Long wave propagation on large roughness

Koji Fujima

National Defense Academy, Yokosuka, Japan[1]

Abstract. Wave transformation on large obstacles was examined through hydraulic experiments and numerical simulations. A numerical simulation taking into account velocity distribution and the turbulence model reproduced well the variation of wave height observed in the experiments. However, it is not easy for numerical simulation by using shallow water wave equation without considering those to reproduce the experimental results. An empirical roughness coefficient was estimated to equate the experimental transmission coefficients to the numerical ones evaluated by the shallow-water wave equation. The proper roughness coefficient ranges from 0.05 to 0.15.

1. Introduction

Shallow-water (long) wave theory such as nonlinear shallow-water theory and nonlinear dispersive long-wave theory is generally used in tsunami numerical simulation. Because long-wave theory is based on the assumption that velocity distribution is almost uniform vertically, it is difficult to reproduce the complicated phenomena occurring near rocks, submerged breakwaters, or where the water depth suddenly changes. However, if an appropriate water depth and roughness coefficient are used in a numerical simulation, we may expect that simulation to reproduce the run-up height accurately. However, the relationship between the roughness coefficient and bottom conditions are not well understood. Thus, at present, the roughness coefficient is generally given by a simple distribution in actual tsunami simulation, although water depth and the roughness coefficient have a large influence on the computed results. Furthermore, engineers determine the value of the roughness coefficient empirically. In addition, when the width of bottom obstacles is smaller than the grid size used in a simulation, engineers have to determine the water depth of that grid without any guidelines. Thus, in the present study, appropriate water depth and the roughness coefficient, which leads to good reproducibility of a simulation, is discussed in relation to bottom obstacles whose size is large but smaller than the grid size.

2. Experiments

In this study, rectangular obstacles are used as models for bottom disturbance. In the hydraulic model experiments, water depth, h, was set to 20 cm. Two kinds of obstacles were used. With a smaller obstacle, the height, k, was 3.5 cm and the width, w, was 4.5 cm; with a larger obstacle, $k = w = 10$ cm. Obstacles were set at the bottom of the flume with an interval of 0.5 m or 1 m in part of a wave flume. The length of the obstacle region was 4 m. Figure 1 shows the schematic sketch of the experimental setup. The wave

[1]Department of Civil and Environmental Engineering, National Defense Academy, Yokosuka 239-8686, Japan (fujima@cc.nda.ac.jp)

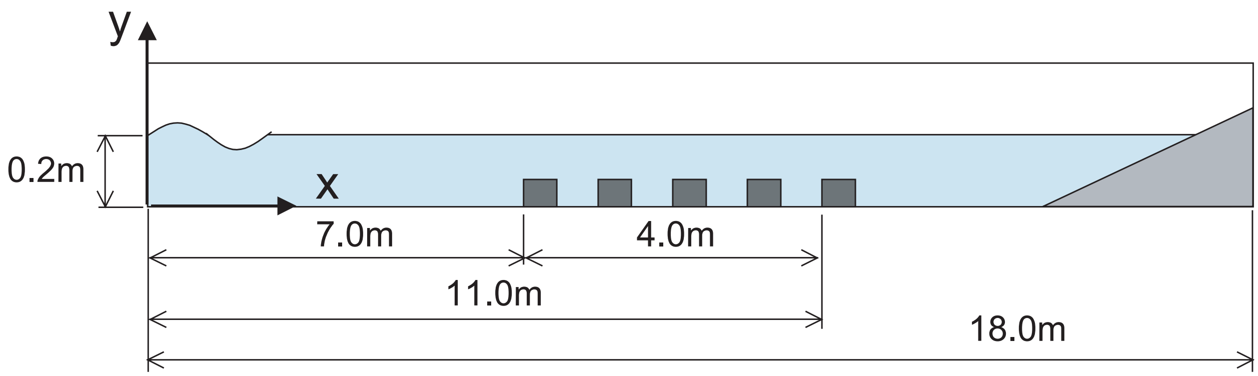

Figure 1: Experimental setup.

period of the incident wave, T, was set to 1.5, 1.8, and 5 s, and incident wave height was 1.5 cm to 2.5 cm. Capacitance-type wave gages were used to measure the distribution of wave height.

However, an incident wave whose period was longer than 5 s could not be generated in the hydraulic experiment because of the restriction of the setup. The depth-to-wavelength ratio is 1:35 for the cases of $T = 5$ s, then it seems to be classified as a shallow-water wave. However, an incident wave with a longer period is more realistic when applied to a tsunami. Thus, a numerical experiment using CADMAS-SURF (SUper Roller Flume for Computer Aided Design of MAritime Structure) code was conducted for such cases. The CADMAS-SURF code was developed by a joint project of several Japanese institutes. With this code, two-dimensional Reynolds-averaged Navier-Stokes equations are solved implicitly, water surface is evaluated by the VOF (Volume Of Fluid) method, bottom configuration in a grid cell is determined by a porous-body media method, and a k-ϵ model is used for turbulence closure. The validity of the CADMAS-SURF simulation was checked by comparing computed results with measured results in hydraulic model experiments. Figure 2 shows time history comparisons of water elevation computed by CADMAS-SURF and that measured in the model test. In almost all cases, a CADMAS-SURF simulation reproduced the experimental results successfully, except for a case where considerable Bragg-scattering appeared. Therefore, it is concluded that this simulation is available for a numerical experiment on wave propagation on large obstacles. Then, for the case of a wave whose period is very long, a CADMAS-SURF simulation is conducted as a numerical experiment. In the numerical experiment by CADMAS-SURF, the length of a wave flume was set to 50 m, the height of an obstacle was 5 cm, 7.5 cm, and 10 cm, and the interval of an obstacle was 2 m. Water depth, h, was 0.2 m, wave period was 10 s, and wave height was 0.5 cm, 1 cm, and 1.5 cm.

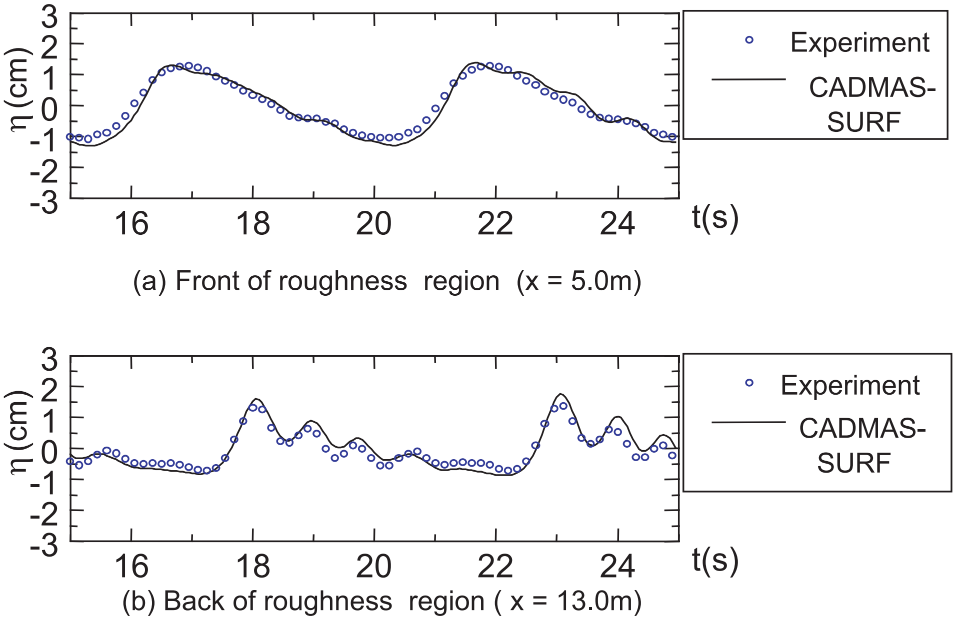

Figure 2: Comparison of time-history of water elevation measured in a hydraulic experiment and computed by CADMAS-SURF (T = 5 s, incident wave height = 2.5 cm, k = 10 cm, interval of obstacle = 0.5 m.

3. Results and discussion

Based on hydraulic and numerical experiments, examinations are conducted on how bottom obstacles (not negligible but smaller than the numerical grid size) should be considered in a tsunami numerical simulation based on a shallow-water wave equation. In this study, the water depth of the grid in which obstacles are located is determined by (1) water depth at the foot of obstacle, (2) water depth averaged in the grid, (3) water depth at the top of obstacle. In all cases, many computations based on nonlinear shallow-water theory and nonlinear dispersive long-wave theory are conducted by varying Manning's roughness coefficient, n, in a range of 0.01 to 0.4. Figure 3 shows comparisons of wave-height distribution obtained by numerical experiment (CADMAS-SURF simulation) and those simulated by a nonlinear dispersive long-wave equation with water depth data determined by method (3). This figure indicates that a long-wave equation gives satisfactory results if an appropriate roughness coefficient and water depth are used in a simulation. If water-depth data was determined by method (1), a reflected wave was not reproduced well. In the case of method (2), a reflected wave was partially reproduced, and method (3) provided the best reproducibility in this study. Figure 4 shows the appropriate roughness coefficient for the nonlinear dispersive long-wave theory obtained by this study. Obtained roughness coefficients have large scattering in a range of 0.01 to 0.2, and most data ranges from 0.05 to 0.15. In addition, an appropriate roughness coefficient increases as roughness height and incident wave height increases. In the most realistic tsunami simulation, roughness coefficient is given by a simple distribution,

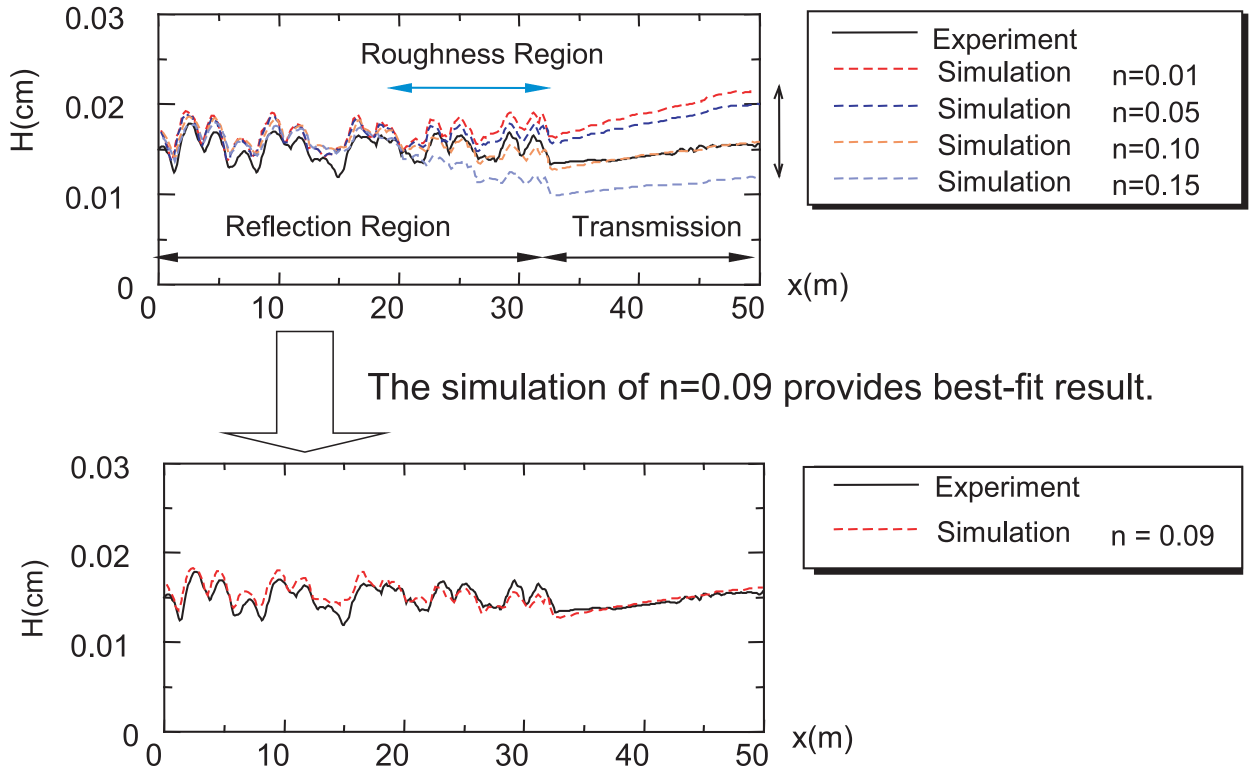

Figure 3: Comparisons of distribution of wave height obtained by experiment and those simulated by nonlinear dispersive long-wave equation ($T = 10$ s, incident wave height $= 1.5$ cm, $k = 10$ cm, interval of obstacle $= 2$ m; water depth is determined by method (3)).

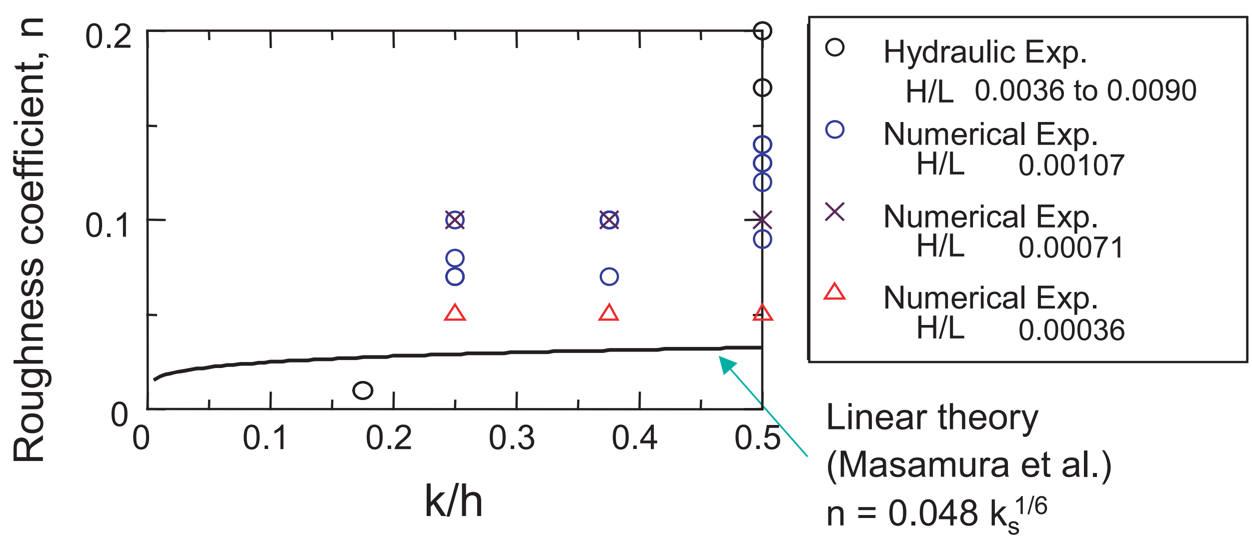

Figure 4: Distribution of roughness coefficient (governing equation is nonlinear dispersive long-wave equation; water depth is determined by method (3)).

and the value is generally about 0.02 to 0.05. However, a roughness coefficient should be determined by considering the bottom conditions. When there is a large obstacle, a proper roughness coefficient is much larger than the one used in the conventional simulations.

When the nonlinear shallow-water theory is selected as the governing equation, the roughness coefficient ranges from 0.01 to 0.07. However, because nonlinear shallow-water theory neglects the dispersion effect, it tends to overestimate the wave celerity and underestimate the growth rate of the transmitted wave. Besides, nonlinear shallow-water theory could not reproduce a wave profile having a secondary wave crest, which was obtained by experiments as shown in Fig. 2.

4. Conclusions

The CADMAS-SURF code is available for numerical experiments on wave propagation on large obstacles. If water depth and a roughness coefficient are selected appropriately, a numerical simulation based on a shallow-water wave equation can reproduce satisfactorily the wave-height distribution obtained by hydraulic and numerical experiments. However, water depth at the top of an obstacle should be used as the water depth of the grid in which the obstacle is located. Proper roughness coefficients range from 0.01 to 0.2 (mainly 0.05 to 0.15), and increase as obstacle height and incident wave height increases.

5. References

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