A Study on Characteristic of Compression Waves in Seaquake Generation Tank *1

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A seaquake generation tank was constructed, in order to verify the validity of the numerical calculation method of seaquake. For the first step of the study, the seismic wave field and pressure distribution in the tank are measured, in order to make clear the characteristic of compression waves in the tank. The measured results will be compared with the calculated results by making use of the boundary integral equation method.

Keywords : *Seaquake Generation Tank, Compression Waves, Three-Dimension, BIEM*

1. Introduction

A very large floating structure, so-called Mega-Float, has attracted attention as means of ocean space utilization. This kind of marine structure had been generally considered to be aseismatic design. However, the effects of vertical motion of the seabed due to an earthquake may not be small, so that it is considered that a so-called seaquake, which is caused by propagation of seismic motion of the seabed through seawater, affects a floating structure.

There have been some studies concerning the effect of seaquakes by making use of theoretical and numerical method [2)3)4)5)6)7)8)9)]. However, there are very few experimental studies about seaquakes [1)]. In order to verify the validity of the knowledge obtained through these numerical studies, the experimental study should be carried out here.

Under such situations, a water tank with vibration generator that can generate the compression waves into water was constructed.

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The main aim of this study is to investigate the characteristic of compression waves in the tank, before the investigation of seaquake. The pressure distributions in the tank are measured by making use of hydrophone and the measured results are compared with the calculated results by making use of boundary integral equation method.

2. Experiment

2.1 Experimetal Condition

The seaquake generation tank mainly consists of two parts as shown in Fig.1. The left figure in Fig.1 is a water tank, and the right figure is a vibration generator. The vibration generator is set up under the water tank and the part of tank bottom that is the circle of a diameter of 0.2m can be oscillated vertically. There is no sound absorbing material in the water tank. The length, the breadth and the standard water depth of the water tank is 1.5m, 1.5m and 1.0m, respectively.

As the first stage of the study, we have to understand the characteristic of compression waves in the tank. Because the tank is bounded by the tank wall that is different from actual sea condition, and we need to investigate the effect of the tank wall on the compression waves. We measured the pressure distributions of the compression wave field in the tank caused by vibration of the part of tank bottom. Taking symmetry of the tank into consideration, the underwater sound pressures of quarter of the water tank in mesh of 0.1m are measured by using a hydrophone(see Fig.2). The frequencies of the vibration part are 100Hz to 1,000Hz and the vibrated acceleration is harmonically $10m/s^2$. The measured results are compared with the numerical calculations based on the formulation which was presented by one of the authors [8].

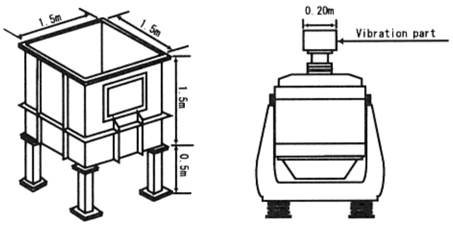


Fig. 1 Seaquake generation tank.

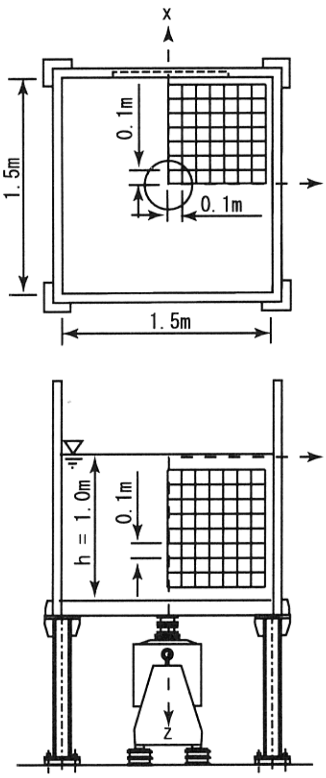
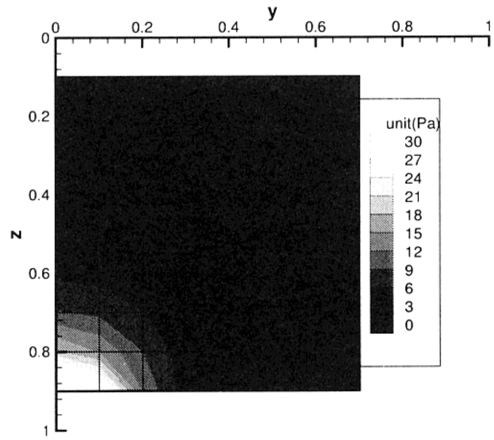


Fig. 2 Measuring point of pressure.

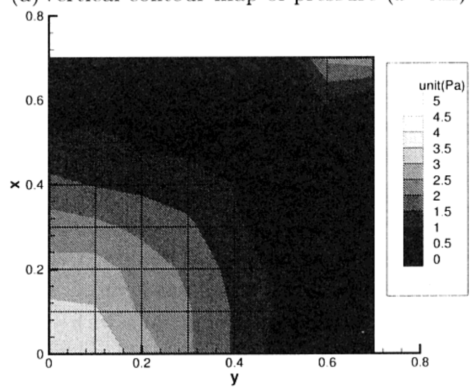
2.2 Experimetal Results

Fig.3 and Fig.4 show the contour map of the pressure in the tank obtained by measurement of pressure distribution. Fig.3 shows the results at 300Hz and Fig.4 shows ones at 920Hz.

In this experimental condition, it may be considered theoretically that there is a resonance at 375Hz in the seismic wave field that is bounded by free surface and rigid bottom. This kind of resonance was not observed in the measured results around the frequency, but the higher pressure distribution was observed around 920Hz. It seems that this is a resonance between each wall. In order to make clear these results, the numerical calculations are carried out and are compared with measured results.

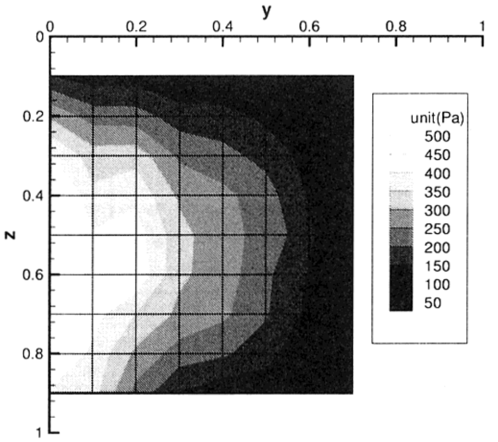


(a)Vertical contour map of pressure (x=0m)

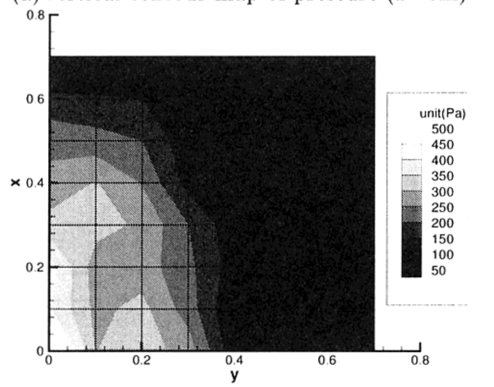


(b)Horizontal contour map of pressure (z=0.5m)

Fig. 3 Contour map of measured pressure in tank (300Hz).



(a)Vertical contour map of pressure (x=0m)



(b)Horizontal contour map of pressure (z=0.5m)

Fig. 4 Contour map of measured pressure in tank (920Hz).

3. Boundary Integral Equation Method

The assumption that the fluid is inviscid, irrotational and compressible is considered. When part of the tank bottom is oscillating vertically and harmonically, the seismic waves propagate into water. The assumption that the tank bottom and wall are perfectly rigid is also considered.

The seismic wave field will be specified by the velocity potential $\Phi(x, y, z; t)$ as follows:

$$\Phi(x, y, z; t) = \mathrm{Re}\left[\phi(x, y, z)e^{i\omega t}\right]. \tag{1}$$

The velocity potential ϕ satisfies the Helmholtz equation

$$\nabla^2\phi + K^2\phi = 0. \tag{2}$$

The velocity potential also must fulfill the following boundary conditions:

$$\left.\begin{array}{llll} [F] & \phi = 0 & \text{on } S_F \\ [B] & \dfrac{\partial\phi}{\partial n} = 0 & \text{on } S_B \\ [E] & \dfrac{\partial\phi}{\partial n} = v_n & \text{on } S_E \\ [W] & \dfrac{\partial\phi}{\partial n} = 0 & \text{on } S_W \end{array}\right\}, \tag{3}$$

where $K = \omega/c$ is the wave number, c is the underwater sound velocity, $\omega = 2\pi f = 2\pi/T$ is the circular frequency, f is the frequency, T is the wave period and v_n is the normal velocity on the seaquake center surface. S_F, S_B, S_E and S_W denote the free surface, the tank bottom surface, the seaquake center surface and tank wall, respectively(see Fig.5). For a high frequency fluid motion with free surface, the so-called memory effect due to free surface waves is negligible.

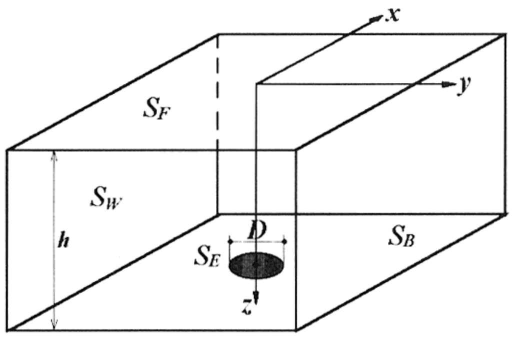


Fig. 5 Coordinate system.

The velocity potential on the boundary surfaces in the considered region are obtained as follows:

$$\phi(P_0) = -2\int_S \left[\phi(Q)\frac{\partial}{\partial n_Q} - \frac{\partial\phi(Q)}{\partial n_Q}\right] G_0(P_0, Q)dS, \tag{4}$$

where S denotes the boundary surface which is enclosing the field, and it can be described as $S = S_W + S_E + S_B$. The kernel function G_0 which is basically defined as the principal solution for the Helmholtz equation is written as follows:

$$G_0(x, y, z; x', y', z') = \frac{1}{4\pi}\left[\frac{e^{-iKr}}{r} - \frac{e^{-iKr_1}}{r_1}\right]. \tag{5}$$

The velocity potential in the considered region are written as follows:

$$\phi(P) = -\int_S \left[\phi(Q)\frac{\partial}{\partial n_Q} - \frac{\partial \phi(Q)}{\partial n_Q} \right] G_0(P,Q) dS, \tag{6}$$

where P, P_0 are points in the compression wave field and on the boundary surface, respectively, and Q is a point of the wave source. The pressure at arbitrary point in the considered region can be obtained as follows:

$$p(P) = -i\rho\omega\phi(P). \tag{7}$$

4. Discussions

The measurements and calculations are compared at the points as shown in Fig.6.

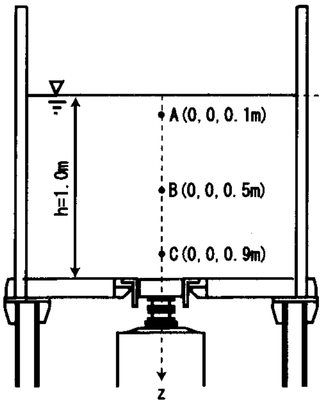


Fig. 6 Comparison points of measurements with calculations.

Figs.7-9 show the comparisons of the measured results with the calculated ones at each point. There are sharp peak values at 375Hz and 1125Hz in the calculated results. As described before, these are caused by resonance in the seismic wave field that is bounded by free surface and rigid bottom. However, these peak values were not observed in the measured results. In general, the calculated results are larger than the measured ones. In the calculation, the assumption that the tank bottom and wall are perfectly rigid is considered, but the wall and the bottom of the tank are elastic in the actual condition. It may be considered that the compression waves is absorbed due to the elasticity of these boundary surface.

Furthermore, there are peak values at 920Hz in the measured results and there are same kinds of peak values around 1070Hz in the calculated ones. In order to investigate the reason of such pressure tendency, the

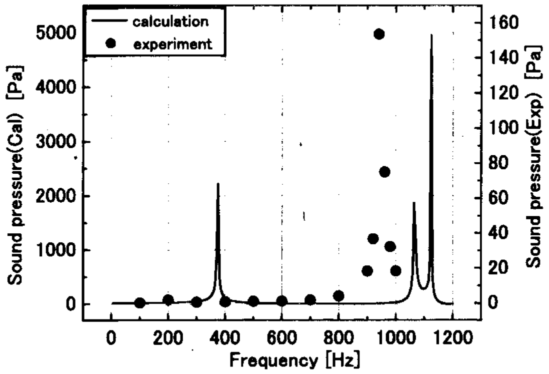


Fig. 7 Comparison of pressures in the tank of measurements with calculations (z=0.1m).

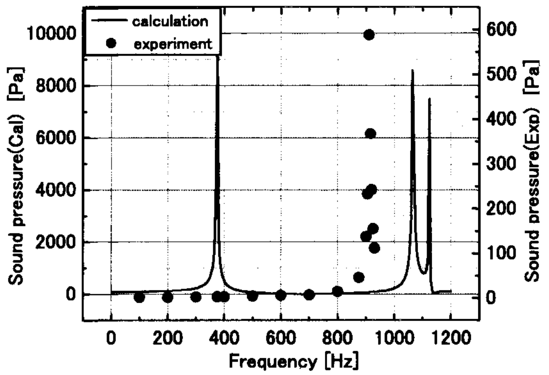


Fig. 8 Comparison of pressures in the tank of measurements with calculations (z=0.5m).

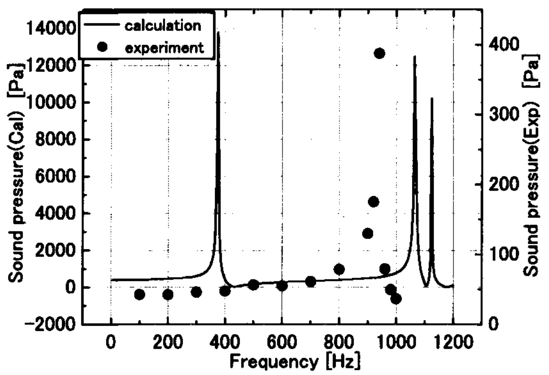


Fig. 9 Comparison of pressures in the tank of measurements with calculations (z=0.9m).

calculation without wall was carried out. The comparisons of both calculated results: i.e. in the case with wall and in the case without wall: are shown in Figs.10-12.

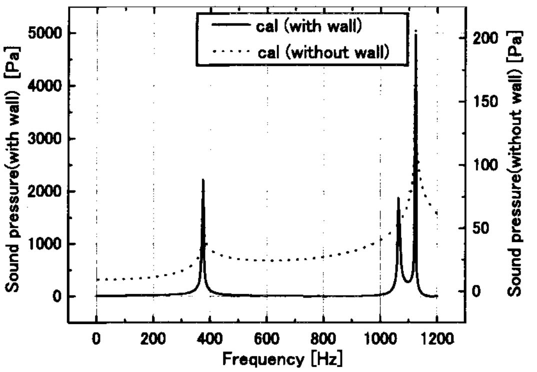


Fig. 10 Comparison of pressures of calculations with wall with calculations without wall (z=0.1m).

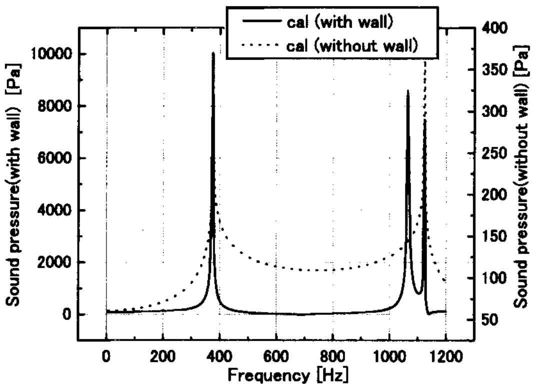


Fig. 11 Comparison of pressures of calculations with wall with calculations without wall (z=0.5m).

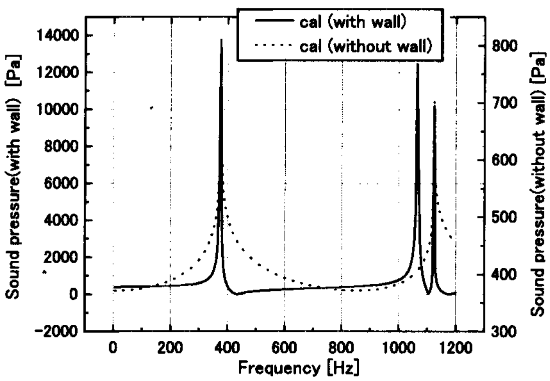


Fig. 12 Comparison of pressures of calculations with wall with calculations without wall (z=0.9m).

As is evident from these figures, it can be considered that the peak of pressure around 1070Hz in the calculation is due to the effect of tank wall. It may seem that the peak at 920Hz in the measurement is also due to the resonance between each wall. However, there is a little bit difference of the peak frequency between measurements and calculation. As described before, it is considered that the wave energy is damping on the wall and the bottom in the experiment. The effect of this energy damping on the resonance frequency in the compression wave field should be investigated in future.

Furthermore, it is clear that the pressure distributions caused by compression waves in the region surrounded by rigid wall become larger than ones in the open boundary and the existence of rigid boundary makes the resonance of compression wave more intense.

5. Conclusions

The characteristic of compression waves in the seaquake generation tank was investigated. The results may be summarized as follows:

1) The resonance of compression wave field surrounded by the free surface and the bottom were not observed clearly in the measurements.
2) The compression waves may be absorbed due to the elasticity of the tank wall and bottom.
3) In general, the existence of rigid boundary may make the resonance of compression wave more intense.
4) The peak of pressure that may be considered due to the resonance of compression wave field between each wall was observed in the measurement.

The characteristic of compression waves in the seaquake generation tank was made clear gradually, but sufficient results have not been obtained. The investigation should be continued, and we will make clear the problem of seaquake in the future.

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