SPHERIC newsletter

9th issue – December 2009

SPH European Research Interest Community

http://wiki.manchester.ac.uk/spheric/

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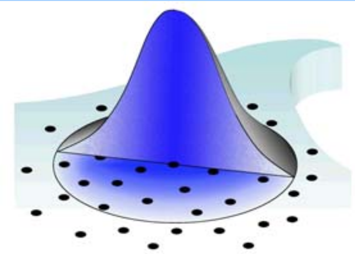

Fifth SPHERIC Workshop 2010

The fifth international workshop organised by the Smoothed Particle Hydrodynamics European Research Interest Community will be the major international event of 2010 in the SPH research field. It will be held at the University of Manchester, U.K., from **June 23rd** to **June 25th 2010**, preceded by a training day (**June 22nd**).

Manchester is one of the most exciting cities in Britain having undergone a breathtaking transformation in the past 15 years. With a population of about 2 million inhabitants including some 100,000 students the city in the north-west of England is close to the Lake District and some of the most beautiful and stunning scenery Britain has to offer and is easily accessible being only 2 hours from London by fast-train and is served by two international airports at Manchester and Liverpool. The University of Manchester is one of the premier institutions in the U.K. and the School of Mechanical, Aerospace and Civil Engineering is one of the largest engineering schools in the country with over 1000 undergraduate students and 400 postgraduate students.

The aim of this scientific workshop is to contribute and focus on new developments and advanced applications of the SPH method. Hence, the **main purposes** of the **5th SPHERIC workshop** are:

- share Smoothed Particle Hydrodynamics experience and developments;
- create an open worldwide and cooperative spirit between SPH researchers;
- encourage favourable exposure for PhD students in the early stage of their career.

The **topics** of the workshop will cover a large range of applications and research into SPH including:

- Astrophysics;
- Solids, Plasticity and Fractures;
- Water Waves, Wave Loads, Numerical Wave Tanks;
- Fluid-Structure Interaction;

(*continued next page*)

- Engineering Applications;
- Mathematical and Fundamental Aspects;
- 'Non-Standard' Formulations;
- Multi-phase SPH ;
- Boundary conditions ;
- Compressibility in Fluids;
- Viscosity and Turbulence;
- Hardware & GPUs;
- Engineering applications;
- Visualization.

The number of presentations will be limited to keep a unique session gathering all the participants. Abstracts and papers will be reviewed by the SPHERIC steering committee. Sessions will be structured according to submitted papers. A template will be provided on the website for paper submission. It is recommended not to spend too much space on standard SPH equations in papers and presentations.

A book of proceedings and a PDF version on a USB stick will be delivered during the workshop. The Libersky student prize will be awarded to the best student contribution (paper and presentation).

This year for the first time, it is planned that the workshop will be preceded by the 2nd UK Astrophysics SPH Forum also to be held in Manchester from June 21st to June 22nd so there will be one whole week of SPH!

Additional information (abstract submission and templates, committees, important notices, program and registration) can be found on the website dedicated to the workshop,
http://www.mace.manchester.ac.uk/5thspheric

The important dates are:

- Abstract submission: 18/02/2010;
- Announcement of selected abstracts: 18/03/2010;
- Early registration deadline: 24/04/2010;
- Proceeding papers submission: 24/04/2010.

Any further information request should be emailed to 5thspheric@manchester.ac.uk.

Ben Rogers
Chairman of the Local Organising Committee

Selected Recent Publications and Ph.D. Theses on SPH

Below is a small selection of references recently added to SPHERIC's online catalogue of SPH literature at http://www.citeulike.org/group/3462. Anybody can access and contribute to this database.

Bierbrauer, F., Bollada, P.C., and T.N. Phillips (2009), *A consistent reflected image particle approach to the treatment of boundary conditions in smoothed particle hydrodynamic*, Comput. Meth. Applied Mech. Eng. **198**:3400.

Violeau, D. (2009), *Dissipative forces for lagrangian models in computational fluid dynamics and application to smoothed-particle hydrodynamics*, Phys. Rev. E **80**:036705.

Grenier, N., Antuono, M., Colagrossi, A., Le Touzé, D., and Alessandrini, B. (2009), *An Hamiltonian interface SPH formulation for multi-fluid and free surface flow*, J. Comput. Phys. **228**:8380.

Colagrossi, A., Antuono, M., and Le Touzé, D. (2009), *Theoretical considerations on the free-surface role in the smoothed-particle-hydrodynamics model*, Phys. Rev. E **79**:056701.

Laigle, D., Lachamp, P., and Naaim, M. (2007), *SPH-based numerical investigation of mudflow and other complex fluid flow interactions with structures*, Comput. Geosc. **11**:297.

Xu, R., Stansby, P., and Laurence, D. (2009), *Accuracy and stability in incompressible SPH (ISPH) based on the projection method and a new approach*, J. Comput. Phys. **228**:6703.

Sigalotti, L. D., López, H., and Trujillo, L. (2009), *An adaptive SPH method for strong shocks,* J. Comput. Phys. **228**:5888.

The following theses are available to download in full at http://wiki.man.ac.uk/spheric.

Capone, T. (2009), SPH numerical modelling of impulse water waves generated by landslides, University of Rome, La Sapienza.

Narayanaswamy, M. (2008), A Hybrid Boussinesq-SPH Wave Propagation Model with Applications to Forced Waves in Rectangular Tanks, The Johns Hopkins University.

Khayyer, A. (2008), Improved Particle Methods by Refined Differential Operator Methods for Free-Surface Fluid Flows, Kyoto University.

Delorme, L. (2008), Sloshing Flows. Experimental Investigation and numerical investigations with Smoothed Particle Hydrodynamics, Universidad Politenica de Madrid.

Crespo, A.J.C. (2008), Application of the Smoothed Particle Hydrodynamics model SPHysics to free-surface hydrodynamics, Universidade de Vigo.

Modelling Water Entry of a Wedge by Multiphase SPH Method

***H. Liu, K. Gong & B.L. Wang**, Dept. of Engineering Mechanics, Shanghai Jiao Tong University, China*

Water entry is part of the general fluid-structure impact problem in the field of naval architecture. The SPH method is attractive for simulation of the violent wave impact problems, *e.g*. Oger *et al*. (2006). Since 2004, some progress has been made at Shanghai Jiao Tong University, applying the SPH method to water entry, dambreaking, sloshing and breaking of solitary waves for the cases of 2-D, axisymmetry 2-D and 3-D problems (see Gong *et al*., 2007).

For water entry problems, the air cavity enclosed by the water may significantly affect the local free surface profile and flow field, and then the hydrodynamic loads acting on the body. A two-phase SPH model has been implemented to solve flows in the water and air domains from the initial stage of water entry to closure of the air cavity. It turns out that numerical results and physical experiments of water entry in the case of a two-dimensional wedge agree well, as shown in Figure 1. To save computational effort, an absorbing boundary is implemented to remove the sound disturbance from the computational domain, see details in Gong *et al*. (2009). By this approach, the computational time can be extended without the limitation of sound wave reflection from solid boundaries, which is a common drawback of weakly compressible SPH method.

The velocity and pressure fields are shown in Figure 2. The pressure of the open cavity equals the atmospheric pressure, shown in relative value. After closure, the pressure in the sealed cavity increases rapidly and becomes equal to the surrounding water pressure. Note that a re-entrant jet is formed after the deep enclosure.

Using OpenMP parallel environment in a SMP DELL T5400 workstation with two 2.5GHz Xeon quad-core, these typical simulations take around one week for multiphase simulations of half a million particles and 300,000 time steps. The speedup factor is up to 6 for the computations at these computational scales.

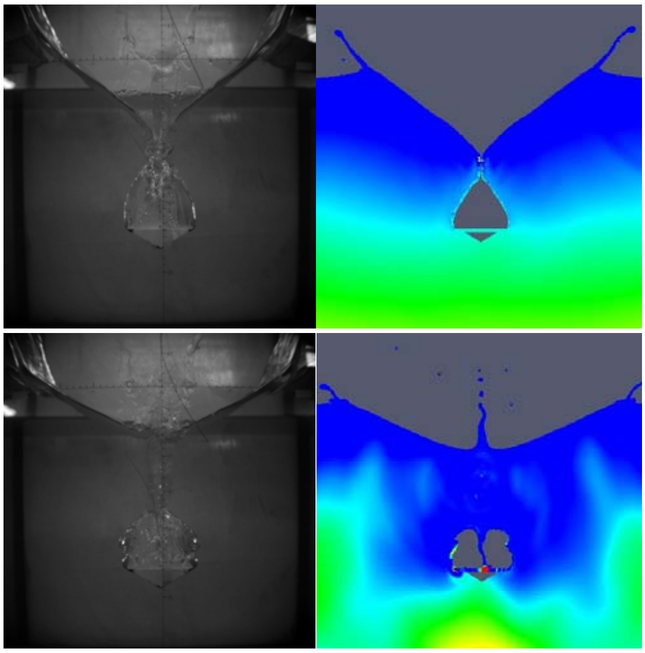

Figure 1 – Comparison between experimental results and computed results for water phase.

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Oger, G., Doring, M., Alessandrini, B. and Ferrant, P. (2006), *Two-dimensional SPH simulations of wedge water entry,* J. Comp. Phys. **213**:803.

Gong, K. and Liu, H. (2007), *Numerical Simulation of Circular Disk Entering Water by an Axisymmetrical SPH Model in Cylindrical Coordinates,* Proc. Vth International Conference on Fluid Mechanics, Aug., Shanghai, China.

Gong, K., Liu, H., Wang, B. (2009), *Water Entry of a Wedge Based on SPH Model with an Improved Boundary Treatment,* Journal of Hydrodynamics, Ser. B. (in press).

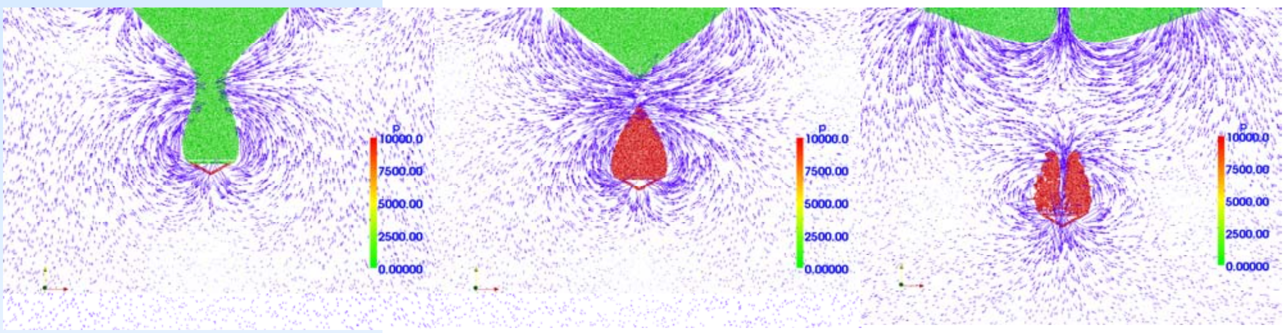

Figure 2 – Pressure (in colour) and velocity vector distribution before and after cavity closure.

Modelling fracture and fragmentation in a thin plate under high velocity impact

R. Das & P.W. Cleary, *CSIRO Mathematics, Informatics and Statistics, Australia*

Fracture and fragmentation are governed by multiple physical processes involving different time and length scales. The sources of fracture are micro and macro voids, micro-structural defects, and cracks. Damage by fracture under high-speed impact is a dominant mode of failure in many applications. Numerical fracture models will ideally predict fracturing events at small and large scales. Their applications can potentially assist in understanding the key mechanisms of fracture and the resulting fragmentation processes. Here we demonstrate the effectiveness of SPH for three-dimensional modelling of fracture resulting from the impact of a projectile on a thin shell structure.

In the collision example shown here, the projectile travels with a velocity of 1000 m/s and collides with a stationary target whose edges are rigidly fixed. The target is a 150 mm ×150 mm × 6 mm plate made of an elastic-brittle ceramic material with a bulk modulus of 56.0 GPa, shear modulus of 26.5 GPa, and density of 2500 kg/m^3. For damage evaluation in SPH, we use a modified form of the Grady-Kipp model (Grady and Kipp, 1980).

Figure 1 shows the evolution of the damage of the target as the projectile collides and penetrates it. As the projectile first contacts the plate, its tip creates very high stresses around the point of contact that produce severe damage there. This localised region of high damage increases in size up to 20 µs, (Figure 1a), creating a region of reduced strength around the impact point. As the conical nose of the projectile penetrates into the target, a number of primary radial cracks are generated and propagate outwards from the highly damaged centre towards the edges of the plate (Figure 1b).

With further penetration, the high impact stresses lead to a fully damaged region in the middle, consisting of a cloud of debris made up of fine fragments of the plate (Figure 1c). The debris zone remains primarily confined to a small region around the initial point of impact and a debris cloud erupts horizontally from the back face of the plate. During the impact and penetration, compressive stress waves are generated at the centre and propagate towards the edges. The interaction of the incident stress waves with the rarefaction compression waves reflected from the fixed edges of the plate slows the radial propagation of cracks. On approaching the plate edges at around 60 µs, the advancing radial crack fronts turn sideways and propagate parallel to the edges (edge cracks, Figure 1c). This phenomenon is known as 'crack arrest'.

Figure 1d shows the final fracture pattern after the complete penetration and exit of the projectile. The creation of cracks parallel to the edges is accompanied by the generation of high stresses here. This leads to the initiation of short cracks emanating from the paths of the radial and edge cracks, which are known as 'secondary' cracks or fractures. The growth of these secondary cracks occurs mainly near the edges of the plate. They also change direction while approaching the plate corners due to the decelerating effect of the compressive stress waves. In contrast to the predominant radial crack propagation in primary fracturing, secondary fracture produces a complex damage pattern including branching, intersection and merging of the cracks near the edges of the plate. The central debris cloud continues to travel in the direction of the projectile and spreads out forming a conical shape, as is starting to occur in Figure 1d.

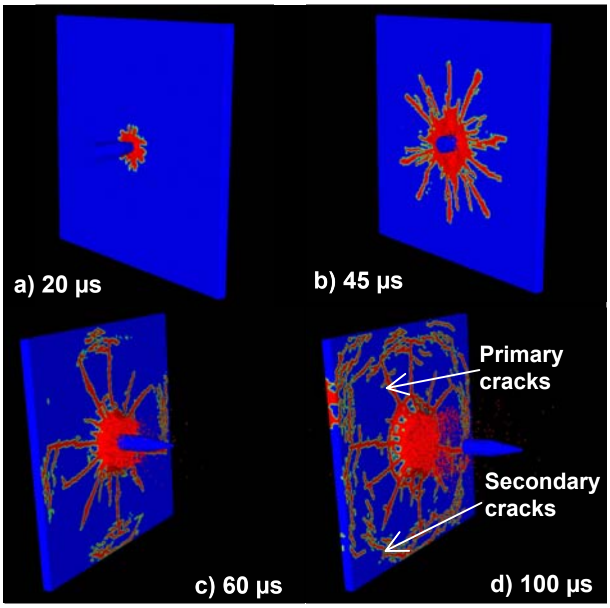

Figure 1 – Fracture process in the plate during collision (blue-red represents damage range of 0-1). Top: view from in front; bottom: view from behind the plate.

This study shows that SPH is an effective numerical tool to model fracture under high-speed impact. SPH simulations offer insights into the key failure mechanisms, and are useful in predicting the failure behaviour in many applications, such as construction (impact-resistant tall structures), defence (high-speed weaponry), and comminution (particle breakage in mills). Understanding failure behaviour is an important prerequisite for the design of fracture resistant structures and for understanding the failure mechanisms of existing structures.

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Grady, D.E. and Kipp, M.E. (1980), *Continuum modelling of explosive fracture in oil shale*, Int. J. Rock Mech. and Mining Sci. & Geomech. Abstr., **17**:147-157.

Computational Geomechanics with SPH

***H.H. Bui & R. Fukagawa**, Department of Civil Engineering, Ritsumeikan University, Japan*

Computational geomechanics often deals with the large deformation and failure of geomaterials, which are very difficult to model using the traditional mesh-based methods such as finite element method (FEM). In such circumstances, applications of SPH to this field would resolve the above difficulty and bring great advantages over the traditional computation methods. Researches on application of SPH to computational geomechanics have been recently conducted at Ritsumeikan University in Japan. In our work, the SPH method has been extended to simulate elasto-plastic behaviour of soil. Several soil constitutive models such as the elastic-perfectly plastic soil model based on Mohr-Coulomb and Drucker-Prager yield criterions, the hardening plasticity soil constitutive model, and the Cam-clay model, have been implemented into the SPH framework, and applied to study such problems as granular flows, bearing capacity of soil, slope stability analysis, landslide and debris flows, coupled soil-water behaviour, seepage failure flow, etc. Results have shown that SPH is very well suited to handling large deformation and post-failure of geomaterials.

Figure 1 shows the application of SPH to simulate gravitational flow of granular material (Bui *et al.*, 2008, 2009a). In this application, Drucker-Prager soil constitutive model with a non-associated plastic flow rule has been adopted. This soil model requires six soil parameters which can be obtained easily from direct shear tests. The SPH tensile instability has been removed using the return mapping algorithm in elasto-plastic computation. It can see that simulation result agrees very well with experiment conducted under the same conditions. The agreement was observed not only on the surface configuration, but also the deformation pattern via square grids plotted on the soil sample. This suggests that SPH can be applied well to investigate behaviours of granular flow.

SPH has also been utilized to evaluate stability of a slope and to simulate post-failure behaviour of soil (Bui *et al.*, 2009b), as shown in Figure 2. Herein, the Mohr-Coulomb soil model has been employed, and SPH formulations have been slightly modified to incorporate the pore-water pressure. It is shown that the safety factor and potential slip surface predicted by SPH are almost similar to those given by FEM and LEM (*i.e.* Bishop's method). A major advantage of SPH is that the post-failure behaviour of a slope can be simulated without difficulty, thereby providing insight to the slope failure mechanism. Further applications of SPH to this field can be found in:

http://sites.google.com/site/hhbuiinfo/sph-applications

The early applications of SPH to computational geomechanics yielded some benefits. However, there are still several issues that need further developments to enhance the performance of this method. These are being conducted in our research group.

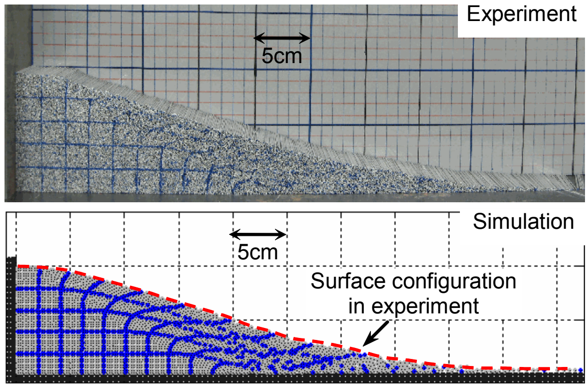

Figure 1 – Simulation of granular flows by SPH.

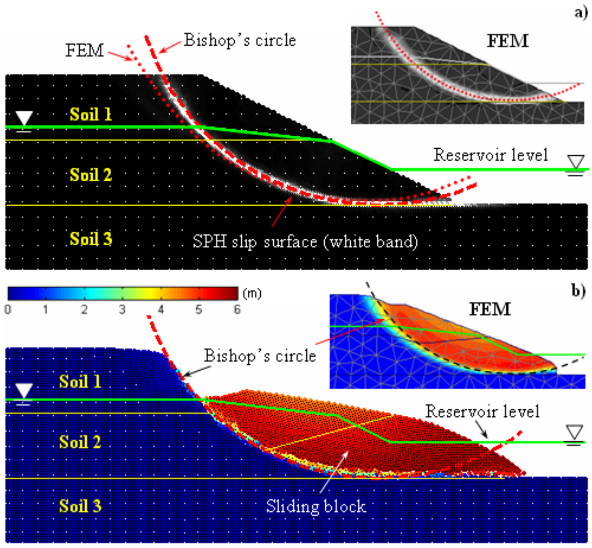

Figure 2 – SPH application to slope stability analysis and slope failure simulation: a) Contour plot of plastic strain; b) Post-failure behavior of a slope.

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References

Bui, H.H., Fukagawa, R., Sako, K., Ohno, S. (2008), *Lagrangian mesh-free particle method (SPH) for large deformation and post-failure flow of geomaterials using elastic-plastic constitutive model*, Int. J. Numer. Anal. Meth. Geomech. **32**:1537-1570.

Bui, H.H., Fukagawa, R., Sako, K., Wells, J.C., (2009), *Numerical simulation of granular materials based on smoothed particle hydrodynamics (SPH)*, Powders & Grains, pp.1578-1581.

Bui, H.H., Sako, K., Fukagawa, R. (2009), *Slope stability analysis and slope failure simulation by SPH*, proc. 17th Int. Conf. on Soil Mech. & Geotech. Eng., (ICSMGE), pp. 1578-1581.

Application of SPH for the evaluation of impact problems in the marine field

***M. Viviani & L. Savio**, Genoa university, Department of Naval Architecture and Marine Engineering, Italy*

Problems involving impact phenomena in the marine field (hull slamming, sloshing in tanks, green water on deck) have been investigated for a long time both theoretically and experimentally. Nevertheless, they are still under investigation, due to the intrinsic difficulties which arise from the high non-linearities involved, such as the strong variations of free surface. For these problems, application of SPH, with its intrinsic ability to treat free surfaces, is particularly attractive with respect to conventional methods, in which a certain mesh is adopted. On the other hand, SPH presents some shortcomings such as the necessity of a fine tuning of some parameters which are very significant (*e.g.* artificial viscosity, sound speed, etc.) and some problems related to pressure evaluation in particular points of interest.

In recent years, DINAV developed an SPH code and applied it for the evaluation of these impact phenomena, with particular interest in obtaining a set of settings (or criteria to obtain settings) which can be used in a broad range of cases, both for 2D slamming cases (Viviani *et al.*, 2009) and 2D sloshing cases (Brizzolara *et al.*, 2009).

Slamming calculations simulating a free fall of a typical wedge shaped section (30° deadrise) and a more complex ship bow section, for which experimental data of previously developed drop tests has been made available within the MARSTRUCT thematic network (Aarsnes, 1996), have been carried out. Tests considered were carried out with different drop speed and different heel angles.

As an example, calculations of pressure time histories for a point on the impacting side of the wedge in correspondence to a drop speed of 2.40 m/s and a heel angle of 14.7° are reported in Figure 1. Similar results were obtained also for bow section and other heel angles/drop speeds. A reasonable agreement between experiments and calculations was found, even if a certain "pressure drift" was observed.

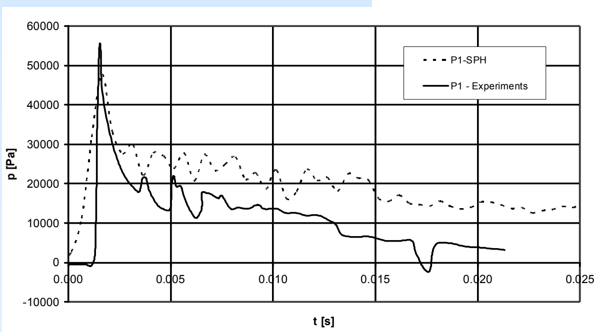

Figure 1 – Wedge section, Drop speed 2.40 m/s, heel angle 14.7°, pressure time history.

Sloshing calculations have been also carried out, to simulate a two-dimensional tank rolling around a horizontal axis with a constant amplitude of 4°, different periods and different water levels, for which experimental data of tests were made available by ETSIN (Delorme *et al.*, 2007). As an example, calculations and measurements of pressure time histories, in case of a filling level of about 18% and with the resonant rolling period, for a sensor placed in correspondence to the calm water level, are reported on Figure 2. As it can be seen, SPH is able to correctly predict pressure peaks caused by the sloshing phenomenon. Finally, the capability of SPH to capture slamming and sloshing kinematics is briefly depicted by Figure 3.

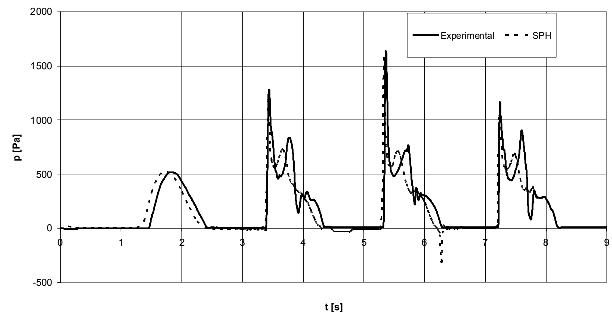

Figure 2 – Filling level 18%, $T = T_0$ (resonant), pressure time history for sensor at calm water level.

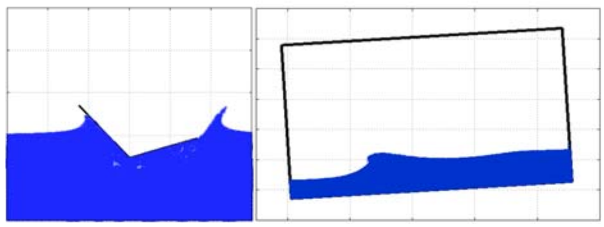

Figure 3 – Kinematics captured by SPH.

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References

Aarsnes, J.V. (1996), *Drop test with ship sections – effect of roll angle*, Marintek Report 603834.00.01.

Delorme, L. and Souto-Iglesias, A. (2007), *Impact Pressure Test Case Description*, ETSIN Report.

Viviani, M., Brizzolara, S., Savio; L. (2009), *Evaluation of Slamming Loads using SPH and RANS Methods*, J. Eng. Maritime Env. **223**(1)17-32.

Brizzolara, S., Savio, L., Viviani, M., Chen, Y., Temarel, P., Couty, N., Hoflack, S., Diebold, L., Moirod, N., Souto Iglesias, A. (2009), *Comparison of experimental and numerical sloshing loads in partially filled tanks*, Proc. 2nd Int. Conf. Marine Structures, 16–18 March, Lisbon.

On the recent improvements in the SPHERA code

***G. Agate** & **R. Guandalini**, Environment and Sustainable Development Dept., ERSE S.p.A., Italy*

ERSE carries out research in the electricity and energy fields, focusing on the improvement of the Italian electricity system from the environmental safety, security and economical points of view. In the framework of a project on power generation and energy sources, safety issues due to interaction between hydropower schemes and the surrounding territory have been considered using, among others, an approach based on the SPH methodology, resulting in the development of the 3-D code SPHERA, completed at the end of 2008.

As a matter of fact, reservoirs and dams may give rise to safety hazards for population and infrastructures where schemes are located, in the presence of particular hydro-geologic circumstances, equipment malfunctioning and/or structural failure; *e.g.*, spillway insufficiency to discharge extreme floods, clogging of dam bottom outlets due to sedimentation, the onset of landslide-induced waves in the reservoir, dam break wave formation due to hypothetical dam collapse, are issues to some of which SPHERA has been applied, since related hydrodynamics problems exhibit flow features (free surface, multiphase, complex geometry, transient flow) which could be well captured using the SPH approach.

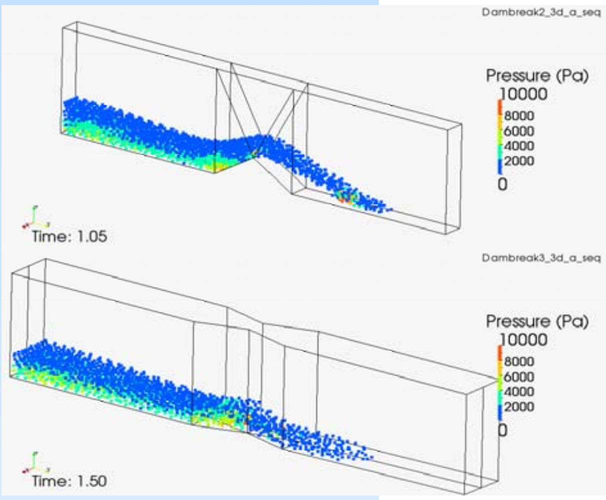

Figure 1 – Preliminary tests.

First of all, the performed simulations have pointed out a number of restrictions for application of the method as implemented to full scale problems. Thus some enhancements have been realized with the aim of successfully applying the code to this class of problems, mainly including:

- a fully 3-D implementation of very irregular domains,
- revision of parallelization techniques in order to increase performance,
- the semi-analytical approach for the boundary conditions, including constraints on flow and velocity,
- the consideration of different materials, both using a multifluid and a fluid/granular approach,
- smoothing techniques for pressure allowing a correct consideration of free surfaces,
- automatic link with open-source pre- and post-processors.

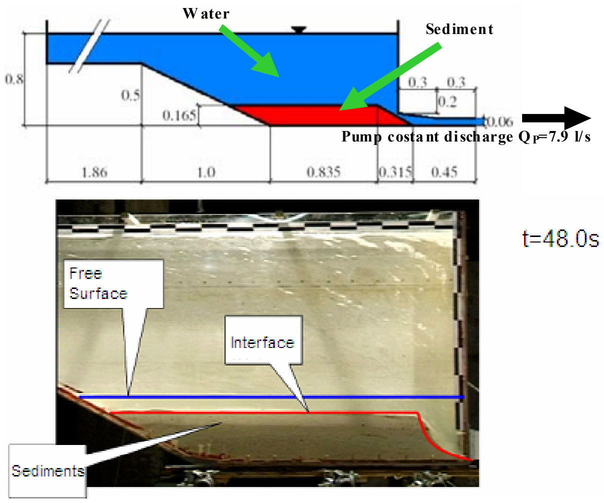

Figure 2 – Scheme of 2-D & 3-D tests on sediment scour and experimental setup.

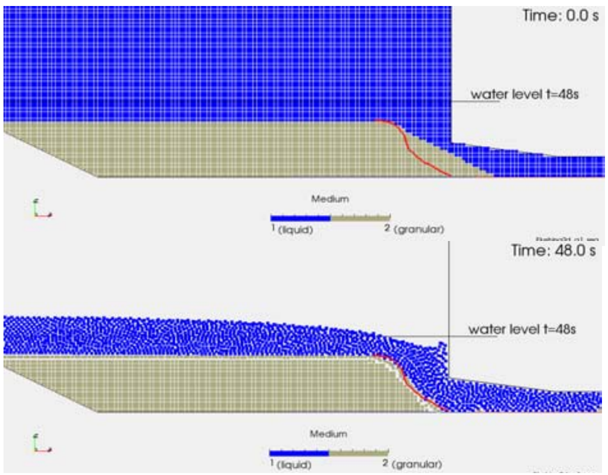

Figure 3 – Results of 2-D simulation of sediment scour. The red line mimics the experimental sediment profile.

The current release of the code has been tested from the point of view of both accuracy and computational cost. After preliminary tests of correctness (Figure 1), simulations have been performed comparing results with experimental data and SPHERIC benchmarks. At first, an experiment realized with a 2-D symmetry has been simulated using SPHERA, considering both 2-D and 3-D representations of sediment scouring (Figure 2). The 2-D simulation exhibits results with a satisfactory agreement against the experimental profile available after 48 s (red line in Figures 2 and 3); the 3-D corresponding simulation is shown in Figure 4.

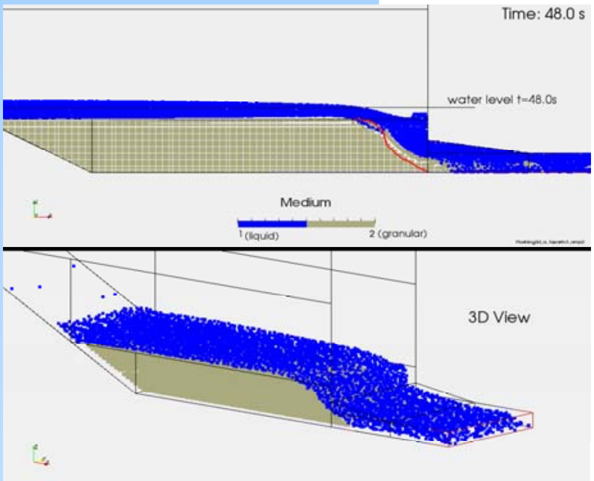

Figure 4 – Results of 3-D simulation of sediment scour.

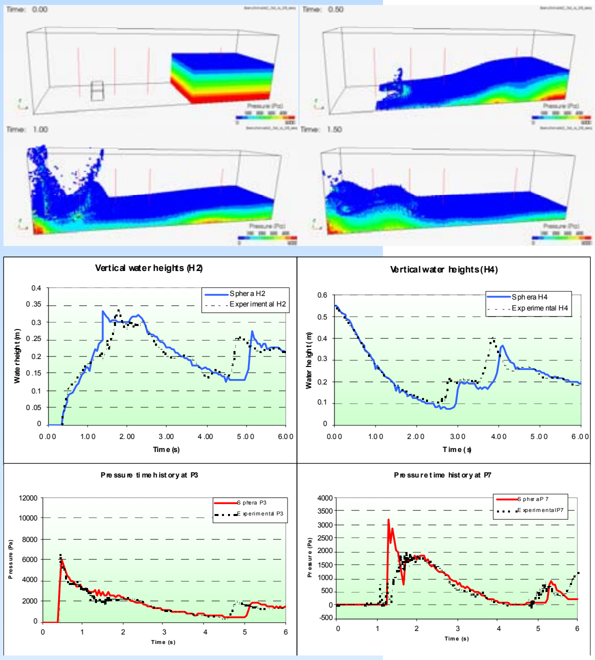

Figure 5 – 3-D SPHERIC benchmark testcase #2. Black dotted lines: experimental; other lines: computed.

In Figure 5 is shown the simulation of the SPHERIC benchmark case 2. As shown in figure, the results can be considered in a good agreement with the reference ones accounting for the fact that in our model no time law for the flood gate opening has been considered: it disappears instantaneously.

Considering the satisfactory results of the tests, activities are now in progress in order to simulate more complex flow within a three-dimensional stilling basin downstream of a dam spillway, to simulate hydrodynamic problems related to dam and reservoir safety issues and to simulate other interesting benchmarks.

Finally, Figure 6 shows some preliminary speed-up results, which we expect to improve soon.

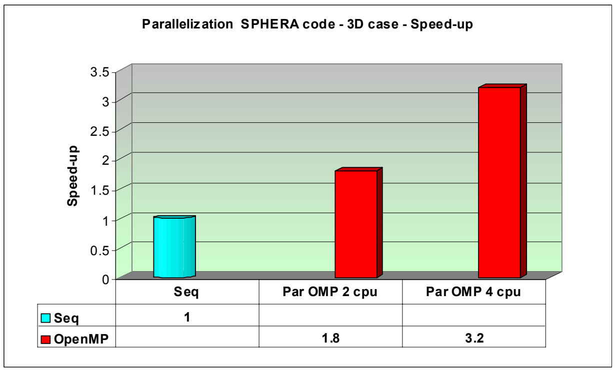

Figure 6 – Preliminary speed-up figures for 3-D benchmark.

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Acknowledgments

This work is dedicated to the memory of Andrea Maffio, who passed away on June 23, 2009.

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