Chapter 6

Conclusions

6.1 Conclusions

In this thesis, the 2D numerical simulation models using the shallow water equations and the Boussinesq equations for tsunami wave were examined and validated, the phase-field model (PFM) was developed for the 3D free surface flow analysis that the accuracy and robustness have been examined. And then, a 2D-3D hybrid tsunami numerical model using the overlap method based on an arbitrary grid was developed, and it was parallelized by using the MPI method for simulating efficiently the large-scale tsunami. Numerical examples were examined to show the validity and the effectiveness of the hybrid model by comparing with observation data. The tsunami by the 2011 Great East Japan Earthquake was also simulated.

The findings obtained in this study is summarized in each chapter as follows:

In **Chapter 1**, the background of this study was reviewed. The features of each method were summarized in the review of previous studies. The organization and the objectives of this thesis have been provided.

In **Chapter 2**, the governing equations for 2D tsunami simulation were described, the stabilized finite element method based on the SUPG method has been applied in terms of the discretization forms. For the first numerical example, the characteristics of the propagation of solitary wave were investigated by comparing the linear/nonlinear shallow water equations and the linear/nonlinear Boussinesq equations, the results of the nonlinear Boussinesq equations were in the best agreement with the experimental results. By the numerical examples of the wave-making problem and the large-scale tsunami run-up simulation, the applicability and effectiveness of the nonlinear shallow equations and the nonlinear Boussinesq equations were confirmed. The AR technology was also applied as a visualization method for the real terrain tsunami, which was shown to be a useful technology to help people understand the tsunami phenomenon and improve the quality of education for tsunami disaster.

In **Chapter 3**, the VOF method and the phase-field model (PFM) were introduced as the interface-capturing method for the free surface flow simulation, the Allen-Cahn equation which is one of the governing equation for the phase-field model was solved by the stabilized finite element method. The efficiency and accuracy of the VOF method and the PFM were investigated by several numerical examples. For the rotating cylinder problem, the PFM was able to reproduce the interface better than the VOF method. It was found that the overshoot/undershoot, observed by the VOF method, can be reduced by the PFM. The width of the interface and the interface energy for the PFM were investigated, and we found that the interface width can be chosen as 2 or 3 times of the representative length of elements and the interface energy with a large value may result in a shrink deformation. From the dambreak problem with a structure, it was found that the shape of drag force acting on the structure by using the PFM was in good agreement with the experimental result, and the mass conservation by PFM was also better than the VOF method. We also introduced a volume correction method for the free surface flow simulation, which was shown to be an effective method to conserve the volume of the flow problem without inflow and outflow. The efficiency and the applicability for the present method using the PFM to compute the fluid force acting on the structure were confirmed.

In **Chapter 4**, the 2D-3D hybrid tsunami numerical model using an overlap method based on an arbitrary grid was developed. The details of the 2D-3D overlapping method were discussed by using a flowchart, and a switch model was proposed to reduce the computational burden for the large-scale tsunami simulation. For the first numerical example of the dambreak with structures, the results showed that the 3D domain can be chosen arbitrary, the grids also can be arbitrary which were useful to capture the complex geometry of structures or real terrains. Also, the robustness of the present method has been confirmed. The second numerical example of the solitary wave problem was used to test the 2D-3D hybrid model using structured mesh and unstructured mesh, and the 2D-3D hybrid model using the VOF method and the PFM. By comparing numerical results with experimental results, both numerical results by using structured mesh and unstructured mesh were in good agreement with experimental results. Furthermore, the 2D-3D hybrid model using the PFM was more stable than the VOF method, and the results of surface profile was also better simulated. The third numerical example was to investigate the width for choosing the overlap domain. By simulating the wave problem around a breakwater, it was found that the width of about 4 elements of the overlap domain could give satisfactory results.

In **Chapter 5**, the parallel 2D-3D overlapping method and the parallel wetting and drying treatment for the 2D analysis model have been proposed. As a result, the large-scale 2D-3D hybrid tsunami numerical model has been developed. As a numerical example, the tsunami by the Great East Japan Earthquake was simulated, the efficiency and the applicability of the present method for the large-scale terrain was confirmed.

Based on the aforementioned facts, conclusions are given as follows:

- The phase-field model using the Allen-Cahn equation based on the stabilized finite element method was developed to be an effective and robust method for simulating free surface flows.
- The proposed 2D-3D hybrid tsunami numerical model using the overlap method based on an arbitrary grid can compute effectively the wave propagation in ocean by a 2D model and in the area with structures by a 3D model.
- The proposed large-scale 2D-3D hybrid tsunami numerical model is capable of simulating efficiently tsunamis over a large-scale terrain.

6.2 Recommendation for Future Work

Recommendation topics for improving and extending the current work are provided as follows:

- To simulate tsunami propagation through the entire metropolitan area of a city in 3D using the 2D-3D hybrid model, fine meshes in both 2D and 3D domains are needed.
- To examine the tsunami simulation of real terrain with observed inundation data.
- To apply a volume correction method for the present 2D-3D hybrid model.
- The continuum surface force (CSF) model can be introduced into the PFM model which may increase the accuracy of the free surface flow simulation.
- To apply the present 2D-3D hybrid model to the fluid structural interaction (FSI) problems.
- To develop a 2D Boussinesq model solved by the DG method, which is expected to increase the robustness of the 2D numerical model in comparison with the CG method.

Appendix A

Boussinesq Equations (1D) Solved by the DG Method

A.1 Introduction

In recent decades, great attention has been paid to use the discontinuous Galerkin (DG) method [88] to solve the shallow water equations. Because the shallow water equations are hyperbolic, a discontinuous solution may be generated that the DG method is more suitable for the shallow water equations. However, as mentioned in Chapter 2, the Boussinesq equations are also very useful in tsunami simulation.

In this study, the objective is to develop a 2D Boussinesq model using DG method to instead the 2D continuous Galerkin (CG) model in the proposed 2D-3D hybrid model. However, in this thesis, only the 1D Boussinesq model solved by the DG method is developed. To eliminate numerical oscillations, slope limiter [89] based on the water depth and flow rate is used. The thin water layer technique based wetting and drying treatment [90] with fixed meshes is adopted. The total variation diminishing (TVD) Runge-Kutta time scheme [91] is used to temporal discretization. A numerical example of solitary wave propagation is simulated to demonstrate the effectiveness of the presented methods.

A.2 Governing Equations

The conservative form of one-dimensional Boussinesq equations are given by:

$$\partial_t \mathbf{U} + \nabla\cdot\mathbf{F} + \partial_t \mathbf{D} = \mathbf{S}, \tag{A.1}$$

where $\mathbf{U}$ is the conservative variable vector, $\mathbf{F}$ is the flux vector, $\mathbf{D}$ is the dispersion term, and $\mathbf{S}$ is the source vector. These terms can be expressed as:

$$\mathbf{U} = \begin{bmatrix} \zeta \\ q \end{bmatrix}, \mathbf{F} = \begin{bmatrix} F^{(1)} \\ F^{(2)} \end{bmatrix} = \begin{bmatrix} q \\ q^2/H + g(H^2 - h^2)/2 \end{bmatrix},$$

$$\mathbf{D} = \begin{bmatrix} 0 \\ -\frac{h^2}{3}\frac{\partial}{\partial x}(\nabla \cdot q) \end{bmatrix}, \quad \mathbf{S} = \begin{bmatrix} 0 \\ g\zeta\frac{\partial h}{\partial x} \end{bmatrix},$$

where $\zeta,\ H,\ h,\ q,\ g$ are the elevation of the free surface measured from the geoid (positive upwards), total height of the water column, static water depth, flow rate per unit width, gravitational acceleration.

In order to solve Eq. (A.1), we seperate it into the following equations,

$$\frac{\partial \zeta}{\partial t} = -\frac{\partial F^{(1)}}{\partial x}, \tag{A.2}$$

$$\frac{\partial q}{\partial t} = g\zeta\frac{\partial h}{\partial x} - \frac{\partial F^{(2)}}{\partial x} - \frac{\partial}{\partial x}(\frac{1}{\lambda}z), \tag{A.3}$$

where λ and z are auxiliary parameters,

$$\lambda = -3/h^2, \tag{A.4}$$

$$z - \frac{\partial}{\partial x}(\frac{\partial q}{\partial t}) = 0. \tag{A.5}$$

For Eqs. (A.2), (A.3), two auxiliary parameters are applied, $G^{(1)} = -\frac{\partial F^{(1)}}{\partial x}$, $G^{(2)} = g\zeta\frac{\partial h}{\partial x} - \frac{\partial F^{(2)}}{\partial x}$, they can be rewritten as,

$$G^{(1)} + \frac{\partial F^{(1)}}{\partial x} = 0, \tag{A.6}$$

$$G^{(2)} + \frac{\partial F^{(2)}}{\partial x} = g\zeta\frac{\partial h}{\partial x}. \tag{A.7}$$

Then the Eqs. (A.2), (A.3) can be rewritten as,

$$\frac{\partial \zeta}{\partial t} = G^{(1)}, \tag{A.8}$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial x}(\frac{1}{\lambda}z) = G^{(2)}. \tag{A.9}$$

Then substitute Eq. (A.9) into Eq. (A.5), we can get,

$$z + \frac{\partial}{\partial x}(\frac{1}{\lambda}w - G^{(2)}) = 0, \tag{A.10}$$

whrere w is an auxiliary variable defined as,

$$w + \frac{\partial}{\partial x}(-z) = 0. \tag{A.11}$$

The above Eqs. (A.6)∼(A.11) constitute the DG model of Boussinesq equations. If $z = 0$, the model will be change into the model of shallow water equations.

A.3 Spatial Discretization by DG Method

Appling the DG method to the equations over a element Ω_e gives:

$$G_j^{(1)} = \mathbf{A}_j F_j^{(1)} + \mathbf{B}_j^+ \hat{F}_j^{(1)} - \mathbf{B}_j^- \hat{F}_{j+1}^{(1)}, \tag{A.12}$$

$$G_j^{(2)} = \mathbf{A}_j F_j^{(2)} + \mathbf{B}_j^+ \hat{F}_j^{(2)} - \mathbf{B}_j^- \hat{F}_{j+1}^{(2)} + \mathbf{C}_j S_j, \tag{A.13}$$

$$\begin{aligned} z_j = {} & \mathbf{A}_j F_j^{(z_1)} + \mathbf{B}_j^+ \hat{F}_j^{(z_1)} - \mathbf{B}_j^- \hat{F}_{j+1}^{(z_1)} \\ & + \mathbf{A}_j F_j^{(z_2)} + \mathbf{B}_j^+ \hat{F}_j^{(z_2)} - \mathbf{B}_j^- \hat{F}_{j+1}^{(z_2)}, \end{aligned} \tag{A.14}$$

$$w_j = \mathbf{A}_j F_j^{(w)} + \mathbf{B}_j^+ \hat{F}_j^{(w)} - \mathbf{B}_j^- \hat{F}_{j+1}^{(w)}, \tag{A.15}$$

$$\dot{\zeta}_j = \mathbf{C}_j G_j^{(1)}, \tag{A.16}$$

$$\dot{q}_j = \mathbf{A}_j F_j^{(q)} + \mathbf{B}_j^+ \hat{F}_j^{(q)} - \mathbf{B}_j^- \hat{F}_{j+1}^{(q)} + \mathbf{C}_j G_j^{(2)}. \tag{A.17}$$

where, $\mathbf{A}_j = \mathbf{M}_j^{-1} \mathbf{\Phi}_\mathbf{n}'^\mathbf{T} \mathbf{W}_n$, $\mathbf{B}_j^+ = \mathbf{M}_j^{-1} \mathbf{\Phi}^+$, $\mathbf{B}_j^- = \mathbf{M}_j^{-1} \mathbf{\Phi}^-$, $\mathbf{C}_j = \frac{h_j}{2} \mathbf{M}_j^{-1} \mathbf{\Phi}_\mathbf{n}^\mathbf{T} \mathbf{W}_n$. $\mathbf{M}_j$, $\mathbf{B}_j$, $\mathbf{W}_n$, $\mathbf{\Phi}_\mathbf{n}$, h_j are mass matrix, Legendre basis function, weight matrix, basis function, element length. And $F^{(z_1)}$, $F^{(z_2)}$, $F^{(w)}$, $F^{(q)}$ are defined as follow,

$$F^{(z_1)} = \frac{1}{\lambda} w, \tag{A.18}$$

$$F^{(z_2)} = -G^{(2)}, \tag{A.19}$$

$$F^{(w)} = -z, \tag{A.20}$$

$$F^{(q)} = \frac{1}{\lambda} z. \tag{A.21}$$

A.4 Numerical Flux Functions

Since a discontinuity is allowed across the element interface, the numerical flux normal to the element interface can be attained from the local Riemann solver given the left and right states. The Local-Lax Friedrichs flux [92] is used, and it is defined as follow,

$$\hat{\mathbf{F}}_j = \frac{1}{2}\Big(\mathbf{F}(\mathbf{U}_j^-) + \mathbf{F}(\mathbf{U}_j^+)\Big) - \frac{\lambda_{\max}}{2}(\mathbf{U}_j^+ - \mathbf{U}_j^-), \tag{A.22}$$

$$\begin{aligned}\lambda_{\max} = \max(&|u^+ - c^+|, |u^- - c^-|,\\ &|u^+ + c^+|, |u^- + c^-|),\end{aligned} \tag{A.23}$$

$$c^+ = \sqrt{gH^+}, c^- = \sqrt{gH^-}. \tag{A.24}$$

For $\hat{F}^{(z_1)},\ \hat{F}^{(z_2)},\ \hat{F}^{(w)},\ \hat{F}^{(q)}$, the average numerical fluxes are applied,

$$\hat{F}_j^{(z_1)} = \frac{1}{2}(F_j^{(z_1)-} + F_j^{(z_1)+}), \tag{A.25}$$

$$\hat{F}_j^{(z_2)} = \frac{1}{2}(F_j^{(z_2)-} + F_j^{(z_2)+}), \tag{A.26}$$

$$\hat{F}_j^{(w)} = \frac{1}{2}(F_j^{(w)-} + F_j^{(w)+}), \tag{A.27}$$

$$\hat{F}_j^{(q)} = \frac{1}{2}(F_j^{(q)-} + F_j^{(q)+}). \tag{A.28}$$

A.5 Temporal Discretization

A.5.1 Runge-Kutta Method

The TVD Runge-Kutta time integration scheme should be one order higher than the space discretization as shown in the previous study [93]. In this paper, the second-order TVD Runge-Kutta scheme [91] is used, because the $p = 1$ is used. Eqs. **(A.16)**, **(A.17)** can be written into the following form:

$$\dot{\mathbf{U}} = \mathbf{R}_{hp}(\mathbf{U}), \tag{A.29}$$

and the second-order TVD Runge-Kutta scheme is given by:

$$\mathbf{U}^* = \mathbf{U}^n + \Delta t \mathbf{R}_{hp}(\mathbf{U}^n), \tag{A.30}$$

$$\mathbf{U}^{n+1} = \frac{1}{2}\mathbf{U}^n + \frac{1}{2}\mathbf{U}^* + \frac{1}{2}\Delta t \mathbf{R}_{hp}(\mathbf{U}^*). \tag{A.31}$$

The Courant-Friedrichs-Lewy (CFL) condition is given by [88]:

$$\Delta t \leq \min\Big(\frac{h_e}{(\lambda_{\max})_e(2p+1)}\Big). \tag{A.32}$$

A.5.2 Computational Procedure

The computational procedure for solving the DG model of Boussinesq equations is as follow,

- To compute $G_j^{(1)}$ and $G_j^{(2)}$ by solving the Eq. (A.12) and Eq. (A.13).
- To substitute Eq. (A.15) into Eq. (A.14) to compute out z_j. We should note that the w_j is not computed directly.
- To solve the Eqs. (A.16), (A.17) by using TVD(Total Variation Diminishing) Runge-Kutta method. ζ_j and q_j can be computed out.

A.6 Slope Limiter

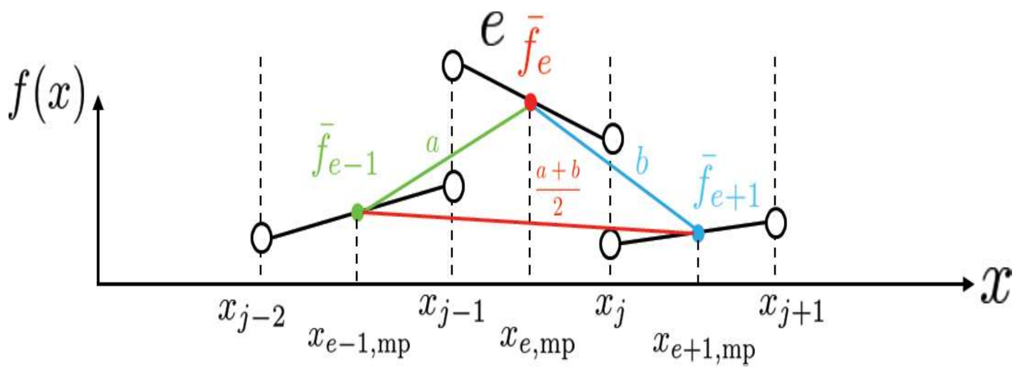

Figure A.1 **Slop limiter**

For the shock wave, unphysical spurious oscillations are observed near shock discontinuities by the DG methods. To overcome this drawback, the slope limiter [89] is applied to the water level variation ζ and the flow rate q (**Figure A.1**).

In an element e, the slope limiter for a variable f can be written as:

$$f(x) = \bar{f}_e + (x - x_{\mathrm{mp}})\sigma_e, \qquad x_{j-1} \leq x \leq x_j, \tag{A.33}$$

where $\bar{f}_e$ is the average value of a variable over an element, x_{mp} is the midpoit of the element. f can be ζ or q, and here the monotonized central slope limiter is used, it can be written as:

$$\sigma_e = \frac{[\mathrm{sign}(a) + \mathrm{sign}(b)]}{2} \min\left(\frac{|a+b|}{2}, 2|a|, 2|b|\right). \tag{A.34}$$

The upwind slope a, the downwind slope b, and the central slope $(a+b)/2$ are given by:

$$a = \frac{\bar{f}_e - \bar{f}_{e-1}}{x_{e,\mathrm{mp}} - x_{e-1,\mathrm{mp}}}, \tag{A.35}$$

$$b = \frac{\bar{f}_{e+1} - \bar{f}_e}{x_{e+1,\mathrm{mp}} - x_{e,\mathrm{mp}}}, \tag{A.36}$$

$$\frac{a+b}{2} = \frac{\bar{f}_{e+1} - \bar{f}_{e-1}}{x_{e+1,\mathrm{mp}} - x_{e-1,\mathrm{mp}}}, \tag{A.37}$$

where $x_{e,\mathrm{mp}}$ is the midpoint of element e.

A.7 Wetting and Drying Treatment for DG Method

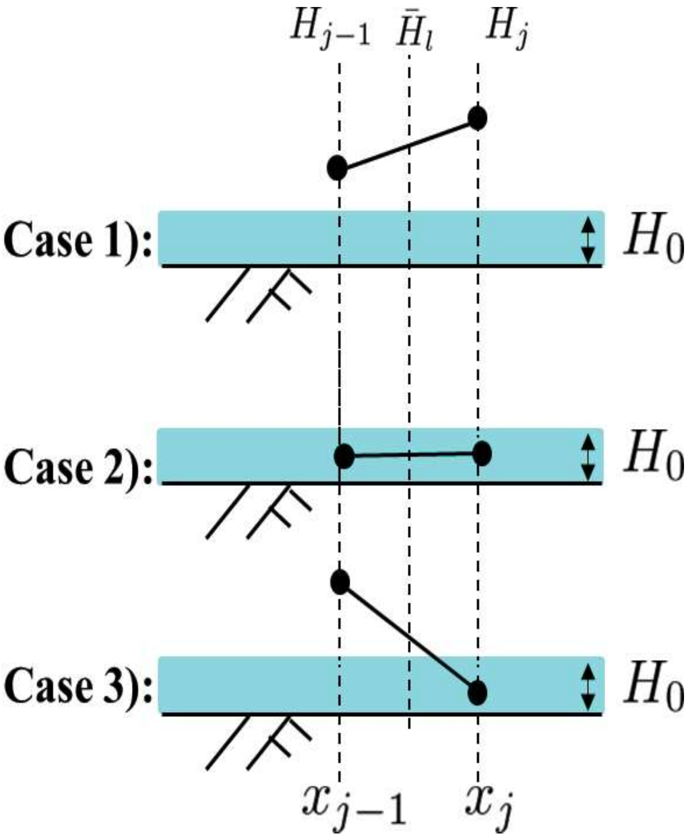

Figure A.2 **Wetting and Drying Treatment**

The shallow water equations are strictly hyperbolic for $H > 0$. To handle the dry bed ($H = 0$) problem, the wetting and drying treatment of Bunya *et al.* [90] based on the concept of the thin water layer technique is employed in this work. In this method, a sufficiently small depth H_0 and zero velocity are defined at the dry nodes.

Comparing H_0 with the average water depth $\bar{H}_l$ of an element l ($x_{j-1} \leq x \leq x_j$), the water depth of nodes (H_{j-1},H_j), the wet nodes and the dry nodes can be determined. Then the wetting and drying treatment can be defined as the following three cases (**Figure A.2**):

1). If $H_{j-1} \geq H_0$, $H_j \geq H_0$, then
$\hat{H}_{j-1} = H_{j-1}$, $\hat{H}_j = H_j$,

$\hat{q}_{j-1} = q_{j-1}$, $\hat{q}_j = q_j$,

2). If $\bar{H}_l \leq H_0$, then

$\hat{H}_{j-1} = \bar{H}_l$, $\hat{H}_j = \bar{H}_l$,

$\hat{q}_{j-1} = 0$, $\hat{q}_j = 0$,

3). If $\bar{H}_l > H_0$, $H_j < H_0$, then

$\hat{H}_{j-1} = H_{j-1} - (H_0 - H_j)$, $\hat{H}_j = H_0$,

$\hat{q}_{j-1} = q_{j-1} + q_j$, $\hat{q}_j = 0$,

where $\hat{H}_{j-1}$, $\hat{H}_j$, $\hat{q}_{j-1}$, $\hat{q}_j$ are the updated water depth and flow rate of the nodes of the element l.

A.8 Numerical Example

A.8.1 Propagation of Solitary Wave Problem

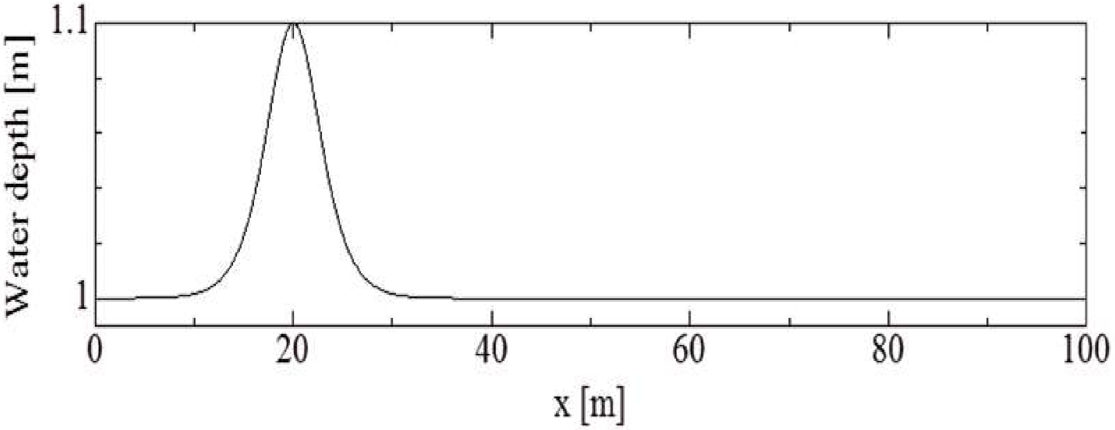

Figure A.3 **Computational model**

In order to evaluate the performance of the Boussinesq equations, the propagation of solitary wave problem shown in **Figure A.3** is simulated. Two cases of mesh is used. For the case A, $\Delta x = 1m,\ \ \Delta t = 0.02s$. The case B, $\Delta x = 0.1m,\ \ \Delta t = 0.005s$.

The surface elevation profiles at t =5s, 10s, 15s, 20s are shown in **Figure A.4**, **Figure A.5**. We can see the results by using Boussinesq equations are better agree with the reference results [94] than the results of shallow water equations.

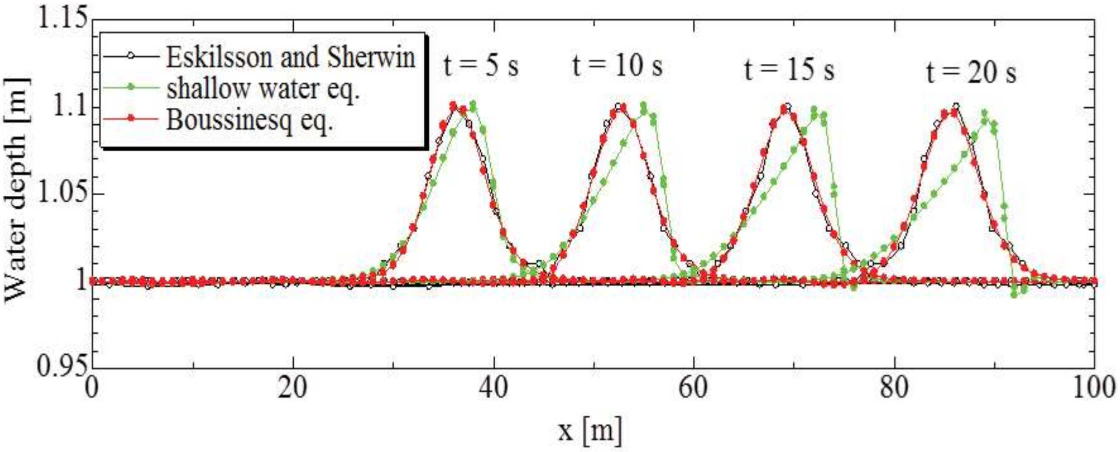

Figure A.4 **Results of case A** ($\Delta x = 1m$)

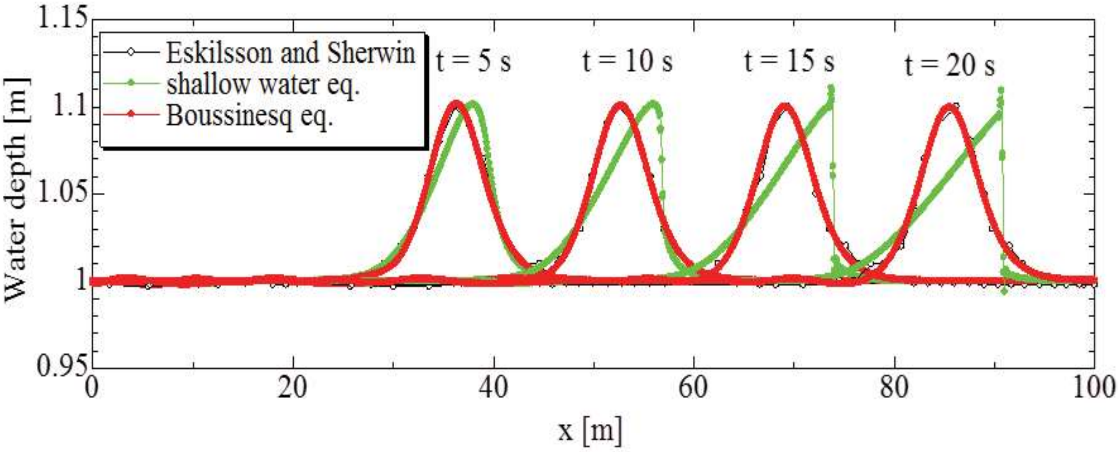

Figure A.5 **Results of case B** ($\Delta x = 0.1m$)

A.9 Summary

In this study, the Boussinesq model (1D) solved by the DG method has been developed. From the simulation of the propagation of solitary wave problem, the analysis results are in good agreement with the reference results.

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Associated Publications

Journal Articles (Peer Review)

1. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: A 2D-3D Hybrid Method Using the Overlapping Method Based on Arbitrary Grid for Tsunami Analysis, *Journal of Japan Society of Civil Engineers*, Ser. A2 (Applied Mechanics (AM)), **72**, issue 2, pp. I_285-I_293, 2016 (in Japanese).
2. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: Studies on Accuracy and Large-scale Promotion for the 2D-3D Hybrid Tsunami Analysis Method, *Journal of Japan Society of Civil Engineers*, Ser. A2 (Applied Mechanics (AM)), **73**, issue 2, pp. I_387-I_396, 2017 (in Japanese).
3. Maiko Hanadate, Nao Ikeda, **Guoming Ling**, Kazuo Kashiyama, Hideo Miyachi, Yuuji Maeda, Takeshi Nishihata：A Markerless Augmented Reality System for Water Environmental and Disaster Prevention Simulations and Its Applicability, *Journal of Japan Society of Civil Engineers*, Ser. F3 (Civil Engineering Informatics), **73**, issue 2, 2017 (in Japanese). (in press)

International Conference Papers

1. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: Development of a 2D-3D hybrid tsunami numerical model based on stabilized finite element method, *The 18th International Conference on Finite Elements in Flow Problems (FEF2015)*, Taipei, Taiwan, 2015.3.
2. **G. Ling**, K. Kashiyama and J. Matsumoto : A 2D-3D hybrid model based on stabilized finite element method for tsunami runup simulation, *CODE2015*, pp.49, Tokyo, Japan, 2015.12.14.

3. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: A 2D-3D hybrid model using overlapping method based on the stabilized FEM, *ECCOMAS Congress 2016*, MS 413-2, ID7912, Crete Island, Greece, 2016.6.09.
4. **Guoming Ling**, Junichi Matsumoto and Kazuo Kashiyama: Verification and application of a 2D-3D hybrid numerical model for tsunami simulation, *FEF2017*, Rome, Italy, 2017.4.
5. **Guoming Ling**, Junichi Matsumoto and Kazuo Kashiyama: Large Scale Tsunami Simulation by 2D-3D Hybrid Method based on Arbitrary Domain, *COMPSAFE2017*, Chengdu, China, 2017.10.
6. M. Ota, **G. Ling** and K. Kashiyama: Stabilized finite element method based on VOF method for free surface flow using LES, *CODE2015*, pp.52, 2015.12.
7. Junichi Matsumoto,**Guoming Ling**, Hiroki Hanazawa, Kazuo Kashiyama: Finite element parallel computing for a coupling method of 2D shallow water flow and 3D gas-liquid two-phase flow, *ECCOMAS Congress 2016*, MS413-2, ID11071, 2016.6.
8. Junichi Matsumoto, **Guoming Ling**, Hiroki Hanazawa, Kazuo Kashiyama: Large Scale Interaction Analysis using Stabilized MINI Element of 2D Shallow Water Flow and 3D Gas-Liquid Two-Phase Flow, *WCCM XII&APCOM VI*, MS102, Paper No.151788, 2016.7.
9. Kazuo Kashiyama, **Guoming Ling**, Junichi Matsumoto: 2D and 3D Finite Element Analysis for Tsunami Waves, *14th U.S. National Congress on Computational Mechanics*, Montreal, Quebec, Canada, 2017.7.
10. Sho Ito, **Guoming Ling**, Kazuo Kashiyama: A Discontinuous Galerkin Method with Moving Boundary Treatment for Solving the Shallow Water Equations, *COMPSAFE2017*, Chengdu, China, 2017.10.
11. **Guoming Ling**, Junichi Matsumoto, Ethan J. Kubatko, Kazuo Kashiyama: Improvement and application of the large-scale 2D-3D hybrid tsunami numerical model, *WCCM2018*, New York City, America, 2018.7. (accepted)

Domestic conference papers

1. **Guoming Ling**, Makiko Ota, Kazuo Kashiyama: An Evaluation of the Fluid Force Acts on a Structure Based on the VOF Stabilized Finite Element Method, *28th CFD Symposium*, A03-1, 2014.12 (in Japanese).
2. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: Anteika Yuugenyousohou ni motozuku 2jigen-3jigen Hybrid Tsunami Kaiseki Model no Kouchiku (Development of 2D-3D hybrid tsunami numerical model based on the stabilized finite element method), *42nd Conference of Kanto Branch of Japan Society of Civil Engineers*, 2015.3 (in Japanese).
3. **Guoming Ling**, Junichi Matsumoto, Taiki Fumuro, Kazuo Kashiyama: Development of a 2D-3D hybrid tsunami numerical model based on the stabilized finite element method, *18th Applied Mechanics Symposium*, 100046, 2015.5 (in Japanese).
4. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: Development of the 2D/3D Tsunami Simulation and its Hybrid Model Based on the Finite Element Method, *Proceedings of the conference on computational engineering and science*, **20**, 4p, 2015.6 (in Japanese).
5. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: VOF Anteika Yugenyousohou ni motozuku 2jigen-3jigen Hybrid Tsunami Kaiseki Model no Kouchiku (Development of a 2D-3D hybrid tsunami numerical model based on the VOF stabilized finite element method), *Japan Society of Civil Engineers 2015 Annual Meeting*, CS8-004, 2015.9 (in Japanese).
6. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: A 2D-3D hybrid method using the overlapping method based on arbitrary grid for tsunami analysis, *19th Applied Mechanics Symposium*, 100102, 2016.5 (in Japanese).
7. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: Development of a 2D-3D Hybrid Tsunami Numerical Model Using the Arbitrary Grid, *Proceedings of the conference on computational engineering and science*, **21**, 4p, OS3-2, C-6-1, 2016.6 (in Japanese).
8. **Guoming Ling**, Kazuo Kashiyama: Discontinuous Galerkin hou ni yoru Sensui Chouha Nagare Kaiseki ni kansuru Kentou (Invesigation of shallow water flow analysis by Discontinuous Galerkin method), *Japan Society of Civil Engineers*

2016 Annual Meeting, II-097, 2016.9 (in Japanese).

9. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama, Study on Improvement of Accuracy for Free Surface Flow Analysis, *20th Applied Mechanics Symposium*, C000153, 2017.5 (in Japanese).
10. **Guoming Ling**, Junichi Matsumoto, Kazuo Kashiyama: Development of 2D-3D tsunami hybrid model by using phase-field model based on stabilized finite element method, *Proceedings of the conference on computational engineering and science*, **22**, 4p, B-10-5, 2017.6 (in Japanese).
11. **Guoming Ling**, Sho Ito, Ethan Kubatko, Kazuo Kashiyama: DG hou ni yoru Boussinesq Houteishiki ni motoduku Tusnami Kaiseki Model no kouchiku (Development of a tsunami numerical model based on Boussinesq equation by DG method), *Japan Society of Civil Engineers 2017 Annual Meeting*, CS13-003, 2017.9 (in Japanese).
12. Makiko Ota, Kazuo Kashiyama, Taiki Fumuro, **Guoming Ling**: LES wo mochiita VOF Anteika Yuugenyousohou ni yoru Ryuutairyoku no Seido Kensyo (Verification for the accuracy of free surface flow using stabilized finite element method based on the LES), *42nd Conference of Kanto Branch of Japan Society of Civil Engineers*, 2015.3 (in Japanese).
13. Makiko Ota, **Guoming Ling**, Kazuo Kashiyama: Studies on Numerical Accuracy of Free Surface Flow by Stabilized Finite Element Method Based on Large Eddy Simulation, *Proceedings of the conference on computational engineering and science*, **20**, 4p, 2015.6 (in Japanese).
14. Makiko Ota, **Guoming Ling**, Kazuo Kashiyama: LES wo mochiita VOF Anteika Yuugenyousohou nimotoduku Jiyuhyoumen Nagare Kaiseki no Seido Kensyo (Verification for the accuracy of free surface flow based on stabilized finite element method using the LES), *Japan Society of Civil Engineers 2015 Annual Meeting*, CS8-015, 2015.9 (in Japanese).
15. Hiroki Hanazawa, Sho Ito, **Guoming Ling**, Ethan Kubatko, Kazuo Kashiyama: Shallow water flow analysis based on DG-FEM, *30th CFD Symposium*, C01-2, 2016.12 (in Japanese).
16. Sho Ito, **Guoming Ling**, Hiroki Hanazawa, Ethan J. Kubatko, Kazuo Kashiyama: Investigation of the accuracy and mass conservation of DG-FEM for shallow water flow analysis, *20th Applied Mechanics Symposium*, C000153,

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17. Sho Ito, **Guoming Ling**, Hiroki Hanazawa, Kazuo Kashiyama: DG-FEM to shallow water flows considering the moving boundaries, *Proceedings of the conference on computational engineering and science*, **22**, 4p, B-10-3, 2017.6 (in Japanese).
18. Sho Ito, **Guoming Ling**, Ethan J. Kubatko, Hiroshi Okawa, Kazuo Kashiyama: Furenzokusei wo yuusuru Mondai ni okeru DG-FEM no Yuukousei no Kentou (Investigation of the effectiveness of DG-FEM in the problems with discontinuity), *Japan Society of Civil Engineers 2017 Annual Meeting*, CS13-008, 2017.9 (in Japanese).
19. Maiko Hanadate, Nao Ikeda, **Guoming Ling**, Kazuo Kashiyama, Hideo Miyachi, Yuuji Maeda, Takeshi Nishihata: A Markerless Augmented Rearity System for Water Environmental and Disaster Prevention Simulation, *Proceedings of the symposium on civil engineering informatics*, **42**, pp.85-88, 2017 (in Japanese).