SPHERIC newsletter

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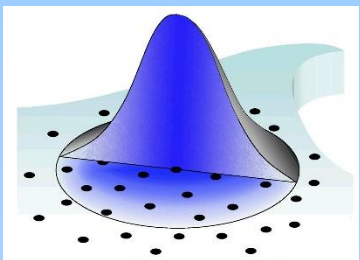
Contact: benedict.rogers@manchester.ac.uk



2017 SPHERIC Beijing International Workshop

*By **Moubin Liu**, Chair of the Local Organization Committee*

The 2017 SPHERIC Beijing International Workshop (or SPHERIC Beijing 2017) was held in Peking University on October 17-20, 2017. This is an important event of 2017 in the field of Smoothed Particle Hydrodynamics (SPH) and related particle-based methods. This was also the first time that the SPHERIC Workshop was held beyond Europe.

The SPHERIC Beijing 2017 organization committee received abstracts from China, France, Germany, UK, Italy, Spain, Switzerland, Ireland, USA, Japan and Australia, and 56 abstracts were selected to present in the SPHERIC Beijing 2017. This demonstrates just how active the field is, with works ranging from traditional hydrodynamics to solids, fluid-structure interaction, high performance computing and industrial applications.

More than 130 delegates attended this SPHERIC Beijing International workshop. The workshop was preceded by a training day (October 19, 2017) attended by 55 participants. After an introduction to the SPH method by Dr Ben Rogers (University of Manchester, UK), Prof. Xiangyu Hu from the Technical University of Munich and Prof. Yuantong Gu from the Queensland University of Technology gave two lectures on multiphase modelling in SPH and Advanced modelling for biomechanics and biomedical systems respectively. The afternoon session was arranged by the DualSPHysics team (Dr. Ben Rogers, Dr. Jose Dominguez and Dr. Jose González-Cao) and devoted to execution, visualization and analysis of SPH data, based upon practical examples with the open-source SPH solver DualSPHysics.

Over the three days (October 18 to 20, 2017), the 15 workshop sessions gave an excellent overview of the varied SPH activity occurring around the world. The two 45- minute keynote lectures were given at the beginning of the first and second days of the workshop by Prof. David Le Touzé from the Ecole Centrale Nantes with the title of "Smoothed Particle Hydrodynamics, fact checking: from theory to applications" and Prof. J. S. Chen from the University of California, San Diego with the title of "An Implicit Gradient Reproducing Kernel Particle Method: Theory and Applications".

The banquet took place at the Yu Xian Du Royal Restaurant, which is also a modern Museum of the Chinese Imperial Cuisine. The Chairman of the International Association of Computational Mechanics, Prof. Wing Kam Liu from Northwestern University, USA, also attended the Banquet as a special guest. During the banquet, the Student Prizes were awarded to P. N. Sun (Best Paper Award) from Harbin Engineering University, China, Z. L. Zhang (Outstanding Paper Award) from Peking University, and Sam Raymond from the Massachusetts Institute of Technology, US. A short presentation was made by Dr. Nathan J. Quinlan from National University of Ireland Galway to announce the 13th SPHERIC International Workshop in Galway, Ireland in 2018, and Prof. A. M. Zhang from the Harbin Engineering University to announce the SPHERIC International Workshop in Harbin, China in 2019.

We appreciate the support of the Journal of Hydrodynamics (JHD) and the International Journal of Computational Methods (IJCM). JHD and IJCM kindly agreed to publish selected high-quality papers from the Workshop on a Special Column (JHD) and a Special Issue (IJCM).

The SPHERIC Beijing 2017 has been supported by the National Natural Science Foundation of China (NSFC), the Chinese Society of Theoretical and Applied Mechanics (CSTAM), Beijing Innovation Centre for Engineering Science and Advanced Technology (BIC-ESAT), Institute of Ocean Research, and State Key Laboratory for Turbulence and Complex Systems of Peking University.

More information about the 2017 SPHERIC Beijing International Workshop can be found at http://ocean.pku.edu.cn/SPHERIC_Beijing/index.php.htm.

The δALE-SPH model: an improved δ-SPH scheme containing particle shifting and ALE formulation

***P.N. Sun, A.M. Zhang**, College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China*

***A. Colagrossi, S. Marrone & M. Antuono,** CNR-INSEAN, Marine Technology Research Institute, Rome, Italy*

δ-SPH is a popular SPH variant and has been shown to be robust in solving hydrodynamic problems. Nevertheless, there are still some drawbacks that limit the application of this model, and more in general of SPH itself, such as flow evolutions with negative pressures which excite tensile instability. In Sun *et al.* (2017a), a Particle Shifting Technique (PST, see Lind *et al.*, 2012) was combined with the δ-SPH scheme, creating the δ^+-SPH scheme, to tackle these challenging problems. A shifting formula under the weakly-compressible hypothesis was proposed in that work. It was shown that PST allows for a uniform particle configuration through small continuous resettlements. δ^+-SPH has shown remarkable improvements in solving some challenging benchmark test cases characterized by negative pressures, see Sun *et al.* (2017a, 2017b). However, the particle shifting leads to consistency issues due to the violation of the link between particle masses, volumes and positions which, in turn, can induce conservation problems.

In our paper, the δ^+-SPH scheme is further extended by combining with an Arbitrary Lagrangian Eulerian (ALE) formulation as recently proposed in Oger *et al.* (2016). A new scheme based on the δ-SPH model is developed, namely δALE-SPH, aiming to improve the consistency and conservation of the δ^+-SPH model.

δALE-SPH is validated by several challenging benchmarks. Here we present the results for the Taylor-Green flow at Re=100. In the previous literature, attention was focused on the formation and breaking of filament structures at the initial stage. The filament structures are due to the inherent Lagrangian characteristic of SPH method and it can be removed by using PST (Lind *et al.*, 2012). However, in weakly-compressible SPH models, PST has to be implemented carefully; otherwise the inconsistency due to particle shifting may lead to a completely wrong evolution.

After a validation of the decay of the overall kinetic energy, the pressure evolution has been analysed. The pressure distribution on the whole fluid region is plotted in 3D views in Figure 1. The pressure distribution is smooth thanks to the density diffusive term in the δALE-SPH model. The pressure evolution at the centre of the fluid region is plotted in Figure 2 for four different particle resolutions. It is worth noting that, to the authors' knowledge, this is the first time that the pressure evolution in the Taylor-Green flow is compared with the analytic solution. Thanks to the novel proposed density equation with a density diffusion involved, the pressure evolution is stable and agrees fairly well with the analytic solution.

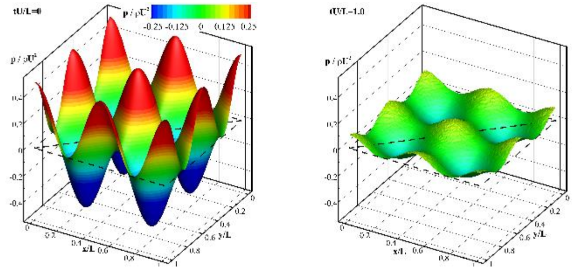


Figure 1 – Pressure distributions in the 2D Taylor-Green flow at tU/L=0 (left) and tU/L=1 (right): the vertical axis represents the pressure amplitude and the two horizontal axes the positions.

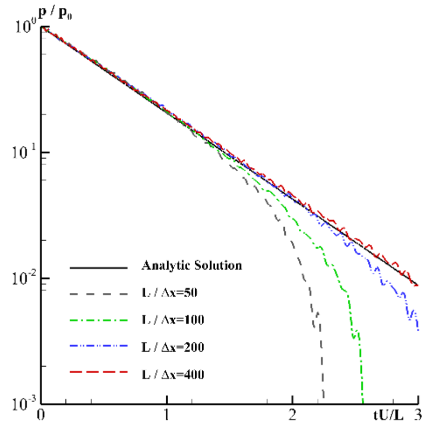


Figure 2 –Time evolution of the pressure measured at the centre of the Taylor-Green flow.

Contact: sunpengnan@hrbeu.edu.cn

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Numerical study of the mechanism of explosive/impact welding using an improved SPH method

***Z. L. Zhang*[1]*, M. B. Liu*[1,2*]**, [1]*BIC-EAST, College of Engineering, Peking University, Beijing 100871, China*
[2]*State Key Laboratory for Turbulence and Complex Systems, Peking University, Beijing 100871, China*

Explosive welding (Figure 1) involves processes like the detonation and explosion of explosive, impact of metal structures and strong fluid-structure interaction with complex features such as interfacial waves and jet generation. However, most of previous works simply treat the explosive welding as the high velocity impact of two plates while ignoring the explosion process due to the large deformation and moving interfaces. To date, the associated mechanism inherent in explosive welding is also not well understood.

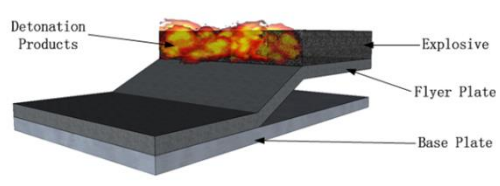

Figure 1 – 3D schematic diagram of explosive welding.

In this work, for the first time, a novel smoothed particle hydrodynamics (SPH) model is developed to simulate the whole process of explosive welding with the wavy interface and jetting phenomenon well captured.

When modeling explosive welding with SPH, the strong density inhomogeneity causes difficulty in numerical simulation, and this may be the reason why the impact welding model is usually used as a simplified approach. To deal with this problem, an adaptive density solution is developed. There are two frequently used approaches in approximating density in SPH,

$$\dot{\rho}_i = \rho_i \sum_{j=1}^{N} \frac{m_j}{\rho_j} \mathbf{v}_{ij}^{\beta} \cdot \frac{\partial W_{ij}}{\partial \mathbf{x}_i^{\beta}} \quad (1), \qquad \dot{\rho}_i = \sum_{j=1}^{N} m_j \mathbf{v}_{ij}^{\beta} \cdot \frac{\partial W_{ij}}{\partial \mathbf{x}_i^{\beta}} \quad (2).$$

Considering that conventional SPH does not have 1st-order consistency, Eq. (1) is not satisfied exactly, while it is effective and flexible in modelling problems with large density ratio. In contrast, Eq. (2) is obtained from exact mathematical transformation and should be more rigorous and have better accuracy. However, as no density ratio appears in Eq. (2), when modelling problems with large density ratio, the density discontinuity for interface particles can cause numerical oscillation and can further terminate the simulation. It can be attractive to combine Eqs. (1) and (2) to deal with problems with large density ratio at comparatively good accuracy and flexibility. Then a new density adaptation algorithm is developed by

$$\dot{\rho}_i = \sum_{j=1}^{N} \frac{\rho_i + \psi_i \rho_j}{\rho_j (1+\psi_i)} m_j \mathbf{v}_{ij}^{\beta} \cdot \frac{\partial W_{ij}}{\partial \mathbf{x}_i^{\beta}} \,. \qquad (3)$$

It is seen that through adjusting the parameter ψ, it is possible to control the contributions to density approximation from Eqs. (1) and (2). Let's define a dimensionless variable k_i as $k_i=\rho_{i,\min}/\rho_{i,\max}$, where $\rho_{i,\min}$ and $\rho_{i,\max}$ represent for the maximal and minimal density values of the particles for a concerned particle i in its support domain. Hence, we aim to obtain a function relationship $\psi_i=\psi(k_i)$ which is adaptive with the change of density, as shown in Figure 2. Since pressure of the explosive gas is calculated from density using the JWL equation of state, and the instability due to density ratio will lead to pressure instability in a scale of $e^{-1/\eta}$. Based on such considerations, $\psi_i=1/\ln k_i$ is adopted in this paper. For a system with different materials, therefore, a density adaption can be conducted when density ratio is huge (for more details, see Liu *et al.*, 2017).

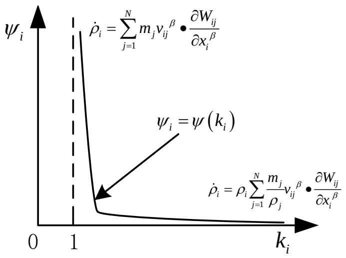

Figure 2 – Schematic diagram of function $\psi_i = \psi(k_i)$.

Using the novel density adaptation algorithm in the SPH model, typical phenomena in explosive welding such as the wavy interface, jetting formation, temperature and pressure distribution at the interfaces are investigated (Figure 3), which are usually difficult for grid based methods. The mechanisms of wave formation are investigated, while two well-known mechanisms namely, the jet indentation mechanism and the vortex shedding mechanism are studied with the present simulations.

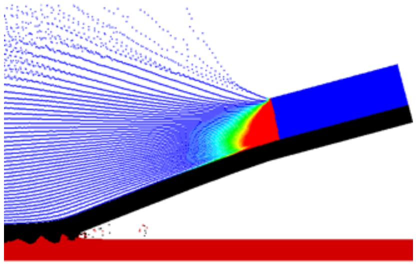

Figure 3 – Wavy interface and jet formation in explosive welding.

Contact: zlzhang@pku.edu.cn.

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Augmenting SPH simulations of mixed-mode failure with the Material Point Method

***S. Raymond, B. Jones, R. Pramanik, K. Pan, T. Douillet-Grellier** & **J. Williams** Geonumerics Group, Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge MA, USA*

A study of mixed-mode failure in rocks was conducted using SPH and MPM. These two meshless methods possess many similar qualities as numerical techniques. A simple coupling algorithm between the two methods can be used and was shown to be effective for an example solid mechanics loading problem (Raymond et.al, 2016). A common issue in meshless simulations is the application of exact boundary conditions. Since these arise naturally from the derivation of the MPM technique (Lemiale *et al*., 2010), it is an ideal candidate to couple with SPH simulations where such boundary conditions are required. As MPM is still a relatively unknown method, a comparison with SPH in modelling failure in solids presents a useful benchmark. A simulation of rock failure using the 2D Brazilian test shows that SPH and MPM produce similar results that agree well with analytical solutions to the stress field and both methods are shown to produce the same failure patterns.

Due to its handling of large deformation and its foundation in hydrodynamics, SPH research has largely focussed on fluid mechanics with fewer works relating to solid mechanics. As the derivation of SPH doesn't account naturally for exact boundary conditions and the presence of the tensile instability, solids modelling normally requires more numerical treatments than fluid modelling. It is possible that a similar but alternative method, like MPM, could prove preferable when modelling particular systems. This would allow for more flexible solution procedures while still preserving many, if not all, of the best aspects that SPH possesses. To see if MPM can be a suitable alternative, this work focuses on the modelling of rock failure using a Drucker-Prager plasticity and Grady-Kipp damage coupled constitutive model.

Two models were created with SPH and MPM to be as similar as possible. In SPH since the resolution is governed by the smoothing length, which also controls the number of particles, for MPM there is some ambiguity. This is because the cell size controls the spatial resolution of the gradient calculations, like acceleration and strain rate, but the number of particles per cell controls the number of particles in the simulation. For these models, the spatial resolution was matched since plasticity and damage are sensitive to spatial resolution. The simulations were run until the specimens had failed completely. Figure 1 shows the schematic of the Brazilian test, a commonly used test for rock materials. As both simulations were run using second order explicit solvers, the loading on the top and bottom edges was achieved with a fixed velocity condition. The angle of loading was chosen to be 7°.

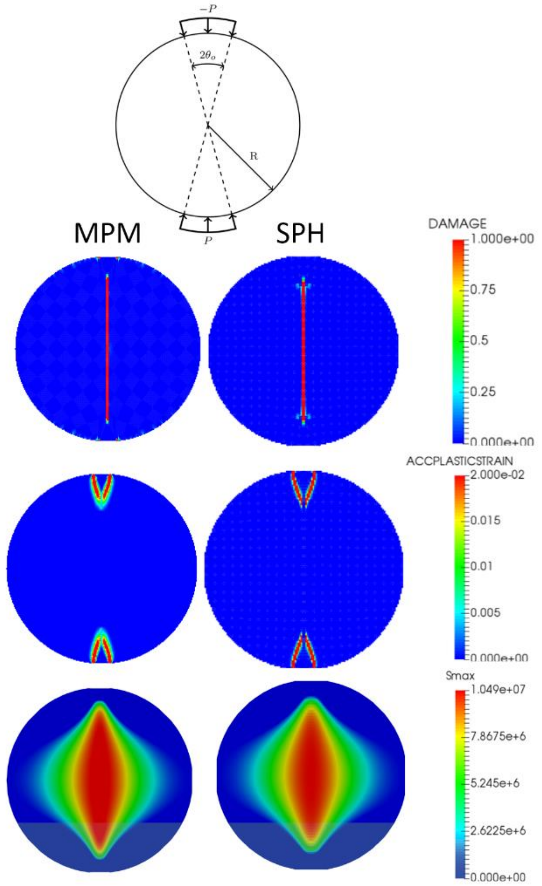

Figure 1 – The Brazil test is a widely used test to determine the tensile strength of rock materials. In this figure SPH and MPM are shown to produce the same result in terms of the final damage path, accumulated plastic strain and stress state.

Contact: sjr@mit.edu.

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Fully Nonlinear Numerical Simulation of Fluid-Structure Interaction based on Smoothed Particle Hydrodynamics and Structural Finite Element Method

***C. Ma** & **M. Oka**, National Maritime Research Institute, 6-38-1, Shinkawa, Mitaka-shi, Tokyo, Japan*
***K. Iijima**, Osaka University, 1-1 Yamadaoka, Suita, Osaka, Japan*

To analyse the hydroelastic-plastic phenomenon for ships or offshore platforms with large dimension, a numerical tool is established in this research where the Smoothed Particle Hydrodynamic (SPH) model is coupled with the Structural Finite Element (FE) model. Open source DualSPHysics is utilized to evaluate the nonlinear hydrodynamic problem such as green water or slamming. Parallel calculation based on GPU is carried out for SPH model to achieve a high calculation efficiency. Meanwhile, structural FE model is built in Abaqus which can deal well with not only the elastic, but also the plastic behaviour of structure. Structural FE analysis is accelerated by CPU parallel computing.

The partitioned algorithm is used to weakly couple the fluid and structure models. In SPH model, the fluid and structure are built by the fluid particles and boundary particles relatively. The same FE structure model is also created in Abaqus. By the user-subroutine function VDload supplied by Abaqus, the structure displacement/velocity and fluid pressure are transferred between the SPH and Abaqus model. Open code DualSPHysics is reconstructed and compiled to Dynamic Link Library (DLL) which can be directly called from the subroutine VDload in each time step.

During the coupling process, the coordinates and velocity of boundary particles are calculated based on the interpolation/extrapolation results of displacement and velocity of mesh surface centre of structure model. Interpolation/extrapolation projection index between the boundary particle ID and mesh ID is initially generated based on the relevant coordinates.

In DualSPHysics, it is difficult to achieve the stable pressure exactly on the surface of boundary particles. Due to the existence of possible gap between the boundary and fluid particles, there may not be sufficient neighbour fluid particles to interpolate the correct pressure on the boundary surface, and this can cause an irregular fluid pressure. In this research, artificial pressure probes (APP) are generated with the same number of boundary elements as the structural FE model. These APPs are located on the normal direction of corresponding structural boundary meshes with distance equal to 1.5 times of smoothing length. The coordinates of APPs are automatically updated during the simulation according to the deformation of the structural FE model. The pressure on APPs is interpolated based on the pressure of neighbour fluid particles and kernel function.

To validate the performance of the proposed FSI model, several benchmark tests are conducted. Fig. 1 and 2 show the comparison for the elastic gate model test.

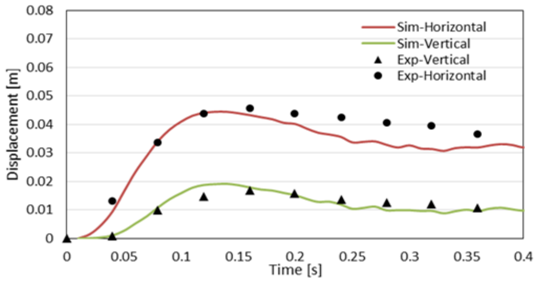

Figure 1 – Comparison of gate tip horizontal and vertical displacement.

Contact: ma-chong@nmri.go.jp

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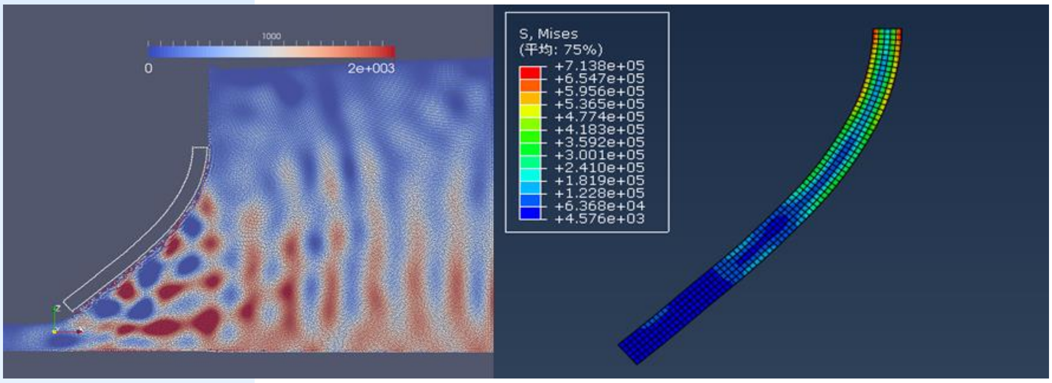

Figure 2 – Distribution of fluid pressure and structural stress for elastic gate benchmark test.

Prof. Monaghan Honorary PhD from Universidad Politécnica de Madrid (UPM)

A. Souto-Iglesias, *CEHINAV, DMFPA, ETSIN, UPM*

On June the 17th, 2017, Prof. Joe Monaghan was conferred with an honorary PhD by Universidad Politécnica de Madrid (UPM). The ceremony took place in the UPM's Naval Architecture School, to which Antonio Souto-Iglesias, the proponent, belongs. The award recognises the outstanding contributions of Prof. Monaghan to the creation and development of the Smoothed Particle Hydrodynamics method. After its initial joint development in the 1970's with Robert Gingold, SPH was extended by Prof. Monaghan to deal with free-surface incompressible flows in the early 1990's, becoming suitable for studying the generation and collapse of large amplitude water waves. It is this application that sets the context for the fact that UPM's Naval Architecture School promoted this appointment. As the main researcher on the SPH method through all these years, Prof. Monaghan has published a large number of influential papers, cited thousands of times, and has been invited to many keynote lectures around the globe.

The conferring brings to the forefront a topic, computational methods in fluid mechanics, which has transformed the way fluid mechanics is treated in industry and academia. For this reason, the nomination received support from persons from various related fields, such as Prof. Darlymple, a leading figure in Coastal Engineering, from Prof. Oñate and his group in Barcelona Tech, an international authority in computational mechanics, from Professors of Hydrodynamics such as Rung, Francescutto, Thiagarajan and Stansby, the latter holding the Reynolds chair in the University of Manchester.

The nomination was also supported by Dr. Emilio Campana, former head of INSEAN model basin and now director of the Engineering Division of the Italian Research Council, and also by Prof. Pulvirenti from University of Rome La Sapienza, a leading mathematician in the field. The nomination was supported by important local figures such as Mr. José María Grassa, who has been for almost 30 years the head of the reference harbour laboratory in Spain; Prof. Rodolfo Bermejo, full professor in Applied Mathematics at UPM; and Next Limit's CEO Víctor González.

SPHERIC chairman Ben Rogers and proponent Antonio Souto-Iglesias spoke during the event to introduce the figure of Prof. Monaghan to the audience. A number of participants in 2017 Ourense's SPHERIC Workshop, which had ended the day before, travelled to Madrid to attend the event.

Figure 1 – Prof. Monaghan with UPM rector.

Contact: antonio.souto@upm.es

Figure 2 – Some attendees to the event. From left to right: Ziane Latifa, Miguel Zavala-Ake, Salvatore Marrone, Andrea Colagrossi, David Le Touze, Mateo Antuono, Peter Stansby, Stephano Sibilla, Joe Monaghan, Antonio Souto-Iglesias, Victor González, Renato Vacondio, Tony Dalrymple, Ben Rogers, Daniel Duque, José María Grassa)

3rd DualSPHysics Users Workshop

***Renato Vacondio**, Department of Engineering and Architecture, University of Parma (Italy)*

On 13-15 November 2017, the Department of Engineering and Architecture welcomed delegates of the 3rd DualSPHysics Users Workshop, held at the University of Parma (Italy).

DualSPHysics is an open-source SPH code jointly developed by the Universidade de Vigo (Spain), the University of Manchester (UK), the University of Parma (Italy), Technical University of Lisbon (Portugal) and Flanders Hydraulics (Belgium). The freely available SPH software package (www.dual.sphysics.org) uses the computing power of graphics processing units (GPUs) to put the power of mini-supercomputers in the hands of engineers and researchers and has been downloaded thousands of times since its release in 2011 (Crespo et al., 2015). Following the success of the two Users Workshops in 2015 and 2016, users and developers of the DualSPHysics code showed how they have been applying and modifying the code.

Day 1 started with a hands-on session devoted to execution, visualization and analysis of SPH data, based upon practical examples with the open-source SPH solver DualSPHysics using the new graphical user interface DesignSPHysics. Day 2 started with Prof. Peter Stansby presenting his vision about the state-of-the art and the future of SPH, with particular focus on Incompressible SPH. Then, two different keynotes given by Dr. Corrado Altomare and Dr. Ricardo Canelas illustrated the latest developments of DualSPHysics respectively for waves and multi-physics simulations. After lunch, three sessions where dedicated to presentations by delegates on applications and new code development. At the end of Day 2 the banquet took place at the unique location of “Teatro Regio”.

Frist part of day 3 was dedicated to 2 different keynotes on High Performance Computing, Dr. Athanasios Mokos illustrated how he extended DualSPHysics to exploit the computational capability of a large GPU cluster, whereas Dr. Jose Domínguez presented the implementation for multiGPU systems.

In the last part of day 3 Alex Chow showed how he developed an Incompressible SPH solver for GPU in the framework of DualSPHysics and Andrés Vieira presented the new GUI interface named DesignSPHsysics.

The workshop finished with the keynote of Dr. Benedict Rogers, who presented different successful applications of DualSPHsysics to very complex multiphysics and multiphase flows.

With the success of the 3rd workshop, the 4th DualSPHysics Users Workshop is already planned for 22-24 October 2018 in Lisbon. Further information will appear on the dualsphysics website in the following weeks.

The presentations from the 2017 workshop are available on the workshop website: http://dual.sphysics.org/usersworkshop/

3D Bedrock Channel Evolution with SPH Coupled to a Finite Element Earth

N. Richmond & P. Koons, *University of Maine, 04469, Maine, USA*

P. Upton, *GNS Science, Lower Hutt 5040, New Zealand*

An enduring obstacle to reliable modelling of the short and long-term evolution of the stream channel-hillslope ensemble has been the difficulty of estimating stresses generated by stream hydrodynamics. To capture the influence of complex 3D flows on bedrock channel evolution, we derive the contribution of hydrodynamic stresses to the stress state of the underlying bedrock through a SPH approximation of the Navier-Stokes equations as calculated by the DualSPHysics code (Crespo, 2015). Coupling the SPH flow solutions to the stress-strain formulation of the Failure Earth Response Model (Koons, 2013), or FERM, provides three-dimensional erosion as a function of the strength-stress ratio of each point in the computational domain.

Traditional numerical approaches to bedrock channel incision rely on empirical relationships and tuning parameters which abstract the physics of Earth processes. Capturing the 3D component of complex flows with SPH provides a more complete description of the stream channel-hillslope ensemble. Fluvial stresses derived from boundary forces calculated via DualSPHysics are added to the other components of the total stress state in FERM. From the coupling of SPH and FERM we gain a 3D physics-based erosion scheme and a two-way link between complex flows and hillslope dynamics in a finite element framework. This novel approach allows the resulting geomorphic response to be quantified for bedrock channels with complex geometries and lithologies.

Central to the FERM approach is the treatment of failure of Earth materials as a function of the local differential stress and the local material strength of any point in the domain. This treatment accommodates the presence any quantifiable stresses acting in a landscape (e.g., fluvial, coastal, glacial, tectonic, seismic, etc.) and strength heterogeneity in Earth fabric. Rather than determining an erosion rate, the time dependence is shifted to the return period of the stressors which shape the landscape, allowing erosion to be explored in terms of both high and low-frequency stresses. This approach naturally lends itself to examining event-based erosion, and by extension, exploration of hazardous erosional events as a function of a high-discharge scenarios.

The present coupling scheme requires that DualSPHysics run until the initializing perturbations settle out, at which point the force computations for boundary particles are exported to FERM, which calculates erosion via finite element analysis to provide a new topography to DualSPHysics. Future implementations of coupled DualSPHysics-FERM will abandon periodic boundary conditions in favour of prescribed inlet discharge conditions, and the Discrete Element Method will be used to constrain the motions of failed blocks.

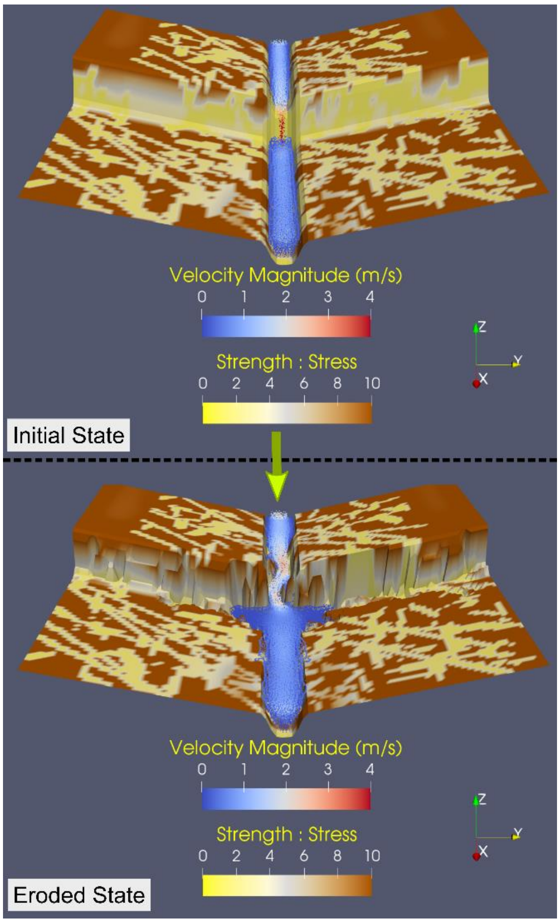

Figure 1 – Here, a 20 m x 20 m knickpoint model with 2 m vertical fault scarp and heterogeneous strength is shown in its initial and eroded states. After 10 cycles of coupled DualSPHysics-FERM, weak material is removed by the differential stresses generated by the channel and surrounding hillslope.

Contact: nicholas.richmond@maine.edu

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Articles nominated for the 2018 Joe Monaghan Prize

A. Colagrossi, *CNR-INSEAN, Rome*

The Joe Monaghan Prize was created in 2015 to recognize SPH researchers who have made outstanding advances in recent years on one or more of the SPHERIC Grand Challenges. The Joe Monaghan Prize will be awarded during the 13th SPHERIC Workshop in Galway. A secret ballot of attendees will determine the winner. Authors of the winning publication will give an invited lecture during the 14th SPHERIC Workshop.

After the nomination procedure, which ended on the 31st of October, six articles have been selected. Their eligibility has been confirmed by the steering committee during the last Autumn meeting. The Reviewers agreed that these papers have made outstanding advances on the first two Grand Challenges, namely:

1) Convergence, consistency and stability

2) Boundary conditions.

The selected articles (ordered according to the publication year) are:

#	AUTHOR	TITLE	Journal	YEAR	GC
1	S. Marrone, M. Antuono, A. Colagrossi, G. Colicchio, D. Le Touzé, G. Graziani	*δ-SPH model for simulating violent impact flows*	Comput. Methods in Appl. Mech. Engrg.	2011	**1+2**
2	S.J. Lind, R. Xu, P.K. Stansby, B.D. Rogers	*Incompressible smoothed particle hydrodynamics for free-surface flows: a generalised diffusion-based algorithm for stability and validations for impulsive flows and propagating waves*	J. Comput. Phys.	2012	**1**
3	S. Adami, X.Y. Hu, N.A. Adams	*A generalized wall boundary condition for smoothed particle hydrodynamics*	J. Comput. Phys.	2012	**2**
4	Dehnen, W., Aly, H.	*Improving convergence in smoothed particle hydrodynamics simulations without pairing instability*	Mon. Not. R. Astron. Soc.	2012	**1**
5	Ferrand, M., Laurence, D. R., Rogers, B. D., Violeau, D. and Kassiotis, C.	*Unified semi-analytical wall boundary conditions for inviscid, laminar or turbulent flows in the meshless SPH method.*	Int. J. Numer. Meth. Fluids.	2013	**1+2**
6	D. Violeau & A. Leroy	*On the maximum time step in weakly compressible SPH*	J. Comput. Phys.	2014	**1**