SPH METHOD. APPLICATIONS IN DAM ENGINEERING.

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Summary. CEDEX has developed SPHERIMENTAL. It is a CFD model based on the SPH method encoded in FORTRAN CUDA. This software is used in the hydrodynamic design of hydraulic structures and in dam engineering research studies. The paper presents the characteristics of the code and shows some cases of studies carried out. Also NAYADE, a massive visualization tool by Wavecrafter is showed, that allows postprocessing results with millions of particles in real time.

1 INTRODUCTION

Hydrodynamical study of hydraulics structures, such as the spillways of dams, traditionally has been carried out through physical models, very expensive and long execution times. Nowadays, three-dimensional numerical models are being applied that, in addition to reducing time and costs, allow us to deepen the physics of the problem. However, the road traveled to reach this point has been a great challenge.

Initial sequential code version[1] gave very promising results[2] but it had computation times and memory requirements that made it impossible to apply them to real cases. A parallel MPI version, for CPU clusters, allowed to simulate real cases for first time, enabling calibrations of the method with experimental data from physical model test[3]. But computation times were still excessively long, limiting its use as a design tool. Keep in mind that usully, in a study of a spillway, it is necessary to carry out dozens of simulations with different flow rates and geometries.

GPU supercomputing techniques and continuous increasing of compute capabilities of these devices, have allowed to drastically reduce calculation times and incorporate numerical modeling to the usual work practice. Now a days, in CEDEX Hydraulic Laboratory, hybrid physical-numerical modeling has been standardized. Studies are approached in a global way through numerical modeling, with SPHERIMENTAL model[4], limiting physical experimentation to aspects of detail and, of course, of research. Analysis and post-processing of simulations of millions of particles also presents difficulties. NAYADE is a visualization software developed by Wavecrafters, designed for real time rendering of millions of elements, with stereoscopic capabilities, it allows the use of VR equipment and record video of the simulations.

2 SPHERIMENTAL

SPHERIMENTHAL solves 3D Navier–Stokes equations for a weakly compressible flow by men SPH method. This allows Navier–Stokes equations, to be integrated using an explicit time scheme. Integrations are computed with a Taylor Vortex Green third order Runge-kutta numerical scheme. The boundary condition method used by SPHERIMETAL is the proposed one by Monaghan[5] using of repulsive forces according to the Lennard-Jones scheme. This method has a low computational cost and is very suitable for reproducing complex geometries[6]. SPHERIMENTAL code also incorporates the possibility to set open boundary conditions with input and output of fluid particles from the calculation domain. It also has a calibrated friction boundary condition[7].

Searching of interaction pair method employs an auxiliary three-dimensional Cartesian mesh that covers entire domain. The method assigns a "hash" (label) code to all particles that is the same at each cell. This hash code is calculated based on the spatial coordinates of each particle[8]. This let to reduce de searching area to neighbor cells. To optimize performance and achieve coalescence in memory access, all particles are reordered according to a spatial criterion, by the cell in which they are located. SPHERIMENTAL incorporates a system based on operations with atomics (parallel operation that avoids overwriting conflicts with different execution threads), which is 4 times more efficient than a sorting method with the "radix-sort" algorithm[9]. To optimize the use of memory, no structures are used to store the interaction pairs. The calculation of derivatives is done simultaneously to the search of interaction pairs, which allows not to store this information. This makes it possible to compute $3.8 \cdot 10^6$ particles for each Gb of RAM memory of the graphic card.

In the visualization and post-processing parts of the process there were several challenges to handle. First is the high number of particles of these simulations, most of them changing their position, then the high resolution of modern screens forces you to render millions of pixels sixty times per second. With VR equipment the load is double as you have to render both righ and left eyes perspectives. With those challenges in mind the whole pipeline was optimized, from reading the data from disk, swapping the data for every time step in memory, as the simulations data sizes exceed available RAM memory, to the rendering in the screen.

3 APPLICATIONS ONN DAM ENGINEERING

Some works that are being carried out using the hybrid modeling technique in the Hydraulic Laboratory are present below. Figure 1 corresponds to the study of the Angostura dam spillway (Perú). It lets to apreciate the flow derivation structure to a transfer tunnel. This structure consist on a channel in curved plant with a side weir. In operations with high flows there is an unequal distribution of the flow along the weir, phenomenon that can be compared in physical and numerical models.

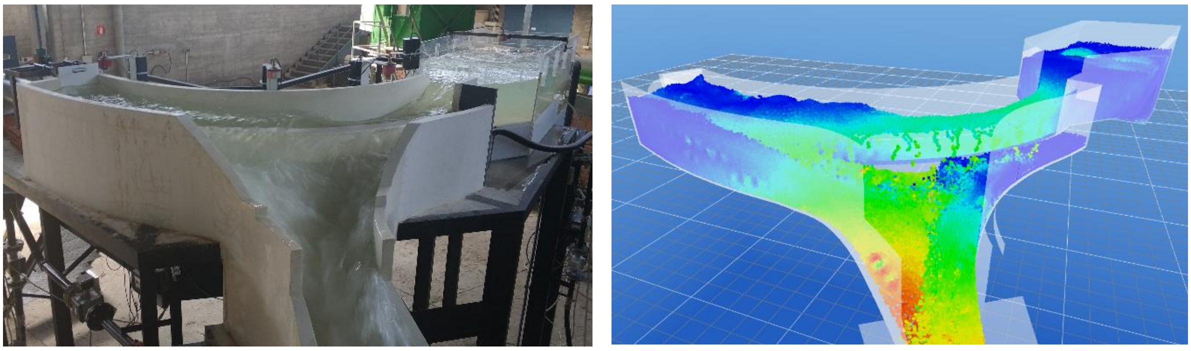

Figure 1: Side spillway of Angostura dam (Perú).

Figure 2 shows a comparison between numerical model and prototype during the verification tests that were carried out in the rehabilitation study of the mid-level outlet of the Bárcena[10] dam (León, Spain). In this work, hydraulic operation of the new spillway has been checked and design improvements have been introduced.

In research field, we are working on a sediment transport module that allows carrying out studies of local erosion in bridge piers or under ski jumps jets impact. Likewise, we are developing an aeration module that will allows studying interaction of water and air flows in hydraulic structures. As example, figure 3 is shown, from the study of the Nagore[6] dam (Navarra). The well spillway of this dam traps large air pockets generating very violent transients in the gallery with large pressure oscillations that produce a significant water transport in its exit path.

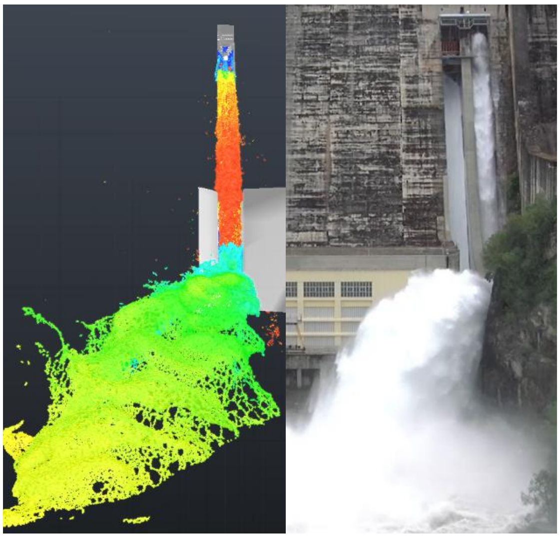

Figure 2: Middle mid-level outlet of Bárcena dam (León, Spain).

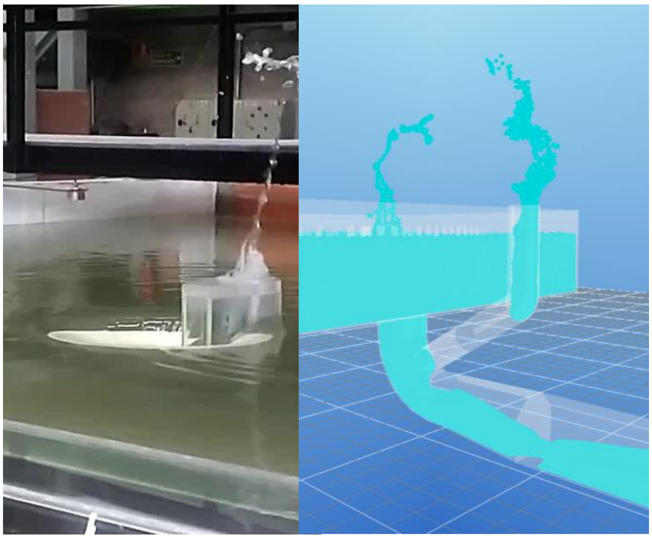

Figure 3: Well spillway of Nagore Dam. Air occluded phenomena in spillway gallery.

4 CONCLUSIONS

Now a days, use of three-dimensional numerical model for the study of hydraulic structures of dams is a reality, thanks to GPU based supercomputing techniques. They have helped to reduce computations time drastically, allowing to perform complex hydrodynamics analysis in a short time.

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