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Experimental study on tsunami wave load acting on storage tank in coastal area

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A B S T R A C T

Damage to storage tanks in coastal area due to tsunamis can cause extensive fires. In order to prevent damage to storage tanks, tsunami wave loads acting on a storage tank have to be investigated. This study aims at investigating the features of the tsunami wave loads and the method for estimating them. In a wave basin, the tsunami wave load acting on a storage tank is measured under both conditions of the presence of the surrounding tanks and of no surrounding tanks. Inundation depth and horizontal velocity on the storage site are also measured under the condition of no surrounding tanks, which are used for estimating the tsunami wave load. The vertical component of the tsunami wave load is estimated by buoyancy based on the static pressure calculated from the inundation depth. The horizontal component of the tsunami wave load is estimated by Morison equation. The analysis shows that Morison equation estimates the measured impulsive force at the beginning of the inundation.

1. Introduction

Damage to storage tanks in large industrial complexes can lead to a spill of gas or oil, which is one of the main causes of extensive fires. Fires in large industrial complexes can last long and spread out surrounding areas because a large amount of gas and oil is stored. A massive tsunami struck the northeastern coast of Japan in 2011. The tsunami caused serious damage to large industrial complexes facing the sea. In several industrial complexes, there were extensive fires.

A huge tsunami generated at Nankai trough located south of Japan is predicted to strike Japan in the near future. That means that the Nankai trough tsunami will strike large industrial complexes located along coastlines. Therefore, we need to take countermeasures against tsunami striking in large industrial complexes. In order to prevent damage to storage tanks in large industrial complexes, tsunami wave loads acting on them have to be investigated and estimated. Tsunami wave loads acting on structures have been conducted by many researchers.

Cross (1967) investigated the tsunami impact forces acting on vertical walls. Ramsden and Raichlen (1990) measured the fluid force and the pressure acting on vertical walls due to bore. Recently, tsunami wave load acting on three dimensional structures has been conducted. Asakura et al. (2002) measured the fluid force acting on structures on land by tsunami overflowing into the land. The Federal Emergency Management Agency FEMA (2008) indicated a procedure for estimating tsunami wave load. Arnason et al. (2009) measured the tsunami wave load acting on vertical columns and the water particle velocity around the columns in detail. Fire and Disaster Management Agency of Japan FDMA (2009) proposed an equation for estimating tsunami wave load acting on a storage tank. Fujima et al. (2009) measured a pressure distribution on a model building on land due to tsunami inundation flow. Nouri et al. (2010) measured the fluid load and pressure due to bore acting on both cylindrical and square structures placed on a dry bed. Arimitsu et al. (2012) measured tsunami wave load acting on vertical columns and proposed an equation for estimating the tsunami wave load. Wei et al. (2015) computed tsunami bore load acting on bridge piers using SPH. Shafiei et al. (2016) measured the tsunami wave load and pressure acting on a square prism structure. However, few studies have been conducted in which tsunami wave load acting on cylindrical storage tanks were investigated. In addition, the

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influence of the presence of surrounding storage tanks on tsunami wave load acting on a tank has not been investigated.

In this study, tsunami wave loads acting on model storage tanks were measured under both conditions of the presence of the surrounding storage tanks and of no surrounding tanks. The target storage tank is a relatively smaller tank whose volume is less than 2000 kl. The reason for it is that a large number of storage tanks with the volume of less than 2000 kl are placed in coastal zones of Osaka Bay, Japan, which is one of the areas that the Nankai trough tsunami will strike. The experiment was conducted in a wave basin, in which horizontally two-dimensional fluid motion is generated. From the measured tsunami wave load, the features and the estimation of the tsunami wave load acting on the storage tanks were discussed.

2. Hydraulic experiment

2.1. Experimental setup

The hydraulic experiment was conducted in a wave basin at Technical Research Institute, Naruo, Toyo Construction Co., Ltd. The wave basin is 30 m long, 19 m wide and 1.5 m deep. Tsunami waves like solitary waves were generated in the wave basin by piston type wave maker which has the maximum stroke of 1.5 m. A model harbor was constructed in the wave basin shown in Fig. 1. A model storage site on which model cylindrical storage tanks were placed was located in the model harbor. The blue rectangle in the figure is the storage site, which is 1.8 m long and 2.9 m wide. Yellow slender structures in the figure are breakwaters. In the model storage site, 12 cylindrical storage tanks can be placed in total. Tsunami waves were obliquely incident on the storage site. The model cylindrical storage tanks were made of acrylic plastic and were 15 cm in diameter and 10 cm in height. Fig. 2 shows a plan view of the storage site. The cylindrical storage tanks are numbered as shown in the figure (1—F, 1—M, 1—B and so on). Fig. 3 shows a photograph of the model cylindrical storage tanks placed on the model storage site. The storage site was surrounded by walls against oil spill. The walls were 1.0 cm high. The model scale was assumed to be 1:100. The diameter and height of the cylindrical storage tank used in this experiment are 15 m and 10 m in prototype, respectively. This is not a huge tank but a relatively smaller tank. However, this is our target storage tank as mentioned before.

The water surface elevation was measured offshore (in front of the wave maker). The inundation depth on the storage site was measured at each point where cylindrical storage tanks were placed by capacitance-type wave gauge. The horizontal water particle velocity 1.0 cm above the surface of the storage site was measured at each point of cylindrical storage tanks by electromagnetic velocity meter installed on the surface of the storage site. The horizontal and vertical tsunami wave loads acting on the cylindrical storage tanks were measured by three-component force transducer installed under the surface of the storage site. Fig. 4 shows a rough sketch of the cross section of the force measuring device. There was a gap of 2 mm between the cylindrical storage tank and the surface of the storage site in order to measure the tsunami wave load. Therefore, the inundated tsunami also flowed under the cylindrical tanks. The water surface elevation, the inundation depth on the storage site, the horizontal water particle velocity and the tsunami wave load were recorded at the sampling rate of 1000 Hz. All the recorded data were analyzed without using any filter.

2.2. Procedure for measurement

Two kinds of incident wave were generated in the wave basin. The one (Wave 1) is a wave like a solitary wave with the maximum rise in the water surface of 6.9 cm at the offshore measuring point. The other (Wave 2) is that of 9.7 cm at the offshore measuring point. Wave 1 has the maximum rise in the water surface which is equivalent to a typical tsunami height striking the southern coast of

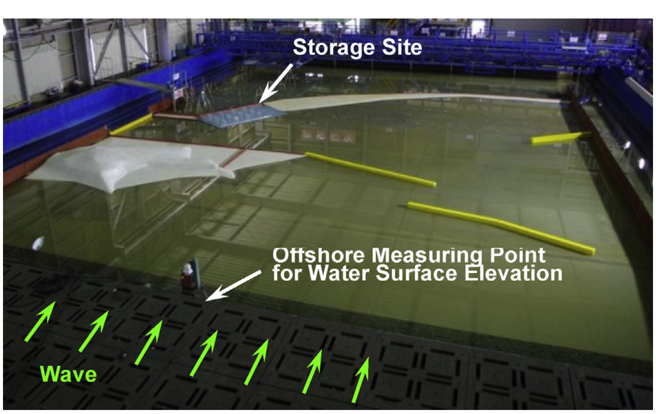

Fig. 1. Wave basin and model harbor.

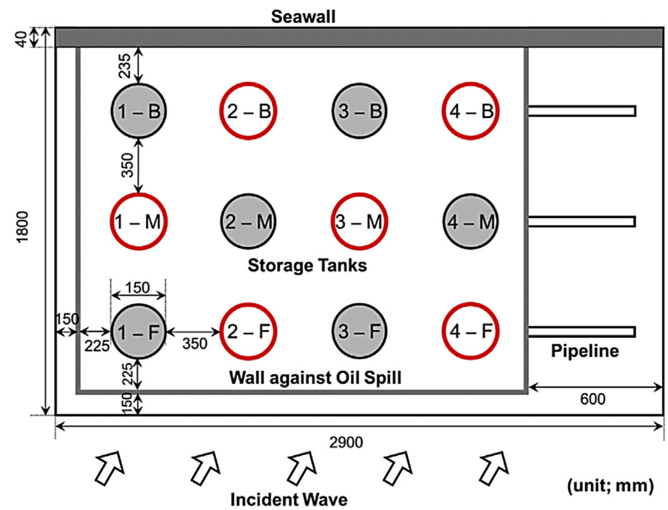

Fig. 2. Plan view of storage site.

Fig. 3. Cylindrical storage tanks placed in industrial complex.

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