Numerical Simulation for Overflow Behavior of Water Tank with Sloshing under Seismic Motion

Background

The sloshing of large oil storage tanks occurred in Tomakomai, 200km from the hypocenter of the 2003 offshore Tokachi Earthquake (M8.0), which included a long period ground motion. In order to prevent damage from sloshing, a code for large oil storage tanks of the Japanese fire laws concerning wideband characteristic of seismic motion was revised in 2006. On the other hand, the calculation method for maximum response wave height of sloshing has been adopted to apply velocity potential theory, which was based on assumption of linear and irrotational flow. Therefore, it is necessary to reduce over estimation of this method, because it is not possible to consider nonlinearity of sloshing regarding turbulent flow and overflow of water.

Objectives

To develop numerical simulation method for nonlinear sloshing phenomena with overflow of water;

Principal Results

1. Shaking Table Tests of Rectangular Water Tank

Shaking table tests were conducted for rectangular water tank filled to the maximum capacity in order to recognize overflow behavior with sloshing. Fig.1 shows the test configuration. Fundamental sloshing phenomena during strong earthquake motion in 2003 off Tokachi were found out such as wave heights, dynamic water pressure, overflow of water and complex wave surface shapes using image-based measurement (Fig.2).

2. Numerical Simulation for Overflow Behavior of Water

(1) Development of numerical simulation method for nonlinear sloshing

The two dimensional finite-difference method of incompressible fluid with rectangular cells involved free surface motion and enabled the coalescence and separation of water (Fig.3). The features of this method were introducing turbulence model equation and considering exactly conservation of mass.

(2) Validation of accuracy

Numerical simulations using this method were carried out on these sloshing tests. These analysis results agreed well with tests results in time histories of wave heights, overflow of water and wave shapes (Figs 4, 5). Realistic estimation methods for overflow of water during earthquake were proposed by these studies.

Future Developments

The simple evaluation method of overflow water with sloshing considering characteristic of input seismic motion will be prepared and fluid structure coupled with sloshing behavior in oil storage tank of floating roof type will be investigated.

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Reference

M. Sakai, et.al. 2007, “Nonlinear sloshing response evaluation method for rectangular tank with overflowing water,” CRIEPI Report N06031 (in Japanese).

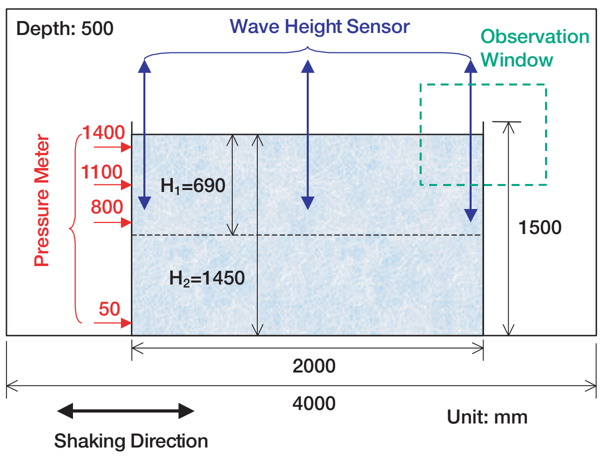

Fig.1 Test apparatus of rectangular water tank

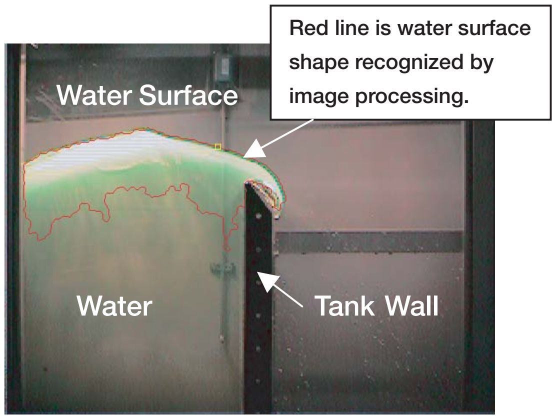

Fig.2 Recognition of water surface shape using image base measurement

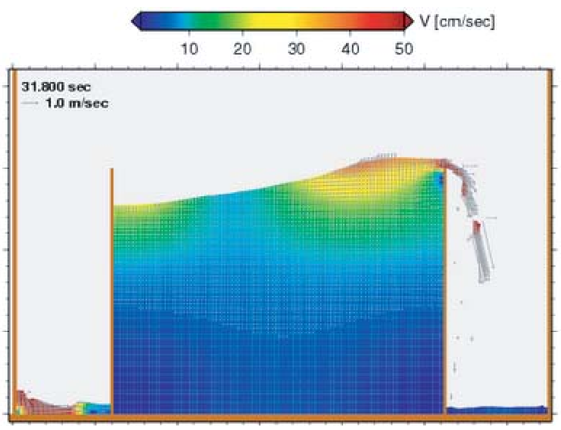

Fig.3 Sloshing response snapshot of numerical simulation result

Turbulent flow analysis of incompressible fluid performing coalescence and separation was developed. Overflow of water from the wall could be solved.

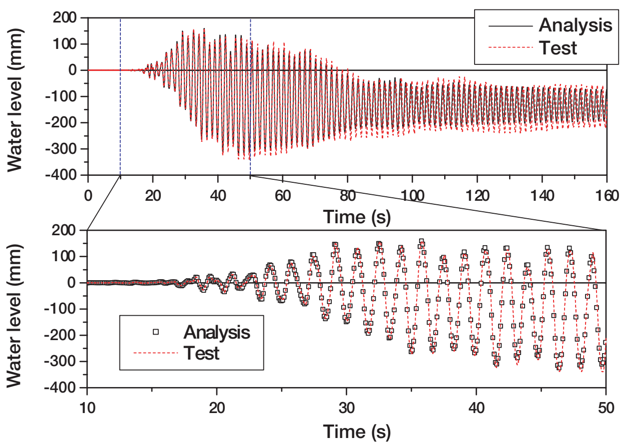

Fig.4 Comparison of time histories of water level between test and analysis

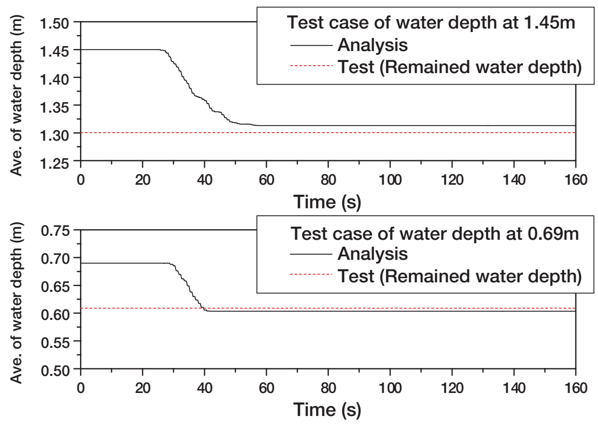

Fig.5 Comparison of time histories of average water depth between test and analysis