Development of Seismic Sloshing Simulation Code for an Oil Tank Covered with a Floating Thin Roof

Background

Oil reserved in a tank without rigid roof is usually covered with a floating thin plate to suppress the escape of the oil vapor from the free surface. In such an oil tank, an earthquake could induce a large displacement of the floating roof due to the sloshing of the reserved oil, possibly leading to severe structural damage of the floating roof and catastrophic fire accident as experienced in the Tokachi-oki earthquake in 2003. To simulate the sloshing behavior in a computer, dynamic interaction of liquid and structure should be taken into account. Since prohibitively time-consuming computation is required to do so with a conventional method, development of a new method, which allows the simulation with reasonable computation time, is needed in practice.

Objectives

The purpose of this study is to conceive an efficient computational model to simulate the interaction of oil and the floating roof, and to code the numerical algorithm as a software, SMART-slg, which enables us to predict and evaluate the deformation of a floating roof.

Principal Results

1. Proposal of a new interaction model

In the conventional model, fluid and structure are treated separately as shown in Fig.1 (a) and the computation is iterated many times until the displacement and stress at the fluid surface are almost equal to those of the structure (lower surface) at the interface. In the present model, on the other hand, a floating roof is immersed at the fluid surface as shown in Fig. 1 (b), assuming that the thickness of the structure is thin enough to neglect. The effects of structural mass and flexural rigidity are taken into account as a pressure boundary condition of the fluid flow equations in the proposed model. Since the displacement and stress of fluid and structure are continuous at the boundary of the merged model by nature, the new model allows us to deal with the structural and fluid equations in a monolithic manner, leading to non-iterative numerical scheme. The set of structural and fluid equations of the merged model is spatially discretized with the finite element method, and coded as a FORTRAN-based software, SMART-slg. Because the finite element method is good at approximating curved surface of a cylindrical tank, and because the proposed scheme is non-iterative, practical computation of the dynamic sloshing behavior of an actual oil tank with a floating roof is possible at far less expensive computational costs.

2. Verification of SMART-slg code

To evaluate the validity of the proposed interaction model and the developed code, two water sloshing experiments in a rectangular tank with and without a floating aluminum plate (Sato et al.,2007)*1 were analyzed with the SMART-slg. As the external exciting acceleration, a time-series of acceleration measured at the shaking table of the experiment (Fig.2) was used in the computations. In Fig.3 (a), the time histories of the water elevation are compared between the experiment and the computation without a floating aluminum plate. It turns out that the numerical result agrees with the experimental measurement in terms of the phase and the amplitude. The time histories of the displacement of the floating aluminum plate are compared in Fig.3 (b). It is seen in this case that the sloshing is damped more in the experiment than in the computation. The reason for the difference is because the friction between the tank wall and the plate edges is not modeled in the present computational model. Considering that the frictional force is proportional to the contact area (square of scale), and that the external force due to earthquake excitation is proportional to the fluid volume (cube of scale), we can expect that the effect of the friction force is comparatively small in a large-scale oil tank, and that the computation with the present model would yield reasonably conservative results in terms of the sloshing height and deformation of a floating roof.

Future Developments

The software will be applied to an actual oil tank to evaluate the sloshing and floating roof deformation and to propose a reasonable design strategy pursuing both safety and economy.

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Reference

Y. Eguchi, 2008, “Development of SMART-slg to simulate sloshing in an oil tank with a floating roof”, CRIEPI Report N07025 (in Japanese)

＊1：Y. Sato, M. Sakai, K. Sato, S. Higashi, Sloshing Performance of 2D Floating Roof Tank, Proc. of 2007 JSCE Annual Meeting, pp.1133-1134, Japan Society of Civil Engineers (JSCE), 2007.

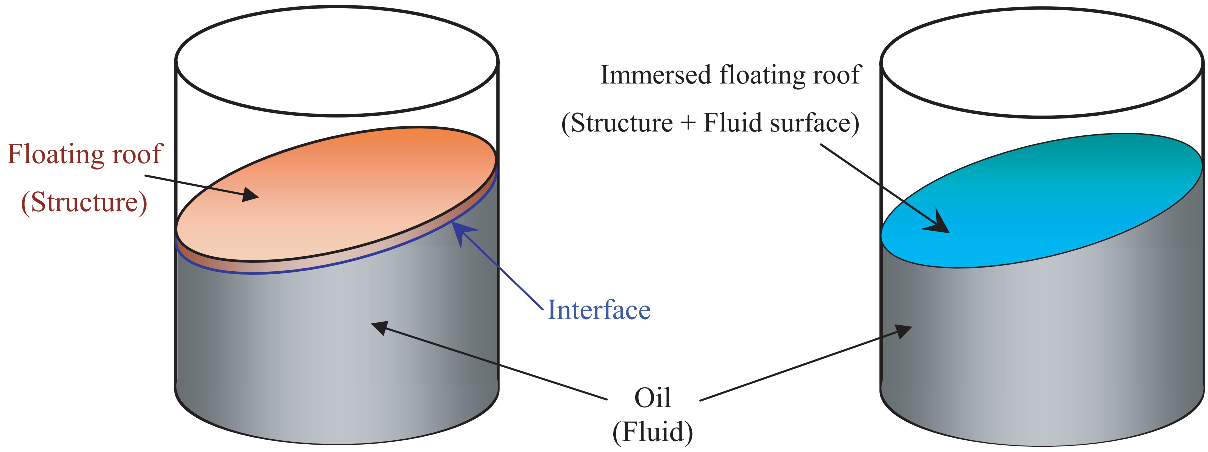


Fig.1(a) Conventional model (b) Present model

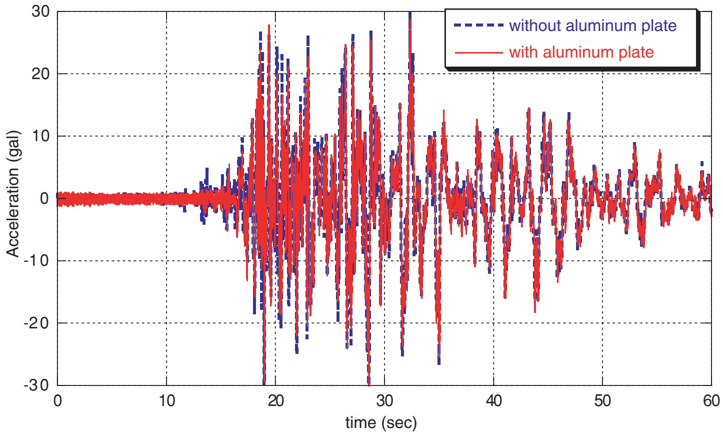


Fig.2 Acceleration used for computation

(Time scale and amplitude are reduced in the experiment by factors of 0.455 and 0.5, respectively, for the original seismogram obtained at Tomakomai at the Tokachi-oki earthquake 2003 with the Kyoshin Net system of the National Research Institute for Earth Science and Disaster Prevention.)

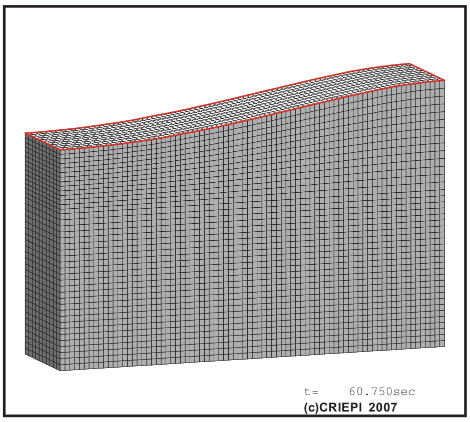
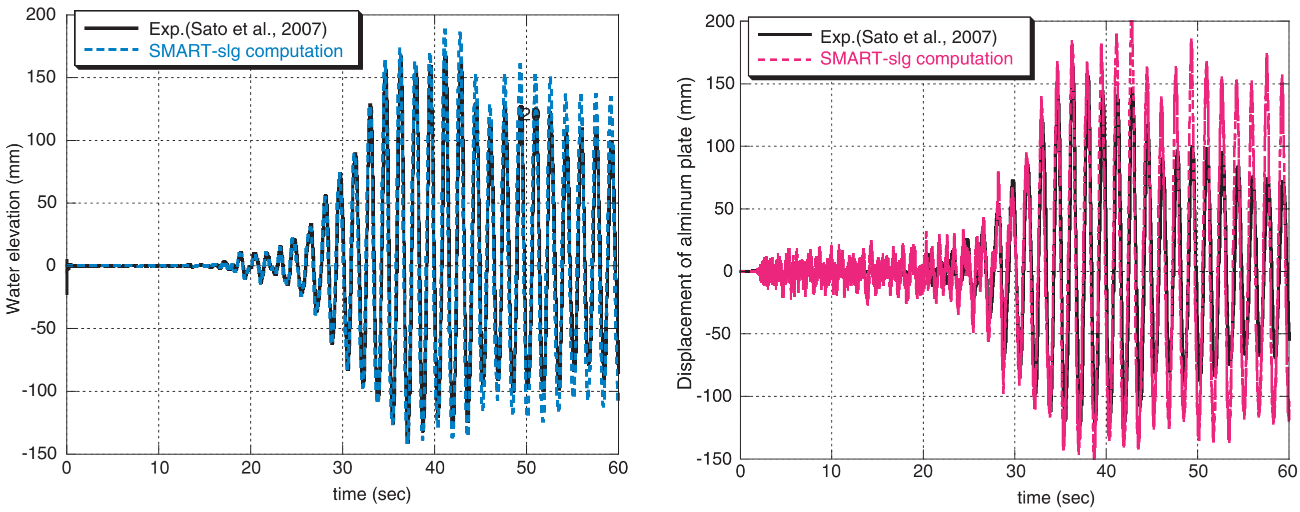


Fig.3 Aluminum plate deformation computed

(The red line denotes edge of the aluminum plate, and the grid line represents the finite element mesh subdivisions.)



(a) Water elevation without floating roof model (b) Aluminum plate displacement with floating roof model

Fig.4 Time histories of sloshing height measured and computed