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研究課題名（和文）Development of a computational method for hydroelastic multiphase water slamming problems

研究課題名（英文）Development of a computational method for hydroelastic multiphase water slamming problems

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研究成果の概要（和文）：本研究では，流力弾性を考慮したスラミング現象解析のための流体－構造連成解析手法の開発，特に１）封入空気の挙動の精緻なモデル化のための粒子法の高度化，２）流体－構造非線形高精度連成モデルの構築を主目的とした．１）では，高精度化手法Optimized Particle Shiftingを開発し，既往の密度平均に代わる手法として混相流解析へと援用した．本成果はそれぞれJournal of Computational Physicsに掲載，第12回SPHERICにて発表した．２）では，激流を伴う完全ラグランジュ型構造非線形解析手法の開発に取り組んだ．4編の学術誌にて開発した各種連成解析手法を発表した．

研究成果の概要（英文）：This study aimed at proposing a coupled FSI (Fluid-Structure Interaction) solver for hydroelastic slamming with two major aims of 1) further development of a particle-based multiphase computational code for more precise modeling of entrapped air dynamics in water slamming, 2) accurate coupling of a refined multiphase flow model with a non-linear elastic structure model for precise modeling of hydroelsatic slamming. As for the first aim to avoid use of conventional density averaging schemes, a new scheme, namely, Optimized Particle Shifting (OPS), was proposed and then a multiphase algorithm comprising of this scheme was developed. As for the second aim, significant efforts were devoted to development of fully-Lagrangian meshfree FSI solvers that can precisely model the related non-linear hydroelastic slamming problems. Several fully-Lagrangian meshfree solvers with different coupling schemes were developed with the results being published in four journal papers.

研究分野： 計算力学

キーワード： 粒子法　流体－構造連成解析（FSI）　hydroelastic slamming　混相流

１．研究開始当初の背景

The so-called slamming phenomenon, corresponding to high velocity impact of solid bodies on fluid surface, is of significant importance in ocean engineering. The phenomenon is often characterized by strong interactions in between deformable structures and air-water fluid flows. Accurate prediction of slamming induced impact pressures and their corresponding structural responses would be of crucial importance in design of related ocean systems.

２．研究の目的

This study had two major aims, 1) further development of a particle-based multiphase computational code for more precise modeling of entrapped air dynamics in water slamming, 2) accurate coupling of a refined multiphase flow model with a non-linear elastic structure model for precise modeling of hydroelastic slamming.

３．研究の方法

For achievement of the first goal, a challenge corresponded to presence of a mathematical discontinuity of density at air/water interface. Utilization of density smoothing schemes was found to have adverse effects on reproduced physics of entrapped air and thus, an algorithm incorporating a new technology, namely, Optimized Particle Shifting (Khayyer et al., 2017a), was developed to reproduce the air/water interface in a physically/mathematically consistent manner. In addition, different coupling schemes and different elastic structure models were proposed/considered to achieve an advanced fully-Lagrangian hydroelastic Fluid Structure Interaction (FSI) solver.

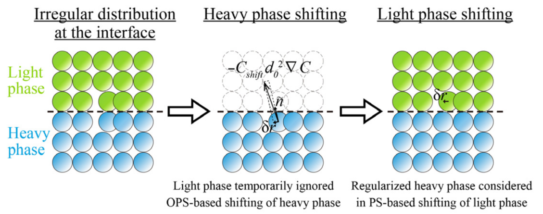

Fig. 1 A two-step particle shifting process in multiphase OPS method

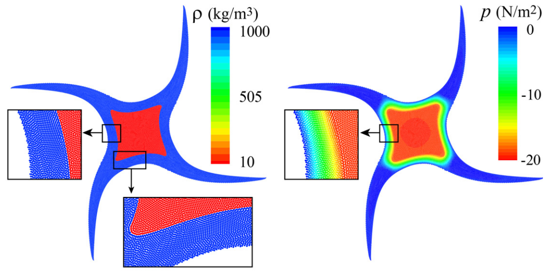

Fig. 2 Typical snapshot corresponding to simulation of a multi-fluid square patch

４．研究成果

The outcomes of this study can be summarized as follows: i) development of a novel projection-based particle method for simulation of multiphase flows of large density ratios and discontinuous density fields at the phase interface. The method comprises of a specific computational algorithm utilizing the recently developed Optimized Particle Shifting (OPS) scheme. ii) development of several coupled FSI solvers, all being fully-Lagrangian and meshfree, for precise modeling of hydroelastic slamming.

Fig. 1 depicts a schematic sketch of the proposed two-step shifting process to guarantee regularity of particles and thus, stability and accuracy in developed multiphase method with utilization of OPS scheme.

Fig. 2 presents a typical result of developed multiphase method in simulation of a benchmark test corresponding to rotating square patch of multi-fluids. The proposed method results in a stable and accurate simulation with continuous pressure and highly regular particle distributions at the phase interface. The OPS scheme was developed and presented in Khayyer et al.

(2017a). The multiphase OPS was presented during 12th SPHERIC workshop.

In development of coupled FSI solvers, an important matter corresponds to accurate imposition of interface boundary conditions including continuity of normal stresses. In this study, a so-called FSA (Fluid-Structure Acceleration) scheme was carefully considered and implemented to achieve a more consistent and precise coupling for calculation of hydroelastic slamming. Fig. 3 portrays the achievement of normal stress continuity through incorporation of so-called FSA scheme. Detailed description of this scheme is presented in Khayyer et al. (2018a).

Fig. 4 portrays a typical snapshot corresponding to hydroelastic slamming of a marine panel reproduced by a proposed fully-Lagrangian meshfree FSI solver which benefits from refined schemes including the FSA coupling scheme (Khayyer et al., 2017b,c; 2018a). Several other coupled fully-Lagrangian meshfree FSI solvers are developed and preliminary presented in Khayyer et al. (2018b).

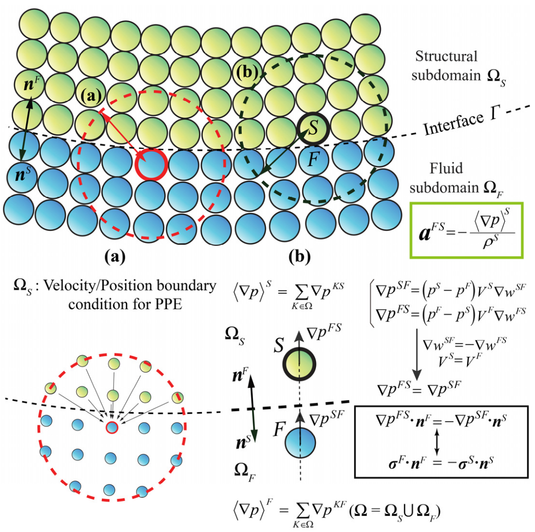

Fig. 3 Schematic sketch of the Fluid-Structure Acceleration-based (FSA) coupling scheme, (a) structure particles providing boundary conditions in calculation of fluid's pressure, (b) normal stress continuity at the fluid-structure interface (Khayyer et al., 2018a)

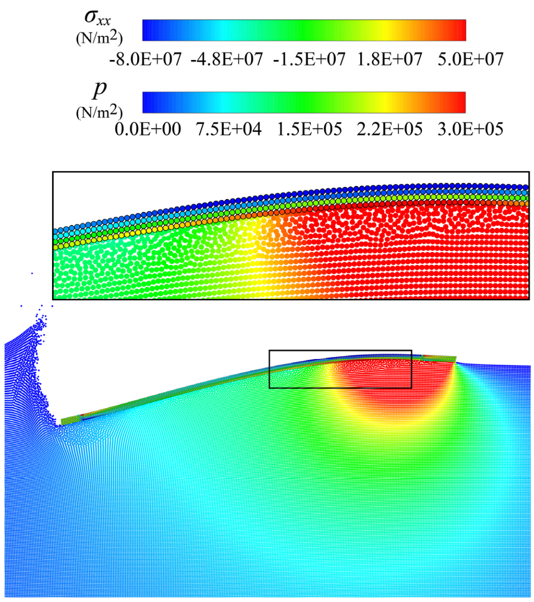

Fig. 4 Typical snapshot corresponding to hydroelastic slamming of a marine panel by an Enhanced ISPH-SPH FSI solver (Khayyer et al., 2017b, 2018a)

The snapshot presented in Fig. 4 corresponds to an Enhanced ISPH (Incompressible SPH)-SPH (Smoothed Particle Hydrodynamics) coupled solver with projection-based ISPH being considered for the fluid, while explicit SPH being considered for the structure partition. The governing equations correspond to continuity/Navier stokes for fluid and linear/angular momenta for structure.

To achieve the best possible level of accuracy, conservation properties and a deep understanding of performances of possible fully-Lagrangian meshfree FSI solvers, other computational frameworks including projection-based MPS (Moving Particle Semi-implicit) and Hamiltonian MPS or SPH were also considered with several results presented in Khayyer et al. (2018b).

Fig. 5 illustrates a typical snapshot corresponding to high velocity impact of an elastic aluminum wedge reproduced by an Enhanced MPS-MPS FSI solver (Khayyer et al., 2017c, 2018b). The presented snapshot portrays qualitatively accurate pressure/stress fields.

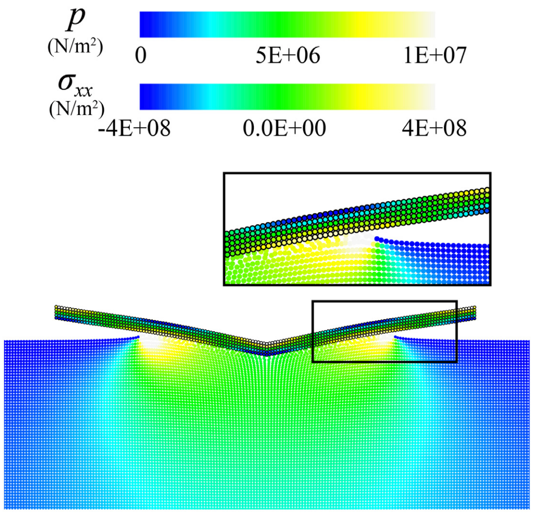

Fig. 5 Typical snapshot corresponding to high velocity impact of an elastic aluminum wedge by an Enhanced MPS-MPS FSI solver (Khayyer et al., 2017c, 2018b)

Indeed, detailed validations were conducted through consideration of several benchmark test cases to verify the performance of structure model as well as coupled FSI solver with both qualitative and quantitative comparisons with analytical and experimental data. Another important point that should be highlighted here is that in all cases the developed FSI solvers or multiphase method are free of any artificial numerical stabilizers and all schemes are founded on clear physical/mathematical backgrounds.

In summary, clear achievements are gained and research is ongoing for further development of proposed multiphase particle method as well as further advancements of proposed fully-Lagrangian meshfree FSI solvers from rigorous mathematical/physical point of view. In coupling the multiphase method with FSI solvers the proposed schemes including multiphase OPS and FSA coupling schemes would be highly effective to result in physically consistent and numerically stable results. Several remaining challenges correspond to violent multiphase flows including turbulence as well as hydroelastic slamming of composite structures. These challenges are to be targeted in future.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計　５　件）

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⑤ Khayyer, A., Gotoh, H., Falahaty, H., Shimizu, Y. and Nishijima, Y.: Towards development of a reliable fully-Lagrangian MPS-based FSI solver for simulation of 2D hydroelastic slamming, *Ocean Systems Engineering - An International Journal*, 7(3), 299-318, 2017c [Refereed]

〔学会発表〕（計　3　件）

① Khayyer, A., Gotoh, H., Shimizu, Y. and Teng, K.W.P.: Two novel projection-based particle methods for multiphase flows with large density ratios and discontinuous density fields, *12th international SPHERIC workshop*, Ourense, Spain, 159-166, June 15-17, 2017.

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〔図書〕（計　　件）

〔産業財産権〕
○出願状況（計　　件）

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〔その他〕
ホームページ等

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