論文の要旨

題目:
An Eulerian Scheme with Lagrangian Particles for Computing Fluid Structure Interaction with Nonlinear Free Surface Flow in Marine Engineering

（船舶海洋工学における非線形自由表面流れを伴う構造流体連成解析のためのLagrange粒子付Euler型スキーム）

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In sea state, a ship as massive sea transportation is moving forward in severe wave condition. Therefore, ship resistance increases due to encountered by waves, and it significantly affects the ship operation and fuel consumption. In additions, under strongly interaction wave-ship the ship experiences a wave load which can accelerate a fatigue failure and influence ship performance, ship structure and passenger comfort. In naval architect, ocean and hydraulic engineering field, numerical researchers have developed several computational fluid dynamics (Computational Fluid Dynamics) tools. Recently many ongoing research in marine engineering have been attempted to yield CFD tool toward accurate tool with considering CFD requirements. These can predict wave impact as hydrodynamic effects due to strongly nonlinear wave-body interactions, however, involvement of hydroelastic effects associated with capturing nonlinear free surface flows on a ship motion under severe wave condition is still rarely devoted.

In this study, we have developed a coupled Eulerian scheme with Lagrangian particles as a model which combines CIP method and SPH method to combine the advantages and to compensate the disadvantages in both grid based method and particle based method as shown in chapter 2. The objective of development is to verify usefulness of the present method in design process. The model has two kinds of Lagrangian particles, i.e. SPH and free surface particle, on Eulerian grids to correct interface tracking error. The two types of Lagrange particles are collocated and attracted with highly accurate captured nonlinear free surface under resolved region with Eulerian grid.

In chapter 3, in the present studies, firstly we evaluated seakeeping performance of a tanker motion in wave, the model was applied to ship-wave interaction in more practical problems. The heave, pitch motion and added wave resistance were compared with both experimental and theoretical results. Also it was applied to ship propulsion performance of a
Fishing boat in calm water to predict and investigate ship resistance, pressure distribution acting on the ship hull, and velocity filed around a ship. Furthermore, we applied the developed model to seakeeping performance of a high-speed Ferry in waves with strongly nonlinear effects, e.g. wave breaking with air bubble. Here, we conducted experiment of resistance and motion in circulating water tunnel and towing tank, respectively. Furthermore, we developed the model in order to clarify hydroelastic behaviors in predicting hydroelastic effects on a ship motion in nonlinear wave with breaking. Here, the ship has been considered as an elastic body in both numerical simulation and experimental work. For validating with our developed model, we conducted some experiments of water entry cylindrical body and rectangular body problems and dropping test of ship.

In chapter 4, to validate an interface capturing with different density, the proposed numerical method has been applied in a number of benchmark problems, i.e. rigid body rotation of Zalesak's Disk, single vortex field, three dimensional deformation field, a complex geometry of stanford bunny. As a result, we confirmed that the proposed method can resolve the thin surface layer at the maximum stretching, maintains the interface and loses very little volume and horse.

In chapter 5, the developed numerical method have been applied to resistance of the fishing boat, the Tanker, and High speed Ferry. The resistance of the all ship was in good agreement with experimental result. Then, it was the highly conservative scheme that the volume error in water phase is less than $0.003\%$ during the calculation time. Regarding the prediction of motion performances of the tanker, fishing boat and high speed ferry in nonlinear wave with breaking, the heaving and the pitching motions showed in good agreement with experimental results and Strip theory results. The maximum error of liquid volume was less than 0.05%, this means that the developed numerical model remained stable. Some phenomena of the high-speed ferry and the tanker motions in waves with breaking was able to be captured under the fully nonlinear interaction between the ship and waves in chapter 6.

In chapter 7, the water entry tests of the elastic cylindrical model, the elastic rectangular bodies and the ship model with elastic motion, the computed internal strain and stress were in good agreement with our experimental results. Based on the application to ship motion in nonlinear wave, hydroelastic response due to impulsive pressure was higher on bow part whereas the highest whipping response was occurred on stern part. The highest impulsive pressure was measured at bow flare when $\lambda/L_{pp}=1.0$. Then, the large heave and pitch motions were influenced by slamming and then they contribute to more severe bow slamming loads.

In chapter 8, in future works, the computational efficiency and stability of the Eulerian scheme with Lagrangian particles will be further investigated rigorously toward robust, useful and applicable model in marine engineering field. Our numerical method will consider small
size of Lagrangian particle to capture small size of water droplets and air bubbles. Ship motion in beam sea and following wave is important study as well. Therefore, our developed method will be applied to those cases. Furthermore, experiment of ship motion with elasticity will be conducted as well. For long-term plan, we will have some efforts to improve the numerical method to capable compute ship hydrodynamic and ship hydroelastic that a ship is completed and equipped with other motion equipment such as propeller, rudder, wing stabilizer or bilge keel, bow thruster, etc.