2011 International Conference on

Advanced Computer Science and Information Systems

(Proceedings)

Mercure Convention Centre, Jakarta

December 17th-18th, 2011

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Faculty of Computer Science

Universitas Indonesia

Welcome Message from General Chairs

On behalf of the Organizing Committee of this International Conference on Advanced Computer Science and Information Systems 2011 (ICACSIS 2011), we would like to extend our warm welcome to all of the presenter and participants, and in particular, we would like to express our sincere gratitude to our plenary and invited speakers.

This international conference is organized by the Faculty of Computer Science, Universitas Indonesia, and is intended to be the first step towards a top class conference on Computer Science and Information Systems. We believe that this international conference will give opportunities for sharing and exchanging original research ideas and opinions, gaining inspiration for future research, and broadening knowledge about various fields in advanced computer science and information systems, amongst members of Indonesian research communities, together with researchers from Germany, United Kingdom, Rusia, Australia, Japan, South Korea, Malaysia, Thailand, Vietnam and other countries.

This conference focuses on the development of computer science and information systems. Along with 5 plenary and 3 invited speeches, the proceedings of this conference contains 66 papers which have been selected from a total of 134 papers from fourteen different countries. These selected papers will be presented during the conference.

We also want to express our sincere appreciation to the members of the Program Commitee for their critical review of the submitted papers, as well as the Organizing Commitee for the time and energy they have devoted to editing the proceedings and arranging the logistics of holding this conference. We would also like to give appreciation to the authors who have submitted their excellent works to this conference. Last but not least, we would like to extend our gratitude to the Ministry of Education of the Republic of Indonesia, the Rector of Universitas Indonesia, and the Dean of the Faculty of Computer Science for their continued support towards the the ICACSIS 2011 conference.

Sincerely yours,
General Chairs
Ito Wasito

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Welcome Message from the Dean of Faculty of Computer Science, Universitas Indonesia

On behalf of all the academic staff and students of the Faculty of Computer Science, Universitas Indonesia, I would like to extend our warmest welcome to all the participants to the Mercure Convention Centre in Ancol, Jakarta on the occasion of the 2011 International Conference on Advanced Computer Science and Information Systems (ICACSIS).

Just like the previous two events in this series (2009 in Depok and 2010 in Bali), I am confident that ICASIS 2011 will play an important role in encouraging activities in research and development of computer science and information technology in Indonesia, and give an excellent opportunity to forge collaborations between research institutions both within the country and with international partners. The broad scope of this event, which includes both theoretical aspects of computer science and practical, applied experience of developing information systems, provides a unique meeting ground for researchers spanning the whole spectrum of our discipline. I hope that over the next two days, some fruitful collaborations can be established.

I also hope that the special attention devoted this year to the field of pervasive computing, including the very exciting area of wireless sensor networks, will ignite the development of applications in this area to address the various needs of Indonesia's development.

I would like to express my sincere gratitude to the distinguished invited speakers for their presence and contributions to the conference. I also thank all the program committee members for their efforts in ensuring a rigorous review process to select high quality papers.

Finally, I sincerely hope that all the participants will benefit from the technical contents of this conference, and wish you a very successful conference and an enjoyable stay in Jakarta.

Sincerely,
Professor T. Basaruddin Ph.D
Dean of the Faculty of Computer Science
Universitas Indonesia

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Welcome Message from Vice Minister of Education Ministry of Education and Culture of the Republic of Indonesia

Ladies and Gentlemen, speakers and guests of the 2011 International Conference on Advanced Computer Science and Information Systems, or simply ICACSIS 2011, Good Day, Assalamu'alaikum Wr. Wb.

Allow me to first express my gratitude towards our honorary chairs and our honored speakers from all around the world, who have spared their valuable time to contribute to this conference along with all the other distinguished participants who have assembled here in Jakarta, over the next two days, for academic discussions on advanced computer science and information systems.

In today's information age, it seems that there is no longer an aspect of life that is unaffected by the advances of information and communication technology, or ICT. The Ministry of Education and Culture of the Republic of Indonesia recognizes that ICT has a huge role to play in addressing national issues and is committed to supporting research on how ICT can further solve these problems.

In recognition of the importance of ICT in national development, the Indonesian government's recently unveiled Master Plan for the Acceleration and Expansion of Indonesia's Economic Development (MP3EI) includes ICT as a crucial component of its 22 primary activities. This master plan is a bold initiative which aims to make Indonesia one of the world's 10 biggest economies by 2025, taking GDP to $4.5 trillion and increasing the per capita income from $3000 now to $15,000. One of the strategic initiatives of this Master Plan is to encourage large scale ICT investment, including the provision of essential infrastructure such as affordable and usable broadband throughout the archipelago.

Such initiatives will be expected to serve as an enabling technology, and the government sees the national education sector – particularly higher education – as one of the catalysts to leverage this technology to directly impact Indonesia's national competitiveness. To that end, the Ministry encourages researchers and academics to improve national competitiveness through outstanding research achievements in the field of ICT. There are many research areas which can improve Indonesia's competitiveness, ranging from e-Government solutions that improve efficiency and effectiveness of public services, to information retrieval systems that are able to support information requirements at lightning speed through various online media, to the state-of-the-art discoveries in fields such as nano technology and pervasive computing, which are expanding the horizons of what can be achieved with ICT.

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The Ministry appreciates the efforts conducted by the organizing committee that has worked hard through this conference to achieve two important objectives towards the development of advanced computer science and information systems. Firstly, it is to disseminate the state of the art of research and development in ICT, cognizant of its significant value for Indonesia's future. Secondly, it is intended to provide a media for exchanging ideas and information concerning ICT. I am convinced that the scholars who have gathered here at this conference will bring valuable contributions to this discipline.

Finally, I want to convey my deep appreciation and gratitude to the Faculty of Computer Science, Universitas Indonesia, and all of our distinguished plenary and invited speakers. I hope this conference will be enlightening for all of us, and I hope also that we will be able to continuously collaborate to push the frontiers of science and solve the problems of our nation.

Sincerely,
Professor Musliar Kasim
Vice Minister of Education
Ministry of Education and Culture of the Republic of Indonesia

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Program At Glance

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Professor, Dept. of Micro-Nano Systems Engineering Nagoya University.

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A Finite Volume Method for Shallow Water Flows on Triangular Computational Grids

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***Abstract*—This paper presents a finite volume method used to solve the two-dimensional shallow water (wave) equations and how the finite volume method is implemented in ANUGA software. This finite volume method is the numerical method underlying the software. ANUGA is open source software developed by Australian National University (ANU) and Geoscience Australia (GA). This software uses the finite volume method with triangular domain discretisation for the computation. Three test cases are considered in order to evaluate the performance of the software. Overall, ANUGA is a robust software to simulate two-dimensional shallow water flows.**

I. Introduction

The shallow water (wave) equations have emerged as important mathematical models to describe water flows. Some of its developments and applications are given in [1], [2], [3], [4].

One old work with a big impact is the analytical dam break modelling done by Ritter [5]. The dam break problem is now becoming a standard benchmark to test the performance of numerical methods. Even though this problem is originally modelled for one-dimensional shallow water equations, it can also be treated as a two-dimensional problem, which we present in this paper as a planar dam break problem. In addition, it can also be extended to a circular two-dimensional problem.

Another interesting benchmark problem is the oscillation of water on a paraboloid canal (channel) developed by Thacker [6]. This problem involves a wetting and drying process, a process that is well-known to be very difficult to resolve [7], [8], [9], [10], [11]. We note that Yoon and Cho [12] used this type of problem to test their numerical method.

One open-source software used to simulate two-dimensional shallow water flows is ANUGA, named after Australian National University (ANU) and Geoscience Australia (GA). This software uses a finite volume method as the underlying mathematical background. We will present this finite volume method and test the performance of ANUGA using the planar dam break problem, circular dam break problem, and oscillation on a paraboloid channel. ANUGA uses triangular domain discretisation for the computation.

The remainder of this paper is organised as follows. In Section II, we present the shallow water equations governing water flows. Section III is devoted to the finite volume method. Section IV briefly describes the ANUGA software. Section V contains three numerical simulations. Finally, Section VI concludes the paper with some remarks.

II. Shallow water equations

The two-dimensional shallow water (wave) equations are [13], [14], [15], [16], [17], [18]

$$\mathbf{q}_t + \mathbf{f}(\mathbf{q})_x + \mathbf{g}(\mathbf{q})_y = \mathbf{s}\,, \tag{1}$$

where $\mathbf{q} = [h\ uh\ vh]^T$ is the vector of conserved quantities consisting of water depth h, x-momentum uh, and y-momentum vh. Here, u and v are velocities in the x- and y-direction; $\mathbf{f}(\mathbf{q})$ and $\mathbf{g}(\mathbf{q})$ are flux functions in the x- and y-direction given by

$$\mathbf{f}(\mathbf{q}) = \begin{bmatrix} uh \\ u^2h + \frac{1}{2}gh^2 \\ uvh \end{bmatrix} \tag{2}$$

and

$$\mathbf{g}(\mathbf{q}) = \begin{bmatrix} vh \\ vuh \\ v^2h + \frac{1}{2}gh^2 \end{bmatrix}\,; \tag{3}$$

the source term including gravity and friction is

$$\mathbf{s} = \begin{bmatrix} 0 \\ -gh\,(z_x + S_{fx}) \\ -gh\,(z_y + S_{fy}) \end{bmatrix} \tag{4}$$

where $z(x,y)$ is the bed topography, and $S_f = \sqrt{S_{fx}^2 + S_{fy}^2}$ is the bed friction modelled using Manning's resistance law

$$S_{fx} = \frac{u\eta^2\sqrt{u^2+v^2}}{h^{4/3}} \tag{5}$$

and

$$S_{fy} = \frac{v\eta^2\sqrt{u^2+v^2}}{h^{4/3}} \tag{6}$$

in which η is the Manning resistance coefficient. It should be noted that the stage (absolute water level) w is given by $w := z + h$.

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Integrating (1) over an arbitrary closed and connected spatial domain Ω having boundary Γ and applying the Gauss divergence theorem to the flux terms, we get the integral form

$$\frac{\partial}{\partial t}\int_{\Omega}\mathbf{q}\,d\Omega+\oint_{\Gamma}\mathbf{F}\cdot\mathbf{n}\,d\Gamma=\int_{\Gamma}\mathbf{s}\,d\Omega \qquad (7)$$

where $\mathbf{F}=[\mathbf{f}(\mathbf{q})\ \mathbf{g}(\mathbf{q})]^T$ is the flux function, $\mathbf{n}=[\cos(\theta)\ \sin(\theta)]^T$ is the outward normal vector of the boundary, and θ is the angle between $\mathbf{n}$ and the x-direction. Equation (7) is called the integral form of the two-dimensional shallow water wave equations.

The rotational invariance property of the shallow water wave equations implies that

$$\mathbf{F}\cdot\mathbf{n}=\mathbf{T}^{-1}\mathbf{f}(\mathbf{Tq}) \qquad (8)$$

where $\mathbf{T}$ is the transformation matrix

$$\mathbf{T}=\begin{bmatrix}1&0&0\\0&\cos(\theta)&\sin(\theta)\\0&-\sin(\theta)&\cos(\theta)\end{bmatrix}. \qquad (9)$$

Therefore, (7) can be rewritten as

$$\frac{\partial}{\partial t}\int_{\Omega}\mathbf{q}\,d\Omega+\oint_{\Gamma}\mathbf{T}^{-1}\mathbf{f}(\mathbf{Tq})\,d\Gamma=\int_{\Gamma}\mathbf{s}\,d\Omega. \qquad (10)$$

III. Finite volume method

After the spatial domain is discretized, we have the equation constituting the finite volume method over each triangular cell of the grids [14]

$$\frac{d\mathbf{q}_i}{dt}+\frac{1}{A_i}\sum_{j\in\mathcal{N}(i)}\mathbf{H}_{ij}\,l_{ij}=\mathbf{s}_i \qquad (11)$$

where $\mathbf{q}_i$ is the vector of conserved quantities averaged over the ith cell, $\mathbf{s}_i$ is the source term associated with the ith cell, $\mathbf{H}_{ij}$ is the outward normal flux of material across the ijth edge, and l_{ij} is the length of the ijth edge. Here, the ijth edge is the interface between the ith and jth cells. The flux $\mathbf{H}_{ij}$ is evaluated using a numerical flux function $\mathbf{H}(\cdot,\cdot;\cdot)$ such that for all conservation vectors $\mathbf{q}$ and normal vectors $\mathbf{n}$

$$\mathbf{H}(\mathbf{q},\mathbf{q};\mathbf{n})=\mathbf{F}\cdot\mathbf{n}. \qquad (12)$$

Furthermore,

$$\mathbf{H}_{ij}=\mathbf{H}(\mathbf{q}_i(m_{ij}),\mathbf{q}_j(m_{ij});\mathbf{n}_{ij}) \qquad (13)$$

where m_{ij} is the midpoint of the ijth edge and $\mathbf{n}_{ij}$ is the outward normal vector, with respect to the ith cell, on the ijth edge. The function $\mathbf{q}_i$ is obtained from the averaged values of quantities in the ith and neighbouring cells.

Now let $\mathbf{n}_{ij}=[n_{ij}^{(x)}\ n_{ij}^{(y)}]^T$. From (12) and (13), we have

$$\mathbf{H}_{ij}=\mathbf{f}[\mathbf{q}_i(m_{ij})]n_1+\mathbf{g}[\mathbf{q}_j(m_{ij})]n_2 \qquad (14)$$

Here, we recall the algorithm to solve the two-dimensional shallow water equations given by Guinot [13]. In the semi-discrete framework, four steps are considered as follows:

1) For each interface (i,j), transform the quantity $\mathbf{q}_i$ and $\mathbf{q}_j$ in the global coordinate system (x,y) into the quantity $\hat{\mathbf{q}}_i$ and $\hat{\mathbf{q}}_j$ in the local coordinate system system $(\hat{x},\hat{y})$. The water depth h is unchanged as it is a scalar variable, while the velocities u and v are transformed into $\hat{u}$ and $\hat{v}$. Therefore, the new quantities in the local coordinate system are

$$\hat{\mathbf{q}}_i=\mathbf{T}\mathbf{q}_i \quad\text{and}\quad \hat{\mathbf{q}}_j=\mathbf{T}\mathbf{q}_j\,, \qquad (15)$$

where $\mathbf{q}_i=[h_i\ (hu)_i\ (hv)_i]$ and $\mathbf{q}_j=[h_j\ (hu)_j\ (hv)_j]$ are, respectively, the quantities in the global coordinate system. The matrices $\mathbf{T}$ and $\mathbf{T}^{-1}$ are

$$\mathbf{T}=\begin{bmatrix}1&0&0\\0&n_{ij}^{(x)}&n_{ij}^{(y)}\\0&-n_{ij}^{(y)}&n_{ij}^{(x)}\end{bmatrix} \qquad (16)$$

and

$$\mathbf{T}^{-1}=\begin{bmatrix}1&0&0\\0&n_{ij}^{(x)}&-n_{ij}^{(y)}\\0&n_{ij}^{(y)}&n_{ij}^{(x)}\end{bmatrix}. \qquad (17)$$

2) Compute the flux $\hat{f}$ at the interface (i,j). In the local coordinate system, the problem is merely a one-dimensional Riemann problem, as the flux vector is parallel with the normal vector of the interface. Therefore, the equations to be solved are

$$\hat{\mathbf{q}}_t+\hat{\mathbf{f}}(\hat{\mathbf{q}})_{\hat{x}}=\mathbf{s} \qquad (18)$$

with initial condition given by $\hat{\mathbf{q}}_i$ on one side of the interface (i,j) and $\hat{\mathbf{q}}_j$ on the other side of the interface (i,j). It should be stressed that at this step, we do not need to integrate (18) for the quantity $\hat{\mathbf{q}}$, but all we need is the value of the flux $\hat{f}$. Hence, applying either the exact or approximate Riemann solvers to compute the flux $\hat{f}$ at the interface (i,j) is enough. Note that here the source term does not need to be transformed in the local coordinate system, since it involves scalar variables only.

3) Transform the flux $\hat{\mathbf{f}}$ back to the global coordinate system (x,y), so the flux at the midpoint of the interface (i,j) in the global coordinate system is

$$\begin{aligned}\mathbf{H}_{ij}&=\mathbf{T}_{ij}^{-1}\hat{\mathbf{f}}\\&=\mathbf{T}_{ij}^{-1}\tilde{\mathbf{f}}(\hat{\mathbf{q}}_\mathbf{i};\hat{\mathbf{q}}_\mathbf{j};\mathbf{s}_\mathbf{i};\mathbf{s}_\mathbf{j})\\&=\mathbf{T}_{ij}^{-1}\tilde{\mathbf{f}}(\mathbf{T}_\mathbf{ij}\mathbf{q}_\mathbf{i};\mathbf{T}_\mathbf{ij}\mathbf{q}_\mathbf{j};\mathbf{s}_\mathbf{i};\mathbf{s}_\mathbf{j}).\end{aligned} \qquad (19)$$

Here, $\tilde{\mathbf{f}}$ is the flux computed with a Riemann solver for the one-dimensional problem stated in step [ii].

4) Finally, solve (11) where $\mathcal{N}(i)=\{0,1,2\}$, as triangular grids are considered, for $\mathbf{q}_i$. We multiply $\mathbf{H}_{ij}$ with l_{ij} in order to get the flux over the interface (i,j). This is because the flux

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at the midpoint of the interface (i, j) is $\mathbf{H}_{ij}$, and the length of the interface (i, j) is l_{ij}.

IV. ANUGA SOFTWARE

ANUGA is an open source (free software) developed by Australian National University (ANU) and Geoscience Australia (GA) to be used for simulating shallow water flows, such as floods and tsunamis. The mathematical background underlying the software is the finite volume method presented in the previous section. The interface of this software is in Python language, but the mostly expensive computation parts, such as flux computation, are written in C language. A combination of these two languages provides two different advantages: Python has the flexibility in terms of software engineering, while C gives a very fast computation.

A simple simulation using ANUGA generally has five steps in the interface code. These five steps are importing necessary modules, setting-up the computational domain, setting-up initial conditions, setting-up boundary conditions, and evolving the system through time [14]. The necessary modules to be imported are anuga[1] and some standard libraries such as numpy, scipy, pylab, and time. The simplest creation of the triangular computational domain is in the rectangular-cross framework, which returns points, vertices, and boundary for the computation. The initial condition includes the definition of the topography, friction, and stage. The boundary conditions can be chosen in several ways depending on the needs: reflective boundary is for solid reflective wall; transmissive boundary is for continuing all values on the boundary; Dirichlet boundary is for constant boundary values; and time boundary is for time dependent boundary.

A thorough description of this software is available at http://datamining.anu.edu.au/anuga.

V. COMPUTATIONAL EXPERIMENTS

This section presents some computational experiments using the finite volume method with ANUGA as the software used to perform the simulation. For simplicity of the experiments, frictionless topography is assumed. Three different test cases are considered: a planar dam break problem, circular dam break problem, and water oscillation on a paraboloid channel.

The numerical settings are as follows. Even though ANUGA is capable to do the computations with unstructured triangular grids, we limit our presentation only to the structured triangular grids for brevity with rectangular-cross as the basis. The spatial reconstruction and temporal discretisation are both second order with edge limiter. A reflective boundary is imposed. The numerical flux is due to Kurganov et al.[19]. SI units are used in the measurements of the quantities.

[1]Uppercased word 'ANUGA' refers to the name of the software, whereas lowercased word 'anuga' refers to the name of ANUGA module in programming. See ANUGA User Manual [14] for the details of anuga.

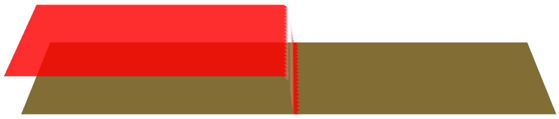

Fig. 1. Initial condition for the planar dam break problem.

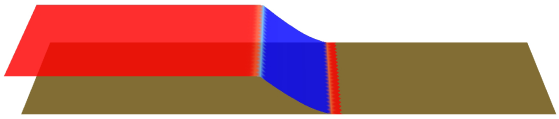

Fig. 2. Water flows 0.5 second after the planar dam is broken.

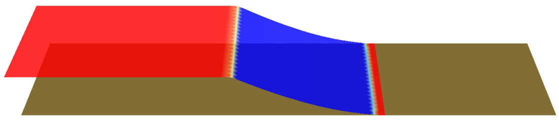

Fig. 3. Water flows 1.0 second after the planar dam is broken.

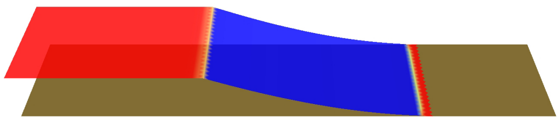

Fig. 4. Water flows 1.5 seconds after the planar dam is broken.

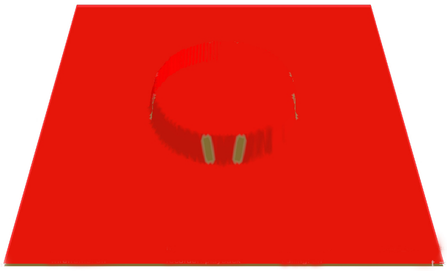

Fig. 5. Initial condition for the circular dam break problem.

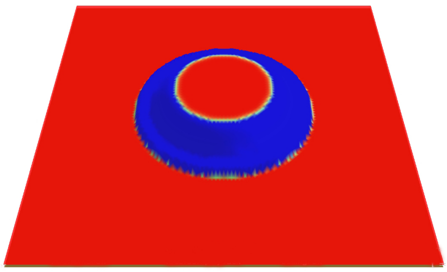

Fig. 6. Water flows 0.5 second after the circular dam is broken.

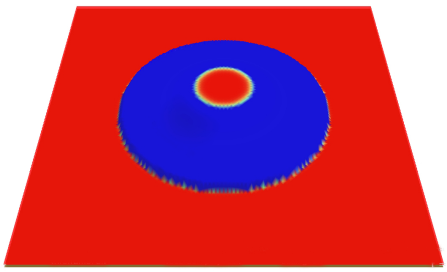

Fig. 7. Water flows 1.0 second after the circular dam is broken.

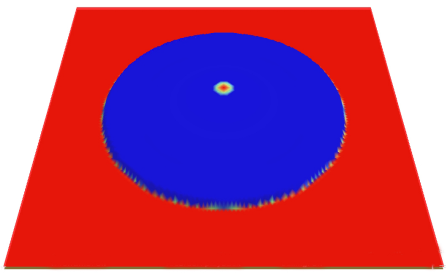

Fig. 8. Water flows 1.5 seconds after the circular dam is broken.

A. Planar dam break problem

Consider a flat topography without friction on a spatial domain $\{(x, y)|(x, y) \in [-50, 50]\times[-10, 10]\}$. Suppose that we are given a planar dam break problem with wet/dry interface bewtween the dam, where we have 10 meters water depth on the left of the dam, but dry area on the right. The dam is at $\{(0, y)|y \in [-10, 10]\}$. The simulation is then done to predict the flow of water after the dam is removed. Note that this dam break problem is actually a one-dimensional dam-break problem, but here we treat this as a two-dimensional problem.

The domain setting is as follows. The spatial domain is discretised into 100 by 20 rectangular-crosses, where each rectangular cross has 4 uniform triangles. This means that we have $8 \cdot 10^3$ structured triangles as the discretisation of the spatial domain.

The water surface and topography are shown in Figures 1 to 4. In particular, Figure 1 shows the initial condition, that is, the water profile at time $t = 0.0$ s. After the dam is broken, the profiles at time $t = 0.5, 1.0, 1.5$ s are illustrated in Figure 2, Figure 3, and Figure 4 respectively. At 1.5 seconds after dam break, the water flows to the right for a distance almost 30 m. This agrees with the analytical solution (30 m) for the one-dimensional dam break problem.

B. Circular dam break problem

Now suppose that we have a circular dam break problem with wet/wet interface between the dam. Consider a circular dam, where the point of origin is the centre, having 20 m as its radius. The water depth inside the circular dam is 10 m, while outside is 1 m. The spatial domain of interest is $\{(x, y)|(x, y) \in [-50, 50]\times[-50, 50]\}$. Similar to the planar dam break problem, the simulation of this test case is then done to predict the flow of water, after the dam is removed.

The domain setting is as follows. The spatial domain is discretised into 100 by 100 rectangular-crosses, where each rectangular cross has 4 uniform triangles. This means that we have $4 \cdot 10^4$ structured triangles as the discretisation of the spatial domain.

The water surface and topography are shown in Figures 5 to 8. In particular, Figure 5 shows the initial condition, that is, the water profile at time $t = 0.0$ s. After the dam is broken, the profiles at time $t = 0.5, 1.0, 1.5$ s are illustrated in Figure 6, Figure 7, and Figure 8 respectively. At 1.5 seconds after dam break, the water floods to the surrounding area approximately 25 m outwards.

C. Oscillation on a paraboloid channel

This test case is adapted from the work of Thacker [6] and Yoon and Chou [12]. Suppose that we have a spatial domain $\{(x, y)|(x, y) \in [-4000, 4000]\times[-4000, 4000]\}$. We define some parameters $D_0 =$

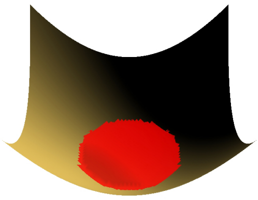

Fig. 9. Initial condition for the oscillation problem.

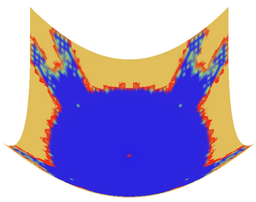

Fig. 10. Water flows at time $t = 0.5T$ for the oscillation problem.

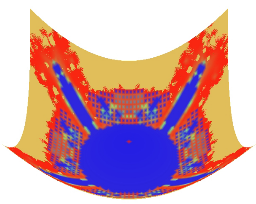

Fig. 11. Water flows at time $t = T$ for the oscillation problem.

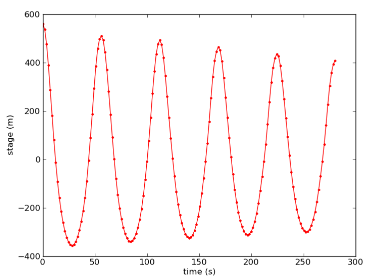

Fig. 12. The water surface corresponding to the origin until $t = 5T$ for the oscillation problem.

1000, $L = 2500$, $R_0 = 2000$ such that

$$A = \frac{L^4 - R_0^4}{L^4 + R_0^4}, \quad (20)$$

$$\omega = \frac{2}{L\sqrt{2gD_0}}, \quad (21)$$

$$T = \frac{2\pi}{\omega} \quad (22)$$

are the amplitude of oscillation at the origin, the angular frequency, and the period of oscillation. Furthermore, the topography is given by

$$z(x, y) = -D_0\left(1 - \frac{r^2}{L^2},\right) \quad (23)$$

and the initial water level (the initial wet region) is

$$h(x, y) = D_0\left[\frac{\sqrt{1 - A^2}}{1 - A\cos(\omega t)} - 1 - \frac{r^2}{L^2}\left(\frac{1 - A^2}{(1 - A\cos(\omega t))^2} - 1\right)\right] \quad (24)$$

where

$$r = \sqrt{x^2 + y^2}. \quad (25)$$

The domain setting is as follows. The spatial domain is discretised into 50 by 50 rectangular-crosses, where each rectangular cross has 4 uniform triangles. This means that we have 10^4 structured triangles as the discretisation of the spatial domain.

The simulation is then done to perdict the flow of the water. According to Thacker [6], the flow will be a periodic oscillation. The simulation, using the numerical method and software discussed in this paper, indeed shows this periodic motion. The water profiles at time $t = 0, T/2, T$ are shown in Figure 9, Figure 10, and Figure 11 respectively. In addition, the periodic motion of the water surface corresponding to the origin is depicted in Figure 12. From the numerical results, we see a minor damping of the oscillation. However, a perfect method or software should not produce this damping. Although it may be impossible to have a perfect method, we take this for future research for the ANUGA software to minimise or eliminate this kind of damping. We also see from the numerical results that a negligible amount of water is left over in the supposed-dry area.

VI. Conclusions

This paper has presented a finite volume method used to solve the shallow water equations. The method underlies ANUGA software. ANUGA was tested using three numerical simulations. We infer from the simulation results that ANUGA can solve nicely the wetting problem. For the drying problem, some very small amount of water, which is negligible, may be left over on the supposed-dry area. Regardless of what we have investigated, we need to note that different parameters or numerical settings generally lead to different results.

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