ON-SITE EVALUATION OF A FISH-FRIENDLIER TIDE GATE DESIGN

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ABSTRACT

Recent National Legislation as well as European Directives aim for a better *state* of our rivers and therefore stress the need for river restoration, giving more space for the river, solving fish migration issues etc. In Flanders (northern part of Belgium), a major part of recent water management projects deal with restoring the possibility for fish to migrate upstream, mainly overcoming sluices and gated weirs. However, along the tidal reach of the Schelde, numerous tide gates are in place to prevent the upstream movement of (brackish) estuarine waters into small tributaries and hence hamper fish to migrate freely. The idea of installing so-called "pet doors" is not new. But the reason why this seemingly simple solution cannot be found everywhere is probably the lack of data on its working principle. Therefore a research program was elaborated to evaluate different fish-friendlier tide gate designs in order to establish some guidelines for water management in practice.

Keywords: Schelde-estuary, Actualised Sigmaplan, Fish migration, Tide gate, Pet door

1 INTRODUCTION

1.1 ACTUALISED SIGMAPLAN

Due to changing physical circumstances and new insights in water management, recently an actualisation of the Sigmaplan (safety plan of the tidal river Schelde) was elaborated. The so-called Actualised Sigmaplan aims for satisfying safety and ecological needs along the river Schelde in a sustainable way. Therefore different restoration techniques are elaborated which combine safety with estuarine restoration, eg. dike strengthening together with more space for the river, flood control areas with or without a controlled reduced tide, non-tidal wetlands, … Figure 1 shows the overall setting of the Actualised Sigmaplan and gives an overview of the set of measures contained within.

1.2 EFFECT OF TIDE GATES ALONG THE SCHELDE-ESTUARY

To control the flow of creeks and sloughs into the Schelde-estuary, outlet structures with tide gates are installed within the dikes. Tide gates close during incoming tides and hence keep low-lying lands from being flooded. Unfortunately closed tide gates hinder or prevent fish migration and hence cause a loss of valuable habitat for nourishment and reproduction. For an illustration of the entire gate cycle as water levels change, one is referred to Giannico & Souder (2005).

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Figure 1. General overview of the Actualised Sigmaplan.

1.3 PILOT PROJECT LIPPENBROEK

Pilot project Lippenbroek is a flood control area (FCA) with a controlled reduced tide (CRT). During storm surges (on average once a year) the FCA is filled via a lowered levee (Figure 2, top). In addition, a well designed sluice system allows limited semi-diurnal water exchange between this FCA and the estuary. Twice a day tidal water flows in at high tide through inlet sluices with high sill levels (+4.70 – +5.30 m AD) (Figure 2, middle) and flows out at every low tide through outlet sluices with low sill levels (Figure 2, bottom). A tide gate (1.8m x 1.8m with sill at +1.50 m AD) is attached to the lower outlet structure. Goal is to obtain inundation characteristics similar to natural tidal marshes.

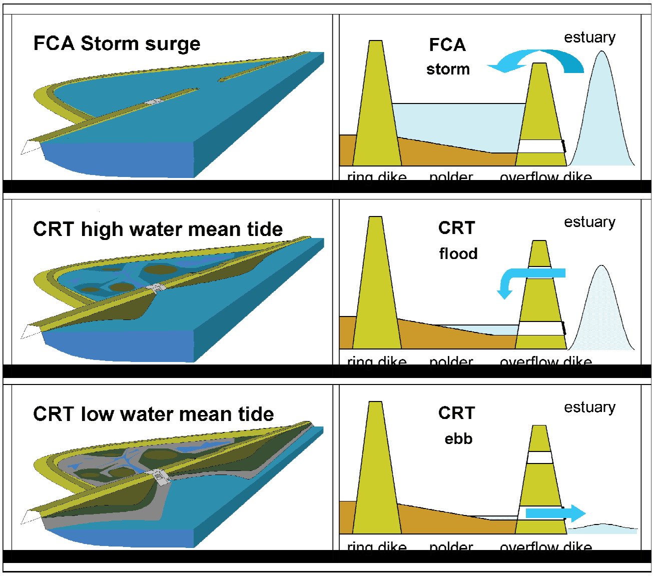


Figure 2. Overview of the FCA/CRT-principle.

In 2006 Lippenbroek started functioning as freshwater intertidal habitat and has been studied and monitored since (Maris *et al*, 2008). In order to enhance benthic colonisation, fish passage will be facilitated through a "fish-friendlier" gate design at the outlet.

2 TRADITIONAL AND NEW TIDE GATE DESIGNS

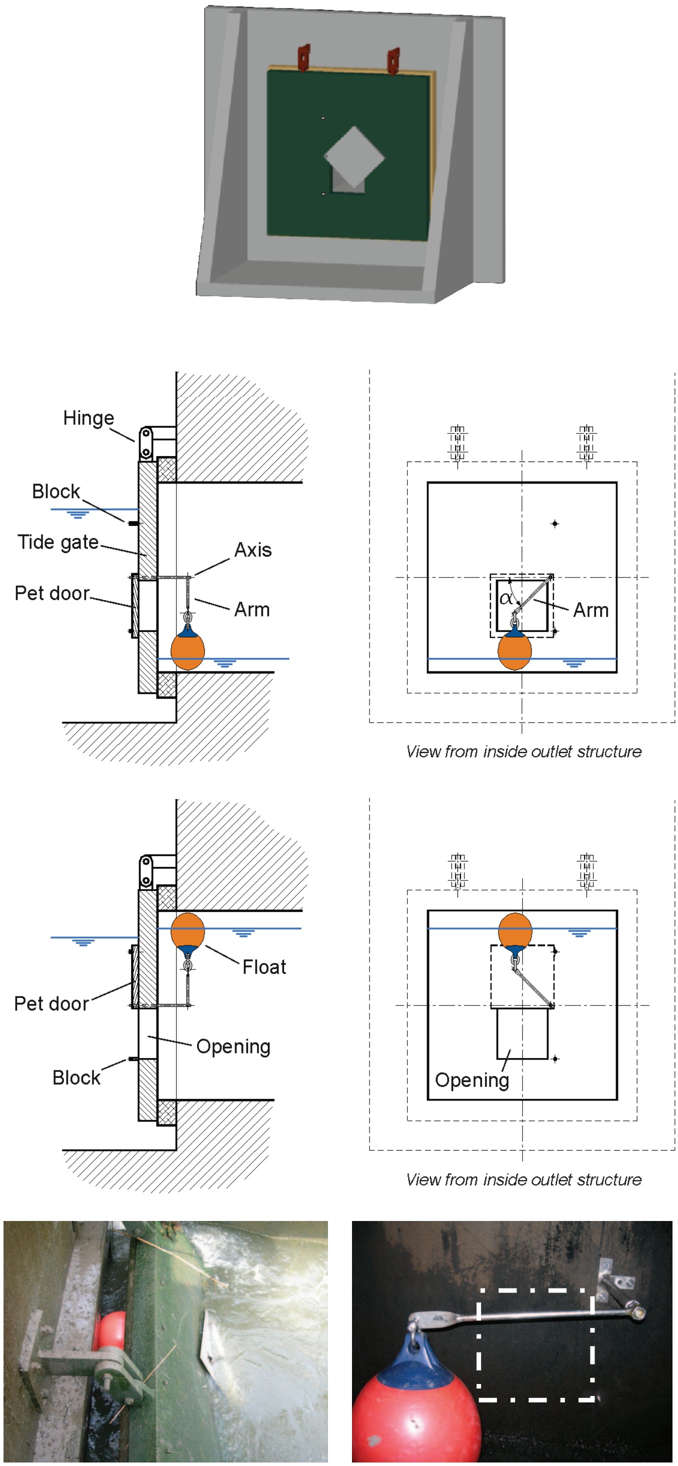
Fish passage problems at tide gates are in fact a combination of two separate processes: first passage past the tide gate followed by passage through a culvert.

The many different types of tide gates that exist can be grouped into two major categories; traditional designs and new designs. Traditional tide gates are all top hinged or chained. New designs vary from side- or bottom hinged (with a trip mechanism) to self-regulating buoyant structures (Giannico & Souder, 2005). The amount of time and degree of opening of the tide gate given a difference in water level are functions of its type, weight, buoyancy and area, the resistance of the hinges, whether the door is tilted, etc. According to Charland (2001), smaller doors remain open for longer periods and, as a result, they facilitate fish passage. Therefore three basic types of so-called "pet doors" can be found in literature: top-, bottom- and side-hinged (Vereecken *et al*, 2006). Top-hinged pet doors with float are opened by rising water levels at the downstream side allowing water to flow upstream, bottom-hinged pet doors are closed from the moment connectivity is realised in order to prevent leakage. Finally, opening of side-hinged pet doors is hindered by a small opening of the tide gate it self. So, all these pet doors have there drawbacks.

Important parameters that need to be considered when designing culverts for fish passage are invert elevation, water velocity and water depth inside the culvert, water turbulence, drop inside the structure and/or at outlet, resting pools, debris accumulation at inlet, bottom and side roughness, etc. (Vereecken *et al*, 2006).

3 A NEWLY DESIGNED "PET DOOR"

The newly designed "pet door" presented in this paper is 'top-hinged', but hinges slightly different from traditional tide gates. Figure 3 gives an impression of the functioning of the newly designed "pet door". At low water levels within the outlet structure, the pet door is in closed position. When the water level at the downstream side of the outlet structure rises, the pet door is pressed against the tide gate and remains in closed position. At first, an increase of the water level within the outlet structure is not able to push the float and open the pet door. Only when the pressure difference between the upstream and downstream side of the gate becomes small enough, in this case when the downstream water level has reached high tide and once again started its descend and at the same time upstream water level had risen due to rainfall or CRT-operation, the float overcomes the forces exerted by the downstream water level and the pet door opens suddenly. Due to a pressure gradient from downstream to upstream, a small amount of (unwanted) tidal water flows upstream through the structure. Because the downstream water level is sinking, the pressure gradient rapidly changes direction and water is flowing downstream through the open pet door, while the regular (bigger) tide gate is not yet influenced by this too small pressure difference.



View from downstream (pet door is open) View from inside outlet culvert (no opening yet)

Figure 3. Functioning of the newly designed “pet door”.

3.1 HYDRAULIC BEHAVIOUR AND EFFECTS ON MIGRATORY FISH

3.1.1 HEAD DISHARGE RELATION

Water levels and flow velocities at the outlet of Lippenbroek are measured continuously and validated based on discharge measurements. The flow discharge through the outlet structure could be predicted fairly well using the Bélanger discharge equation for broad-crested weirs, giving a discharge coefficient (C_d) equal to 0.92.

For free surface flow: $$Q = C_d \frac{2}{3}\sqrt{\frac{2}{3} g}\, b\, h_{upstream}^{1.5}$$

Due to tidal movement of the Schelde, the outlet sluice is regularly operating under submerged (drowned) flow conditions. For drowned flow conditions, the broad-crested weir formula is modified as follows:

For $\frac{h_{downstream}}{h_{upstream}} \geq m$: $$Q = C_d \frac{2}{3}\sqrt{\frac{2}{3} g}\, b\, h_{upstream} \left[\frac{h_{upstream} - h_{downstream}}{1 - m}\right]^{0.5}$$

Besides the use of downstream water levels, the use of a modular limit (m) is proposed to correct for the influence of drowned flow conditions. Prior to the installation of the pet door, the modular limit was chosen 0.7.

On March 16th 2009, the newly designed "pet door" with an opening of 40cm x 40 cm was installed. Because no two tides are the same, recorded flows before and after installation of the pet door cannot be easily compared. In order to evaluate the hydraulic behaviour of the pet door, a comparison is made between recorded discharges and those calculated using the originally fitted weir formula.

From Figure 4 it can be seen that for both situations, calculated discharges show good agreement with the measured ones. At first glance; it can be stated that the head discharge relation of the tide gate is hardly influenced by the presence of the pet door. On the other hand, when the pet door is fully operational, an increase in under-estimating the (recorded) outflows by the original weir formula can also be deduced from Figure 4 (especially for recorded flows between 1.5 – 2.0 m³/s), in particular for drowned flow conditions (Figure 5).

Figure 3 shows that the pet door opens when the outlet is operating under submerged flow conditions, ie. when the river Schelde and FCA Lippenbroek are connected and hence, fish migration is not impossible. An under-estimation of the outflow under submerged flow conditions suggests the necessity to increase the modular limit (m) when the pet door is in place (Figure 5). Although it should be mentioned that the use of weir formulas is less accurate for drowned flow conditions, it can be stated that the newly designed pet door leads to an increase in flow currents (in the order of 40%) under submerged conditions.

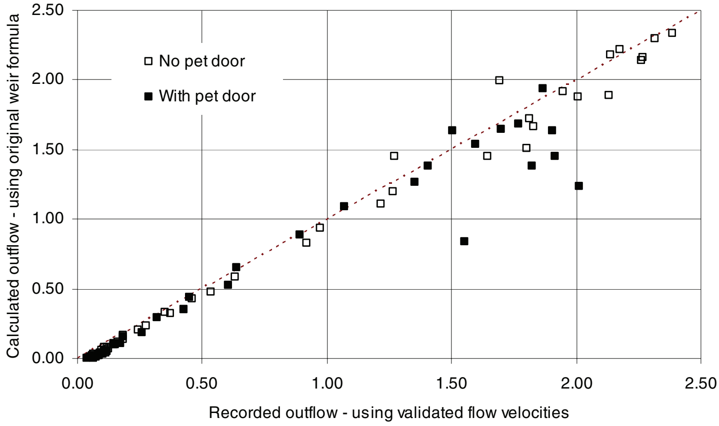


Figure 4. Measured and calculated outflow (m³/s) with and without "pet door".

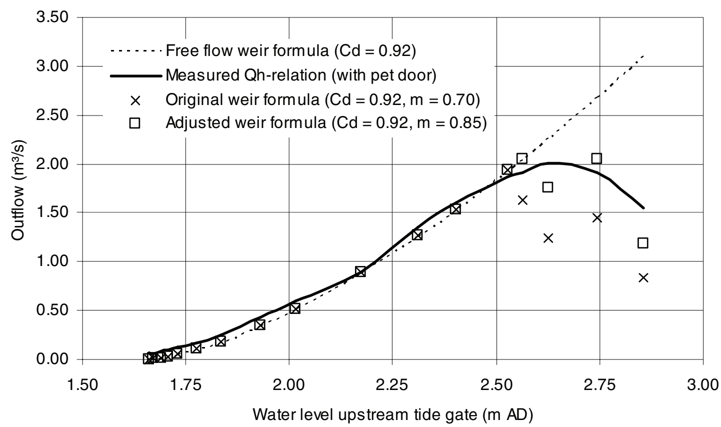
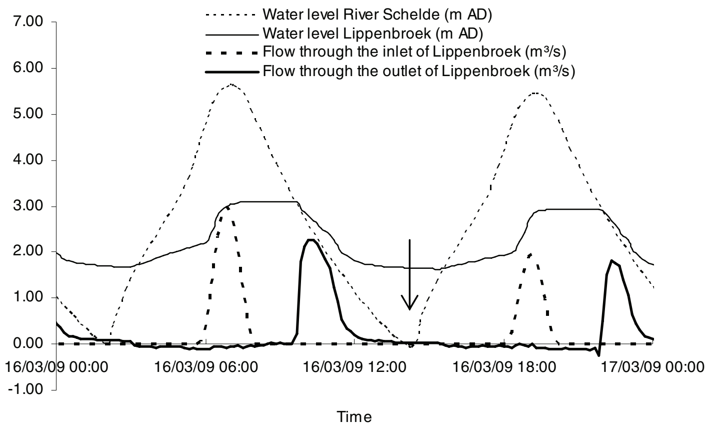


Figure 5. Upstream water level versus flow discharge through the outlet structure.

3.1.2 LEAKAGE AND ROBUSTNESS

As mentioned above the float can be pushed upward when the downstream water level is slightly higher then the upstream water level and therefore generating a possible leakage inherent to the design. It was seen that during proper functioning of the pet door, observed leakage was only slightly higher then the one prior to installation. From Figure 5 it can be seen that maximum leakage no longer occurs when the highest pressure differences are measured up- and downstream form the tide gate, but steadily increases towards the start of positive outflow (partially through an already open "pet door"). On the other hand, maximum leakage remains below 0.2 m³/s resulting in a cumulative leakage of <1500 m³ which is acceptable compared with a 0.1 m³/s and 1000 m³ on average with no "pet door" present. Moreover, the pet door was observed to be self-cleaning. Debris caught in the opening was flushed away with increasing flows. Nevertheless, trash racks at both sides are recommended.

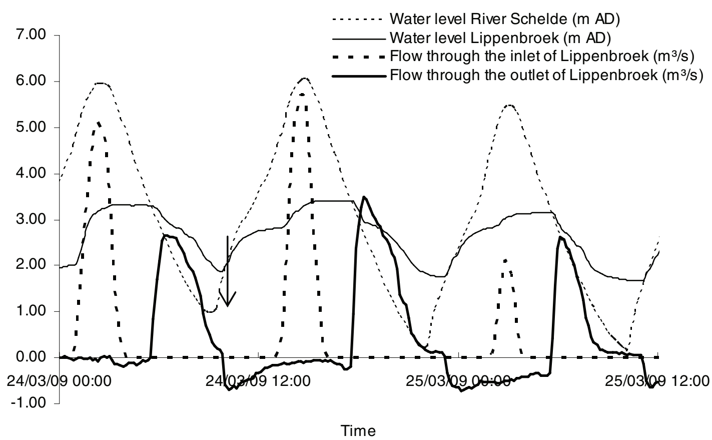
However, after two weeks of operation, it was noted that the pet door (in this case only 5 mm of thickness) was bended due to strong flow currents. As a consequence the 'block was no longer able to hold the pet door in its closed position, letting the pet door hinging to far, leaving more or less half of the gap open. An unintended and not negligible leakage was generated as shown in Figure 6. This problem can probably be overcome by strengthening the pet door, applying a minimum thickness of 10 mm.



↓ Installation of “pet door”

Figure 5. Negligible leakage through a properly functioning pet door

Finally, the major drawback of this design is a potentially incomplete closure of the pet door due to persisting high upstream water levels. With the next incoming tide a potential enormous amount of unwanted water will flow in, giving rise to potential damages. In order to reduce the possibilities for such an event, the angle of the arm to which the float is fastened, can be optimised. Secondly, the pet door was installed somewhat higher then the sill level of the outlet, namely at +2.00 m AD. Because of the hydraulic gradient within the outlet structure, the chances of an unclosed pet door are again minimised.



↓ Start malfunctioning of “pet door”

Figure 6. Not negligible leakage through a malfunctioning pet door from March 24th 2009 and onward (leakage up to 0.5 m³/s and 10.000 m³ each tide)

3.1.3 QUALITATIVE EVALUATION REGARDING FISH MIGRATION

So far, this newly designed pet door is not yet evaluated for the migration of fishes in and out of the flood control area. Based on the hydraulic behaviour of the tide gate, a preliminary evaluation of the functioning of the pet door as a fish passage can be made. The addition of inundated areas to the stream corridor particularly favours species that make essential use of backwaters along the river during their life history. Previous investigation of fish migration from the Schelde into Lippenbroek indicated that only a limited number of fish enters the FCA through the outlet sluice (Simoens *et al*, 2007). Without a pet door fishes can only enter the inundation area when the upstream pressure is larger than the downstream pressure and the large regular tide gate opens. The new pet door already starts to open when the downstream water level is higher than the upstream level. The longer opening time of the tide gate should allow fishes to enter the FCA more rapidly during the tidal cycle and increase their migration opportunities. However, the success of the pet door largely depends on the extent the fishes are attracted towards the opening. Fishes could be attracted by the downstream current coming from the tide gate during ebb tide. Additionally, the position of the pet door may determine which species are able to pass the opening. Before the installation of the pet door, bottom dwelling species like juvenile flatfishes were observed to enter the FCA through the tide gate. As the opening of the pet door is located in the middle of the tide gate, it seems less likely that benthic fishes use this entrance. Other species that dwell in the water column on the other hand, may benefit more from the new opening. Field experiments are necessary to evaluate whether fishes are able to find the opening and pass the culvert.

4 CONCLUSION

Despite of regular inspections in combination with continuous monitoring, due to the potential unwanted leakage and forthcoming safety issues, at this point, Flemish water authorities remain very sceptic regarding the installation of “pet doors”. In order to convince water authorities to implement fish-friendlier tide gates more experience and quantitative data is needed regarding operating and fish-friendliness of so-called “pet doors”. Not only the hydraulic behaviour needs to be examined, also the added value in terms of migration should be addressed.

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