# SLOSHING ANALYSIS IN A TANK USING A DEPTH AVERAGED FLOW MODEL IN GENERALIZED CURVILINEAR MOVING COORDINATE SYSTEM

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In this study, the sloshing characteristics in a tank on an oscillation table were examined. Sloshing is a free surface flow problem in a tank which is subjected to forced oscillation such as in seismically excited rigid tanks. Clarification of the sloshing phenomena is very important in the design of the tank. A depth averaged flow model in generalized curvilinear moving coordinate system (Hosoda et al. 1996) was applied to calculate flow field, in which the pressure distribution was assumed to be hydrostatics. Furthermore, the depth averaged flow model considering the effects of vertical acceleration was also used and the linear solutions in both cases were derived. The sloshing characteristics obtained from the numerical results and the linear solutions were verified by comparing with the experimental results.

Firstly, the laboratory experiment was conducted under various hydraulic conditions (Table 1) and the characteristics of water surface profile were investigated. It was found that the water surface elevations in the vertical direction are bigger, as the amplitude of vibration in shaking table is larger. It was also found that the higher wave numbers of water surface profiles are, the higher frequency is.

Based on the experimental hydraulic conditions, the shallow water equation was applied to simulate the flow fields using both numerical and linear solutions, in which the pressure distribution was assumed to be hydrostatic: but, this assumption is not valid when calculating waves and flows such as in a seashore region where the wave numbers are higher, which means the wavelength is shorter compared with the flow depth. So, the depth averaged flow model considering the effects of vertical acceleration (Boussinesq equation) was also applied based on the linear solution.

For small amplitude of vibration and frequency, it was found that the numerical results are consistent with the linear solutions and all three solutions agree with the measurements (Figs are not shown).

On the other hand, in case of large amplitude, the numerical solution agrees with the experimental results (Fig. 1). It is thought that because in this case the amplitude is large, there exist non-linear effects, which could not be reproduced by the linear solutions.

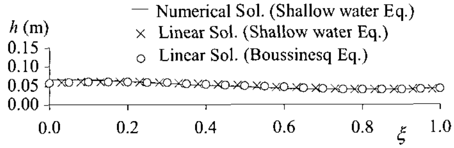
In case that the frequency is high, it was observed that the linear solution in shallow water equation is different from the one in Boussinesq equation and the agreement between the later and experimental results is satisfactory (Fig. 2). The possible explanation for this is that, the linear solution based on the Boussinesq equation is in good agreement with measurements, due to the fact that the effects of vertical acceleration is taken into consideration.

Table 1. Hydraulic conditions

| Case | $h_0$ (m) | $f$ (Hz) | $T$ (s) | $d$ (m) |
|---|---|---|---|---|
| 1 | 0.05 | 0.5 | 2.0 | 0.01 |
| 2 | 0.05 | 0.5 | 2.0 | 0.03 |
| 3 | 0.05 | 1.5 | 0.67 | 0.004 |
| 4 | 0.10 | 1.0 | 1.0 | 0.01 |

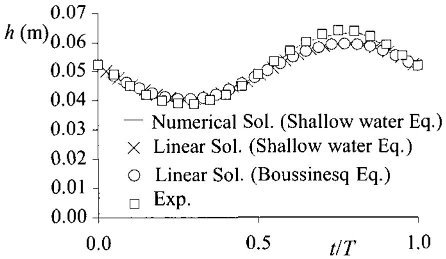
($h_0$: initial depth, $f$: frequency, $T$: time period, $d$: amplitude of vibration)

(i) Exp.



(ii) Calculated results and linear solutions

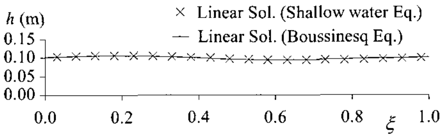
(a) Temporal variation of water surface profiles



(b) Temporal variation of depth at fixed point

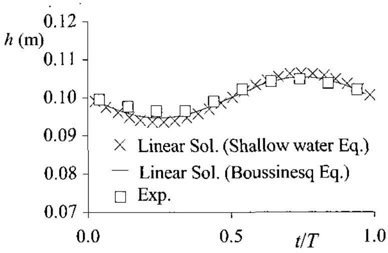
Fig. 1 Comparison with Exp. (Case2)

(i) Exp.



(ii) Calculated results and linear solutions

(a) Temporal variation of water surface profiles



(b) Temporal variation of depth at fixed point

Fig. 2 Comparison with Exp. (Case4)

## REFERENCES

Hosoda, T., Nagata, N. and Muramoto, Y. (1996). "Numerical analysis of unsteady open channel flows by means of moving boundary fitted coordinate system," *J. Hydraulic, Coastal and Environmental Eng.*, No. 533/ II-34, pp. 267-272 (in Japanese).