Slip Phenomena by Occurrence of Air Film Between Tank and Basement

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ABSTRACT

In this paper we deals with slip phenomena of oil tanks. Oil tanks whose bottoms are flat are set on a concrete base and they are not anchored. So, when they are accelerated by an earthquake, they may be rocked or slid. Actually the phenomena have sometimes been observed since Alaska earthquake in 1964. If a tank moves and the pipes attached to the tank brake, the oil leaks out and it is in danger. As for the reason we have discussed whether the coefficient of friction is small or large. But some cases cannot be explained on the viewpoint of the coefficient of friction. Therefore, we tested with a tank model on a flat shaking table. The diameter and the height of the acrylic model is 150mm and the wall thickness is 5mm. The bottom is made of vinyl chloride whose stiffness is lower than the acrylic one. The four pressure transducers are set on the bottom to measure the air pressure between the bottom and the shaking table. Water volume in the tank and the center of gravity of the tank can be changed. The acceleration and the movements of the tank were measured in sweeping a vibration acceleration of the shaking table at a constant frequency. As a floor material, acryl and rubber were chosen. As a result, the acceleration at which the tank begins to slip is less than the theoretical value calculated from the coefficient of friction. Another characteristic is the fact that the tank slips more easily at the higher frequency. The reason is why the air film causes between the bottom and the shaking table after rocking and the film makes it easier to slip. That is, the apparent coefficient of friction is less due to the air film than the real coefficient of friction. The effect is more in case of the higher frequency and the higher coefficient of friction. The water in the tank makes the slip acceleration more or less owing to sloshing.

INTRODUCTION

There are a lot of studies to resist earthquakes, but few studies on a slip of a flat bottom, ground supported tank when an earthquake occurs. In fact, the slip phenomena have sometimes been observed since the earthquake in Alaska in 1964. In Alaska earthquake, it was reported that a part of tank bottom detached off the ground at a moment or the tank with 10 meters diameter and 30 meters height walked. In this paper, we report some experimental results with respect to walking of an acrylic tank model on a shaking table. As a parameter, two kinds of floor were chosen to observe the influence to the walking of the tank due to the coefficient of friction. Moreover, the effects of a sloshing were observed.

EXPERIMENT

An acrylic tank model was made to observe walking or slip of it, which has a 150mm diameter, a 150mm height, a 5mm thickness and 0.6kg weight. The bottom of the tank was made of vinyl chloride.

Four pressure Transducer were attached to the bottom of the tank as shown in Fig.1. The behavior of the tank was measured with two accelerometers and two gap sensors. The weight 0.38kg. is added in some experiments to observe the effect of the total weight. As a material of the floor acryl and rubber were chosen to the influence of the coefficient of friction between the bottom and the floor. The value is in the range from 0.25 to 0.28 for acryl, and in the range from 1.06 to 1.42 for rubber. The coefficient was measured everytime before the experiment, and the value was used to discuss slip or walking. To observe the influence of sloshing the tank model with water was shaked. As a nondimensional water level H_l/R, the value 0.2, 0.5 and 0.8 were taken, where H_l is the height of water and H is the height of the tank model. The tank model with water was shaked with the natural frequency correspondent to the water level.

ESTIMATION OF PRESSURE DISTRIBUTION

Based on the pressure value measured by four pressure transducers, the pressure distribution was estimated and the decrement of drag from the floor by the air pressure between the bottom and the floor was calculated. Four pressure transducers were attached in line on the x-axis. The positions are $(-x_2,0,0)$,$(-x_1,0,0)$,$(x_1,0,0)$ and $(x_2,0,0)$ and the pressure values are p_1, p_2, p_3 and p_4 respectively. The pressure distribution on the x-axis is expressed as the next function,

$$F(x) = ax5 + bx4 + cx3 + dx2 + ex + f \tag{1}$$

From the condition of four pressure values and two boundary pressure values at the atmosphere, the coefficients a to f are determined. In the y direction the pressure distribution is assumed to be a curve of secondary degree. After integrating the pressure in the xy plane under the tank, the decrease of drag between the bottom and the floor is calculated. An image of the pressure distribution is shown in Fig.2.

EXPERIMETAL RESULTS

Minimum Acceleration to Slip or Walk

The minimum accelerations to slip are shown in Fig.3. The real line indicates the theoretical minimum acceleration which is calculated using the weight of the tank model and the coefficient of friction. From these results the minimum acceleration to slip or walk is dependent on the frequency of the shaking table. This reason is why we assume the air film is made between the bottom and the floor and the pressure values by the air film are depend on the frequency of the shaking table. In case of rubber floor, the minimum accelerations to slip or walk are shown in Fig.4. In this case, also, they are depend on the frequency of the shaking table and they become smaller with an increase of the frequency.

Pressure Distribution

Pressure distributions between the bottom of the tank model and the floor are shown in Fig.5. The pressures at the boundary which are -0.075 and 0.075m at the x axis are atmosphere, that is, zero. Four points in the middle were measured with four pressure transducers. The pressure distributions are shown every 0.01 second in Fig.5. The 0.01 second means one tenth period. Under the condition the tank is not always symmetric, when the tank slips or walks in the left direction, the mechanism is considered as follows; in case of (a) the pressure at the right side is higher than that at the left side, when the shaking table is at the right side. Next the tank is at the neutral position when the shaking table is at the neutral position (b). At that position, air flows into the gap from outside. And when the table goes left (c), the tank begins to slip because the coefficient of friction is smaller owing to the air film between the bottom and the floor.

Locking by Sloshing

To observe the effect by sloshing several tests wer e tried under the condition with water in the tank. The parameters are shown in Table 1. The minimum accelerations the tank model begins to slip are shown in Fig.6. The lowest natural frequency f is calculated by the next equation,

$$f=\frac{1}{2\pi}\sqrt{\frac{g}{R}\varepsilon\tanh(\varepsilon\frac{H_l}{R})} \tag{2}$$

Where, ε equals 1.841. In case of H_l/R =0.43, f equals 2.07 Hz, in case of H_l/R=1.07, f equals 2.5 Hz. When no sloshing occurs, the minimum acceleration is smaller than the theoretical one. When sloshing occurs, the minimum acceleration is smaller or larger than the theoretical one. In case of H_l/R =0.43, the minimum value of the minimum acceleration is 1.7 m/s^2 at 2.07 Hz which is the lowest natural frequency. In case of H_l/R =1.07 and 1.71, the minimum value is at 2.5 Hz which is also the lowest natural frequency. At this moment, it is observed the shaking table, the tank and the water are at the same side, as shown in Fig.7.

SUMMARY AND CONCLUSION

From the results of the behavior of the tank model on the shaking table, the slip or walking of the tank at an earthquake may occur owing to the air film between the bottom of the tank and the basement. The tank may slip or walk because the air film makes the apparent coefficient of friction smaller than the theoretical one. Moreover, the effects of the sloshing have to be considered when the dominant frequency of the earthquake is coincident to the sloshing frequency. So when a flat bottom, ground supported tank is designed, it is considered that the apparent coefficient of friction may be smaller than the theoretical one. If that point is not considered, the tank may slip or walk at an earthquake and the structures like connected pipes may be broken.

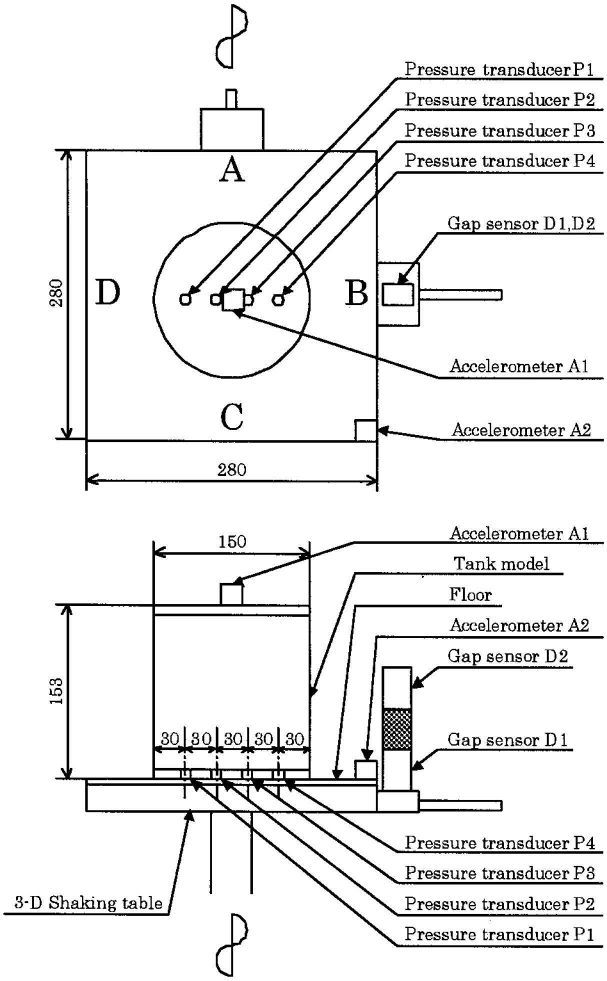

Fig.1 Experimental Apparatus

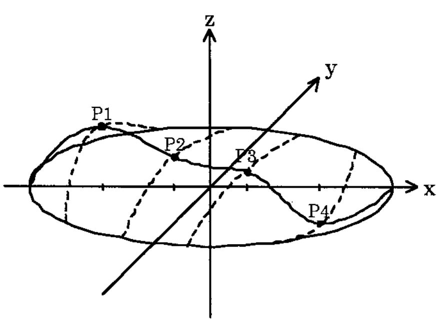

Fig.2 Image of Pressure Distribution

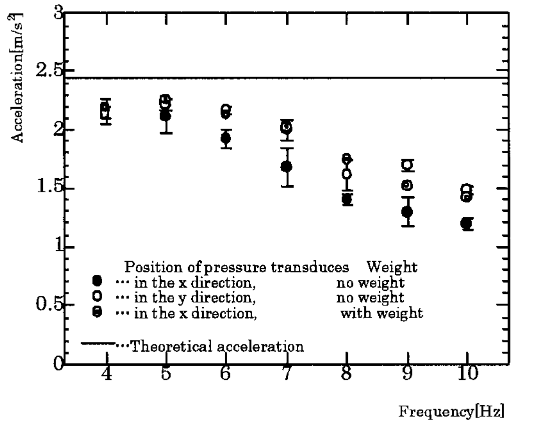

Fig.3 Minimum Acceleration for Slipping in Case of Acrylic Floor

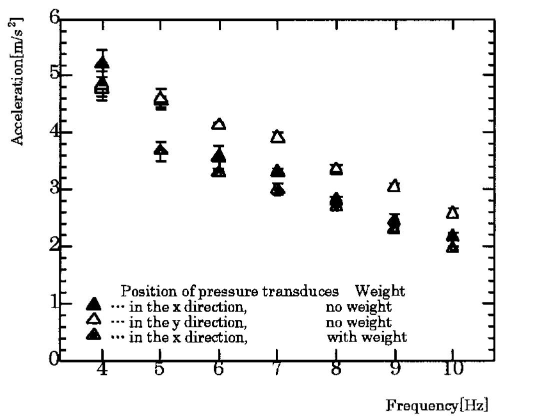

Fig4 Minimum Acceleration for Slipping in Case of Rubber Floor

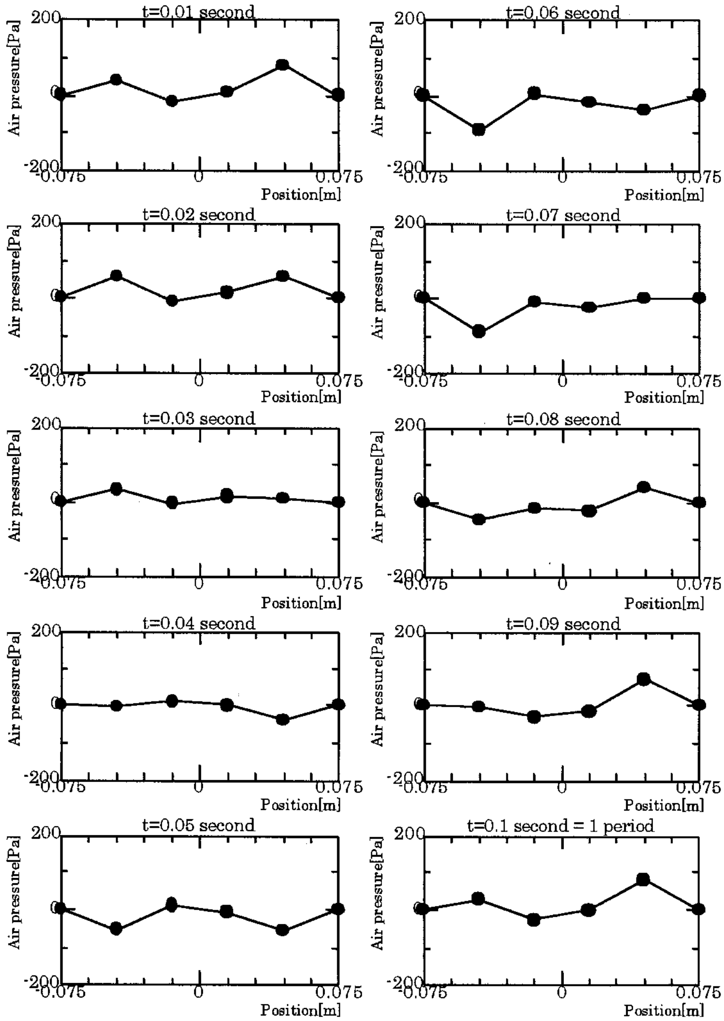

Fig.5 Pressure Distribution Every 0.01 Second

Table 1 Conditions of Test with Water in Tank

H_l/R_i (H_l/H)	Weight[kg]	Coefficient of friction
H_l/R_i=0.43 (H_l/H=0.2)	1.09	0.28
H_l/R_i=1.07 (H_l/H=0.5)	1.80	0.28
H_l/R_i=1.71 (H_l/H=0.8)	2.50	0.28

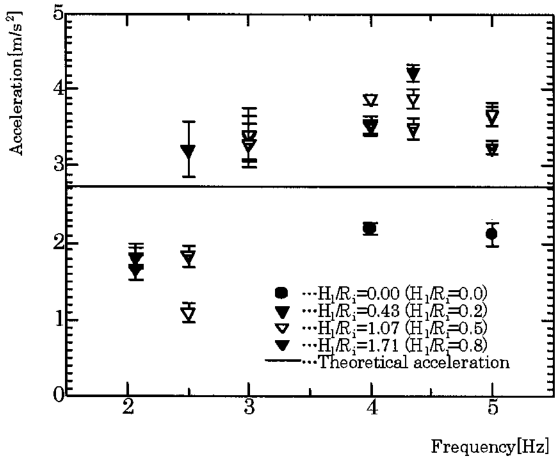

Fig.6 Minimum Acceleration for slipping with Water in Tank

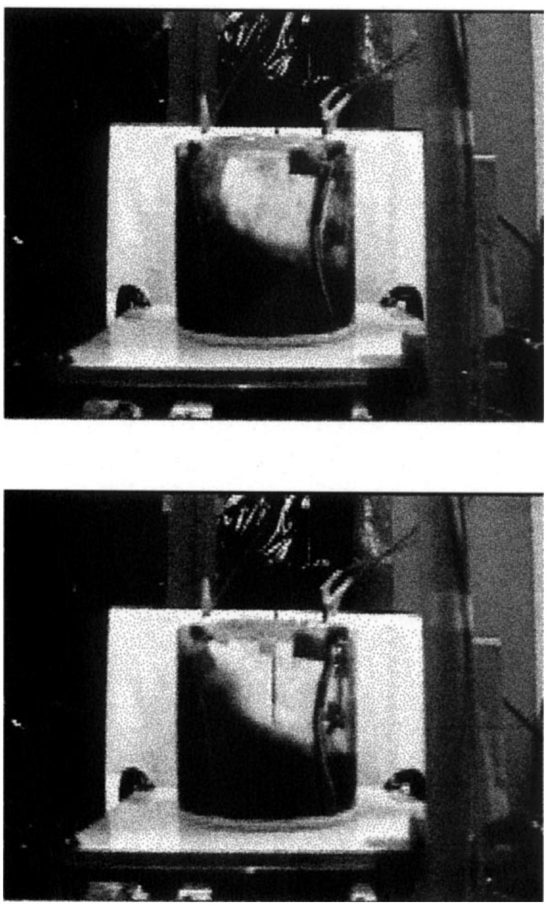

Fig. 7 Sloshing Mode (H_l/R_l=1.07)
Upper Photo:2.07Hz, Lower Photo:2.50Hz