The French Experiment of an Inflatable Weir with Steel Gates

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Zusammenfassung
Die französische Wasser- und Schifffahrtsverwaltung VOIES NAVIGABLES DE FRANCE (VNF) steht vor der Aufgabe, in den nächsten 10 bis 15 Jahren rund 140 handbetriebene Wehranlagen zu ersetzen bzw. zu modernisieren. In einem gemeinsamen Forschungsprojekt mit der CENTRE D'ÉTUDES TECHNIQUES MARITIMES ET FLUVIALES (CETMEF) sollen hierfür, die unter hydraulischen, betrieblichen, wirtschaftlichen und ökologischen Gesichtspunkten, optimalen technischen Lösungen gefunden werden. In Villers-devant-Mouzon in der Nähe von Sedan wird hierzu eine Pilotanlage errichtet, bei der zunächst ein kombiniertes Schlauch-/Klappenwehr und in einem zweiten Schritt ein klassisches Schlauchwehr über einen Zeitraum von drei Jahren untersucht werden soll. Bei dem kombinierten Schlauch-/Klappenwehr handelt es sich um ein patentiertes System der amerikanischen Firma Obermeyer Hydro, Inc., bei dem luftgefüllte Schlauchkörper als Antriebseinheit für Stahlklappen fungieren. Auf Grund des modularen Aufbaus können – wie beim Schlauchwehr – große Wehrfeldbreiten überbrückt werden. Im abgelegten Zustand schützen die Klappen die Schlauchkörper vor Beschädigungen. Das Obermeyer-Wehr ersetzt in Villers-devant-Mouzon ein 17,0 m breites Nadelwehr und besteht aus drei separat angetriebenen Modulen mit einer Breite von jeweils 5,87 m und einer Höhe von 2,00 m. Der vorliegende Beitrag enthält eine detaillierte Beschreibung der Wehranlage, er zeigt ferner die Vor- und Nachteile des neuen Verschlusstyps und gibt einen Überblick über die ersten Erfahrungen seit der Inbetriebnahme im November 2005.

1 Introduction

Voies navigables de France (VNF), the French authority which manages 90 % of French inland waterways, faces the challenge of modernizing or re-building around 140 manually operated weirs within 10 or 15 years. A research program is being conducted jointly with CETMEF (Centre d'études techniques maritimes et fluviales) to establish the best technical solutions with respect to hydraulics, operation, economics and environment.

One of the solutions examined is the inflatable dam, a technology widespread in other countries. To test this technology, it was decided to perform a real life experiment. The testing site was chosen on an existing dam, Villers-devant-Mouzon on the Meuse river, where a first experiment with an inflatable dam was conducted 20 years ago (a failure because the membranes were torn away during a flood) and where a sound concrete structure still exists. Since we encountered the technology of the inflatable dam with steel gates (IDSG) patented by Obermeyer Hydro Inc, it was decided in a first stage to install this type of weir in the opening where this concrete structure existed, then in a second stage (2008) to install a classical inflatable dam in the other opening of the dam. A technical 3-year follow-up will help to evaluate its suitability for inland navigation purposes.

2 Experimental Details

2.1 The Site

The existing dam of VILLERS DEVANT MOUZON is located on the Meuse river (PK 117.74) south of Sedan and 4 km upstream of a large tributary, the Chiers river, which has a significant impact on the discharges and floods of the Meuse up to the dam. It regulates the water depth of the Remilly reach, which is 9.73 km long, of which 4.9 km is an artificial canal built to bypass numerous meanders of the Meuse river, and that begins immediately upstream of the Villers-devant-Mouzon dam. This situation has two effects: the river is not navigable downstream of the dam and the normal downstream water level is very low (which eases the construction and maintenance works), and operation of the dam is constrained so as to limit the current that could disturb vessels' entrance in the canal.

The dam is a needle dam. It is divided into two by an island. The right-hand dam has two openings, each 17 m wide, the left-hand dam has one 17 m wide opening. The old and new experiments are carried out in the left-

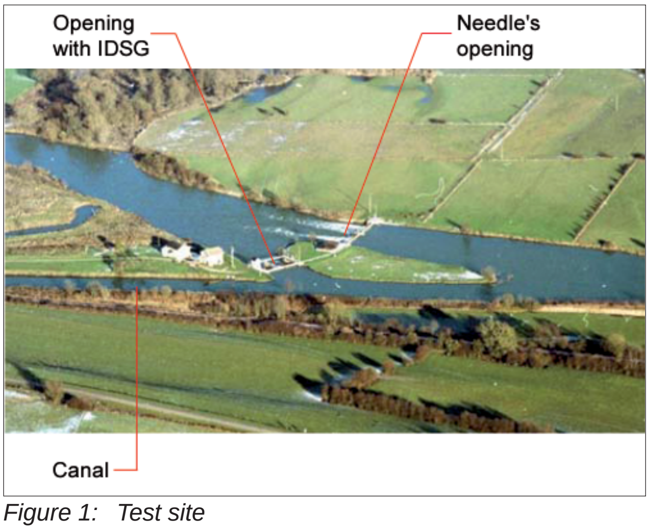

Figure 1: Test site

hand opening. The concrete structure of the last experiment is located immediately downstream of the needle weir, and is in a very good condition.

The road leading to the dam has a small bridge (over the canal) whose maximum load is 3.5 t. This is an important constraint for the works and would have been a real problem for the construction of weir types encompassing heavy parts, like e.g. flap gates. (Figure 1)

2.2 Details of an Inflatable Dam with Steel Gates

The inflatable dam with steel gates is different from a traditional inflatable dam because:

- a flap gate is installed upstream of the bladders;
- a dam is made of several modules as described below.

The flap gate is a steel panel reinforced by vertical steel ribs. It has two main purposes:

- the water pressure is linearly applied to the bladder, avoiding vibrations common to the traditional inflatable dams and allowing precise regulation of upstream water level through the whole range of discharges;–
- the gate overhangs the bladder in every position, thus protecting it from sediments, debris, UV and vandalism.

Each module is 1.5 to 6 meters wide and is built with the following parts:

- an air-filled bladder, manufactured by Obermeyer Hydro Inc., composed of fibre-reinforced rubber (the reinforcement is continuous around the edges of the bladder);
- a steel panel with reinforcing ribs;
- a rubber hinge flap bolted to the gate panel;
- ductile iron clamps to attach the module to anchor bolts sealed in the foundation sill;
- downstream retaining straps (to prevent the flap gate to tip upstream due to upward forces such as wind or high downstream water levels).

IDSG can be best viewed as wicket gates manoeuvred by an underlying pneumatic system (the air-filled bladder) (Figure 2 and Figure 3).

Reinforced rubber bands are bolted to adjacent gate panels ensuring water-tightness. Thus dams can be very wide without piers since a maintenance bridge is unnecessary. An option allows the relative movement of adjacent modules (with two different air circuits, a b-seal ensures water tightness when required), which can be interesting for very wide dams where precise re-

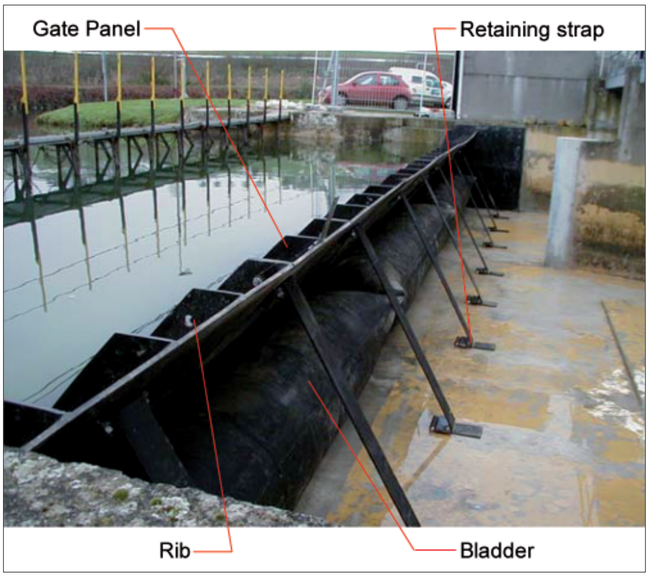

Figure 2: IDSG from downstream

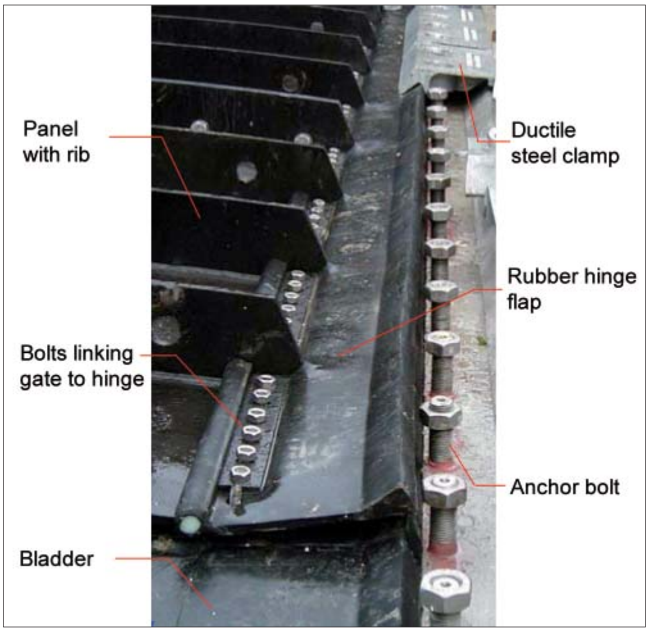

Figure 3: Close-up of anchor line

gulation is obtained by lowering only some of the modules.

Air is supplied by a compressor, via a tank and electric valves. An automatic control system is present.

About 200 such dams exist around the world, their height being between 1 and 8 meters.

Several concepts are patented. In France, the patents are:

- n°WO 03/006747: water control gate and respective actuator (applies to the overall design of the IDSG; not yet applicable, probably applicable as of 2009)

- n°WO 97/08393: connection system for reinforced composite structures (applies to the special wedge-like end of rubber membranes)
- n°WO 2006/026734: high-strength joining system for fibre-reinforced composites (applies to the fabrication process of continuous reinforcement, applicable soon)

2.3 Experimental Goals

These are:

- understanding the different aspects of designing and building such dams;
- experiencing and analysing their mechanic and hydraulic behaviour;
- measuring their regulation capacity for navigation purposes;
- studying environmental impacts;
- studying the capacity to be standardized;
- analysing their operation and maintenance needs;
- estimating their operation and maintenance costs;
- estimating their lifetime.

3 Dam Inspection

The IDSG in Villers-devant-Mouzon is made of three modules each 5.87 m wide, making a total width of 17.69 m. The dam's height is 2.00 m.

3.1 Clamps and Bolts to the Sill

29.5 clamps made of ductile iron anchor the bladders and rubber hinge flap to the concrete sill. Each clamp is 60 cm wide and has a weight of 48.5 kg. They were fabricated in Canada. 59 stainless steel bolts (42 mm in diameter) connect them to the sill. The hinge flap is fabricated by Obermeyer Hydro Inc. and is made of 15-mm thick rubber with 6 layers of polyester-fibre reinforcement. This system ensures water-tightness at the sill.

3.2 Rubber Bladders

The bladders are designed and fabricated like car tyres. These have a composite structure made of layers of EPDM, chlorobutyl rubber, and natural rubber reinforced with four layers of polyester fabric, whose fibres are oriented along two crossed and precise directions, ensuring minimum deformation of the bladder for every state of filling. An external layer of EXX-pro (5 mm thick) improves resistance to abrasion, UV, and chemical attack. They were fabricated by Obermeyer Hydro Inc.

Each bladder weighs 400 kg. Normal pressure is 0.14 MPa (1.4 bar), and limit pressure is 0.18 MPa. Each bladder is connected to the air supply system (stainless steel pipes in the concrete sill) via an underlying flexible pipe.

3.3 Steel Gates

The three steel gates were fabricated in Germany (Dresden) from a 16 mm thick plate. An epoxy coating protects the gates from corrosion. Each gate is made of three parts bolted together on site. Ribs are welded to the plate to resist water pressure and debris. One gate weighs 2.5 t and is the heaviest part of the dam. The gate is bolted to the rubber hinge flap with stainless steel bolts (27 mm diam.) welded at the bottom of the gate.

Two retaining straps are fixed on the downstream side of the gate and to the sill to prevent the flap gate from tipping upstream. They are of the same material as the bladders.

As part of the experiment, and even if it was unnecessary at this site, it was decided that the two right-hand side modules would be bolted together (via a strap of reinforced rubber) and the left-hand side module would be independent. When all three modules are inclined at the same angle, water-tightness between this module and the module in the middle is made by a b-seal.

3.4 Air Supply

Compressed air is the only supply needed. The air compressor is equipped with a dryer and a filter (to ensure air is always clean and dry, avoiding any problems with corrosion or frost). A 300-l tank limits the duration of the compressor's action. Each bladder has an independent air supply, with the same number of electro-valves.

3.5 Control System

The control system uses three types of gauge to keep the upstream water level constant: a water level gauge upstream of the weir, pressure gauges inside the bladders, and an inclination gauge on the flap gates. A water level gauge downstream of the weir is also present, but is not taken into account for control of the dam.

4 The Works

4.1 The Tender

As this type of dam is patented, a special type of tender had to be chosen, but the description of French tender laws is not the subject here.

The contract was concluded with Obermeyer Hydro Inc. on 11 July 2005, the order to start the works was given on 30 August 2005, and the work began on 26 September 2005 and finished on 28 November 2005.

Civil works was done by a local company, SETHY, the IDSG was installed by the Norwegian company Dyrhoff which is the traditional European partner of Obermeyer Hydro.

For this weir size, the classical timeframe is 3 to 4 months for study and production of the IDSG, and 3 days for installation (excluding civil works).

The cost of this dam was € 399,900 excluding VAT (€ 478,280.40 including VAT, cost as in April 2005).

4.2 Main Phases of Works

The main phases of the works are:

1. closure and dewatering of the area of works: upstream closure with the existing needle weir, downstream closure with an earth dike;
2. modification of the existing concrete sill to adapt it to the future dam and placing of the stainless steel air pipes (Fig. 4);
3. placing of polyethylene plates on the abutments as smooth contact surfaces for the lateral seals;
4. sealing of the 59 anchor bolts in the concrete sill (42 mm diam., stainless steel);
5. placing of the 3 bladders;
6. bolting of the three parts of each gate;
7. bolting of the rubber hinge flap to the gates;
8. placing of the gates on top of the bladders (Fig. 5);
9. bolting the assembly gate+bladder to the sill via the 29 ductile iron clamps;
10. assembling the right-hand gates with a reinforced rubber band (bolted on both gates);
11. placing of upstream and downstream water level gauges;
12. installation of electric and electronic equipment in the control house (automat, compressor, air reservoir, valves) (Fig. 6).

Figure 4: Placing of the air pipes

Figure 5: Placing a gate on top of a bladder

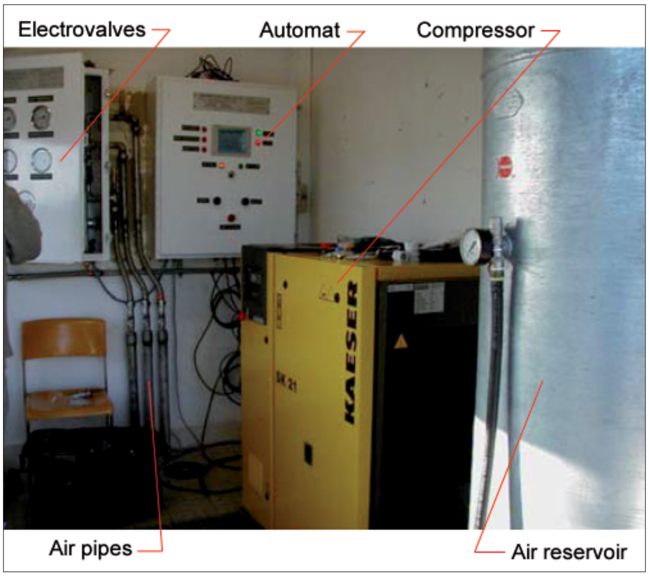

Figure 6: Control house

5 Experimental Follow-Up: First Results

A call for tender was prepared at the beginning of 2006 to carry out the experimental follow-up to ensure an independent analysis of the dam. The contractor is an association of the two French consultancy companies Stucky and Venna Ingénierie. Over a period of 3 years, they will analyse the weir and its functioning (including failures), test several different simulated failures, and asses its answer to the experimental goals cited above.

5.1 First Problems

During the first year, the dam performed satisfactorily to the river hydraulic conditions (high flows of winter 2005-2006). However, in spring 2006 two problems occurred:

- water level regulation had to be carried out manually due to the bad design of the upstream water level gauge (piezometric sensor in a pit that filled with sediment when river flows decreased after the winter floods);
- regulation was not accurate because the inclinometer broke down.

These problems are related only to gauges, not to the IDSG itself. They showed the reliability of the system.

5.2 First Months of the Technical Follow-Up

The analysis of the design of this patented dam concept lead to the conclusion that every detail has been thought of and optimised for its functional purpose.

A comparison with other common weir types showed that IDSG is a technical rival of flap gates and roof weirs (bear trap weir), and has advantages compared to these such as e.g. the simplicity of civil works and the fact that no mechanical parts are needed (parts moving relative to each other causing wear and requiring adjustment) since the moving parts here are made of rubber.

In the case of Villers-devant-Mouzon, comparing the construction cost is not favourable for the IDSG, but this comparison is biased (type of contract, translation costs etc.), and the rubber cost is not compensated by the simpler civil works since the dam has a short length.

On the contrary, the operating costs are estimated to be much lower than the operating costs of other weir types, even if a change of bladders after 20 years is included. The experimental follow-up will have to confirm this point.

6 Frequently Asked Questions (F.A.Q.)

6.1 How Long is the Lifetime of a Bladder?

Obermeyer Hydro estimates the lifetime to be 30 years, whereas we consider it more reasonable to plan for a change of bladders after 20 years (if needed).

6.2 Is it Possible to Repair a Bladder?

Despite the protection of the steel gate, a hole in the bladder (due e.g. to vandalism, sediment, or debris abrasion) is one of the risks. In the case of a small hole, a repair kit like those for tyres is sufficient, and the compressor supplies enough air to keep the bladder full. In the case of a larger problem, a spare bladder is an option.

6.3 How to Manage a Maintenance Closure when no Peers Exist?

When a bladder or the hinge flap needs to be changed, a closure must be made. Lots of solutions exist, but in the case of IDSG the upstream of a module can be dewatered by a caisson placed upstream and pressed against adjacent steel gates. If maintenance needs to be carried out downstream, another type of stop logs can be used, like planks placed between intermediate posts.

No system is provided in Villers-devant-Mouzon since the needle weir is still in place upstream, and the water level downstream is lower than the sill level for most of the time.