Applied Mechanics and Materials Vols 752-753 (2015) pp 1269-1274
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doi:10.4028/www.scientific.net/AMM.752-753.1269

Submitted: 2014-09-17
Revised: 2014-12-04
Accepted: 2014-12-29
Online: 2015-04-20

Simulation of Tsunami Wave Generated by Submarine Slide: Generation, Propagation, Run-Up and Impact

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Keywords: Parallel computing, Submarine slide, Mesh free method, Tsunami.

Abstract. Submarine slides can generate tsunami waves with high affecting coastal structures, human lives along the shoreline and subsea facilities. Unfortunately, submarine slide-generated tsunami is a complicated problem due to the source of sliding. It can be slide down by earthquakes, undersea volcanic eruptions or itself. There are no effective tools that could solve all problems when simulating tsunami waves such as: extremely large deformation, free surface issue, deformable boundary, complicated geometry, time-consuming and costly process. So how to understand substance of tsunami clearly and how to find methods to reduce damage from tsunami wave. This paper will present a parallel computing based on parallel SPHysics, to simulate a comprehensive model of tsunami wave by using Smooth Particle Hydrodynamics (SPH) method.

Introduction

Consequences of the 1998 Papua New Guinea (PNG) which killed more than 2000 people and destroyed completely three villages [1] and the December 2004 Indian Ocean tsunami which causing over 200,000 fatalities and widespread destruction in countries bordering the Indian Ocean [2]. There has been significant improvement in numerical tsunami simulation and recognition that the science requires data from geosciences, oceanography, geography and hydrodynamic disciplines in order to represent reality. Therefore, tsunami phenomenon induced by submarine slide has put us on the challenge in understanding from generation mechanism to propagation and coastal inundation and mitigating the risk from it. Fig. 1 illustrates how submarine landslide can trigger tsunami wave.

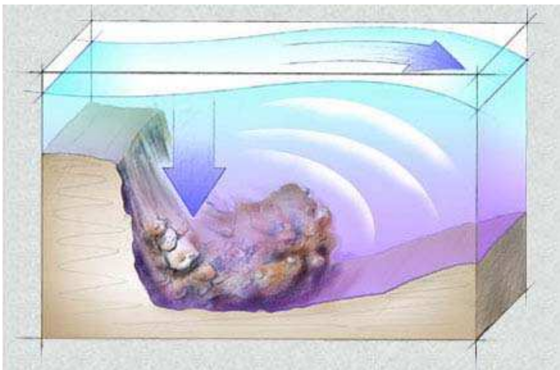

Fig. 1 Tsunami wave generation by submarine landslide [3]

As noted in a state-of-the-art which looks at the slide tsunami hazards, the physical understanding of this hazard is poor, and there is an immediate need for research such that preparation for devastating events like Papua New Guinea and Indian Ocean. This is not simple task due to the complexity and multiscale of process. For this reason, the need for simulation of entire phenomenon is necessary.

Up to now, Computational Fluid Dynamic (CFD) has concentrated one's attention to grid-based method, which two different frames namely: Lagrangian grid and Eulerian grid. Lagrangian methods are represented by Finite Element Method (FEM) while Finite Difference Method (FDM) and Finite

Volume Method (FVM) are the paradigm of Eulerian methods. They are very popular method in numerical simulations to solve different problems in science and engineering. However, the grid-based numerical method is not suitable to simulate all comprehensive of tsunami wave, which can lead to the various problems such as: time consuming complicated geometry, crack propagation, free surface issue and large deformation. Fig. 2 shows all the general methods of CED. Beside the grid-based method, Computational Fluid Dynamic is still developing a new approach is: meshfree method. This is a new method can solve complex problems which no using grid or mesh.

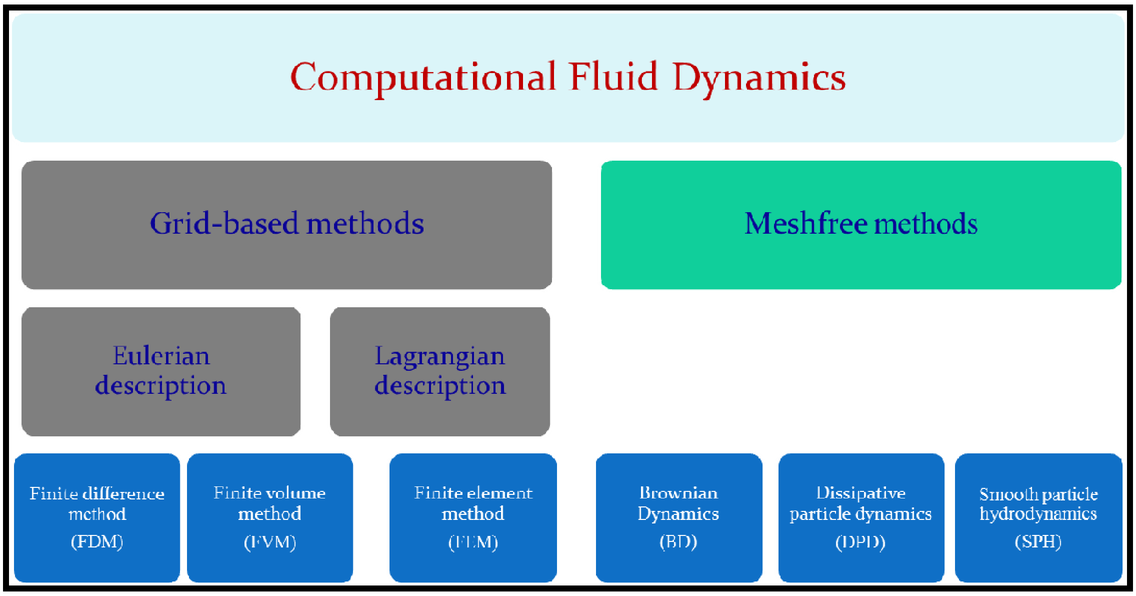

Fig. 2 All methods were used to analysis of Computational Fluid Dynamics [4]

Mesh Free Method

Meshfree method use a set of particles (or nodes) scattered within the problem domain to represent the problem domain and its boundaries. No mesh implies no information on the relationship between the particles is required. The fluid dynamics and solid mechanics are possible applied in meshfree method, however they use different method of approximation.

Smooth Particle Hydrodynamics (SPH) is a truly meshfree method, invented by Gingold and Monaghan (1997); Lucy (1977). The hydrodynamic equations on each particle are integrated in SPH by using Lagrangian formalism. With values of the nearest neighboring particles, SPH can approximate the value of functions at a particle and then particles move according to those values [5]. The integral equations were used to transform these particles by using conservation laws of continuum fluid dynamics. The kernel approximation was used to estimate the field variables at a point. Computationally, the information of particle is evaluated as sums over neighboring particles [6].

The main features of the SPH method, which is based on integral interpolations, are described in detail in the following papers: Monaghan (1982); Monaghan (1992); Benz (1990); Liu (2003); Monaghan (2005). In the SPH, the fundamental principle is to approximate any function $A(\vec{r})$ by:

$$A(\vec{r}) = \int A(\vec{r})' W(\vec{r} - \vec{r}', h) d\vec{r}' \tag{1}$$

Where h is called the smoothing length and $W(\vec{r} - \vec{r}', h)$ is the weighting function or kernel.

SPH is a particle method of Lagrangian nature. It can obtain the time history of the material particles. By deploying particles at specific positions at the initial stage before the analysis. So, the free surfaces, material interfaces, and moving boundaries can all be traced naturally in the process of simulation regardless the complicity of the movement of the particles. SPH does not use a grid/mesh.

This allows a straightforward handling of very large deformations, since the connectivity between particles are generated as part of the computation and can change with time. SPH is suitable for problems where the object under consideration is not a continuum. SPH is comparatively easier in numerical implementation, and it is more natural to develop three-dimensional numerical models than grid based methods.

The limitations in Eulerian methods were solved in the Lagrangian nature of SPH which provides some advantages as given below:

By using those regions, the density number of particles is increased where the wave is described and the time for calculating is not waste in these empty areas.

Without the need of complicated gridding algorithm, the initial conditions can possible program so easily.

SPH has included other physical process so it is very straightforward.

Parallel SPHYSICS

SPHYSICS. SPHysics is a Smoothed Particle Hydrodynamics (SPH) code inspired by the formulation of Monaghan (1992). It is a joint collaboration between several researchers at the Johns Hopkins University (U.S.), the University of Vigo (Spain), the University of Manchester (U.K.) and the University of Rome La Sapienza (Italy).

All these phenomena such as: wave impact on the structures, wave breaking, dam breaks, etc that are possible simulated in SPHysics code. The user, when coding the SPHysics, can easily choose different compiling options.

Square cells of side *2h* (Fig.3) are used to in the computational domain. When a particle located inside computational domain, only the interactions of these particles inside neighboring cells need to be considered. Thus, the computational time will be decreased from N2 operations to NlogN, with N is number of particles.

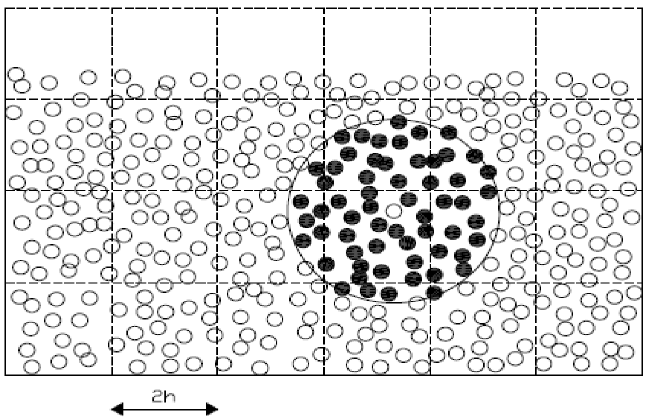

Fig. 3 Particle interaction [7]

The SPHysics code in 2D sweeps through the grid along the x-direction, for each z-level. Around each cell, the E, N, NW and NE neighboring cells are checked to minimize repeating the particle interactions. Thus, for example, when the center cell is i=5 and k=3 (Fig. 4), the target cells are (5,4), (4,4), (6,4) and (6,3). The rest of the cells were previously considered through the sweeping (e.g. the interaction between cell (5,3) and (5,2) was previously accounted when (5,2) was considered to be the center cell).

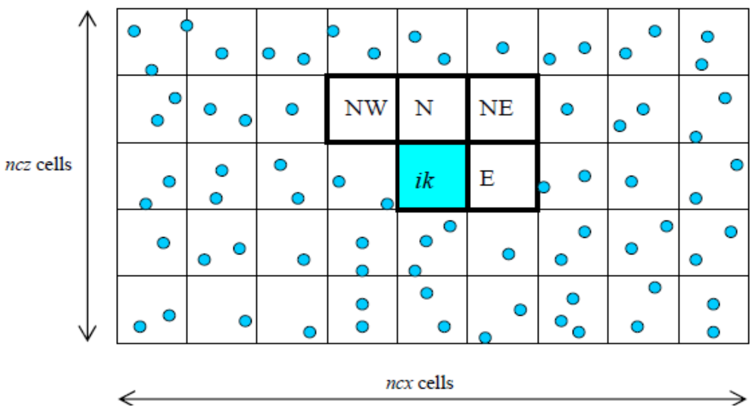

Fig. 4 Sweeping through grid cells [7]

Parallel SPHYSICS. SPHYSICSgen: the initial conditions are created.

Creating Compiling Options. The parallel SPHysics are compiled using the particular features, and the nature problems will be considered in compilation of parallel code. The user can have two choices: MPI FORTRAN compiler or MPI partitioning (i.e. load balancing) [9] to do compilation.

Compiling and Running the Executable. Load Sharing Facility (LSF) and the Submission systems (SGE) are used to in parallel SPHysics code. By using two above frames, parallel SPHysics code can perform simulation of millions of particles with lots of processors [10].

SPHYSICS. From the initial condition, all selected case will be run in this part.

The information of these particles need to transfer between adjacent processors by using the MPI topology. All of subroutines in SPHYSICS can be possible used to calculate each necessary situation (i.e. density, moving objects, etc.).

Grid Sweep. The connectivity of particles between adjacent processors are shown in Fig. 5. In parallel code, the complex task will be distributed amongst processors by using grid sweep.

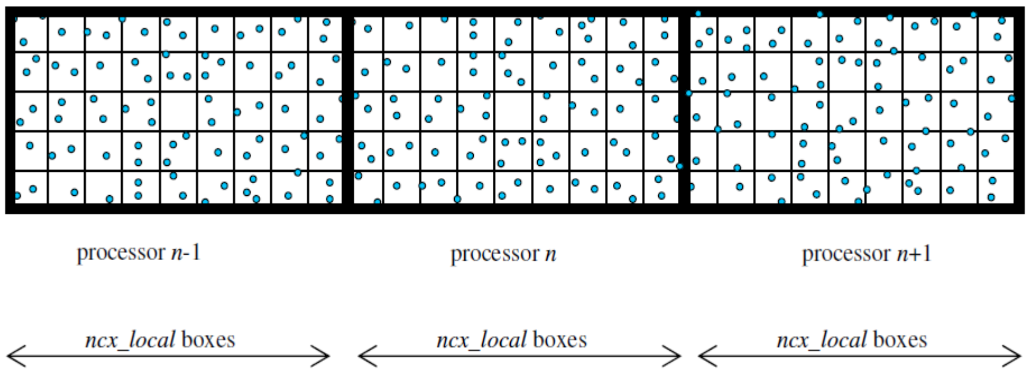

Fig. 5 Domain decomposition in parallel SPHysics [8]

However, the problem happens when the information at the boundary of the processors. The code wants to know the contents of position ii+1 (i.e. E & NE) which lie on a different processors. Alternative for this problem is to use ghost cells of width 2h [11] as shown in Fig. 6.

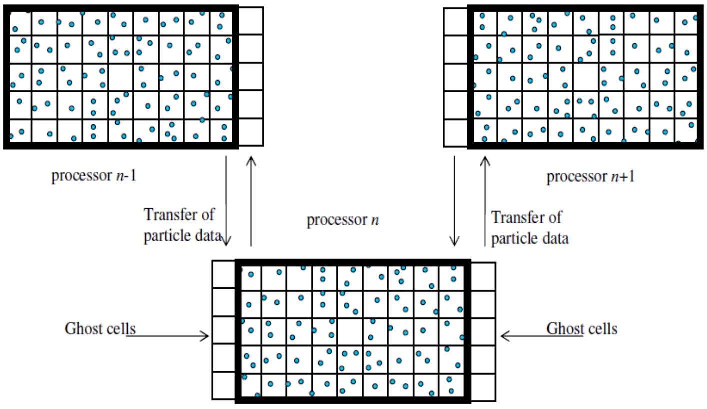

Fig. 6 Importing particle information into ghost cells from neighboring processor [8]

Results

Fig. 7 shows that the difference of number particles between SPHYSICS code and Parallel SPHYSICS code. When the model simulates a larger of particles, the results are more accurate and able to reduce the errors.

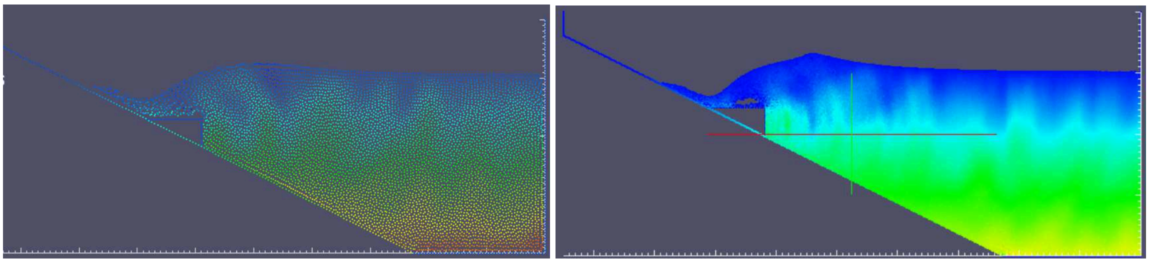

Fig. 7 Difference of number of particles between SPHYSICS code (left) and Parallel SPHYSICS code (right)

Result in Fig. 8 shows that Parallel SPHYSICS code is an application of a unique comprehensive model that covers all aspects of slide induced tsunami from source generation to coastal inundation.

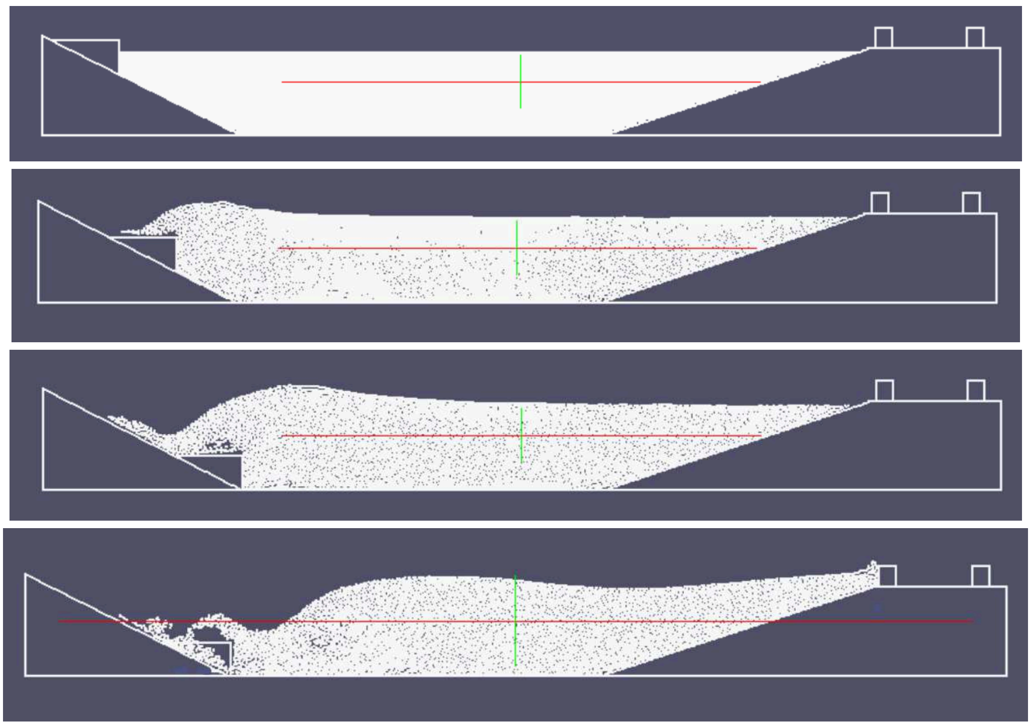

Fig. 8 Results of numerical simulation about tsunami generated by submarine slide

Conclusion

The development of mesh free methods offers a reliable approach to tackle the simulation of such difficult problems. The comprehensive model base on mesh free method that could cover all aspects of tsunami phenomena and provide real-time modeling of the event would be one of good future research direction.

Parallel computing is widely used to reduce the computation time for complex tasks.

That approach still remains limitations need to be improved related to accuracy and stability, inconsistency problem, or non-conservation of linear and angular momentum.

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Advanced Engineering and Technology
10.4028/www.scientific.net/AMM.752-753

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