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SPHERIC

NEWSLETTER

35th issue

SPH rEsearch and engineeRing International Community

SUMMARY

17th SPHERIC International Workshop, 2023

Dr. Georgios Fourtakas
The University of Manchester, UK

The 17th SPHERIC International Workshop took place at Rhodos Palace Hotel in the island of Rhodes, Greece, organised by the University of Manchester, UK.

The SPHERIC training day was held on the day before the workshop with invited lectures from Dr Javier Calderon-Sanchez and Dr Corrado Altomare on “Introduction to SPH” and “SPH and Water Waves”, respectively. The practical training session in the afternoon was organised and delivered by the DualSPHysics team lead by Dr José Domínguez.

The SPHERIC 2023 opening keynote was given by Prof. Viv Kendon from Strathclyde University on Integrating quantum computing with HPC, followed by the keynote of Prof. Antonio Gil from Swansea University on the second day on solid dynamics using first order conservation laws for SPH. On the third day, Prof. Peter Stansby from the University of Manchester delivered a keynote on particle shifting and the future in wave structure interaction on behalf of the Joe Monaghan Prize award winners.

More than 100 delegates took part in the event with 52 oral presentations and 3 keynote lectures. A variety of workshop topics were covered ranging from theoretical and numerical changes (including the SPHERIC Grand Challenges) to artificial intelligence and exotic industrial applications.

In photo: the delegates to the 17th SPHERIC International Workshop.

Prof. Viv Kendon (Strathclyde University) delivering her keynote on "Integrating quantum computing with HPC".

This reflected on the Libersky Prizes with the best student paper awarded to Pablo E. Merino-Alonso for the paper "Energy conservation in ISPH" co-authored by D. Violeau (Universidad Politécnica de Madrid & EDF R&D and Saint-Venant Hydraulics Laboratory). The second-best student paper was awarded to Francesco Ricci for the paper "A variable resolution SPH scheme based on independent domains coupling", co-authored by Renato Vacondio and Angelo Tafuni (New Jersey Institute of Technology & University of Parma). The awards concluded with the third-best paper received by Ruofeng Feng for their work "Coupled flow-deformation problems in porous materials in SPH", co-authored by Georgios Fourtakas, Benedict D. Rogers and Domenico Lombardi (University of Manchester).

The 17th SPHERIC International Workshop concluded by the SPHERIC and local organising committee chairs Dr Renato Vacondio and Dr Georgios Fourtakas. The local organising committee would like to acknowledge the help and support of the SPHERIC Scientific and Steering Committee for their contribution and the University of Manchester, UK for supporting this event.

Prof. Renato Vacondio (University of Parma, SPHERIC Chair) (left) and Dr. Georgios Fourtakas (University of Manchester, Chair of the Local Organizing Committee) (right) delivering the closing addresses for the 17th SPHERIC International Workshop

Coupled flow-deformation problems in porous materials in SPH

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Water flow and deformation of porous materials are natural coupled phenomena involved in many geohazards. Typical examples include rainfall-induced landslides, embankment instabilities due to seepage, and dam failure caused by internal erosion. Accurate predictions of such phenomena are crucial for disaster prevention and mitigation. However, computational challenges exist due to the complexity of multi-physics, phase interaction within the porous mixture, the need of rigorous treatment of hydraulic/mechanical boundary conditions, and large deformations of the mixture at the post-failure stage.

State-of-the-art SPH modelling has achieved some success in addressing complex physics and phase interaction within porous mixtures, as well as the post-failure large deformations (e.g., Blanc and Pastor [1]; Morikawa and Asai [2]; Lian et al. [3]). However, there is still a lack of rigorous methods for enforcing hydro-mechanical boundary conditions (BCs) in SPH, as well as stabilization techniques to ensure stability and accuracy of the simulation. These issues are crucial for the coupling problems because the boundary conditions and the accurate prediction of liquid seepage flow are essential for the reliability of the numerical results, and the analysis of coupled problems is very prone to instability.

Recently, Feng et al. [4] proposed a single-layer two-phase SPH model for unsaturated soils, which allows the analysis of slope failure subjected to extreme rainfall event with a noise-free stress filed.

This work extends the SPH model by Feng et al. [4] to a more general application for coupled flow-deformation problems in porous material. New features have been incorporated to address the difficulties in hydro-mechanical coupling mentioned above. These include the implementation of hydraulic boundary conditions and stress boundary conditions in SPH, improvements to the water phase formulations, and the use of particle shifting for enhanced robustness and stability. The advantage here over the state-of-the-art is the highly accurate noise-free pressure fields, and the ability to handle complex case scenarios for coupled problems that are very likely to trigger instability.

The improved SPH models are validated through the case of 2-D seepage flow through trapezoidal porous dam. The water level at the upstream side is set to equal to the height of the porous media by enforcing the hydraulic head BC while a certain range of water level is assumed at the downstream side where a mix of hydraulic head BC and potential seepage face BC is applied. Figure 1 shows that the calculated pressure field of the seepage flow through the trapezoidal embankment at steady state. The resulting phreatic lines by SPH are highlighted with a dashed blue line, while those by the reference FEM solutions (Pedroso et al. [5]) are marked with a red line. Close agreement between SPH results and finite element solutions are obtained.

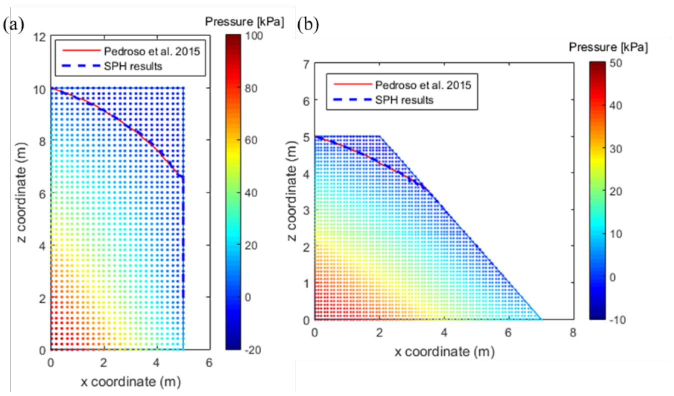

Fig. 1: Contour plot of pressure for the flow through trapezoidal dam with comparison of the phreatic line against finite element solution

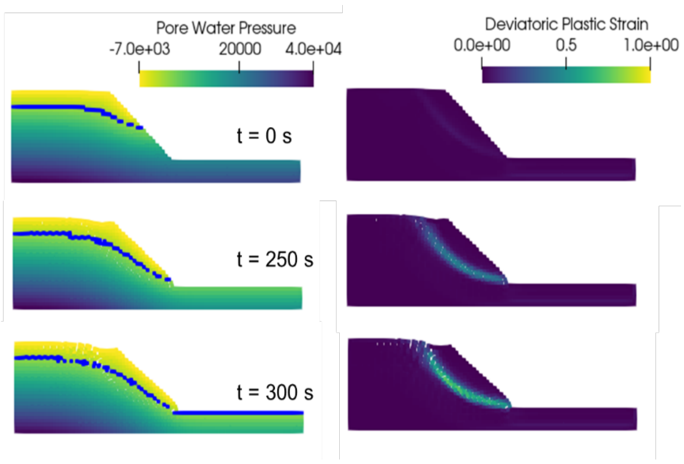

Fig. 2: Pore pressure contour (left column) with the phreatic line (dots) and accumulated deviatoric plastic strain contour (right column) for the embankment failure due to rapid drawdown

The work also presents an exciting application of the model to study the embankment failure due to rapid drawdown. This case refers to the process of the quick reduction of water levels, which is a classical scenario in embankment and slope engineering. The hydraulic head BC is applied to the free surface as a function of time to simulate the change in water level. The water level at downstream side maintains at 3 m for 100 s, and then the drawdown develops for 200 s at a rate of 0.01 m/s until the water level reaches 1m. Figure 2 shows the evolution of pore pressure and deviatoric plastic strain predicted by SPH at different time instant, in which the resulting phreatic lines are marked with dashed blue line. Again, an accurate and noise-free pressure field is reproduced by the proposed method. As the lowering of the water level at downstream side, the sliding surface develops, leading to the instability of the embankment.

The results presented indicates an enhanced predictive capacity of the proposed method that allows the analysis of the porous structure behaviour under extreme scenarios.

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A variable resolution SPH scheme based on independent domains coupling

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Variable resolution in Smoothed Particle Hydrodynamics is essential for simulating several engineering problems characterized by different scales, to the point that this topic is listed as one of the open SPHERIC Grand Challenges [1].

This work presents a new multi-resolution algorithm for weakly compressible Smoothed Particle Hydrodynamics (WCSPH), where an approach based on a domain-decomposition strategy is adopted. The domain is divided into an arbitrary number of different zones, which are connected only through additional Dirichlet boundary conditions enforced by buffer regions.

The physical quantities of SPH particles in the buffers are computed by means of a corrected SPH interpolation over adjacent sub-domains. Specifically, a second-order kernel correction procedure is employed to ensure the proper consistency and accuracy of the interpolation. To model the mass transfer between the sub-domains, a procedure based on the evaluation of the Eulerian mass flux at the domain boundaries is applied.

Particles that belong to a specific zone are created/destroyed in the buffer regions and do not interact with fluid particles that belong to a different resolution zone. One major strength of the presented multi-resolution strategy is that there is virtually no limit to the number of resolution levels that can be deployed, therefore this new model is ideal for simulating multi-scale applications.

The algorithm has been implemented in the DualSPhysics open-source code [2] and optimized thanks to DualSPHysics' parallel framework.

The flow past a circular cylinder for a Reynolds Number equal to Re = 9500 is simulated to assess the proposed approach. The present results are compared against a numerical solution [3] available in the literature.

Although for this Reynolds Number the flow past a cylinder is characterized by a three-dimensional solution, the early development of this flow can be considered two-dimensional and present complex interactions between primaries and secondary vortex in the boundaries layer. In fact, primary vortexes form and detach from the cylinder, resulting in a high unsteadiness that affects the time history of the drag coefficient.

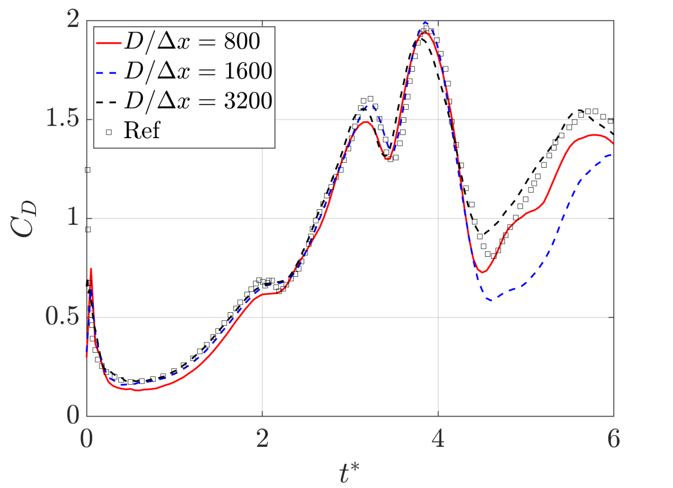

Fig. 1: Drag coefficient for an impulsively started cylinder with Re=9500. The numerical solution is compared with results in [3]

A convergence study is performed, considering maximum resolutions equal to Δx_{min} = 800, 1600, 3200 near the cylinder, which corresponds respectively to 6, 7, and 8 different resolution zones in the entire domain. In Figure 1 the drag coefficient is plotted against time for the three different resolutions near the cylinder. Whereas all three simulations capture the drag coefficient until t = 4, only the one with Δx_{min} = 3200 is capable of reproducing the reference solution for t > 4 when the flow is characterized by a high unsteadiness. Moreover, with higher resolution, the flow remains almost perfectly symmetrical as in the reference solution [3], as visible in Figure 2, where the vorticity contours for $t^* = tU_\infty /D$ are shown. It is remarked that the multi-resolution approach simulation with Δx_{min} = 3200 requires 8 sub-domains, resulting in a number of particles $N \approx 10 \times 10^6$ which can be simulated using 1 GPU, while with a uniform resolution, the particles required with the same resolution would be $N \approx 9 \times 10^9$ which can be achieved only with sophisticated memory-distributed parallelization [4].

The results demonstrate the ability to reduce by several orders of magnitude the computational cost associated with the number of particles without introducing any inaccuracies. Future works will be focused on the extension and the validation

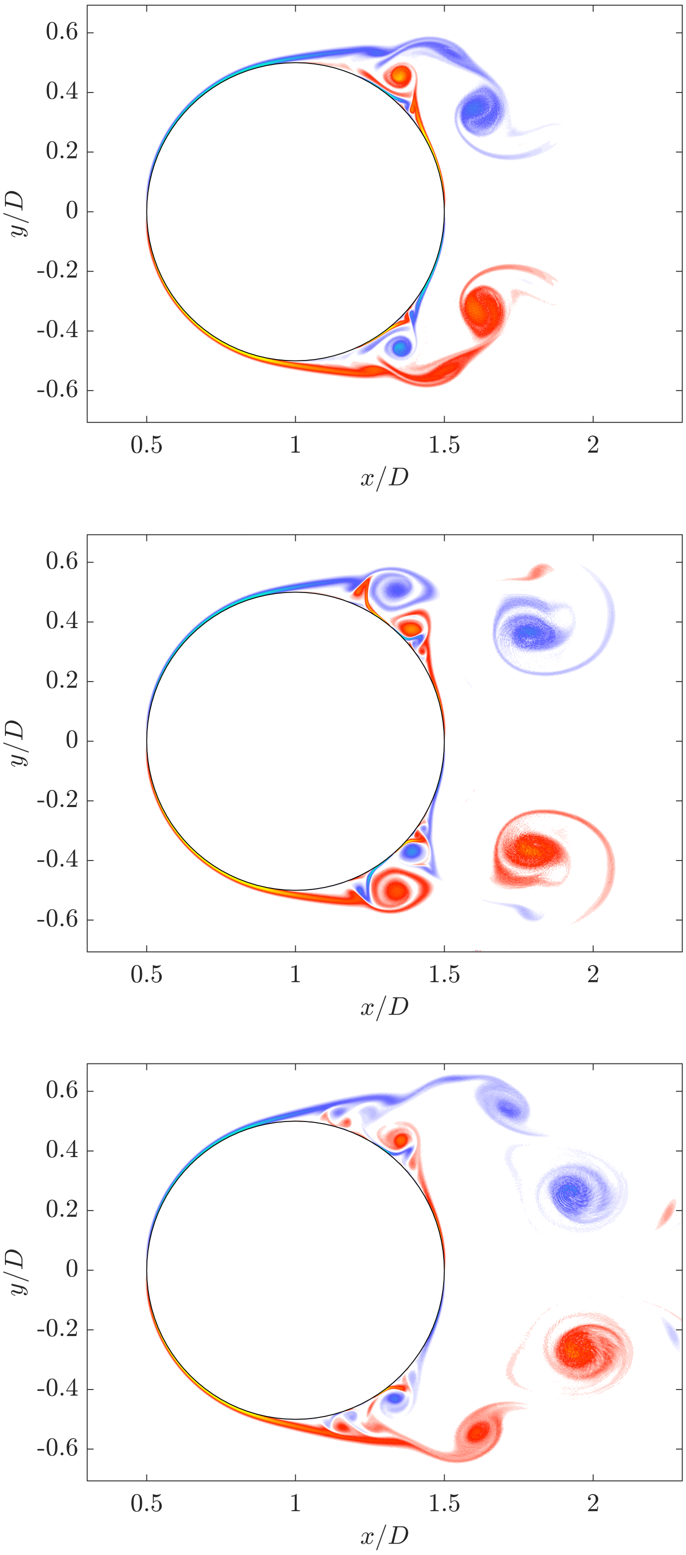

Fig. 2: Vorticity contours for an impusively started cylinder at Re=9500 at t*=4 (top), t*=5 (middle), t*=6 (bottom).

to 3-D flows in DualSPHysics.

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Energy conservation in ISPH

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Energy conservation is a relevant topic in any numerical method. It is linked to other fundamental aspects such as numerical stability and, thus, convergence. Despite ISPH achieving certain popularity among SPH practitioners, energy conservation in this context has rarely been addressed in the literature.

In this work, the problem of energy conservation is assessed through a close inspection of the energy balance. An analytical expression of the error as a function of the discrete pressure field is derived. In the case of the Taylor-Green vortex, an approximative expression of the error is obtained using the functions F_1 and F_2, approximations to the eigenvalues of the discrete divergence-of-gradient and Laplacian SPH operators, respectively.

In the case of non-dissipative incompressible flows, the energy at a given time step can be expressed as a function of the velocity field and the position of each particle. The error is obtained by simply taking the difference between the energy evaluated at two consecutive time steps. Considering the discrete equations of the Chorin-Teman algorithm, that are used to update the flow fields in ISPH, an equivalent expression involving the velocity and pressure fields can be derived. Then, applying the skew-adjointness property and neglecting second-order errors, we derived an expression for the error where one factor corresponds to the difference between the Laplacian and the divergence-of-gradient operators applied to the pressure field. Therefore, it is clear that the error vanishes (thus energy is exactly preserved) whenever the Laplacian is equal to the divergence-of-the-gradient operator, which is not true in general in SPH.

The Taylor-Green vortex flow is an interesting case as the exact pressure field is an eigenfunction of the exact Laplacian and divergence-of-gradient operators. Furthermore, the exact pressure is also an eigenfunction of the discrete SPH version of those operators (Violeau et al. 2018). Assuming that the SPH solution converges to the exact one, the discrete SPH operators applied to the pressure field can be substituted by the product of that field and the corresponding Eigenvalues, which can be approximated by Functions F_1 and F_2 (Violeau, 2014; Violeau, 2015). These functions are also linked to the Fourier representations of the integral SPH operators, as shown in (Macià, F. 2022; Merino-Alonso, P.E. 2023) in the case of the Laplacian. Figure (1) shows the variation of the energy, in the case of the Taylor-Green vortex, as a function of the time. It can be appreciated how the energy balance converges towards exact conservation as the inter-particle distance is reduced, supporting the argument that the numerical solution converges (While convergence can not be rigorously derived from this assertion, we deem it sufficient together with other numerical

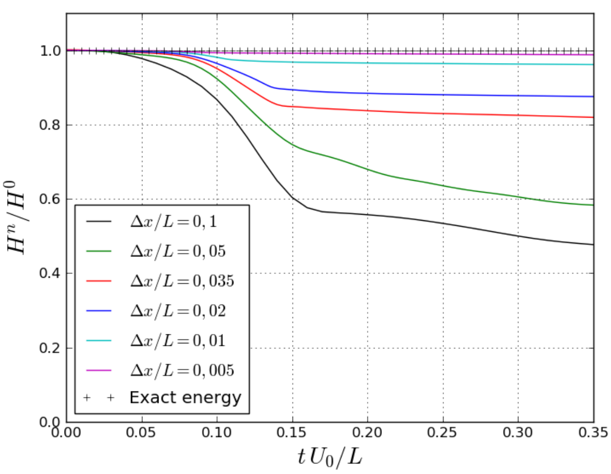

Figure 1. Taylor-Green vortex: kinetic energy for different simulations carried out with Co = 0.1, σ/Δx = 4/√(2/21) and different initial inter-particle spacing.

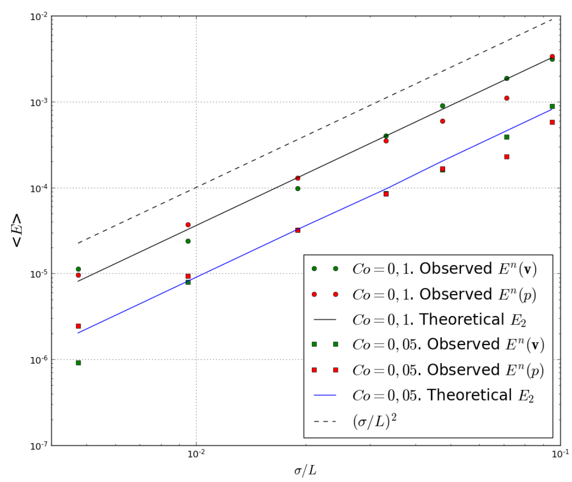

Figure 2. Theoretical prediction E2 and observed errors for Co = 0.05 and Co = 0.1 at a specific given time.

observations).

In this particular case, the expression of the error can be approximated, using functions F_1 and F_2 by a simpler expression, involving only the ratio between the standard deviation of the kernel and the characteristic length of the problem, σ/L, and the Courant number, Co, respectively.

The convenience in using of the standard deviation as main approximation parameter instead of the smoothing length has already been discussed in the literature (Violeau, 2019).

Figure (2) shows a comparison of the error computed directly using the flow fields and the aforementioned approximative expressions for different values of the approximation parameters. It can be appreciated how the error is quite accurately computed, in the case of the Taylor-Green non-dissipative flow, using the simplified formula.

A number of interesting questions arise from this study and are left for future work. Among them we find particularly interesting: (a) Analytically studying the effect of the particle shifting technique on the energy error; (b) Numerically computing the energy error in other canonical fluid dynamics problems, such as the Poiseuille flow, to study whether the error can also be expressed as a simple function of the spatial and time approximation parameters.

These results, together with new insights provided by ongoing research, will soon be sent for publication.

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Particle Methods and Applications Conference (January 22–24, 2024)

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Key dates & rates:

Conference:
January 22–24, 2024

Abstract submission deadline:
September 29, 2023

Early registration: $325
(by September 29, 2023)

Regular registration: $375

Photo: The cathedral in downtown Santa Fe

The Particle Methods and Applications Conference will be held in Santa Fe, NM from January 22–January 24 at the Hotel Santa Fe Hacienda and Spa. One page abstracts may be submitted via email to particles2024@lanl.gov before September 29 for consideration. Los Alamos National Laboratory and Sandia National Laboratories are partnering with SPHERIC to host this conference.

The focus of this conference will be on numerical particle methods, both novel methodologies and innovative applications. The focus is broad to encompass both Smoothed Particle Hydrodynamics (SPH) methods and Material Point Methods (MPM), and variations on either. We hope that the broad focus will allow for these two distinct particle disciplines to learn from each other and possibly lead to fruitful collaborations. While the primary focus is expected to be on methods and algorithms, we encourage potential speakers to submit abstracts featuring novel applications as well.

We will host two distinguished keynote speakers. Prof. Guillaume Oger of Ecole Centrale de Nantes will discuss Fluid Structure Interaction using SPH-FEM methods, and Prof. Yuri Bazilevs of Brown University will discuss Isogeometric Analysis coupled with MPM, and peridynamics.

Register and learn more about the conference here:

http://cvent.me/40eGlg

See you in Santa Fe!

SPHERIC 2024 in Berlin (18 June – 20 June)

Local Organizing Comittee
spheric2024@dive-solutions.de
Dive Solutions

Key dates:

Training Day:
17 June 2024

Workshop:
18–20 June 2024

Abstract submission deadline:
19 January 2024

Selected abstracts announcement
12 February 2024

Early registration deadline
8 March 2024

Final paper submission deadline
26 April 2024

Presenter registration deadline
3 May 2024

The annual SPHERIC International Workshop is a unique event with exclusive focus on the Smoothed Particle Hydrodynamics (SPH) method and associated particle-based schemes. The workshop is part of the SPH research and engineering international community (SPHERIC), dedicated to the development, application, and dissemination of advances in SPH. It brings together researchers and practitioners from academia and industry and focuses on new concepts and applications of the scheme.

The 18th edition of the SPHERIC International Workshop (SPHERIC 2024) will be held in Berlin, Germany. It is organized by Dive Solutions, the particle-based simulation software as a service(SaaS) provider. On 17 June, the day before the workshops, we offer a training day for everyone interested in learning about industry applications of SPH. Attendees will have the unique opportunity to simulate an industry case within an hour using the Dive software.

The SPHERIC International Workshop also includes networking opportunities like the welcome drink, the gala dinner, and the possibility to book an additional social event on 21 June, the day after the workshops. The social event will take you on a tour of the history of the Berlin wall, including the Wall Museum, a boat ride on the river Spree and the eastside gallery.

You can find the programme, the registration page, instructions for delegates and authors and any further information on the dedicated SPHERIC 2024 website. On behalf of the organizing committee, we cordially invite you to share an insightful and enjoyable event with us.

Your local organizing committee
Dive Solutions

www.dive-solutions.de/spheric2024

The new SPHERIC Benchmark section

Salvatore Marrone, Angelantonio Tafuni

Among the actions brought to foster the SPH knowledge and enhance the methodology's accuracy, reliability, and efficiency, the SPHERIC Steering Committee has promoted from its very beginning a Benchmark page on the SPHERIC website. This section collects reference test cases from SPH practitioners and provides standard problems to validate SPH codes. The Benchmark page has been completely restyled to allow searching benchmarks on the base of the topics covered. Additionally, it has been enriched by new test cases, significantly extending the range of applications and physical models previously addressed.

These new activities around the Benchmark SPHERIC webpage are the result of new impulses from the SPHERIC Steering Committee to promote tools for a rigorous validation of the SPH research outputs. Benchmarking is, indeed, a crucial aspect of numerical methods. It involves the comparison of numerical simulation results with known analytical solutions or experimental data to validate and verify the accuracy and performance of computational models.

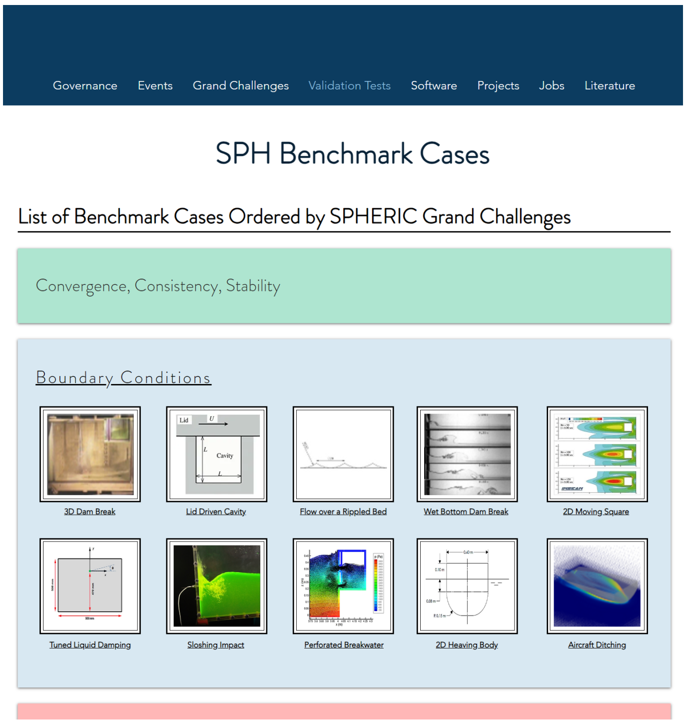

Figure 1. A screenshot from the new SPH Benchmark Cases page on the SPHERIC website, showing the list ordered by SPHERIC Grand Challenge, with the sections 'Convergence, Consistency, Stability' (unopened) and 'Boundary Conditions' (opened) visible.

By providing a standardised set of test cases, benchmarks facilitate a fair comparison between different SPH codes, algorithms, and numerical schemes. This enables researchers to identify strengths and weaknesses in their simulations, ultimately leading to the development of more robust and precise techniques. Each benchmark case includes detailed instructions, reference data, and appropriate metrics to be used for a seamless reproduction of the expected results. This represents a further effort by the SPHERIC Steering Committee on fostering clear and fair research practices within the SPH community.

The new SPHERIC Benchmark session hosts a collection of challenging and diverse benchmark problems designed to assess the capabilities of SPH simulations across various domains. They are now categorised according to two different criteria. Firstly, on the base of the Grand Challenge they refer to:

GC#1: Convergence, consistency and stability
GC#2: Boundary conditions

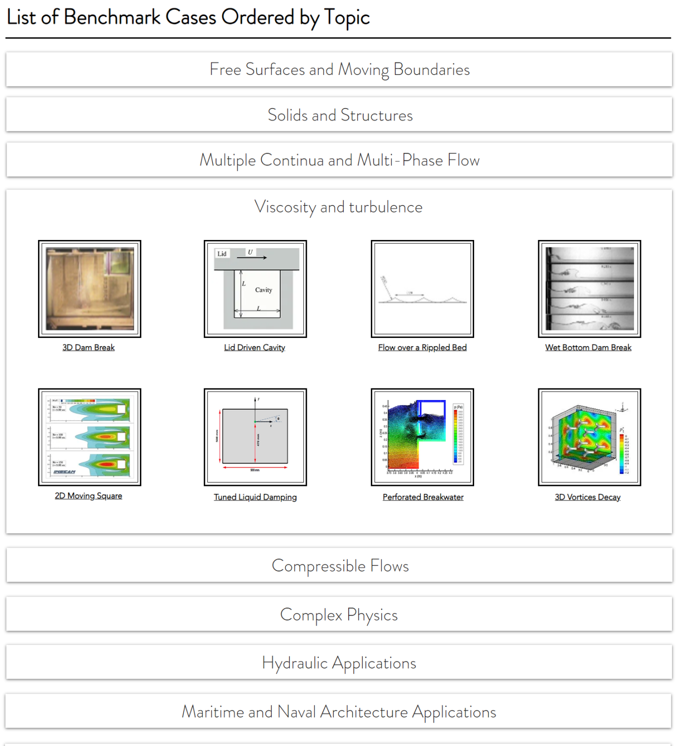

Figure 2. A screenshot from the new SPH Benchmark Cases page on the SPHERIC website, showing the list organized by topic. In the image, the following groups are visible: Free Surfaces and Moving Boundaries, Solds and Structures, Multiple Continua and Multi-Phase Flow, Viscosity and Turbulence (open), Compressible Flow, Complex Physics, Hydraulic Applications, Maritime and Naval Architecture Applications.

GC#3: Adaptivity
GC#4: Coupling to other models
GC#5: Applicability to industry
This can be useful for researchers and engineers looking for a benchmark to validate a new algorithm or technique.

A second categorization is made according to the topics covered by these benchmark cases. The list of topics has been growing continuously over time as the fields of application of SPH keep expanding. Currently, this list includes: Free surface and moving boundaries, Solids and structures, Multiple continua and multi-phase flows, Viscosity and turbulence, Compressible flows, Complex physics, Hydraulic applications, Maritime and naval architecture applications, Biomechanics & human behaviour, Geotechnical applications, Micro-fluidics, Astrophysics, Geophysics, Solids and fracture mechanics, Disaster Simulations.

Finally, the previous numbered-style list of benchmarks is still present at the page bottom. The total number of test cases to date is 20. As most of the pre-existing benchmarks were on hydrodynamics applications, there are topics containing several test cases (e.g. Viscosity and Turbulence) and others which are still waiting for a benchmark to be proposed (e.g. Biomechanics & human behaviour). So, all participants in the SPHERIC community are encouraged to propose and submit a benchmark test case for the topic of their interest.

To propose a new benchmark case, you can download the Template document, fill in all the required information and send it to salvatore.marrone@cnr.it. The document will be revised with the help of scientific committee experts and then published on the SPHERIC Benchmark webpage.

For instance, three new benchmarks have been recently proposed and accepted: two test cases about fluid-structure interaction problems and one addressing conductive heat transfer phenomena. They are (Figure 3):

Test #18: “Flow Past an Elastic Object” by Peng-Nan Sun and Hong-Guan Lyu, Sun Yat-sen University, Zhuhai, China

Test #19: “Dam Break with FSI” by Peng-Nan Sun and Hong-Guan Lyu, Sun Yat-sen University, Zhuhai, China

Test #20: “Impinging Jet Cooling Benchmark” by Loïc Wendling and Shreyas Joshi FIFTY2 Technology GmbH, Germany

The Benchmark session of the SPHERIC website keeps growing and improving with the main goal to help the SPH community with enhancing the SPH method and applying it to real-world problems. Everyone is invited to download benchmarks to validate their SPH codes and also to propose new benchmark cases, especially cases that can address topics which are currently not covered. Should you use one of these benchmark cases in your publications, please do not forget to mention the SPHERIC website in your paper.

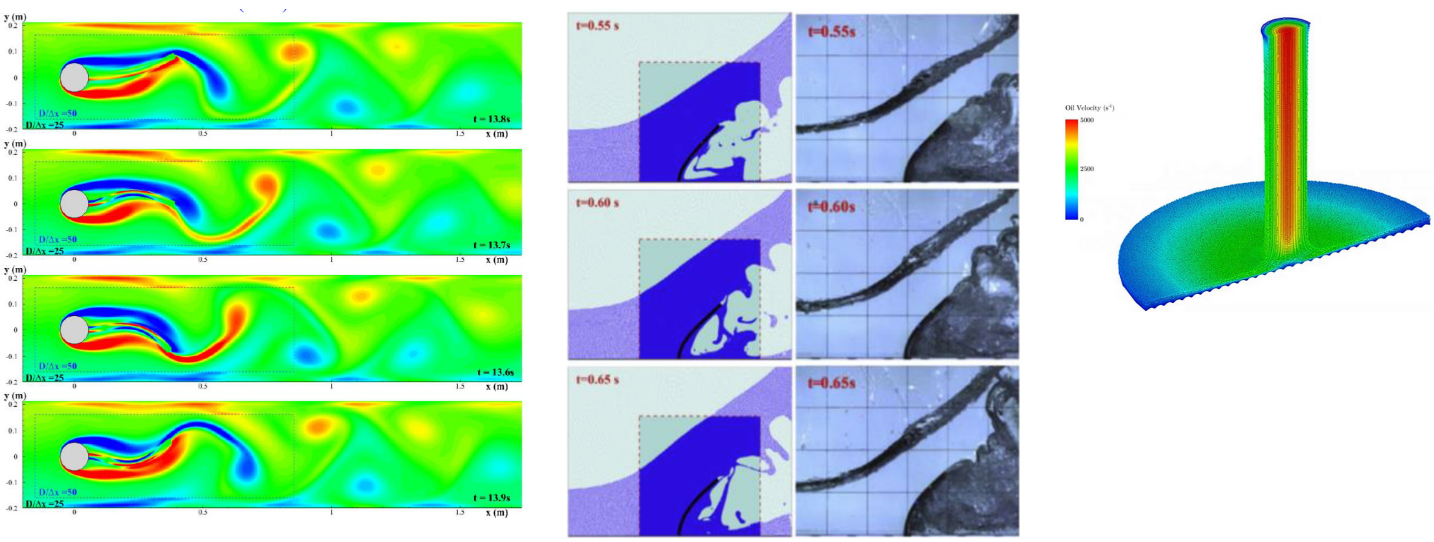

Figure 3: Pictures for the new test cases #18 (“Flow Past an Elastic Object”, left), #19 (“Dam Break wth FSI”, middle) and #20 (“Impinging Jet Cooling Benchmark”, right).

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CNR-INSEAN (Italy)
Cranfield University (UK)
CSIRO Mathematical and Information Sciences (Australia)
E8IGHT Co., Ltd (Republic of Korea)
Ecole Centrale de Lyon (France)
Ecole des Mines of Saint-Etienne (France)
Ecole Polytechnique Fédérale de Lausanne (Switzerland)
EDF R&D (France)
Eindhoven University of Technology (Netherlands)
EPHYTECH (Environmental Physics Technologies S.L)
(Spain)
Escuela Superior Politécnica del Litoral (Equador)
ESI-Group Netherlands (Netherlands)
Flanders Hydraulics Research (Belgium)
Gate Pathshala Educational Services LLP (India)
Hamburg University of Technology (Germany)
Harbin Engineering University (China)
HydrOcean (France)
Institut de recherche d'Hydro-Québec (Canada)
Institute of Applied Physics and Computational Mathematics (China)
Instituto Superior Tecnico (Portugal)
Istituto Nazionale di Geophisica e Vulcanologia (Italy)
Karlsruhe Institute of Technology (Germany)
Kyoto University (Japan)
Laboratório Nacional de Engenharia Civil (Portugal)
Monash University (Australia)
National Taiwan University (NTU) (Taipei, Taiwan, Cina)
National University of Ireland, Galway (Ireland)
National University of Singapore (Singapore)
Nazarbayev University (Kazakhstan)
New Jersey Institute of Technology (USA)
NEXTFLOW Software (France)
Ocean University of China (China)
Peking University (China)
Research Center Pharmaceutical Engineering GmbH (Austria)
Ricerca sul Sistema Energetico – RSE SpA (Italy)
Seoul National University (Republic of Korea)
Shiraz University (Iran)
Swiss Federal Institute of Technology (Switzerland)
Technical University of Madrid (Spain)
Technical University of Munich (Germany)
UNISA CUGRI (University Consortium for Research on Major Hazards) (Italy)
Université du Havre (France)
Université du Luxembourg (Luxemburg)
University of Auckland (New Zeland)
University of Basel (Switzerland)
University of Calabria (Italy)
University of Central Lancashire (UK)
University of Exeter (UK)
University of Genova (Italy)
University of Innsbruck (Austria)
University of Ljubljana (Slovenia)
University of Manchester (UK)
University of Parma (Italy)
University of Pavia (Italy)
University of Plymouth (UK)
University of Pretoria (South Africa)
University of Regina (Canada)
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