, angle and height of the steel gate panel can be controlled, and the upstream water level be kept within a required tolerance. Rubber gates have a number of advantages but the main reasons are the capital and maintenance costs which are supposed to be lower than steel gates. The aim of this contribution is to give a summary at the end of the Working Group lifecycle.

The report of PIANC InCom Working Group (WG) 166 “Inflatable Structures in Hydraulic Engineering” (PIANC 2018) is for owners and operators and focusing on the design, fabrication, construction, operation and maintenance of inflatable gates. A previous report of InCom WG26 focused on the “Design of Movable Weirs and Storm Surge Barriers” (PIANC 2006) which briefly introduces rubber gates (also known as rubber dams, rubber weirs or inflatable dams) and steel-rubber gates (also known as pneumatically actuated gates or Obermeyer gates). It is also referred to the report of WG138 “Mechanical and Electrical Engineering – Lessons Learnt from Navigation Structures” (PIANC 2014), where drive systems are described which are utilized in navigation structures and storm surge barriers.

2 Working Group

InCom WG166 consisted of 13 members from seven countries (Fig. 1). On September 23rd, 2013 WG166 held its kick-off meeting in Maastricht during the PIANC-SMART Rivers Conference. Since the kick-off seven meetings took place in Hanover (March 2014), in Tokyo and Osaka (May 2014), in Paris and Dijon (October 2014), in Gent and Aachen (March 2015), in Albany and Burlington (July 2015), in Nimes (January 2016) and finally in Utrecht (June2016).

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The work was influenced by ongoing projects in Belgium, France and Germany where inflatable gates will be applied on water-ways. Guest experts were regularly invited and contributed indirectly to that report. On-site visits to existing weirs, meetings with operators and administrations and technical excursions to manufacturers were arranged. In the end, many more experts contributed in some way to the report.

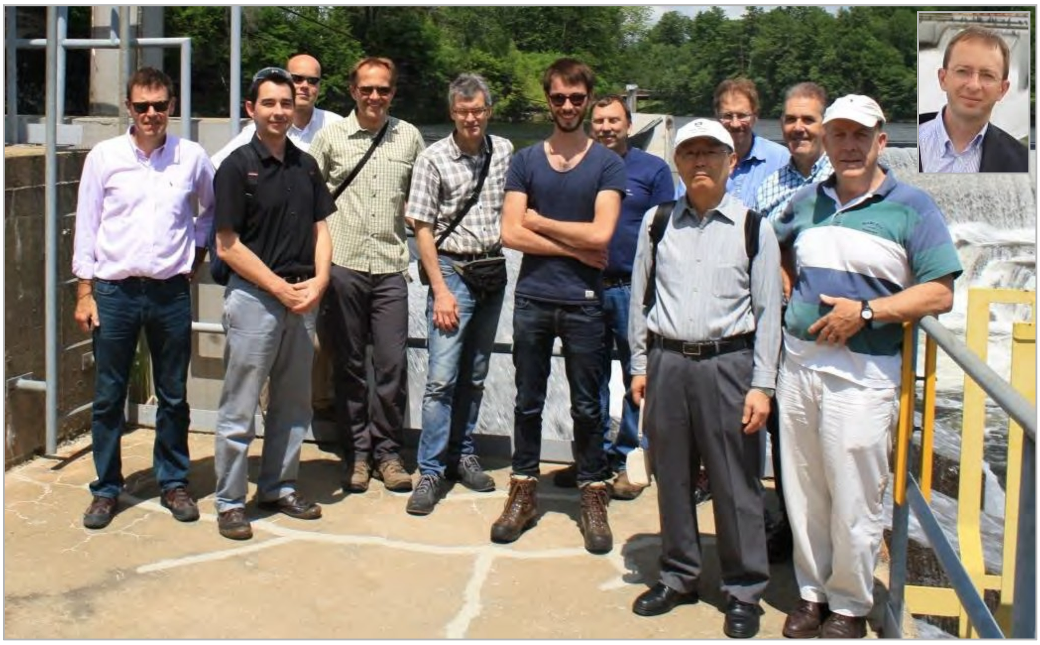

Figure 1: Members of Working Group 166 at Curtis Dam, USA (from left to right): Philippe Rigo, Julien Aubonnet, Peter Jansen, Michael Gebhardt, Thilo Wachholz, Jan-Willem Lechtenberg, Steve Denton (Atlantic Power Corporation), Ichiro Maruyama, Timothy Paulus, Don Mason, Jean-Luc Berterottière and Bart De Heyder (top right)

3 Relevance of inflatable structures for waterways

Rubber gates have a number of advantages when compared with standard steel gates:

- The simplicity and flexibility of the structure is a key consideration in its wide scope of applications. Generally, capital and maintenance costs are considered to be lower than steel gates.
- Moving parts are eliminated (hinges, bearings); no problems due to corrosion or sealing and no lubricants used, which may be harmful to theenvironment.
- Inflatable gates have a high reliability and availability, they can always be deflated to prevent blocking and they are far less affected by settlements or earthquakes.
- Drive mechanisms, such as hydraulic cylinders, electrical actuators or chains (which generally require a great amount of maintenance) are not needed. Inflatable gates are controlled by inflating or deflating leading to a significantly lower level of energy demand.
- The effort for recesses and concrete reinforcement (sill, pier) is lower and the transfer of forces into the weir sill is evenly distributed. Many applications show that rubber gates can be an interesting alternative to steel gates, in particular on sites where they are adapted to existing weir structures.
- The rubber membrane can be installed or replaced within a few weeks so that the construction time is considerably reduced and availability of the movable weir is increased.

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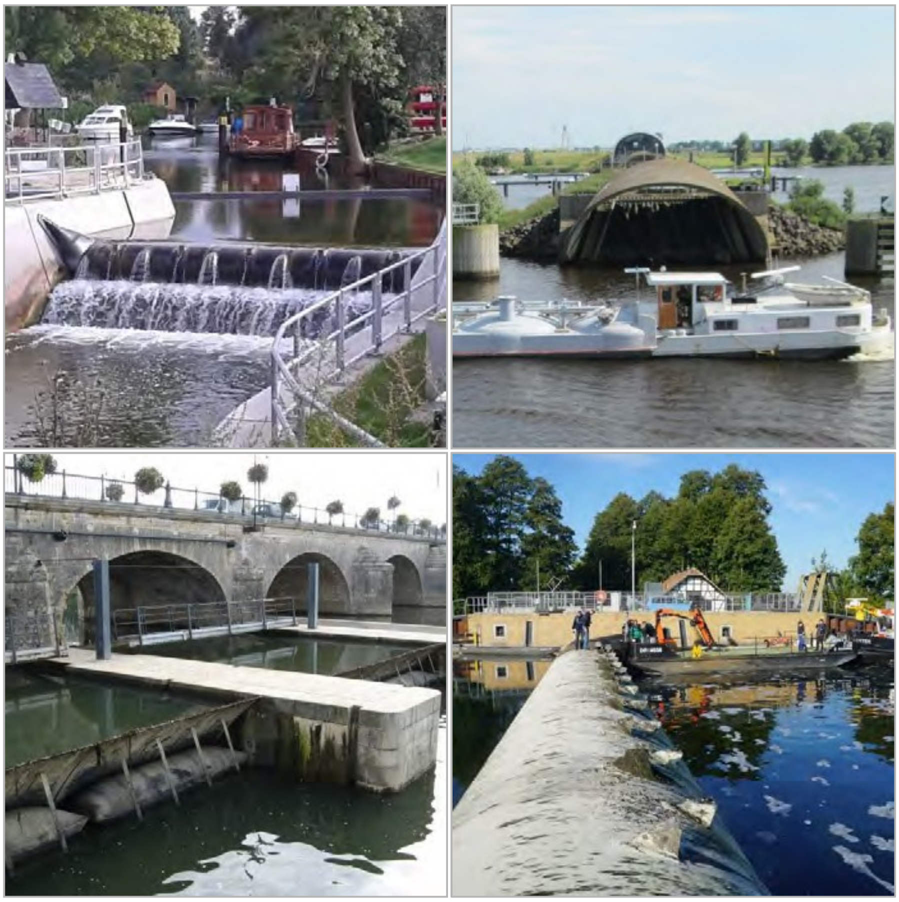
The majority of these advantages apply also to steel-rubber gates, but compared to rubber gates they require some extra maintenance due to the steel gate panels. The capital and maintenance costs are higher. Generally, steel-rubber gates are also simple structures and slightly advantageous regarding the control of flow and water level.

In spite of the advantages, it must also be stated that there are a small number of experienced suppliers and a limited number of manufacturers. Rubber is a complex product requiring special attention for the jointing process or the rubber formula. The report shows the different manufacturing processes in order to inform the reader of possibly weak points of the membrane structure.

Inflatable gates have been used as water control structures for more than sixty years. The world's first rubber gate was installed in Los Angeles County in the USA in the mid-1950s. The first steel-rubber gate was installed at the end of the 1980s. For navigation purposes, the first rubber gate in the German waterway and shipping administration was installed in 2006. Today, five rubber gates are in operation at German waterways (Fig. 2a & d). In the French administration three steel-rubber gates were installed in 2011 (Fig. 2c), and 29 other rubber gates will be installed until 2020 in Northern France. Currently, steel-rubber gates for navigational purposes are also under construction at two sites in Belgium. The Storm Surge Barrier Ramspol (Fig. 2b) is also a waterway application, but a barrier and thus deflated for most of the year. One of the weir spans is navigable for ships. It is still the largest rubber gate ever made since commissioning in 2001.

a) b)



b) d)

Figure 2: Applications of inflatable gates at waterways

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Despite the increasing interest in inflatable gates at inland waterways, the vast majority of inflatable gates were installed for other purposes, mainly irrigation, hydropower, or recreational purposes. The longest list of applications can be found in Japan with almost 4,000 installations. Today, an increasing interest can be found in Asia (China in particular). It is obvious that the number of waterway applications is comparatively small. It is being attempted to provide a comprehensive summary of best practices and to discuss knowledge and experience within the constraints of waterways.

4 Current installations, typical dimensions and lifetime

The report provides an overview of current installations based mainly on reference lists of suppliers and manufacturers. It is not intended to be a complete list, because there is lack of information for instance from China and Eastern Europe. But, it can be assumed that about 5,000 inflatable gates are currently installed worldwide. Today, the largest rubber gate for water level control has a height of 6.0 m and the largest steel-rubber gate has a height of 8.5 m. Regarding the total width the largest weir equipped with rubber gates has a total width of about 640 m, the largest width of one span is about 110 m. Apart from the maximum values the analysis of from about 1,000 inflatable gates installed worldwide shows, that for 88% of the installations the height is less than 3.0 m, for 70% the span width is less than 30.0 m. These average values can generally be considered as typical dimensions of inflatable gates, while the maximum values indicate what is feasible at the moment. In general, inflatable gates are most appropriate for wide spans with a small number of piers, which makes them relatively unobtrusive in the landscape. Compared to rubber gates the number of steel-rubber gates is considerably smaller. Less than 10% of the installations are known to be steel-rubbergates.

With regard to the number of applications it can be concluded that inflatable gates are a proven technology up to a certain limit. It is easy to imagine that setting a limit value for the height of inflatable gates even with proven technology is difficult. In general, the inflatable gate technology is proven up to 3.0 m by a very large number of installations. Up to 5.0 m there are still quite a number of gates with good experiences. For comparison, the application range of the Japanese standard for rubber gates (JICE, 2000) is limited by a height of 6.0 m. Since 1978 this standard gives a solid base for the design and material requirements. Although the Japanese standard doesn´t correspond to other standards worldwide it was the basis for a large number of installations even outside Japan.

Inflatable gates can be used for water level control which is generally the case for hydropower and navigation, although the majority is installed for irrigation purposes, where overflow depth is limited and the rubber gate will be fully deflated above that limit. There exist also a large number of hydropower applications, where the constraints with regard to the upstream water level tolerances are comparable but slightly less restrictive. In order to control the upstream water level for a large discharge range, countermeasures against vibrations, such as deflectors or breakers, have to be adapted.

A property of air-filled types is the so-called V-notch phenomena. A V-notch occurs due to the density differences of air and water. The system becomes unstable and the membrane will be folded or dented. The resulting V-shaped "dent" makes flow rate adjustment difficult and results in a large flow rate per unit width. This is the reason why water-filled types were recommended for the French and German waterway applications. Experiences show, that water-filled rubber gates equipped with a row of breakers allow a regulation of the upstream water level within the required tolerances. For these features, steel-rubber gates have a slight advantage because the gate panels behave like a flap gate and provide a stable nappe separation.

Today, rubber membranes are designed to be UV stable, weather, ozone and heat resistant. According to the Japan Institute of Country-ology and Engineering (JICE) the lifetime of a rubber membrane was originally supposed to be about 30 years for moderate environmental conditions. In fact, about 14% of almost 4,000 installations in Japan are operating more than 35 years with the same rubber membrane. In ten years the proportion will reach 42%. Based on these recent experiences it can be stated that aging didn´t affect the durability of the rubber membrane and the lifetime can be even longer (JICE, 2000).

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5 Conclusions

In recent years, the technology of inflatable gates has been improved and standards have been adjusted as soon as a failure has been detected. Therefore, inflatable gates are an interesting alternative to standard steel gates, enabling savings to be made on the capital spending and maintenance costs, in particular on sites where these gate types are adapted to existing weir structures. An increasing benefit of this technology can be observed, however, failures (although small in number) pushed some to return to the "standard steel technology". Considering this, it is the right time to publish this report and to provide a comprehensive summary of best practices that can be incorporated into the future design of inflatable gates and to aid designers and operators in their preliminary tasks.

WG166 completed about nearly 30 project reviews of inflatable gates which are provided on the PIANC Database (http://www.infrastructure.pianc.directory/index.jsp). Here, projects of inflatable gates are made available next to Navigation Locks and Major Infrastructures.

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