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Performance Evaluation of an ISPH-FEM Coupling Analysis System for Fluid-Structure Interactions Problems

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1.Introduction

As an extreme destructive natural disaster, tsunami has yielded severe causalities and property loss in many countries and regions. It is necessary to understand the behavior of tsunami caused by earthquakes on various spatial scales, such as the spread of tsunami to the coastal area, the impact from the coastal structure to the land area, and the invasion of the structure by waves. For coastal area disaster prevention and disaster mitigation, it is imperative to quantitatively evaluate the impact of the tsunami on coastal structures by numerical simulation.

Considering the interaction of dynamic loads on coastal structures caused by the tsunami, the Fluid-Structure Interaction (FSI) analysis is required. Also, to quantitatively assess the impact of the tsunami on important coastal structures such as breakwaters and highway bridges, the large-scale numerical analysis is required. In recent research, particle methods are a significant class of meshfree methods to predict free surface flows. Among the particle methods, smoothed particle hydrodynamics (SPH) method and moving particle semi-implicit (MPS) method have been widely used [1]. By using relaxation density invariance condition, the stabilized incompressible SPH (ISPH) method [2] can improve the numerical stability of particle methods [3]. For structure analysis, finite element method (FEM) is standard to be used.

In this research, we employed a coupling analysis system to solve 3-dimensional large-scale FSI problems and evaluates its performance under large-scale calculation.

2. ISPH-FEM Coupling Analysis System

The numerical simulation analysis system for this research is developed by coupling the semi-implicit ISPH method to simulate the fluid part and the implicit FEM to simulate the structure part.

(1) Fluid simulation

As a meshfree method, SPH method can ideally be suited to simulate complex boundary dynamic. It is necessary to ensure uniform particle distribution to improve the accuracy of the SPH method in the calculation of incompressible flow; Therefore, by adding different source terms derived from particle density, a stable ISPH method can be proposed.

By modified an in-house SPH code been hybrid parallelized using MPI and OpenMP, we can execute ISPH simulation on the supercomputer.

(2) Structure simulation

By solving the boundary value problems of partial differential equations, the analytical solutions of engineering and mathematical physics problems can be obtained by FEM.

The ADVENTURE system is an open source computational mechanic system designed for analyzing arbitrary shape model with tens of millions or more degrees of freedom mesh. By using a module named ADVENTURE_Solid of this system, which can perform static and dynamic elastic-plastic analysis by FEM, large-scale structure simulation can be efficiently calculated by the high-performance linear solver based on the hierarchical region segmentation method on the supercomputer.

(3) Coupling model

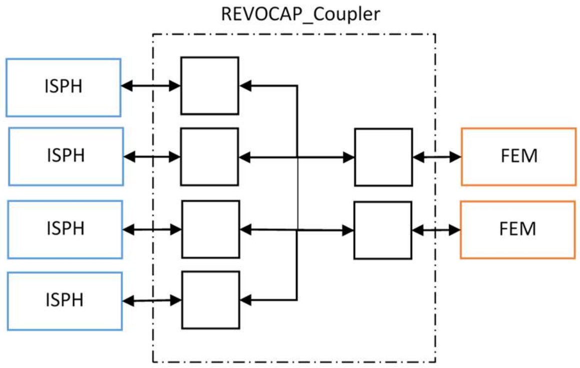

Fig. 1. The data communication by using REVOCAP_Coupler

The open-source coupling analysis platform REVOCAP_Coupler can unify two or more arbitrary single dynamics analysis software among fluid, solid, thermal, etc. By setting the appropriate boundary conditions [4], the result of fluid simulation and structure simulation can be well combined and make it capable of interpolating the physical quantity even between models in which the meshes of the interface are inconsistent. As the Fig. 1, it corresponds to the case where analysis solvers are executed with different parallel

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numbers. With the introduction of REVOCAP_Coupler, the cost for I / O can be reduced by online coupling, and bi-directional coupling becomes possible.

3. Numerical Experiments

In this research, the dam break problem with an elastic obstacle, as the Fig. 2, is demonstrated to verify the analysis system.

The parallel efficiency of the program will be verified on a scale of millions of particles. The scale of the problem is adjusted by changing the particle size of the module. By changing the numbers of MPI processes for fluid and structure, we can get the parallel efficiency of this analysis system under different conditions. Table 1 shows the particle size, numbers of particle and amounts of each MPI processes. In all circumstances, OpenMP's thread parallelism was set to 31. The computation was run on the supercomputer FX100 setting at Nagoya University Information Infrastructure Center.

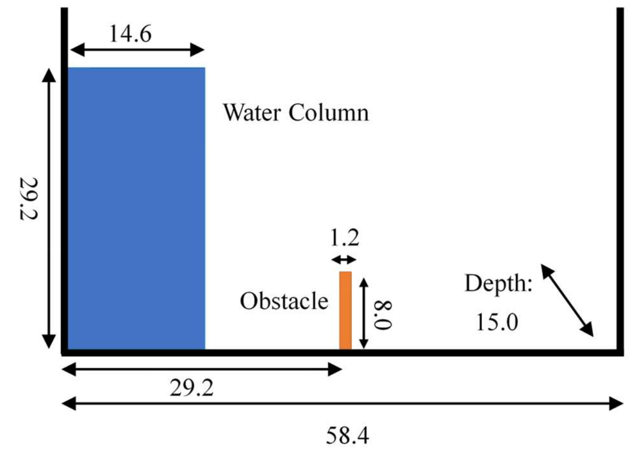

Fig. 2. A dam break problem with an elastic obstacle (unit: cm)

Table 1 Case of numerical experiments

Case	Particle size(cm)	Number of particles	ISPH process	FEM process
1	0.3	1.40 million	4	2
2			8	2
3			16	2
4			4	4
5			8	4
6			16	4

Table 2 Calculation time of each time steps

Case	Fluid(s)	Structure(s)	Coupler(s)
1	2.01	3.78	0.014
2	1.30	3.77	0.014
3	0.83	3.79	0.014
4	1.98	2.06	0.014
5	1.32	2.03	0.014
6	0.84	2.04	0.014

The average computation timings of time steps are shown in Table 2 below.

According to the strong scaling, a work unit with M processing element is T_M, and the amount of time to complete the same unit of work with N processing elements is T_N the parallel efficiency β (%) is given as

$$\beta = \frac{T_M}{\frac{N}{M} \times T_N} \times 100 \quad (1)$$

According to the result, we can draw the following conclusion: for fluid simulation, the parallel efficiency of 8 processes is about 75% of 4 process, and for 16 process is about 59%; for structure simulation, the parallel efficiency of 4 processes is about 92% of 2 process. Also, the coupling model is less affected by other simulation.

4. Conclusion

In this research, a partitioned coupling analysis system developed for the numerical simulation of 3-dimensional FSI problems by adopting the ISPH method and FEM has been employed. To evaluate the performance of this system toward large-scale problems, we demonstrated a dam-break problem with an elastic obstacle. By changing the numbers of MPI processes for fluid and structure, we get the parallel efficiency of this analysis system under different conditions. In the future, we will further improve its parallel efficiency and calculation speed and add new functions according to actual needs.

Acknowledgment

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Reference

[1] Alex D. Chow. et al.: Incompressible SPH (ISPH) with fast Poisson solver on a GPU. Computer Physics Communications Volume 226, May 2018, Pages 81-103

[2] Asai, M., et al.: Coupled tsunami simulation based on a 2D shallow-water equation-based finite difference method and 3D incompressible smoothed particle hydrodynamics, Journal of Earthquake & Tsunami, 2016.

[3] Yang, Q., et al.: Free-surface flow interactions with deformable structures using an SPH-FEM model, Ocean Engineering, 55, pp.136-147, 2012.

[4] Masao Ogino. et al.: Development of a Partitioned Coupling Analysis System for Fluid–Structure Interactions Using an In-House ISPH Code and the Adventure System. International Journal of Computational Methods, Vol. 15, No. 1 (2018)