NUMERICAL SIMULATION OF A NEW SAND TRAP FLUSHING SYSTEM

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Abstract: Typical sand trap flushing systems, such as Büchi and Dufour, require water volumes up to six times the deposited sediment volume for efficient flushing. Furthermore, complete sediment removal particularly in Dufour sand traps can only be realized with drawdown flushing, resulting in operation time and water loss. The objective of the described research project is to improve the flushing system of an existing Dufour sand trap. Numerical simulations, performed with two software packages ANSYS CFX and FLOW-3D, are carried out to investigate the flow dynamics in the flushing system and to investigate the required sediment flushing discharge. The flow in the existing flushing system is first studied to evaluate the actual performance of the system. Numerical simulations of the flow in the new flushing system, using the same sand trap, are performed to assess the induced improvements. A good agreement between the results of the numerical simulations using both software packages is observed. Regarding the velocity field in the flushing channel, the existing system is only efficient on the last third of the channel. In the new system, the velocity magnitude is sufficiently high all along the flushing conduit ensuring a good efficiency of the whole system.

Keywords: Sand trap, Sediment flushing, Mobile cylinders, Numerical simulation.

INTRODUCTION

The Dufour sand trap is a standard hydraulic structure for sediment removal upstream of power plants. Dufour sand traps, especially the type II, are frequent in Europe (Swiss, French and Italian Alps) as well as in other parts of the world (Bouvard 1992). The Dufour sand trap needs a significant water volume for sediment flushing. Furthermore, a drawdown flushing followed by washing the sand trap basin are necessary to re-establish the operational mode. An improved flushing system has been developed for Dufour sand traps to optimize the flushing process. In order to verify the efficiency of the improved design, a joint research project was set up between HES-SO Valais (Haute Ecole Spécialisée de Suisse occidentale) and LCH-EPFL (Laboratoire de Constructions Hydrauliques, Ecole Polytechnique Fédérale de Lausanne). The numerical simulations using the software packages ANSYS CFX and FLOW-3D were performed taking into account the existing and the new flushing systems to confirm the modifications efficiency. The existing Dufour sand trap of the Mörel HPP at Fiesch, Switzerland is taken as reference object.

OBJECTIVE, SELECTION AND DESCRIPTION OF SOFTWARE PACKAGES

The objective of the project is to improve the flushing system of an existing Dufour sand trap by technical means. In a first phase, the study is based on a numerical approach, since a large scale physical model would be required to reduce scale effect on the sediment flushing processes. The latter is very costly and time consuming. Moreover, in a second phase, the possibility to install a prototype flushing system with on-site monitoring and testing can replace the physical model. Experience with recent physical and numerical simulations shows the need for the best possible software package regarding the goal of the study. Flow3D has very good and proven capabilities in free surface flow as well as sediment flushing (Möller 2010). ANSYS CFX is suited for pressure flow in pipes and complex geometries such as the new pressure flushing system with its meshing possibilities. Both software packages are complementary.

FLOW-3D, version 9.4.5 numerically solves the continuity and momentum equations using finite-volume approximation. The flow region is subdivided into a mesh of fixed rectangular cells. Within each cell there are associated local average values of all dependent variables. All variables are located at the center of the cells except for velocities, which are located at cell faces (staggered grid arrangement). Curved obstacles, wall boundaries, or other geometric features are embedded in the mesh by defining the fractional face areas and fractional volumes of the cells that are open to flow (the Fractional Area Volume Obstacle Representation FAVOR method). Most terms in the equations are evaluated using the current time-level values of the local variables explicitly. This produces a simple and efficient computational scheme for most purposes but requires the use of a limited time-step size to maintain computationally stable and accurate results (Flow Science 2011).

ANSYS CFX 12.0, a well-known commercial code based on the finite volume method, solves both the incompressible unsteady 3D Reynolds-Averaged Navier Stokes equations and the mass conservation equation in their conservative form. The set of equations is closed-formed and is solved using a two-equation turbulence model, the Shear Stress Transport model (Menter 1994). The SST model uses the $k-\omega$ model (Wilcox 1993) close to surfaces and the model $k-\varepsilon$ (Launder and Spalding, 1974) far away from the surfaces. The equations were discretized by the backward Euler implicit scheme, second order in time and an advection scheme with a specified blend factor equal to one corresponding to a second order in space (ANSYS CFX 2011).

BACKGROUND OF SAND TRAP DESIGN

Overview

Basically, a sand trap represents a settling basin which is generated by a straight and wide channel. Along the channel, the cross section is usually kept constant to reduce the turbulence effect. The significant parameter of a sand trap is its mean flow velocity. The sediment continuously settles in the basin and is sporadically removed by an appropriate flushing system (Bouvard 1992). At the downstream end of channel, discharge and water level are controlled by an end sill or a gate. The above section of a sand trap serves as a settling area which is generally rectangular in sectional view, and the zone below serves as sediment deposition area which is often trapezoidal. Through a sediment excluder provided at the bottom of the deposition area, the sediment deposits can be evacuated via a flushing channel (Schleiss 2008). A typical sand trap layout is shown in Figure 1.

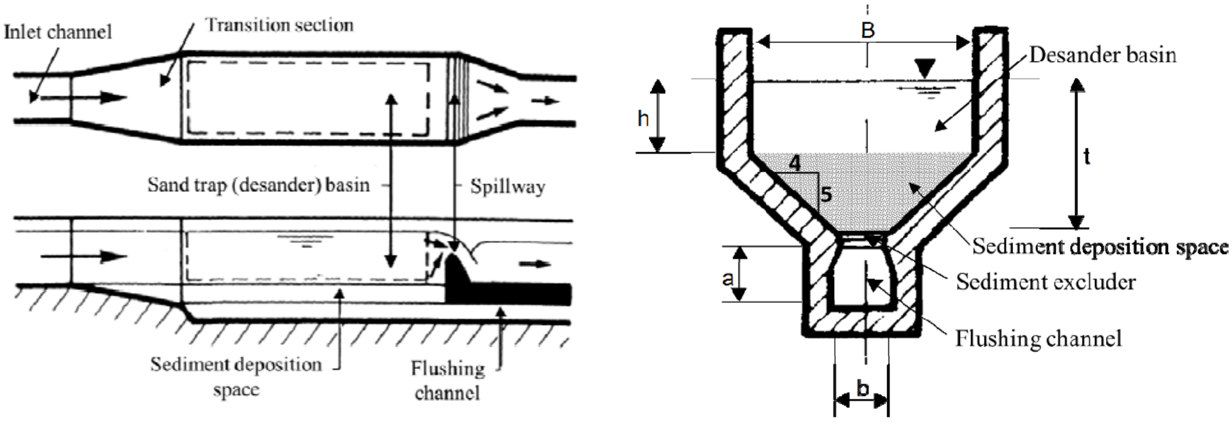

Figure 1 - General layout of a sand trap, Vischer and Huber (1993).

Constructive aspects

The sand traps are normally efficient for a lower limit of sediment grain diameters ranging between 0.2 and 0.3 mm. The height of the sand trap is often given by the topographical conditions. As far as possible, the flushing water and the sediments should flow back to the river. The basin width should be at maximum 1/8 to the sand trap length. Furthermore, the basin width should not exceed twice the depth. For high discharges, several parallel basins are recommended to limit the excavation depth (Schleiss 2008). The key design parameter is, however, the critical longitudinal flow velocity, V_{cr}, that defines the transition between suspension and settling. If $V>V_{cr}$, the particles remain in suspension, and with $V<V_{cr}$ they tend to settle (Bouvard 1992). Sand traps thus require a minimum length, sectional area and bottom slope of the flushing channel. Furthermore, racks may serve tranquilizing the flow.

Dufour sand trap

Dufour sand traps (Dufour 1954) were developed by the Swiss Engineer Henri Dufour (1877 to 1966). These sand traps with a bottom sediment excluder consist of two or more parallel channels with inclined side walls (Figure 2). Sediments and other materials deposit on these walls and then slides or rolls to a gutter as flushing channel, prior to removal trough a scour outlet duct (Bouvard 1992).

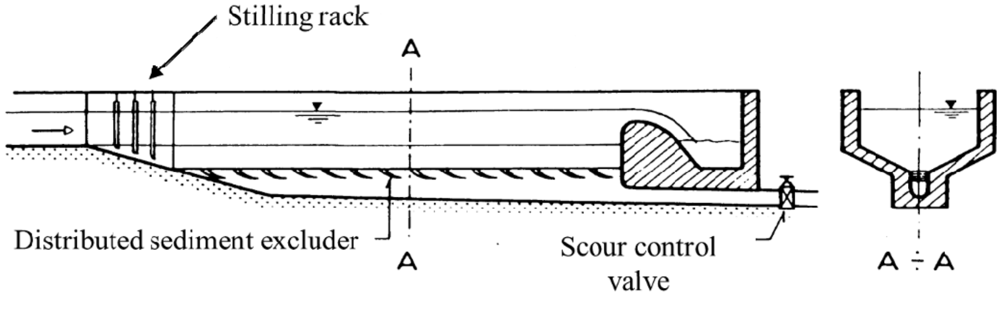

Figure 2 - Schematic Dufour sand trap, Vischer and Huber (1993).

The design problem centers on the sediment excluder. It is arranged in a way so that the washout flow is distributed as uniformly as possible along the trap, to remove deposited material all along. The sediment excluder is made of wood, consisting of 4 meter long modules each having two orifices with a height of 10 cm, formed by gaps between adjacent wooden planks of 2 m length. These wooden planks are slightly inclined. The width of the orifices varies from some 20 cm at the upstream end of the excluder to 10 cm at the downstream end. The gutter below the planks collects the outflow from the excluder, with flow velocities around 2 to 2.5 m/s. The flushing discharge usually reaches up to 10% of the trap design discharge (Bouvard 1992). The flushing channel is controlled by a scour control valve at its end. Normally, this type of sand trap is constructed in twin installations, so that one can be shut down for cleaning purposes.

DESCRIPTION AND SIMULATION OF THE PROTOTYPE USED FOR CASE STUDY

To verify the hydraulic efficiency of the Dufour sand trap, the existing two-basin installation at the Mörel HPP in Fiesch, Switzerland, was chosen as reference object. This sand trap has been constructed in 1942. The minimum and maximum discharges are 5 and 12 m^3/s for each basin. As first step, a drawdown flushing was conducted at the left basin (Figure 3).

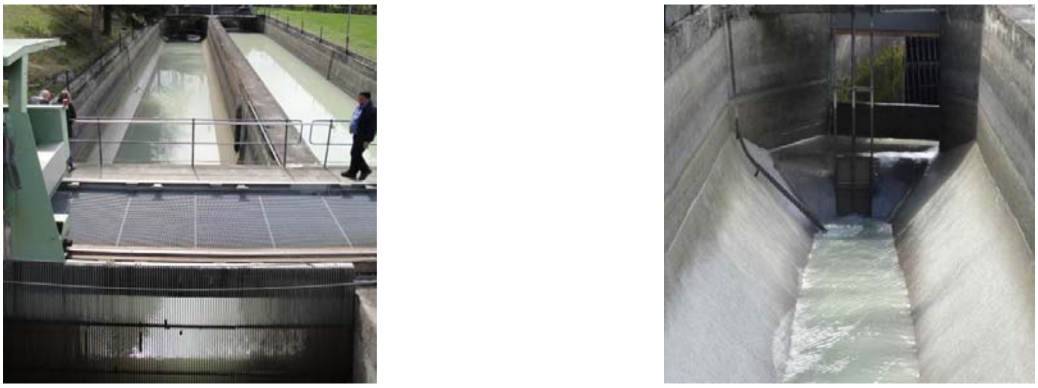

Figure 3 - Sand trap during the drawdown flushing of the left basin, seen in flow direction.

The deposited material was not completely evacuated even during the drawdown flushing, so that the remaining deposits had to be washed out with a small flow supplied by upstream gate opening. Figure 4 shows the remaining deposits on the sediment excluder and the final washing with a small discharge.

Figure 4 - Deposited material remaining above the sediment excluder at the end of drawdown flushing (left), and wooden planks after the final cleaning (right).

The drawdown flushing of the existing system is simulated using FLOW-3D. The simulated evacuation time is about 3 minutes, identical to the observed flushing time on prototype. Figure 5 shows the velocity magnitude and vectors (in magenta) in a longitudinal section along the sand trap center during flushing. The emptying outlet (above the sediment outlet) and sediment outlet (scour control valve) are completely opened as for the in-situ drawdown flushing. As it is shown in Figure 5, the velocity magnitude differs along the flushing channel and increases in particular at last 30% of the channel length.

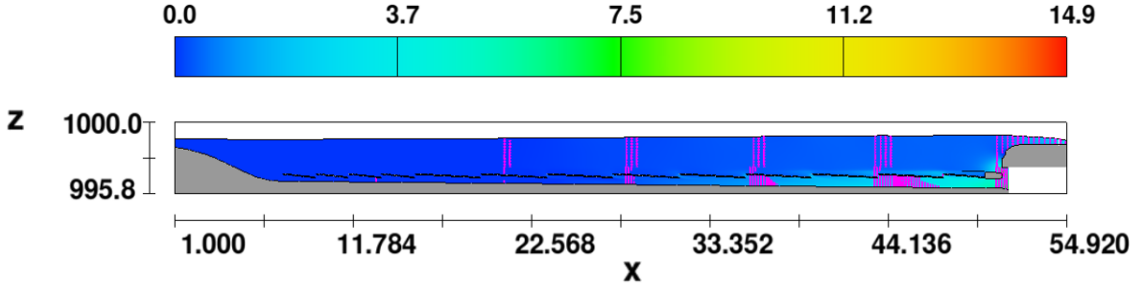

Figure 5 - Velocity magnitude in [m/s] during the draw down flushing with Q_{in}=0 m^3/s, longitudinal section.

Two simulations were also performed without drawdown. A constant inflowing discharge (5 and 12 m^3/s) is provided at the upstream of the sand trap while the sediment outlet is open. Figure 6 shows the velocity magnitude in a longitudinal view of the sand trap with an incoming discharge of 5 m^3/s.

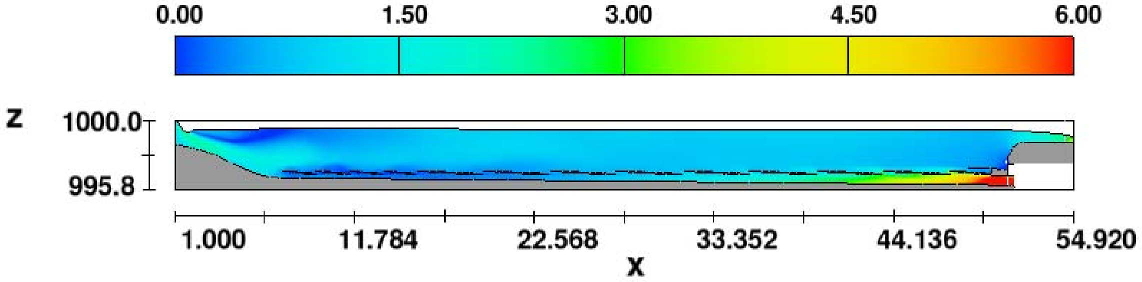

Figure 6 - Velocity magnitude in [m/s] with Q_{in}=5 m^3/s, longitudinal section.

Once more, the flow velocity in the flushing channel is not uniform along the channel and increases up to a value that allows fully suspended sediment transport (Durand 1953) at the last 30% of its length. Besides, the outflowing discharge with both outlets open is around 4 m^3/s, and becomes 2 m^3/s if only the sediment outlet is opened. The flushing is efficient only along a relatively short part of the basin. The flow velocities in the first 35 meters of the channel length are not high enough to evacuate the sediments properly. Furthermore, without drawdown, the flushing discharge is about 1/3 of the inflowing discharge. This water loss is rather high to execute flushing without changing turbine operation mode. Consequently, the only reliable solution is to shut down the basin and to perform drawdown flushing.

NEW FLUSHING SYSTEM

An improved design is provided to optimize the existing flushing system, reduce water losses, and finally to enhance the evacuation of the deposited sediments without drawdown. Note that beside this new system, other options for flushing exist, such as: the HSR system (Truffer et al. 2009), Serpent Sediment Sluicing System (4S) (Lysne et al. 1995), Slotted Pipe Sediment Sluicer (SPSS) and Saxophone Sediment Sluicer (SSS) (Jacobsen 1999). An overall study on sand traps has been performed by Ortmanns (2006). The improved flushing system consists of three basic elements. The flushing conduit, slots on top of the flushing conduit, and several mobile cylinders placed on top of the slots. All these elements are made with PVC or PE. The flushing conduit is mounted in the flushing channel respecting the longitudinal bottom slope. During operation of the sand trap, the mobile cylinders lay on the slots closing them. The flushing is initiated by lifting one of the mobile cylinders by a few centimeters. The flow entering locally by both sides of the slot, evacuates the deposited sediments through the flushing conduit. Figure 7 shows a schematic sketch of the improved flushing system.

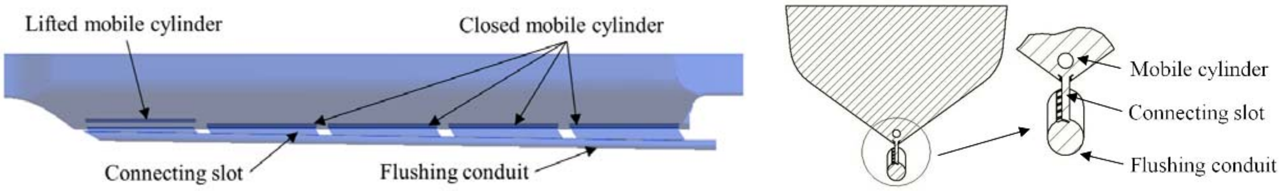

Figure 7 - New flushing system integrated in an existing sand trap, length profile (left) and cross section view (right).

With the improved system, sediment flushing is performed successively. Each mobile cylinder is operated independently from its neighbors. The mobile cylinders are lifted vertically via hydraulic cylinders. The sediment deposit in terms of its height is detected individually at every mobile cylinder by a probe.

HYDRAULIC CHARACTERISTICS OF THE NEW SYSTEM

The improved flushing system is analyzed with FLOW-3D and ANSYS CFX. The velocity magnitude in the sand trap is investigated with the first cylinder raised by 10 cm and an inflowing discharge of 12 m^3/s. Figure 8 shows the FLOW-3D simulation result and Figure 9 the results extracted from ANSYS CFX.

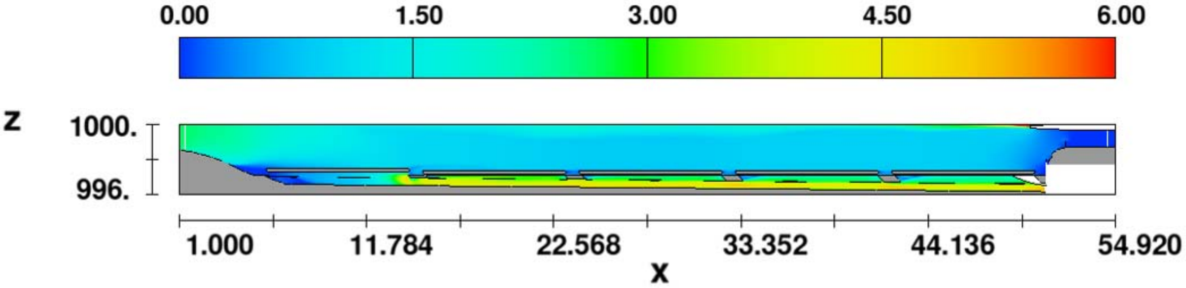

Figure 8 - Velocity magnitude in [m/s] with Q_{in}=12 m^3/s, longitudinal section (FLOW-3D).

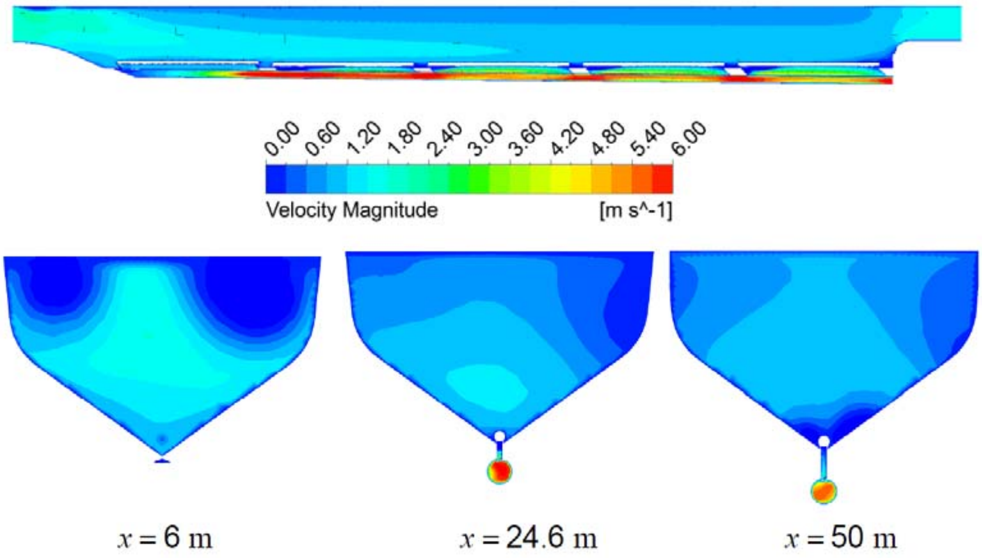

Figure 9 - Velocity magnitude in [m/s] with Q_{in}=12 m^3/s, longitudinal section and three selected cross sections (ANSYS CFX).

The velocity magnitude along the flushing conduit is similar for both software packages. Furthermore, the latter velocity is increased as compared to the initial system (Figure 10).

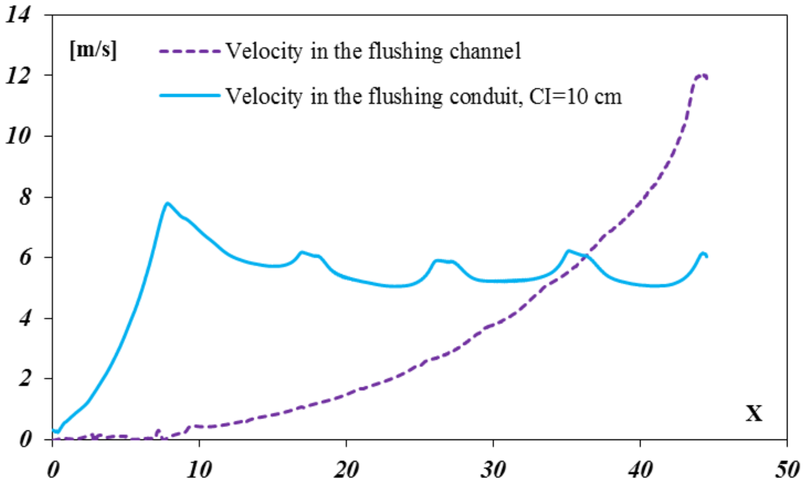

Figure 10 - Longitudinal velocity in flushing systems for the initial and improved system (ANSYS CFX).

Higher flow velocities in the flushing conduit generate an increased sediment evacuation rate with reduced discharge and higher efficiency. The maximum flushing discharge of the improved system is around 1 m^3/s, being 50% of the present system. This allows flushing without drawdown. Regarding the high flow velocities in the flushing conduit, even reduced flushing discharges could be sufficient.

CONCLUSIONS

A new flushing system that can be integrated in existing Dufour sand traps has been designed and tested numerically. The simulations show the hydraulic efficiency of the new design. A maximum flushing discharge of around 1 m^3/s compared to the double of the old system, is required to allow adequate sediment evacuation without drawdown flushing and turbine shutdown. In conclusion, further physical experiments would validate the numerical results.

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