Numerical Simulation of Tsunami in Kamaishi City caused by 2011 Tohoku Earthquake

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1. Introduction

The Tsunami waves induced by 2011 Tohoku Earthquake caused a large damage to the cities located along the Pacific Coast of the Northeast Japan. Numerical simulation of tsunami inundation will be useful to the future planning of the cities. Akoh et al.[*)] proposed a numerical method to simulate the tsunami run-up in city areas in which arrangement of buildings and houses are modeled individually. They showed the model performance for the tsunami inundation in the urban district of the Kamaishi City. However, due to the large computational cost, the method is hard to apply to larger areas. In this study, we improved their method to reduce the computational cost by considering "blocks" instead of individual buildings for areas other than the target zones. The water flow and stagnation among the buildings in the blocks are counted by introducing the permeability of the block outlines.

2. Governing equations and Calculation Condition

The governing equations were the continuity equation for incompressible fluid and the momentum equations with the assumption of hydrostatic pressure, which are summarized into the vector form of Eq.(1). There, h is the local water depth, (M, N) are flow rates of unit width and (u, v) are velocity to the directions of (x, y) respectively; $F(q)$ and $G(q)$ are defined by Eq.(2); S is the source term defined by Eq.(3); Z_b is the ground level; S_{bx} and S_{by} are the ground slope in the x and the y-direction respectively; τ_{bx} and τ_{by} are the bed friction in the x and the y-directions and expressed by Manning's formula as shown in Eq.(4).

$$\frac{\partial q}{\partial t}+\frac{\partial F(q)}{\partial x}+\frac{\partial G(q)}{\partial y}=S,\ q=\begin{bmatrix}h\\M\\N\end{bmatrix},M=hu,N=hv \tag{1}$$

$$F(q)=\begin{bmatrix}M\\ \frac{M^2}{h}+\frac{1}{2}gh^2\\ \frac{MN}{h}\end{bmatrix},G(q)=\begin{bmatrix}N\\ \frac{MN}{h}\\ \frac{N^2}{h}+\frac{1}{2}gh^2\end{bmatrix} \tag{2}$$

$$S_{bx}=-gh\frac{\partial z_b}{\partial x},S_{by}=-gh\frac{\partial z_b}{\partial y} \tag{3}$$

$$\tau_{bx}=-\frac{gn^2}{h^{\frac{7}{3}}}M\sqrt{M^2+N^2},\tau_{by}=\frac{gn^2}{h^{\frac{7}{3}}}M\sqrt{M^2+N^2} \tag{4}$$

The finite volume method using an unstructured triangular mesh system was adopted to solve the equations. The mesh system was constructed using ANSYS ICEM CFD based on the block shapes, which were made by the method described in the next section. The initial and the boundary conditions were same as the calculation by Akoh et al..

3. Blocks and Permeable Walls

Blocks were generated from the landform mesh data included in the GIS data set, in which building shapes are expressed by the coordinates of corners. The wall faces were determined from the coordinates of building corners, and buildings were united to one block if the minimum space between the walls was less than three meters. By repeating the above process, blocks of polygon shape were obtained.

Water penetration rate through the block outlines was assumed to be proportional to the water level difference across the lines, and the permeability constant, C, was determined in three ways: (1) $C=C_0+\alpha R_v$, where C_0 is the permeability constant for each building and assumed 0.01 following Akoh et al., α is an empirical constant, and R_v is the ratio of open space to building space in the block.. (2) $C=C_0+\beta(1-R_s)$ where β is an empirical constant, and $R_s=S_s/(S_g+S_s)$ in which S_s is the summation of building surface area including the bottom and the side faces, and S_g is the corresponding value of blocks. (3) $C=C_0+\{\alpha R_v+\beta(1-R_s)\}/2$ which is the combination of the above two assumptions. α and β were set as 0.01 for

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the test calculations which will be shown in the next section. Figure.1 shows the spatial distribution of R_v and R_s.

4. Results and Discussion

The calculation results are compared in Figure.2(a)-(e) below which C value assumption for each calculation is listed. From the Figure.s, we can see that the calculation results have the same tendency as the observation. However, the maximum inundation depth is about 50cm lower than the observed data. One of the probable reasons is that the permeability coefficient of large buildings in the east coastline is small.

Figure.3(a)-(e) shows the relationship between calculated data and observed data. From the Figure.s, the calculation result of seaside (▲) and west city area (＋) is similar to the observed data. However, the result of east city area (×) becomes larger. Comparing (b) and (c) in Fig.3, the result considering R_v and R_s is closer to the observed data.

As a conclusion, we can see that using "blocks" instead of individual buildings can simulate of tsunami inundation well. The improvement of calculation accuracy is worth to be studied further.

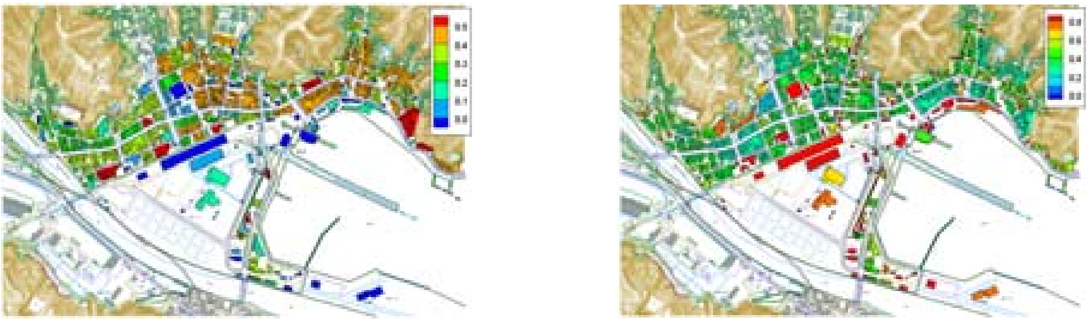

Figure.1　The distribution of R_v and R_s

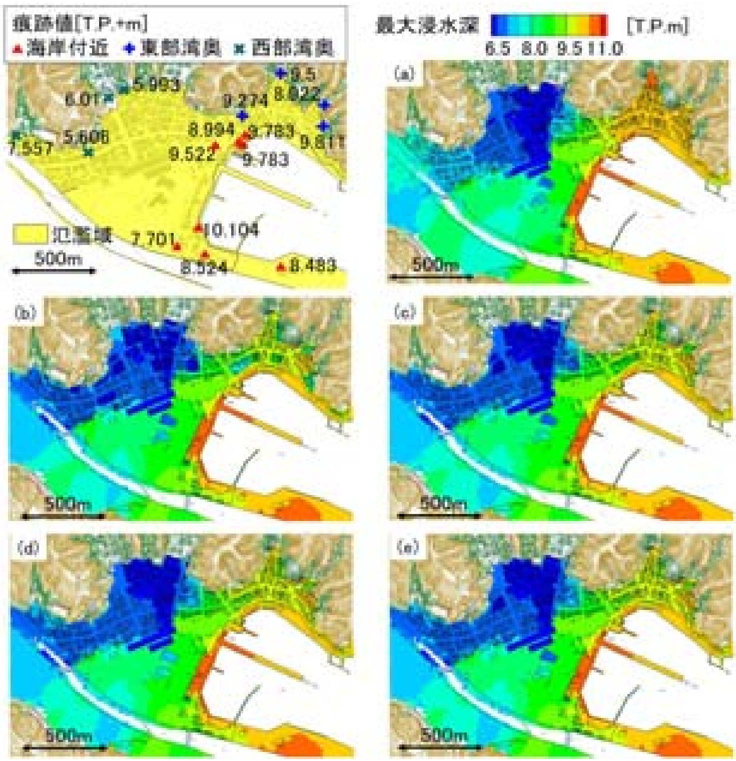

Figure.2　Maximum Inundation Water Depth

(a) observed data; (b) C_0=0.01; (c) $C=C_0+\alpha R_v$, $C_0=\alpha$=0.01; (d) $C=C_0+\beta(1-R_s)$, $C_0=\beta$=0.01;(e) $C=C_0+\{\alpha R_v+\beta(1-R_s)\}/2$, $C_0=\alpha=\beta$=0.01

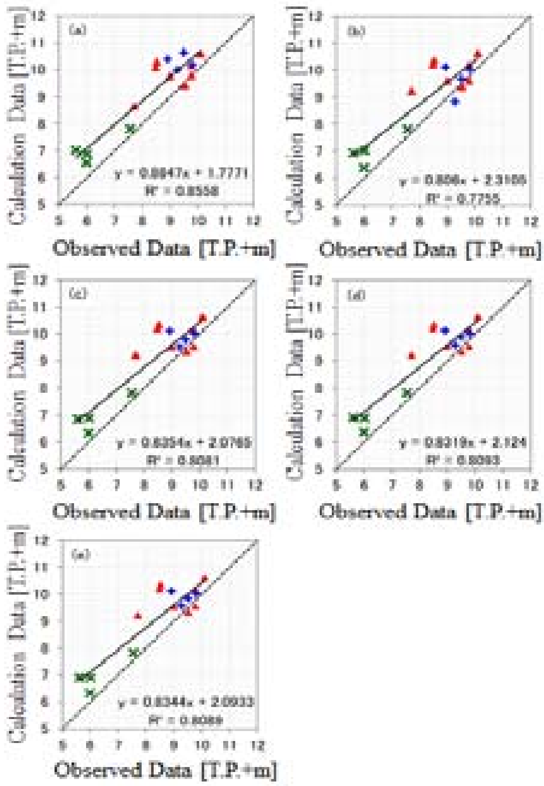

Figure.3　Relationship between Calculated Data and Observed Data

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