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SPH application in the design of hydraulic structures

Hydrolink

SPH APPLICATION IN THE DESIGN OF HYDRAULIC STRUCTURES

BY DAVID LOPEZ, RUBEN DIAZ, JUAN. J. REBOLLO AND VICENTE CUELLAR

The hydrodynamic study of hydraulic structures is challenging for hydraulic engineering. Traditionally this study has been addressed through physical modeling since there was no commercial software to study with this type of design guarantees. Hydraulics structures usually have complex geometries on a violent flow flowing at high speeds where the free surface is very deformable, which greatly hinders proper modeling. Physical modeling has very high costs so it is justified in works of a certain size. In addition, both artisanal construction procedures as laborious instrumentation techniques require sometimes excessive times. For this reason, a numerical tool is essential to complement these studies using hybrid modeling, numerical and physical.

CEDEX (Research and Experimentation Center of Public Works, an autonomous organisation of the central Spanish State Administration) has developed a model based on the SPH method. There is evidence that Lagrangian models and SPH method especially allow to simulate the hydrodynamic flow of this type of infrastructures. The main drawback has been the high computational cost. The computer code MDST is a FORTRAN code (Grassa, 2004) that has evolved since 2004, from a sequential version to a parallel version with MPI (Message Passing Interface) paradigm for supercomputing in cluster. MPI version allows simulating millions of particles and solving real problems. The impressive improvement of the computing capabilities of graphics cards has allowed the development of a version CUDA FORTRAN called SPHERIMENTAL (López, 2013).
At the same time that the capacity of calculation has been improved too, the calibration of SPH method has progressed in in this application field. On the one hand, a turbulence model based on vorticity of particles has been developed to reproduce viscous dissipation due to turbulence, using as test case the hydraulic jump. (López, 2010). In addition to this, a friction boundary condition has also been implemented as essential premise to reproduce the flow in open channels. On the other side, boundary conditions input and output have been introduced in SPHERIMENTAL (López 2012).
A numerical diffusion problem has been detected in studies of wave propagation with SPH which attenuates the energy of the system. Using the test case dam break (Figure 1), a thermodynamic correction method has been implemented in the code (López, 2015).

Figure 1 - Physical and SPH dam break simulation

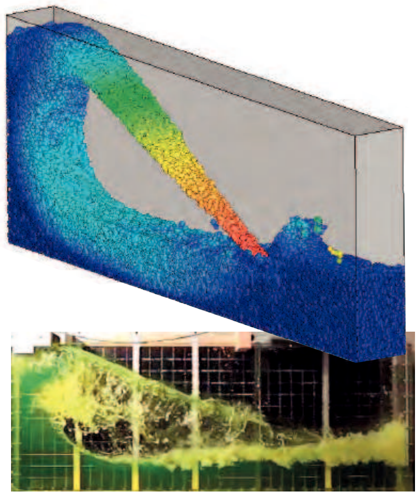
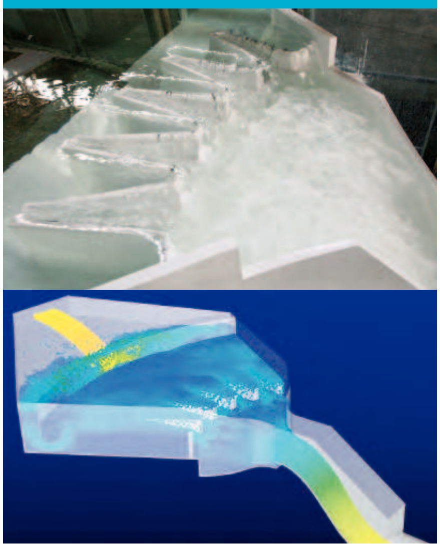


Figure 2 - Physical and SPH simulation of the new Calanda spillway

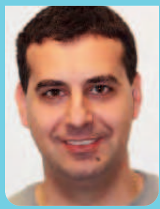


The SPH model has been used in a complementary manner in multiple studies of technical assistance developed in CEDEX, improving the method calibration. The first one was the new spillway of Calanda dam. Currently, this dam has a surface spillway. To increase drainage capacity, a new spillway tunnel was projected on the right side. In this sense, a physical model was used for the spillway analysis. After a laborious tests process, this design showed several failures of flow behavior. Then, to save time, the original design modifications were only carried out with SPH simulations. Moreover, other different types of spillway were analyzed with this numerical method. This numerical study allowed a general vision of the different alternatives in a short lapse of time. A labyrinth spillway was selected as best solution that finally was built in physical model (Figure 2). Since then, in cases where deemed necessary, a preliminary analysis is performed on numerical model to improve the design prior to the study of the physical model.

ALIVESCA project helped to study the influence of side walls in stepped spillways. A study was performed on physical model at the Polytechnic University of Catalonia and CEDEX with SPH to simulate numerically the stepped spillway upper zone where the aeration has less influence. The study looked into the lateral expansion of the flow and also in the analysis of the mechanism of exchange of momentum between the nappe flow and eddies into the steps (Figure 3).

Recently the spillway of Nagore dam has been studied with SPH. It is a rock fill dam with an overflow spillway tunnel. By numerical modeling, the spillway rating curve has been obtained. Moreover, transient phenomena have been analyzed during the initial working phase, when there is a mobile hydraulic jump which moves along the gallery depending of the flow rate (Figure 4). For this study, a correctly reproduction of friction boundary condition is very important, requiring a laborious calibration process.

David López **is Ph.D. in Civil Engineering and member of the State Corps of Civil Engineers. He started working in the Hydraulics Laboratory of the CEDEX in 1993, developing different projects and researches in areas related to hydrodynamic studies of hydraulic structures by using physical and mathematical modelling (SPH), river hydraulics, sediment transport and fluid mechanics.**



Rubén Díaz **is M.Sc. in Civil Engineering and member of the State Corps of Technical Civil Engineers since 2006. He began his professional career in the Hydraulics Laboratory of the CEDEX in 2009. His current interest fields are the physical and numerical modelling of hydraulic structures, hydro-environmental researches and river dynamics.**

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Also, the remodeling of the intermediate spillway of the Bárcena dam has been recently studied. In 1996 a study was conducted at the Hydraulic Laboratory of CEDEX with a physical model test. Construction is running at present. The customer has raised a number of amendments to simplify construction, such as the size reduction of the center pile (Figure 5), providing a short period for this study. This work was performed within two months using numerical simulation with SPHERIMENTAL model, allowing to analyze the flow of the influence area at the drainage intake and check the velocity and vorticity field. The calibration of the friction boundary condition was performed with data of the former physical model.

Another researching line in CEDEX is the EMULSIONA project. This project analyzes the influence on the efficiency of dissipation of energy in a hydraulic jump, aeration inflow in an energy dissipation basin. A physical model has been built for this purpose. The basin is 9 .5 m long, 2 m high and 0.5 m wide, fed by a pressurized flow which introduces a flow velocity of 10 to 20 m / s. the physical model has also a forced aeration system. The experimental data are being used for the calibration of aeration in the SPH model (Figure 6).

Conclusions

The physical and numerical hybrid modeling allows to deepen in the physical basis of the problems analyzed. It also provides more information and help to reduce time and costs of implementing the physical models. Finally facilitates very useful information for calibration of numerical models.

Acknowledges

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Figure 3 - Physical and SPH simulation of a stepped spillway

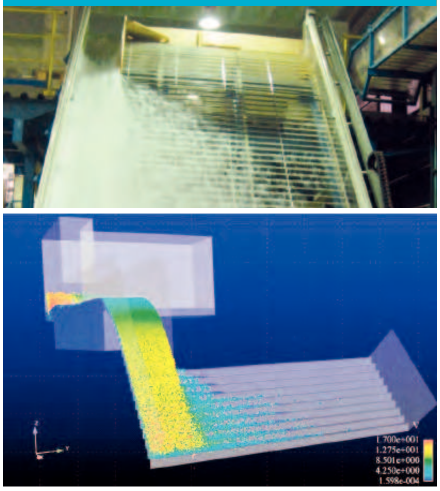

Figure 4 - SPH simulation of Nagore overflow spillway tunnel

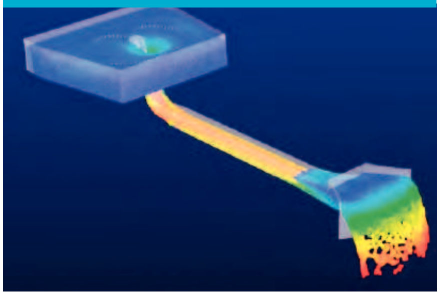

Figure 5 - Physical and SPH simulation of the intermediate spillway of Bárcena dam

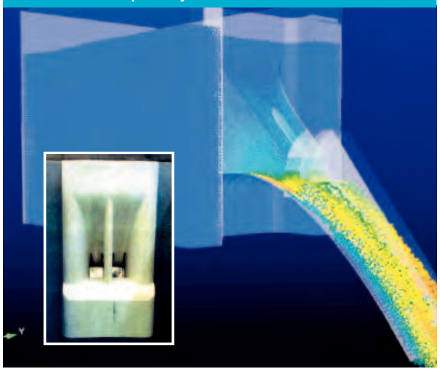

Figure 6 - EMULSIONA Project. Physical and SPH simulation of hydraulic jump