New High Head Leaf Gate Form with Smooth Upstream Face

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Abstract – This paper presents new smooth upstream face high head gate form that heavily reduces hydrodynamic forces in conjunction to a total absence of uplift (negative downpull) forces.

The research work at the Institute of Hydraulic Engineering investigated techniques to reduce the hydrodynamic load on high head gates. Task was achieved with the new smooth upstream high head leaf gate; improved safety for the hydro-machinery equipment and also for concerned parts of the whole project, while minimizing costs.

***Keywords* – Downpull, high-head gate, hydraulic model.**

1. Introduction

As leaf gates are situated at bottom outlets or at turbine inlets. They allow emergency closure of water conducts or regulation of flow. Those gates can be used for regulation for heads up to 50 m or as service gates for heads of 150 m or higher

Modern practice is for slide gates to be operated by hydraulic cylinder hoists. Double hoist-rod types can suffer damage inherent in some high head gates operations. And poor function of the gate may lead to failure of surrounding structure. Robertson, R.A. and Ball, J.W. (1971) and Sagar (1970)[9] emphasize that the evaluation of hydrodynamic forces is of vital importance. These forces can cause serious operating problems including non-closure of the gates or catapulting effect. The main factor, which influences the dimensioning of the hoist hydraulic equipment, is beside the dead load, the vertical hydrodynamic load[8][9][11][12].

Up-to-date research done in many Hydraulic Laboratories Vienna, Karlsruhe and Iowa Grzywienski (1959) [1], Naudascher (1986) [3,5,6] [7], Sagar (1974) [9,10,15], Kienberger (1999) [2], Thang (1990)[4], studied the influence of different gate lips and wet well geometries on the magnitude of the gate hoist force.

The paper presents new smooth upstream face high head gate type that heavily reduces hydrodynamic forces in conjunction to a total absence of uplift (negative downpull) forces.

2. Research Goals

Many experiments were carried out in order to enable an economic dimensioning of hoist hydraulic and to reduce the hydrodynamic load effect. The research work at the Institute of Hydraulic Engineering investigated techniques to reduce the hydrodynamic load on high head gates. Task was achieved; improved safety for the hydro-machinery equipment and also for concerned parts of the whole project, while minimizing costs.

In addition, more safety by modernization and rehabilitation of large hydropower equipment is achieved.

The aim of the experiments, presented in this paper, was the analysis of the influence of the new smooth upstream face high head gate form on the magnitude of the hoist forces.

3. Methods

The method implemented in this paper is experimental. Model studies are hands on engineering. Observations of flow patterns provide immediate information about design flaws. The subject of the study was the three-dimensional analysis of the interaction between the leaf gate and the fluid.

The experiments may be conducted in water or an air tunnel. The experiments in water tunnel have following advantages:

- Concentrated pressure and velocity zones may be better identified;
- A better visual observation of the gate –fluid interaction;
- Data of the experiments and of the calculation are simpler to compare;
- Reproduction of free surface outflow in the model.

The dimensions of the model correspond to the scale of modeling for the lengths of 1:25 (for forces 1:15625). The schematic representation of the entire model and the model measuring and management equipment is given in the Figure 1.

The model consists of:

- Water reservoir which provides the same water head for all leaf gate opening ratios (the same water level in the reservoir).
- The inlet tunnel of the 20 x 20 cm is equivalent to 5.0 x 5.0 m of the prototype. It provides the unobstructed approach flow from the reservoir.
- Fixed wheel leaf gate, rectangular, 222.4 mm wide, 207.6 mm high, and 50 mm thick, with the gate lip inclination of 30°. The leaf gate transfers the loads on the well wall. The sealing face is on the downstream side.
- Wet well in which the gate moves is 250 x 615 mm in the cross-section and 2.2 m high.
- Outlet tunnel, with dimensions 20 x 20 cm, which corresponds to the prototype of 5.0 x 5.0 m, equipped with aeration pipe which aerate the region downstream from the gate.

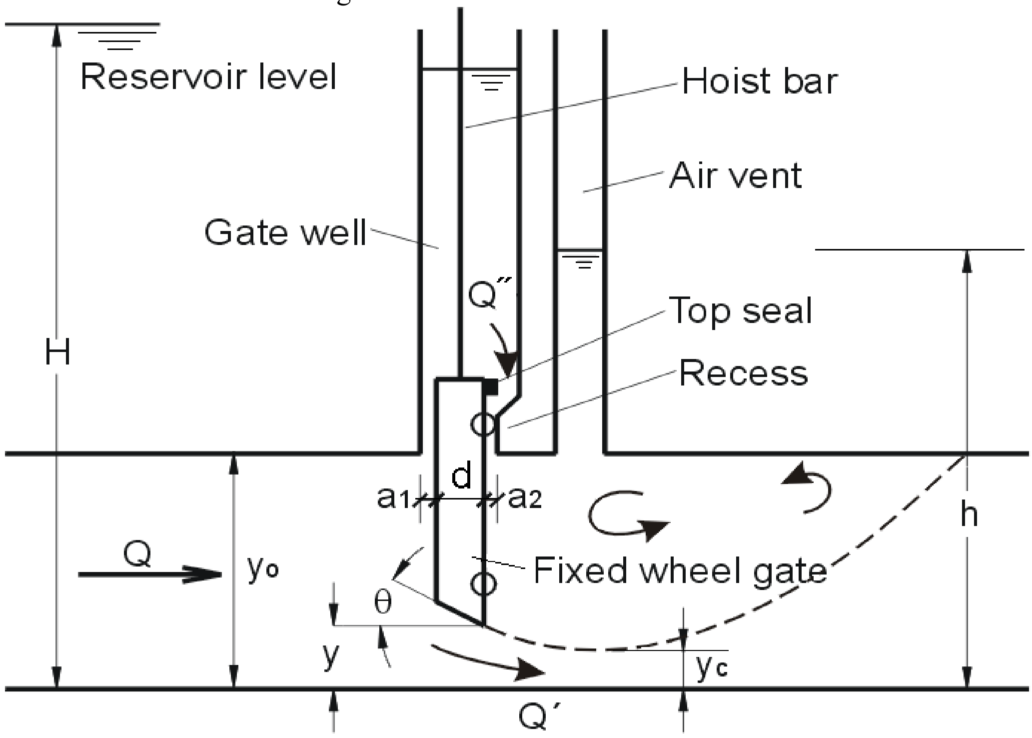


Figure 1 Scheme of the model

Measuring equipment

The servo motor is located on the structure above the well, and it lifts and lowers the gate by two bars. This solution prevents the danger that the gate rotates normally to the tunnel axis, during its movement, producing the movement which is not absolutely vertical. In this case, the additional friction forces would occur in the wheels of the gate. Measuring of the gate hoist force is obtained by two dynamometers connected to the each gate driving bars.

The level of the water head in the reservoir, the pressures in the tunnel in front of the gate, under the gate and behind the gate and pressures in the wet well walls are measured by the piezometric cells[14].

Leaf gate models

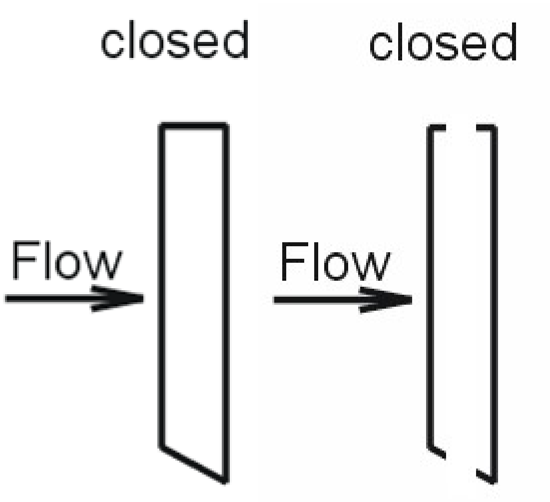
The leaf gate models, the tunnel and the wet wall are made of Plexiglas. The fixed wheels are installed on them. The special attention was paid to the accurate manufacturing, so that the possible geometrical inaccuracy of all the elements of the gate wet well, slots and the guiding rails along which the gate moves could not compromise the validity of the obtained results.

The model of the leaf gate was manufactured as the leaf gate with the smooth upstream face of 222.4 x 207.6 x 50 mm, where measures correspond to the prototype of 5.56 x 5.19 x 1.25 m.

Types of the leaf gates

The analyzed gates are divided into types, in order to facilitate the results comparison:

- A1 type is a leaf gate 222.4 x 207.6 x 50 mm with smooth upstream face and bottom inclination of 30°;
- A4 type is a leaf gate 222.4 x 207.6 x 50 mm with smooth upstream face and 40% perforation (quadratic in cross section of the 50 x 30 mm) which extends from the bottom to the top of the gate. This perforation reduces the inertial momentum of all the main girders.



• Figure 2. 2Schematic representation of the investigated gates

Leaf gate slots

Testing of the leaf gates have been obtained for two types of the slots whose the upstream and the downstream edge are located in the same direction:

- N1 denotes the type of the slot has the size; the slot depth is 25 mm and the width 615 mm

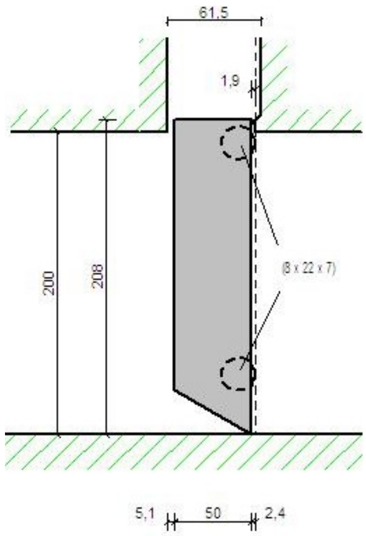
- N2 type of the slot has the size: the slot depth is 15 mm, and the width 615 mm

Gaps between gate and downstream wall of the well

The testing of the leaf gates have been obtained for two different gaps in the wet well. Gaps (distances) of the downstream face of the leaf gate form the downstream wall of the well, that is:

- S1 – For the gap of 2.4 mm between the downstream face of the leaf gate and the downstream wall of the well and the distance of 5.1 mm between the upstream face of the leaf gate and the upstream wall of the well.

- S2 – for the gap of 5.1 mm between the downstream face of the leaf gate and the downstream wall of the well and the distance of 2.4 mm between the upstream face of the leaf gate and the upstream wall of the well.



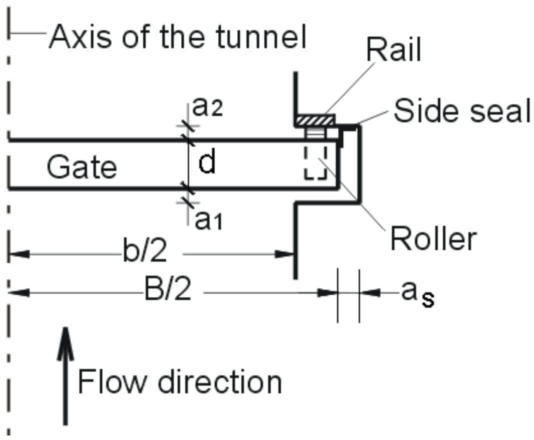


Figure 33 Cross section of the gate model

Water head

Prototype load was simulated on the model by the reservoir. The models of the leaf gates were tested for the following water heads (pressures):

- P1 load corresponds to the water head level of 0.8 m or the pressure on the prototype of 20 meters water head,
- P2 load corresponds to the water head level of 1.6 m or the pressure on the prototype of 40 meters water head,

- P3 load corresponds to the water head level of 2.4 m or the pressure on the prototype of 60 meters water head, and
- P4 load corresponds to the water head level of 3.0 m or the pressure on the prototype of 75 meters water head.

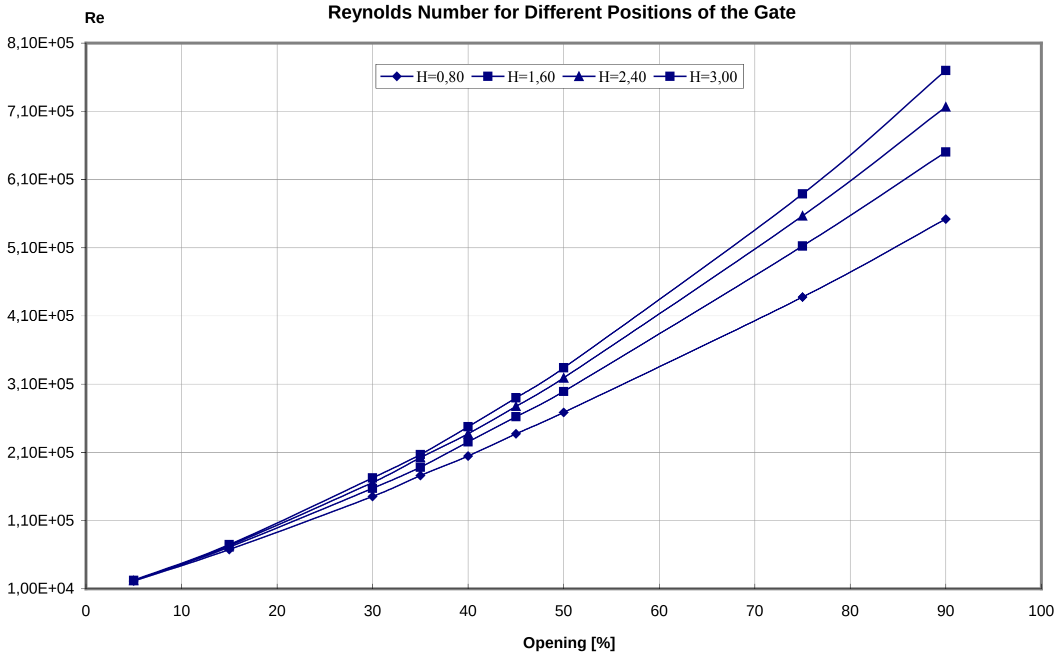


Figure 44 Diagram of Reynolds number in the model

Model investigations

The leaf gate models (A1,A4) were exposed to the pressures P1, P2 P3 and P4. The operating force in dynamometers of the gate lowering, lifting and at rest position was measured for different opening ratio of the leaf gate. Apart from the gate hoist force, the flow rate was continually measured, and on its basis the mean discharge rate under the gate was defined. The hydrostatic pressure was simultaneously measured in the predefined points in the outlet tunnel, in the well, above and under the leaf gate and in the outlet tunnel.

Analysis of the measured force

The measured force is the sum of the hydrodynamic force, the dead weight and the friction in the gate fixed wheels. The continually measured force flow during the hoisting and lowering of the gate for the different opening ration was presented in the following diagrams.

The known hoist force component is the dead weight of the gate, while the relation of the friction in the wheel and the hydrodynamic force is the unknown value. For that reason, the friction in the wheels of the gate was experimentally defined, on the adopted models of the leaf gates, independently of the hydraulic model, using the inclined plane.

Through the research of the adopted models of the leaf gates, the friction coefficient was measured, and for all the types of the adopted leaf gates results in μ=0.01. As the friction force is proportional to the force acting normally to the gate, the maximum friction force occurs when the gate is totally closed (friction force is 1% of the normal force on the leaf gate). With the increasing of the opening, the normal force acting on the gate is reduced, due to the flow, and the friction force reduces. As the pressure on the upstream face of the gate was not measured, it is not possible to accurately determine the friction force for the different positions of the gate.

Measuring technique made not possible the rejection of the influence of friction force on the measured hoist force. However, determination of friction coefficient of gate wheels allowed assumption that grade of accuracy of hydrodynamic force determination due to imperfection of the model assembly (and not from the imperfection of the measuring devices) is within value of maximal friction force. The error is reduced with the increase of the opening ratio of the gate.

4. Results of Experiments

For the gate type A1, gate with smooth upstream face and without vertical openings (Figure 5, Figure 6, Figure 7 and Figure 8), the maximum hoist force occurs in the central part of the diagram and depends on the value of the gate's total pressure, on the slot depth, and on the distance of the gate from the wall of the well.

For the gate type A4 - gate with a smooth upstream face and with vertical openings of 40% (extending from the gate bottom to the gate top) – the maximum hoist force occurs in the first and third section of the downpull curve. (Figure 9 ,Figure 10, Figure 11 and Figure 12).

The maximal downpull in the model for the maximal water level in the reservoir of the laboratory (3.0 m) are given in the Table 1 (all the other levels in the reservoir generate lower hoist forces acting on the gate). The percentage of the reduction of the gate hoist forces, caused by the perforation, is independent from the reservoir level.

Type of the gate	Gate hoist force [N]	Slot depth 25 mm – N1		Slot depth 15 mm – N2	
		Distance from the downstream wall of the well		Distance from the downstream wall of the well	
		S1 (a1=2.4 mm)	S2 (a1=5.1 mm)	S1 (a1=2.4 mm)	S2 (a1=5.1 mm)
A1	Max. →	78.72	45.82	144.28	35.00
A4	Max. →	24.88	11.95	14.61	10.84
Reduction of the hoist force %		68.4	73.9	89.9	69.0

Table 1. Maximal downpull for the gate with smooth upstream face.

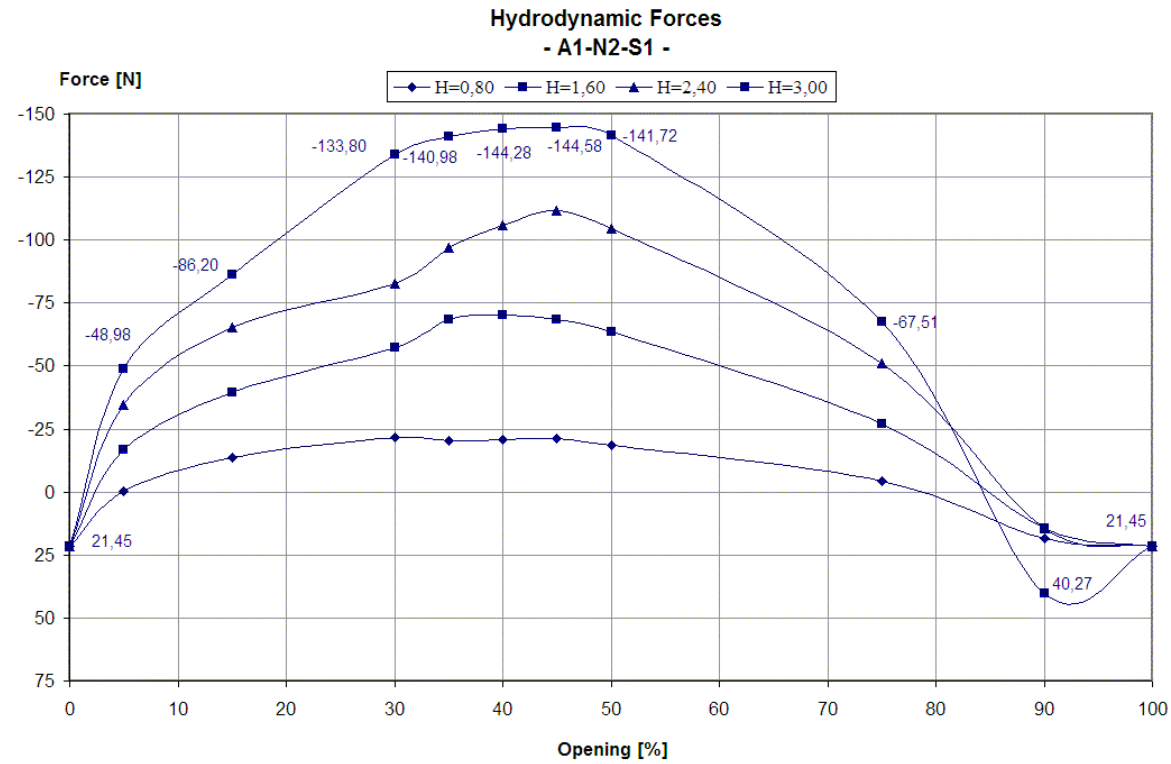


Figure 5. 5 A1-N2-S1 Maximal hoist force of the leaf gate with smooth upstream and without perforations for the slot depth of 15 mm (a1 = 2.4 mm , a2 = 5.1 mm).

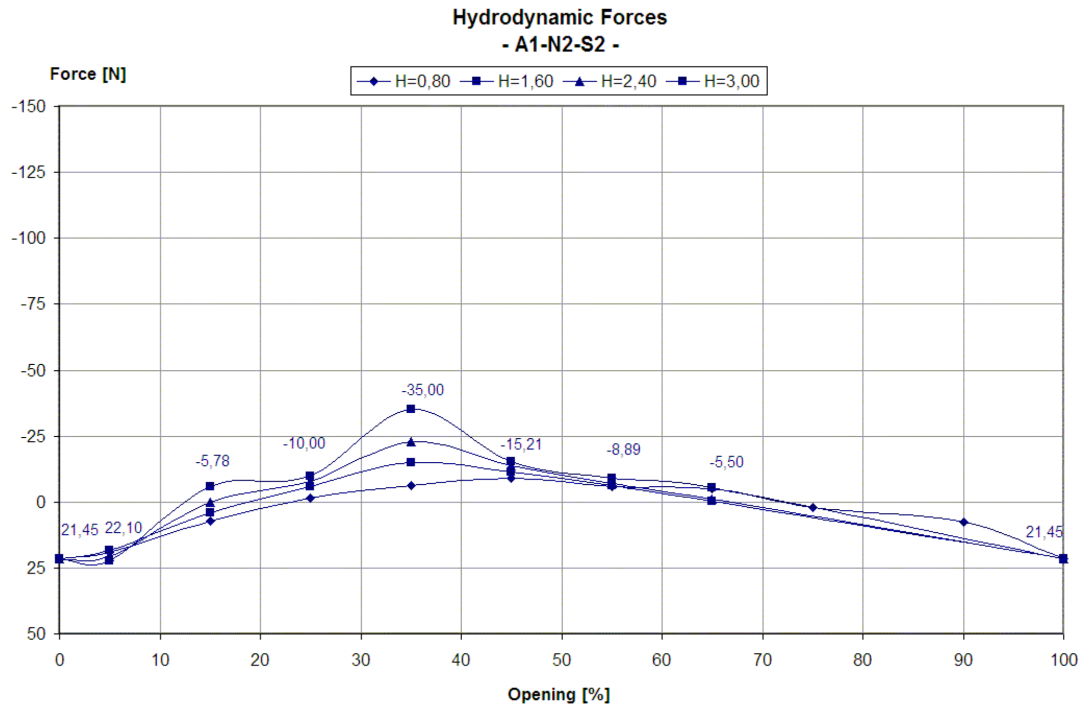


Figure 6. A1-N2-S2 Maximal hoist force of the leaf gate with smooth upstream and without perforations for the slot depth of 15 mm (a1 = 5.1 mm , a2 = 2.4 mm).

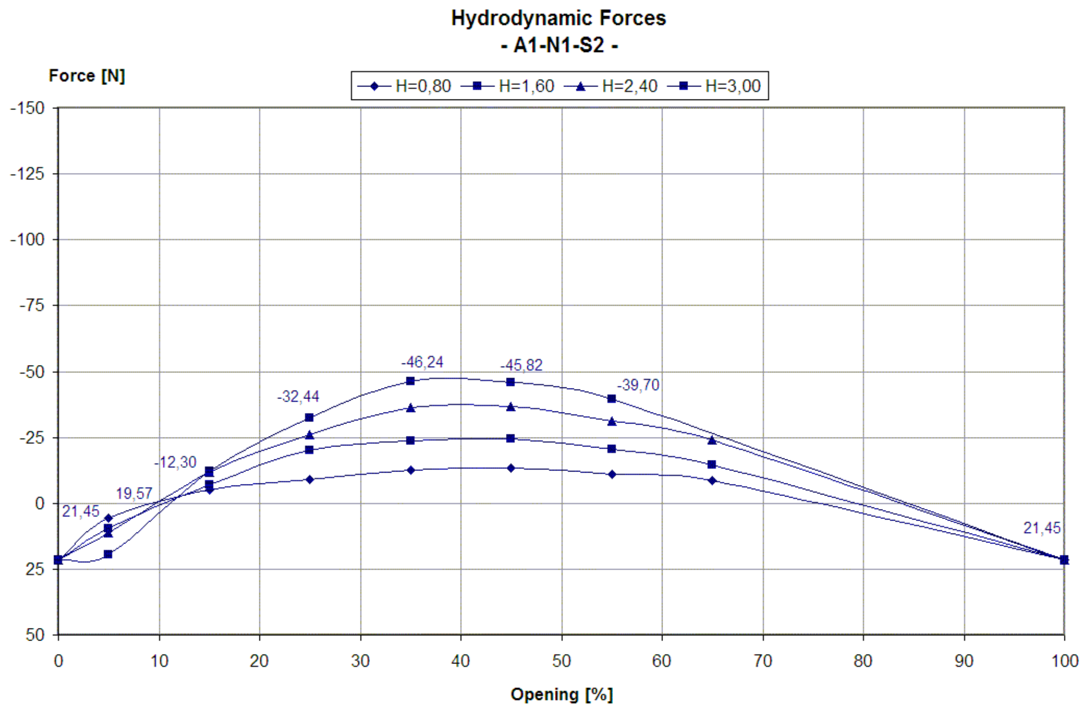


Figure 7. A1-N1-S2 Maximal hoist force of the leaf gate with smooth upstream and without perforations for the slot depth of 25 mm (a1 = 5.1 mm , a2 = 2.4 mm).

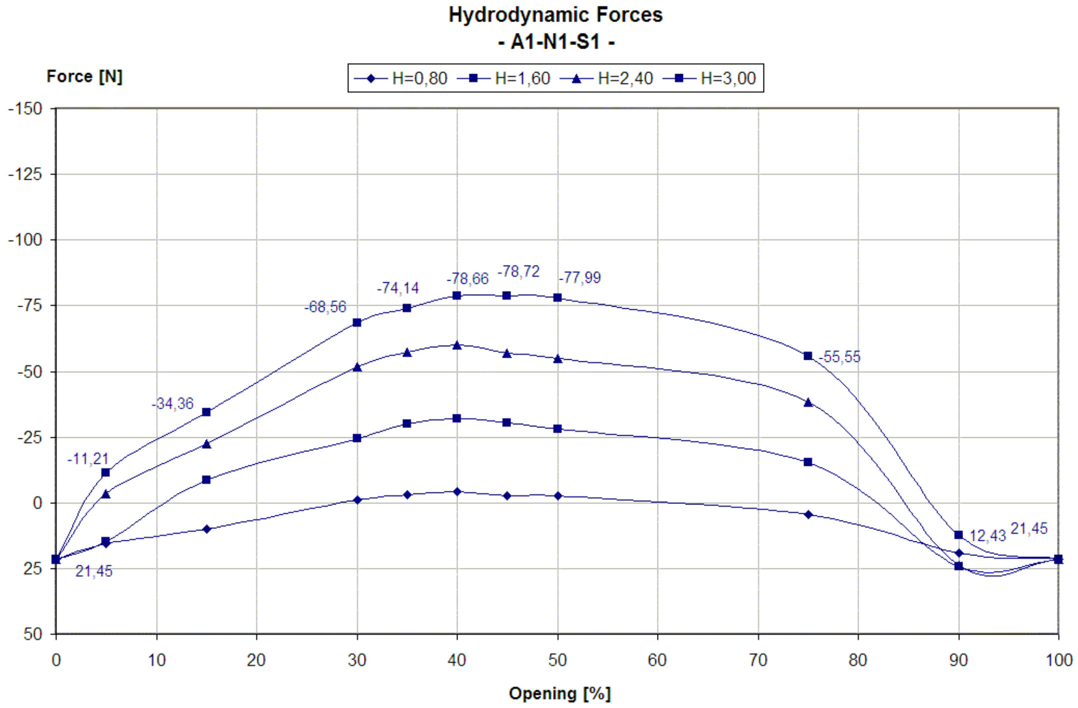


Figure 8. A1-N1-S1 Maximal hoist force of the leaf gate with smooth upstream and without perforations for the slot depth of 25 mm (a1 = 2.4 mm , a2 = 5.1 mm).

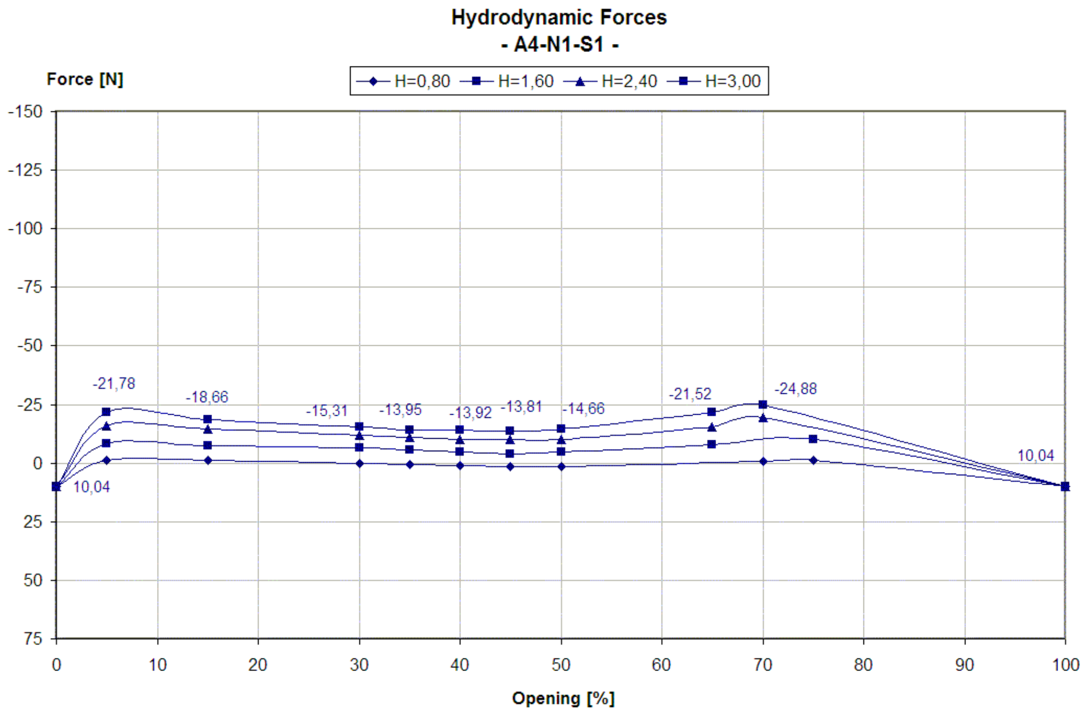


Figure 9. A4-N1-S1 Maximal hoist force of the leaf gate with the smooth upstream with perforations of 40% for the slot depth of 25 mm (a1 = 2.4 mm , a2 = 5.1 mm).

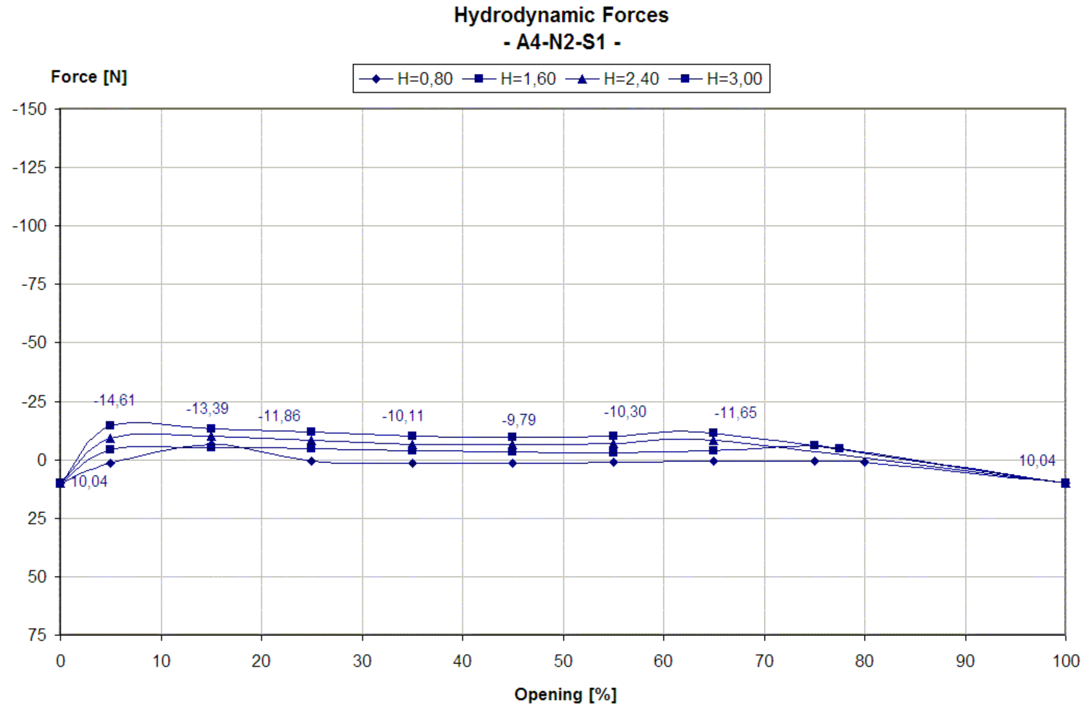


Figure 10. A4-N2-S1 hoist force of the leaf gate with the smooth upstream with perforations of 40% for the slot depth of 15 mm (a1 = 2.4 mm , a2 = 5.1 mm).

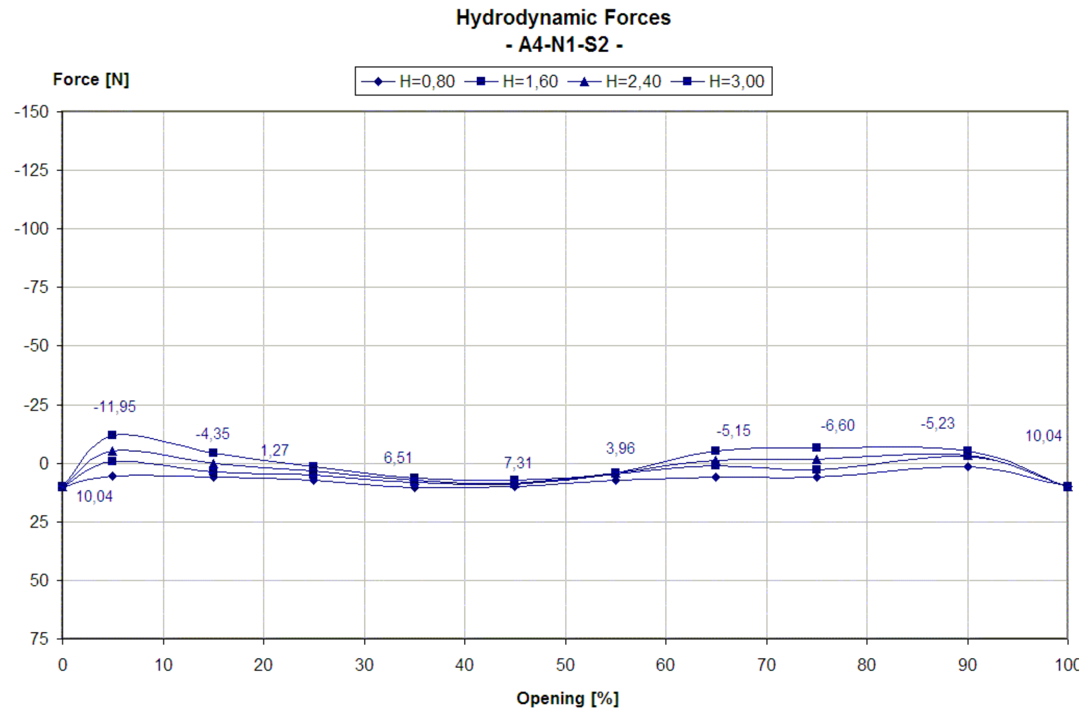


Figure 11. A4-N1-S2 hoist force of the leaf gate with the smooth upstream with perforations of 40% for the slot depth of 25 mm (a1 = 5.1 mm , a2 = 2.4 mm).

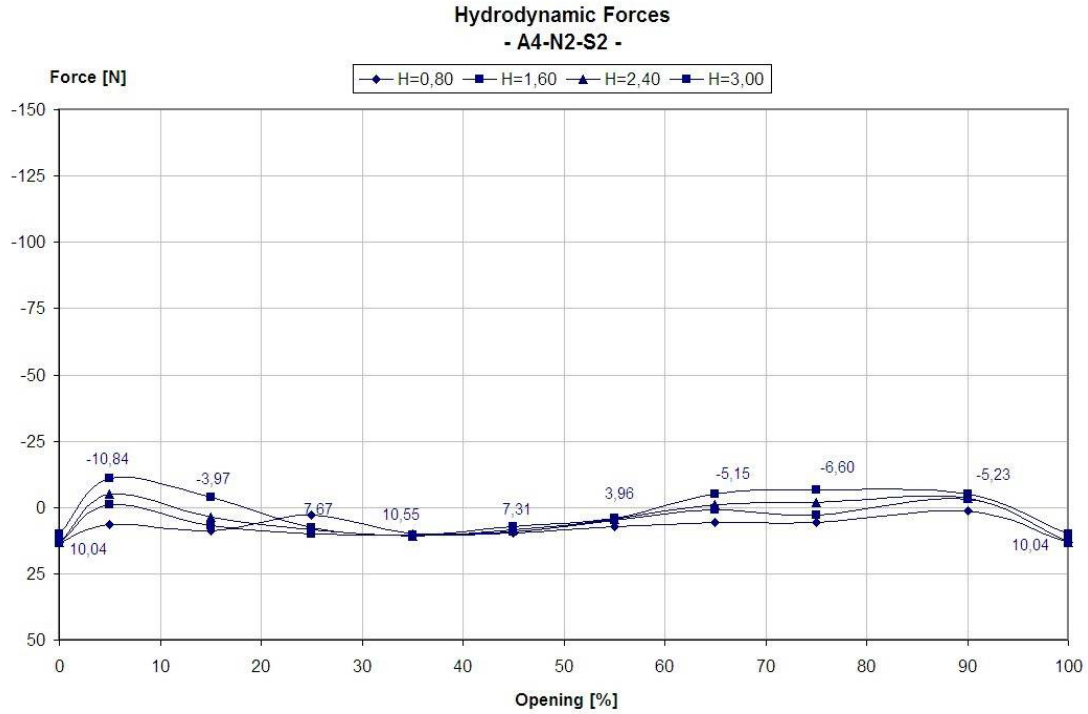


Figure 12. A4-N2-S2 hoist force of the leaf gate with the smooth upstream with perforations of 40% for the slot depth of 15 mm (a1 = 5.1 mm , a2 = 2.4 mm).

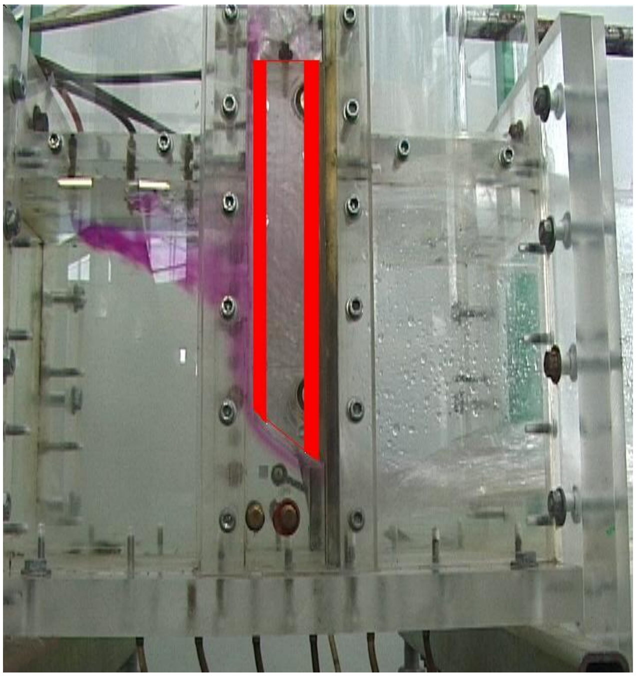


Figure 13 Visualization of streamlines deflection

5. Discussion

The presented diagrams are not based on non-dimensional parameters, in order to show, as realistically as possible, the efficiency of these innovative gate constructions. The non-dimensional representation of the results is usually given in respect to the total static pressure on the gate leaf.

The results refer to gates with smooth upstream face and a gate lip inclination of 30°, without vertical openings A1 and with vertical openings A4. The hydrodynamic forces, measured on the model are shown in (Figure 5 - Figure 12) as a function of the gate opening ratio.

Downpull force varies with the gate leaf position or gate opening and its magnitude depends on many factors. The values of hydrodynamic forces generated from hydraulic model tests, with top seal arranged on the downstream side and for free surface flow condition, is maximized for the gate opening of 35% to 45%.

In the diagrams of the hydrodynamic forces three sections relating to the gate openings are to be distinguished. From the left in the first section the opening ratio of the gate is from 0% up to 30%, in the second or central section the opening ratio is between 30% and 60%, at the third section, the opening of the gate opening ranges from 60% to 100%.

The gate type A4, reduce the hoist force in relation to the gate type A1. The highest reduction of the hoist force (89.9%) was obtained from the leaf gate type A1 which generated the highest hoist forces.

It is identified by hydraulic experiments that the gate slots depth decrease the downpull force, but on the other hand this advantage cannot be employed in cold regions where ice accumulate in the slots (what is particularly critical for the wheels). Second, slots cause disruption of the flow increasing cavitation damage.

Both, variation of downstream gaps size and type of upstream, change the position of stagnation point in the tunnel in front of the gate and boundary streamlines below the gate. As a result the downpull strongly changes.

6. Conclusion

The innovative smooth upstream high head gate form is a scientific contribution of the author to the reduction of downpull forces.

The experiments identified a number of changes in the design, which would reduce downpull and nevertheless the cost. After numerous attempts, an acceptable construction modification was found in the model.

The results of the model tests show that an increase in vertical openings of the gate leaf reduces the hydrodynamic forces significantly.

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