# Effect of Caisson Tilting on the Sliding Distance of a Caisson under Wave Impacts and Introduction of the Effect into Computation of Sliding Distance

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## Abstract

Based on the recent laboratory experiments (Kim *et al.* 2004), comparisons of caisson sliding distance are made between the computations and experiments. The time history model of wave force, which is proposed by Tanimoto *et al.* (1996), is modified in the standing wave part of horizontal and uplift wave forces because of the overestimation of the time history model. The comparison between experimental and computational sliding distance has showed that the caisson tilting increases the resistant force to the horizontal sliding. Therefore, a titling resistant force, which is caused by caisson tilting, is introduced into computation of sliding distance.

*Key words*: Time History Model of Wave Force, Caisson Sliding Distance, Caisson Tilting, Tilting Resistant Force

## 1. Introduction

Since Shimosako and Takahashi (1998 and 1999) proposed a deformation-based reliability design method (Level 3) for caisson breakwaters, recently many studies (Takayama *et al.*, 2000; Goda and Takagi, 2000; Goda, 2001; Takahashi *et al.*, 2001; Hanzawa *et al.*, 2003; Kim and Takayama, 2003) on applications of reliability design method into caisson breakwaters have been carried out with the concept of expected sliding distance (ESD) of a caisson. The ESD of caisson is a statistical value given as an average value of caisson sliding distance (horizontal displacement) during its service lifetime. In the computation of caisson sliding distance (SD), previous studies have a common feature that considers only the horizontal wave force and resistant friction force between caisson and rubble mound without considering the effect of caisson tilting. However, according to the recent laboratory experiments (Kim *et al.*, 2004), the caisson tilting largely affects the sliding distance of the caisson. Therefore, the objectives of present research is to investigate the effect of caisson tilting on the caisson sliding distance based on the experimental results, and to introduce the effect into computation of caisson sliding distance.

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## 2. Hydraulic experiments on the sliding distance and tilting of a caisson

The hydraulic experiments (Kim *et al.*, 2004) were carried out in the wave flume (50 long × 1.0 wide × 1.5m deep) in Ujigawa Hydraulic Laboratory of Disaster Prevention Research Institute, Kyoto University. Two different water depths ($h$=0.4m and 0.55m), and various incident (regular) wave heights and periods ($H_I$=0.15-0.30m, $T_I$=1.5-2.5sec) were employed for caisson model tests. The caisson weights ($W_{\mathrm{air}}$) in air were determined to be as light as the caisson can slide by wave action and were given as 130 and 150kg for $h$=40m, and 170 and 190kg for $h$=55m. Figure 1 and Table 1 shows the outline of experimental set-up and experimental cases, respectively. Especially, water pumps were set in the rear place of caisson to suppress water level rise due to wave overtopping. In Table 1, the symbol × and △ indicates the experimental data which are not used for data analysis on the sliding distance and wave force, respectively, because of too large motion of caisson or noises of data.

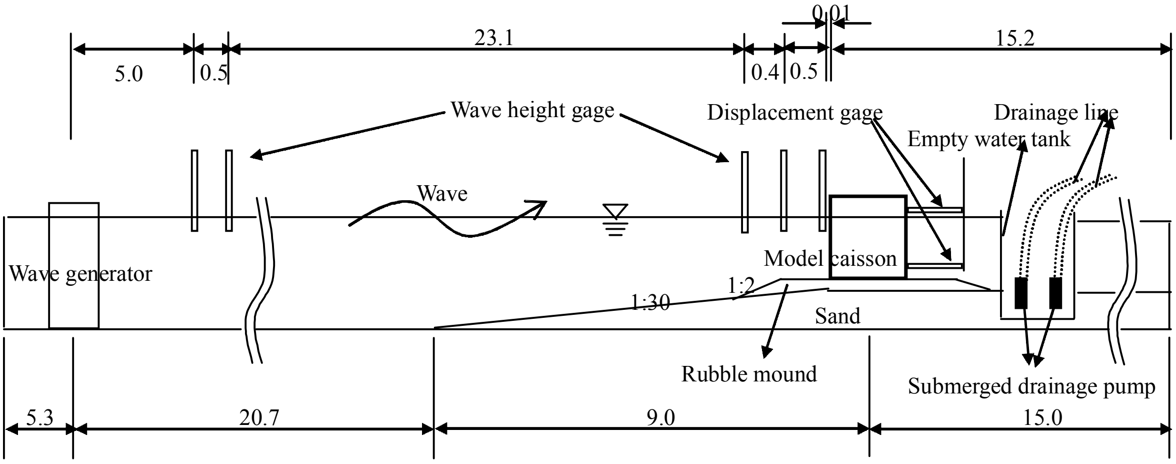


Fig 1. Outline of experimental set-up (unit:m)

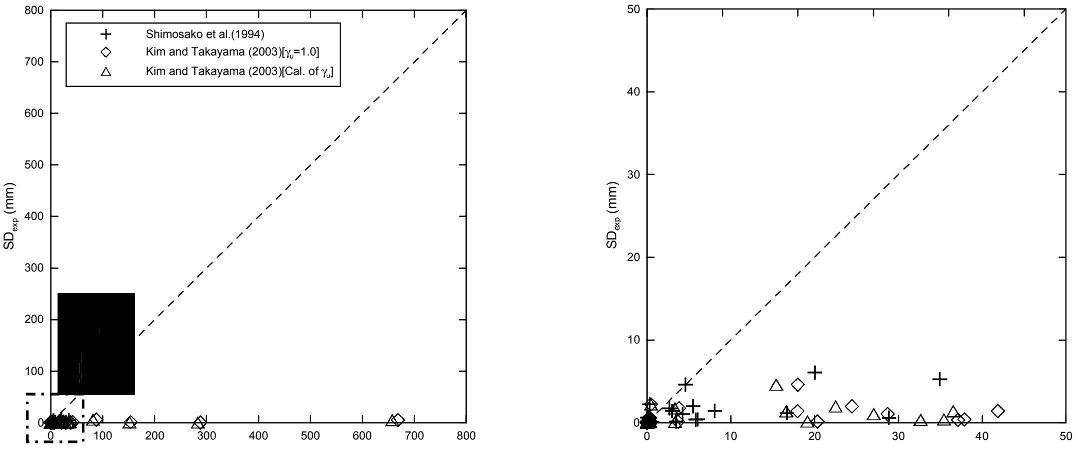
Table 1. Experimental cases

| Set No. | Incident wave conditions | | Water depth($h$)=0.40m | | Water depth($h$)=0.55m | |
|---|---|---|---|---|---|---|
| | $H_I$ | $T_I$ | $W_{\mathrm{air}}$=130kg | $W_{\mathrm{air}}$=150kg | $W_{\mathrm{air}}$=170kg | $W_{\mathrm{air}}$=190kg |
| | | | **(C1)** | **(C2)** | **(C3)** | **(C4)** |
| S1 | 0.15 | 1.5 | | △ | ×△ | ×△ |
| S2 | 0.20 | 1.5 | | | ×△ | ×△ |
| S3 | 0.25 | 1.5 | | | ×△ | ×△ |
| S4 | 0.30 | 1.5 | | | | ×△ |
| S5 | 0.15 | 2.0 | | ×△ | ×△ | ×△ |
| S6 | 0.20 | 2.0 | | | | ×△ |
| S7 | 0.25 | 2.0 | | | | |
| S8 | 0.30 | 2.0 | △ | △ | | |
| S9 | 0.15 | 2.5 | | △ | ×△ | ×△ |
| S10 | 0.20 | 2.5 | | | | |
| S11 | 0.25 | 2.5 | △ | △ | ×△ | |
| S12 | 0.30 | 2.5 | ×△ | ×△ | ×△ | |

## 3. Results

### 3.1 Comparisons of sliding distance between the experiments and computations

To investigate the validity of existing SD calculation models (Shimosako *et al.*, 1994; Kim and Takayama, 2003), comparisons are made between experimental and computational sliding distances as shown in Fig. 2. The symbols $SD_{exp}$ and $SD_{cal}$ represent the experimental and computational SD, respectively. The $SD_{cal}$ computed by our SD model is divided into two kind of solutions according to the modification factor $\gamma_u$, which indicates the reduction rate of uplift standing wave force due to the occurrence of impulsive wave force; one is $SD_{cal}$ (○) computed by setting as $\gamma_u=1$, and the other is $SD_{cal}$ (△) cmputed by using the equation of $\gamma_u$ derived by authors (Kim and Takayama, 2003: Eq. (17)). However, Fig. 2 shows that the value of $\gamma_u$ does not strongly affect sliding distance. The computational sliding distances are larger than experimental sliding distances. Especially, it should be noted that SD calculation model proposed by authors significantly overestimates to the experimental SD.

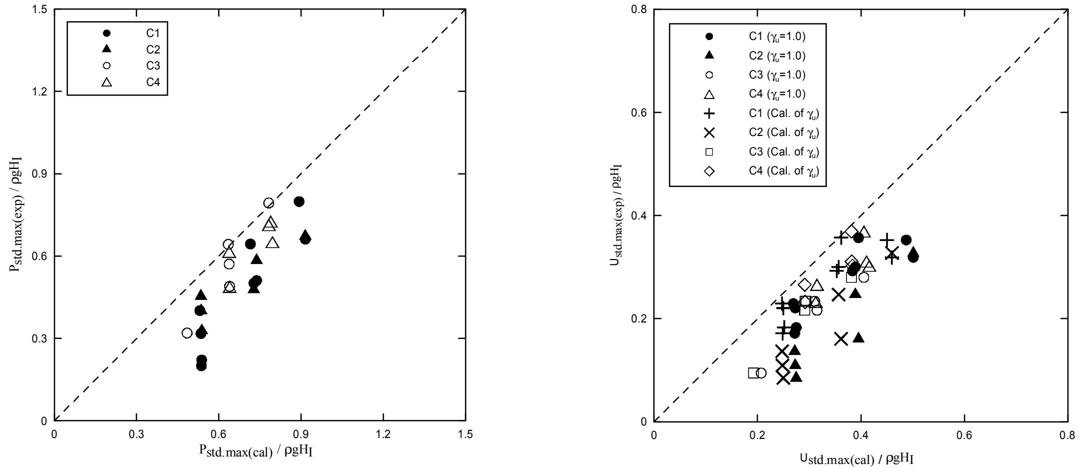


(a) Total result (b) Details in A

Fig 2. Comparisons between computational and experimental sliding distance

### 3.2 Modification of wave force-time history model

The validity of wave force-time history model, which is proposed by Tanimoto *et al.* (1996), was investigated through comparisons with experimental data. The max. impulsive wave forces of time history model closely agree with experimental data, but the max. standing wave forces computed by time history model are larger than experimental data as shown in Fig. 3. Resultantly, the computed max. wave forces are averagely 21% and 26% for horizontal and uplift wave forces, respectively. Based on experimental data, therefore, the time history model is modified by decreasing the standing wave force in time history model.

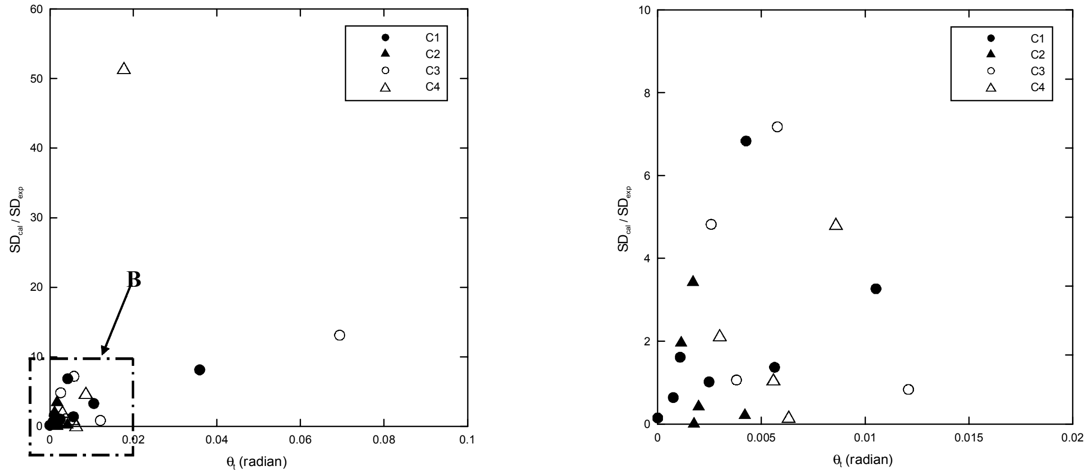


(a) Horizontal wave force (b) Uplift wave force

Fig 3. Comparisons of max. standing wave force between the experiments and time history model

### 3.3 Effect of caisson tilting on sliding distance of caisson

Figures 4 show the relation between $\theta_t$ and SD ratio ($SD_{cal}/SD_{exp}$). The symbol $\theta_t$ represents the caisson tilting, which is defined as tilting angle of caisson under wave action. The symbol $SD_{cal}$ indicates the value calculated by SD calculation model (Kim and Takayama, 2003) for the modified time history model. As the tilting angles become large, the computed sliding distances become larger than those measured in the experiments. Namely, the experimental sliding distance is more decreased than the computed one because of the effect of caisson tilting.



(a) Total result (b) Details in B

Fig 4. Relation between $\theta_t$ and $SD_{cal}/SD_{exp}$

### 3.4 Computation of sliding distance considering the effect of caisson tilting

To introduce the effect of caisson tilting on caisson sliding distance, a tilting resistant force $R(\theta(t))$, which is induced by the caisson tilting due to the driving moment of wave force acting on the caisson, is empirically formulated based on the experimental data. The sliding distance of caisson is evaluated by the following dynamic equation:

$$\left(\frac{W}{g}+M_a\right)\frac{d^2x_G}{dt^2}=P(t)-F_R(t)-R(\theta(t)) \qquad (1)$$

where $x_G$ , $g$ and $t$ denote the sliding distance of a caisson, the gravitational acceleration and the time, respectively, and $W$ and $M_a$ represent the weight of a caisson in air and the added mass. The details of $R(\theta(t))$ and the computational results will be presented in the conference because of limitation of this paper number.

## 4. Conclusions

In the present work, comparisons of caisson sliding distance were made between the computations and experiments. The computational sliding distances are larger than experimental sliding distances. Two kind of reasons were found out through this research; one is the overestimation (averagely 21% and 26% for horizontal and uplift wave forces, respectively) of standing wave force in the time history model of wave force, and the other is the effect of caisson tilting on the sliding distance. The comparison between $\Theta_t$ and SD ratio ($SD_{cal}/SD_{exp}$) has showed that the caisson tilting increases the resistant force to the horizontal sliding. Therefore, based on the experimental data, the time history model of wave force was modified, and the tilting resistant force was introduced into the computation of sliding distance. The computation of sliding distance can be improved by considering the tilting resistant force.

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