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Calisal, S. M.; Akinturk, A.

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Modelling Water Discharge onboard Ships

S M Calisal* and A Akinturk**

*University of British Columbia
Mechanical Engineering Department
2324 Main Mall, Vancouver BC CANADA V6T 1Z4

** National Research Council
Institute for Ocean technology
Kerwin Place, PO Box 12093
St John's NL CANADA A1B 3T5

ABSTRACT

Water collected on decks due to waves or result of accidental structural damages cause loss of stability by what is known as the free surface effects. This study focuses on the modeling of the discharge of the collected water in order to establish relationships between the geometrical characteristics of an open deck or damaged hull - its beam, height of the gap (e.g. freeing port)- and wave parameters such as wave length and wave height. . A two-dimensional model of the discharge was constructed to visualize the free surface and to measure the flow discharge from a flat bottom. In this study, lengths corresponding to the flooded width of the ship, initial water height corresponding to the collected amount of water on deck and discharge gap height corresponding to the freeing port opening were varied systematically. The time domain discharge flow pattern and free surface form were recorded with a digital camera. The digitized frames were captured on a computer and the location and the form of the free surface were computed. The change in volume, discharge rate velocity at the freeing port and various parameters of the discharge kinematics were calculated from knowledge of the free surface. Additionally, CFD solutions to the problem were carried out. This paper reports some of the findings related to the variation of discharge gap height and tank length.

KEYWORDS: green water, water on deck, water discharg

INTRODUCTION

Water collects on open decks of ferries, by a "scooping" action of waves, or as a result of accidents, thus further causing loss of stability. To address this concern various experimental studies were done by researchers to establish the minimum requirements for freeboard to avoid water accumulation on deck at a given sea state [1-3]. Numerical studies in this field include modeling of green water on deck for ship motion calculations, e.g. [4], or loads on the floating body [5], simultaneous intake and discharge through an opening on a floating or submerged body [6], to name a few.

Discharge rates from a two-dimensional model representing a section of a ferry was experimentally studied at the University of British Columbia. The effect of initial water height inside the discharge tank on the discharge rates was reported in [7][6]. The model, initially full of water, was drained by instantaneously opening a freeing port. The measurement of the form of the water surface in the tank and the water discharge rates were the primary objectives of this study. One of the main observations from that experiment was that discharge rate initially accelerated. It took a relatively short time but the flow parameters continuously changed. Similar observations were made when the length of the flooded section of the discharge tank was varied.

Previous work done on steady waterfalls suggested that the depth Froude number of the flow should be equal to one (Fn = 1). However, our experimental work with various initial flooded lengths, as well as initial water heights [7], suggests that the depth Froude number of the discharge flow from the decks is time dependent. Discharge

Froude number based on the water depth starts at zero and increases to a limiting value (different values for different cases) and then starts to decrease.

EXPERIMENTAL MODEL

Modeling Water Discharge

A water tank shown in Figure 1, was constructed with ½ inch clear Plexiglas to simulate the freeing port. The inner dimensions of the tank are: 6 feet long, 1.5 feet high and 1 foot wide. The tank is sealed at one end and water is only allowed to run out of the discharge end. An adjustable gate was installed on the discharge end to control the height of the discharge port. An elastic device was used to open the piano hinged door to start the discharge. The stored energy in the elastic device allowed the quick opening of the door, without interrupting the water flow. A dexion table with four height-adjustable feet was also constructed to support the tank. The adjustable feet allowed the proper adjustment of the table so that the tank was perfectly level. For experiments where a shorter tank length was required, a piece of 1/2-inch Plexiglas divider was placed at the desired location with sufficient support at the back and sealed properly to prevent water leakage.

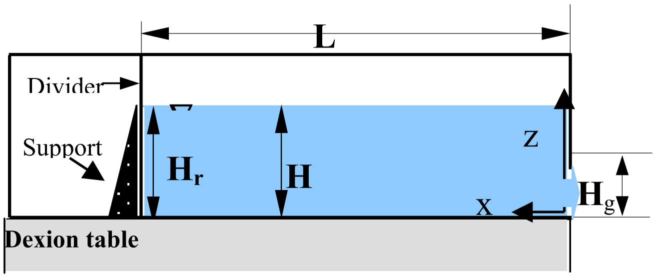

Figure 1. Model for water discharge

Parameters of interest:

In these experiments floodable length (L), initial water height before discharge (H), and height of the discharge gap (H_g) were varied systematically. During the experiments free surface profiles were recorded with a digital camera for later processing to obtain the coordinates of the free surface along the tank and the discharge in time.

Experiments were carried out for the following values of the parameters:

Table 1

Parameter	Values
L (m)	0.61, 1.22, 1.83
H (m)	0.15, 0.25, 0.36
H_g (mm)	50.8, 101.6, 152.4

In total, there were 27 experiments excluding the repeated ones. However, in this paper results for various L and H_g values are presented.

SOME EXPERIMENTAL RESULTS AND DISCUSSIONS

This section presents results obtained in varying the flooded length and the height of the opening for discharge. In obtaining the parameters of interest, such as Froude numbers based on the water height at the far end of the tank, images recorded during the experiments were analyzed and the profiles of the free surface inside the tank were estimated. One such sample image given in Figure 2 together with the estimated free surface profile superimposed on it. It is interesting to note that there was a wave formed inside the tank, which persisted for some time during the discharge in the experiments. The resolution of the images varied with varying flooded lengths: the camera had to be moved away to cover the whole length. At the lowest setting, one pixel corresponded approximately 0.44 cm, such is the case for the figure shown. An error of ±1 pixel in estimating the location of the free surface corresponds to approximately 3.5% full scale. This particularly caused problems at lower water heights and slower discharge rates as the variation of the profile was smaller than the resolution between the time steps. This issue particularly affected Froude number calculations, as it required the estimation of the water heights at the each ends of the tank (Eqn 1). Froude number is based on the water height for the tank defined as:

$$\mathrm{Fn} = {(Q/A)} \Big/ {\sqrt{g * \mathrm{Hr}}} \tag{1}$$

Where Q is the discharged volume per unit time (flow rate), A is the exit cross sectional area, g is the gravitational acceleration and Hr is the water height at the rear end of the flooded section.

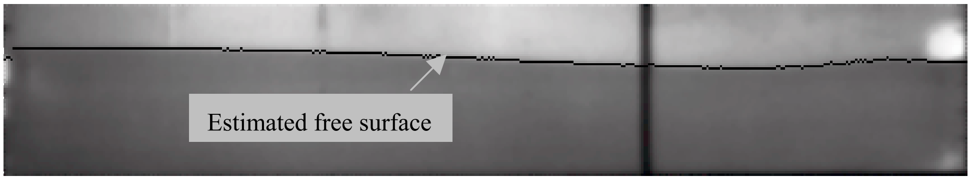

Figure 2. Estimated free surface profile (black line) superimposed on the original image ($L = 1.83$m, $H = 0.25$m and $H_g = 50.8$mm)

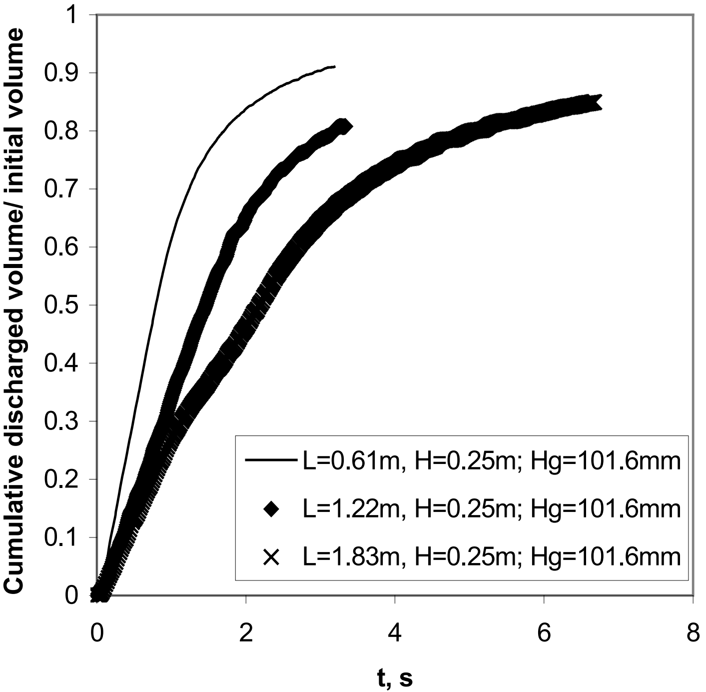

Figure 3 The effects of the flooded length on the cumulative discharged volume/initial volume ratio

The next two figures show the effects of flooded length and the height of the opening on the discharged volume, respectively. As one may expect, the longer the tank, the longer it takes to discharge. Initially, as Figure 4 shows, the discharge rates are the same. However, as expected longer ones are able to maintain higher discharge rates longer. In Figure 5, the corresponding Froude numbers are given. The general trend is that with the instantaneous opening of the gate, the Froude number starts with a non-zero value, reaches around one, and then decreases to zero in time. Again the longer lengths are able to maintain higher Froude numbers longer. There is also a common characteristic of the curves: their oscillatory nature. This might be due to:

- Insufficient resolution in estimating the heights at each end of the tank. Froude number, as given in Eqn. 1, is a function of both of the heights.
- The wave formed inside the tank, e.g. the one given in Figure 2. There will be fluctuations in the water level due to wave, and this will in trun affect the heights

The effects of the height of the opening for discharge are given in the following figures. As one may expect, the smaller the opening is, the longer it takes to discharge (Figure 6). However, for Hg =101.6mm and Hg = 152.4mm, the difference seem to be very small. The discharge rates for these two cases are also very similar (Figure 7). In the experiments reported in this study, there are really two phases of the flow:1) Water level inside the tank is higher than the height of the opening, i.e. there is a pressure head; 2) Water level inside the tank is less than the height of the opening. In the case with the largest opening, the second phase is reached earlier. Though the figures may suggest that for a given length and initial water height, there might be an optimum opening, further investigation is required at this stage to confirm this. The trends in the Froude numbers are similar to the previous case: an increase to a value around one, fluctuate for some time and drop to zero eventually. The reasons given above for the fluctuations are valid in this case as well.

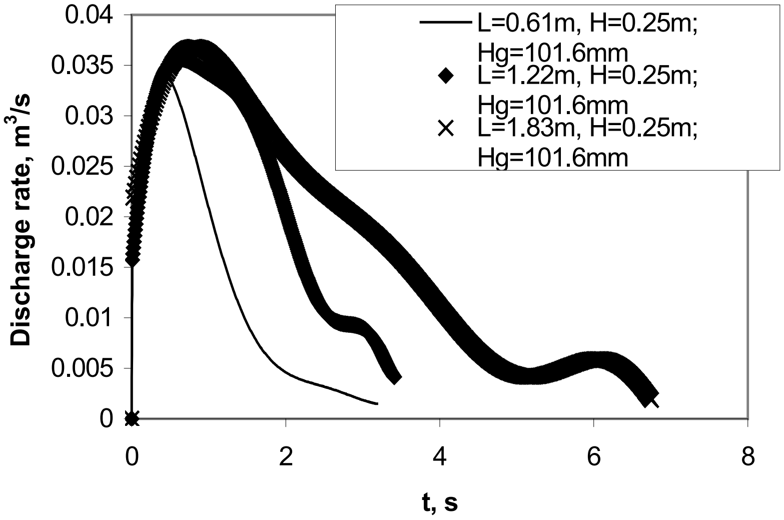

Figure 4 The effects of the flooded length on the discharge rates

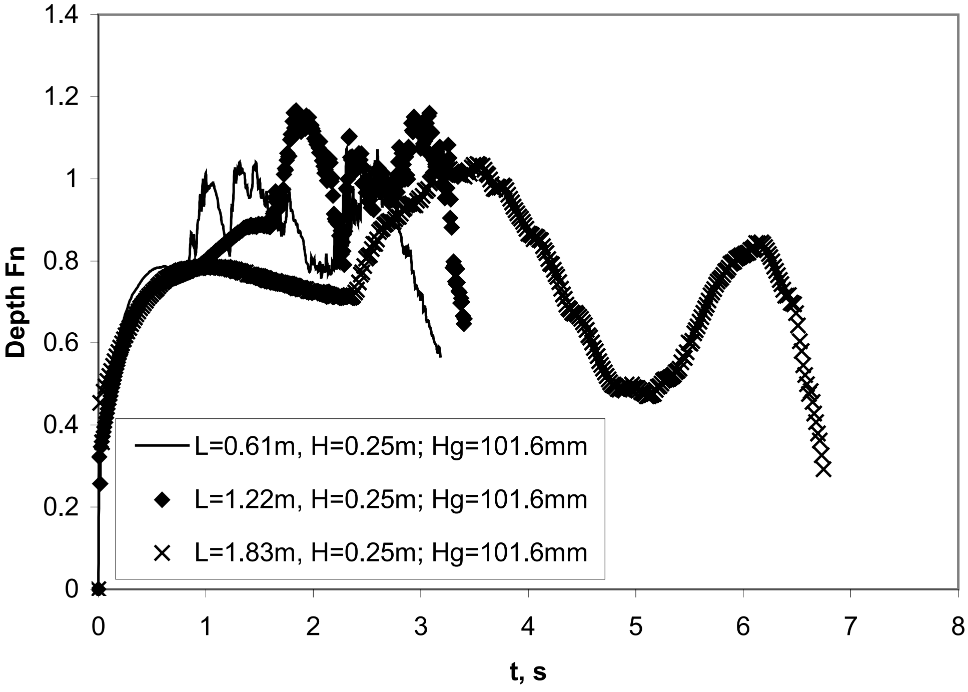

Figure 5 The effects of flooded length on Froude numbers

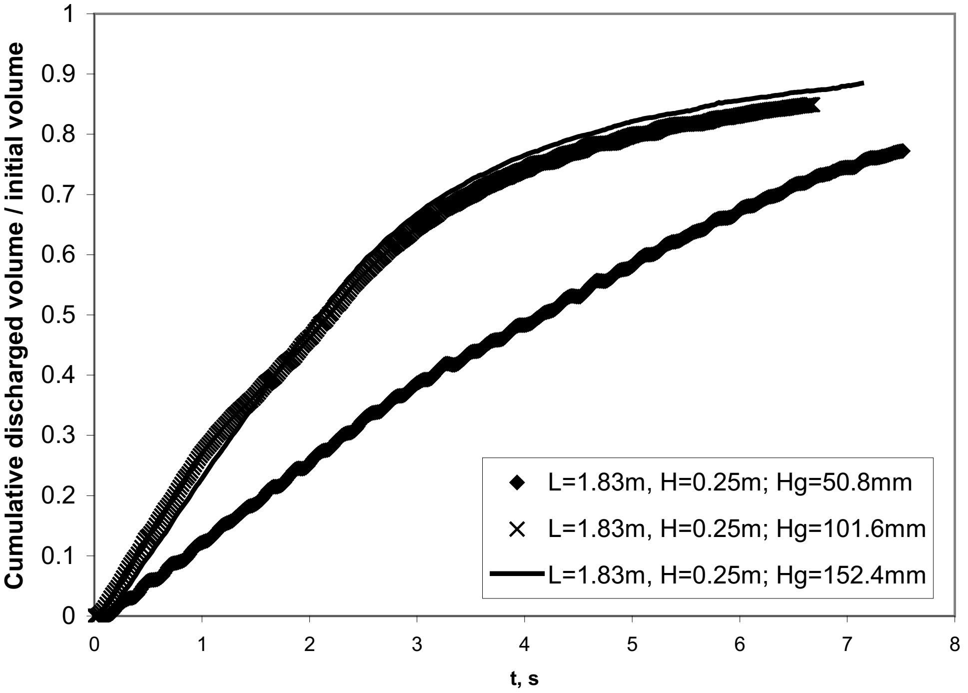

Figure 6 The effects of the height of the opening for discharge on the cumulative discharged volume/initial volume ratio

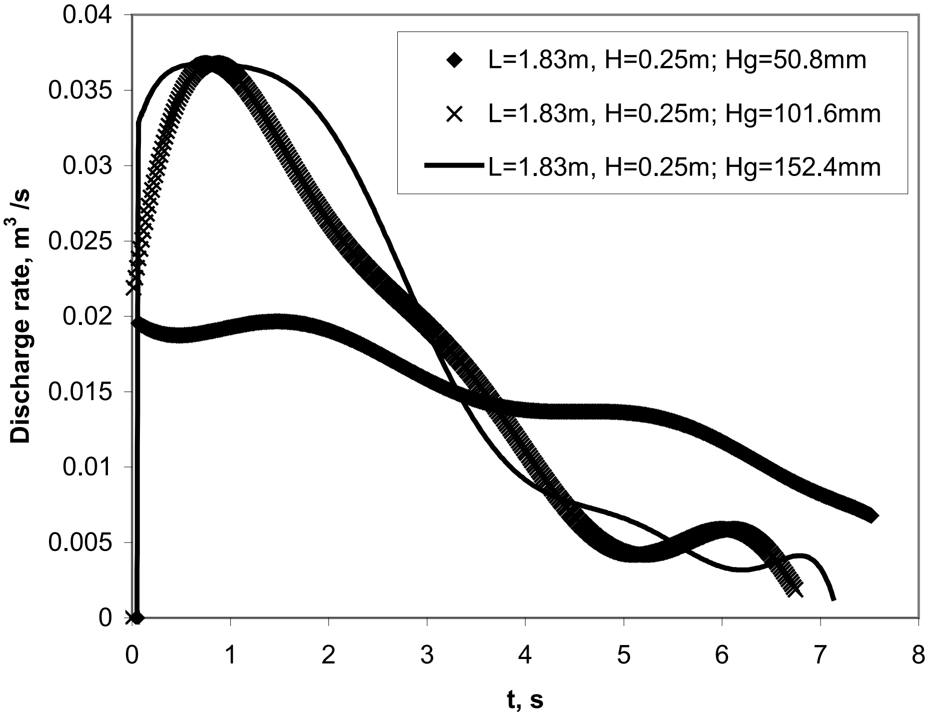

Figure 7 The effects of the height of the opening for discharge on the discharge rates

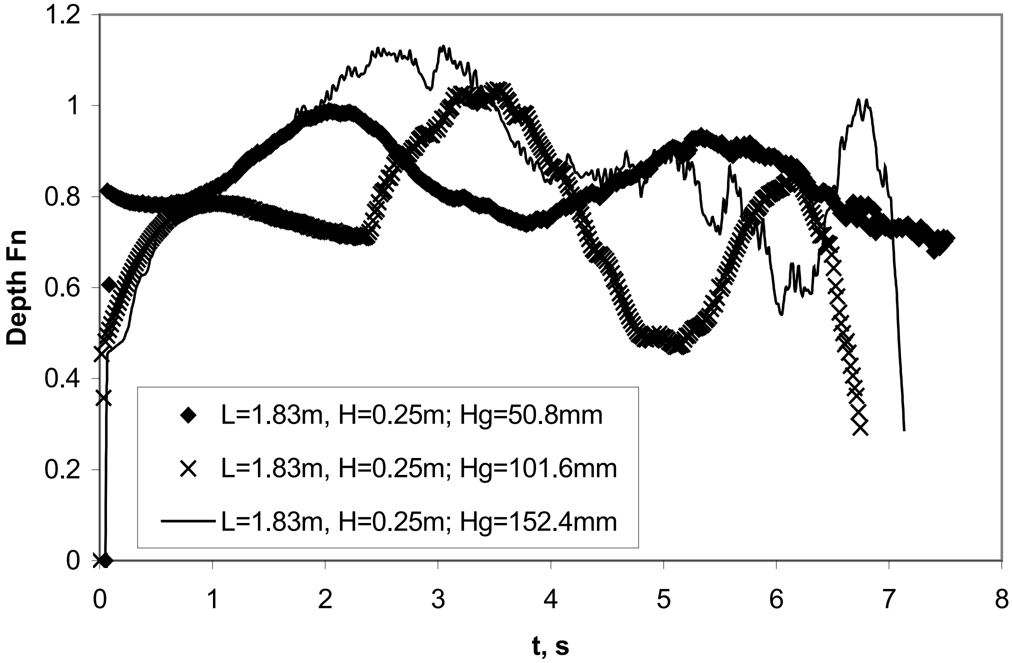

Figure 8 The effect of the height for discharge on Froude numbers

FINAL REMARKS

The present findings of this study are as follows:

- During the discharge experiment, Fn varies in time for the duration of a test. The nature of the variation is influenced by the flooded length of the discharge tank.
- Fn is also depend on the size of the opening.
- A general trend emerges from the experiments that the Froude numbers start with a value less than one, increase to a value around one, fluctuate and then decrease to zero eventually.
- The accuracy level in these results is not sufficient to confidently confirm that Froude number exceeds one However, it is evident that it is certainly not constant during the discharge.

NOMENCLATURE

A	Cross sectional area of the exit opening (m^2)
a	Wave amplitude (m)
C	Wave propagation velocity (m/s)
d	Water depth (m)
F_n	Depth Froude number (see equation (1))
f	Wave frequency (Hz)
g	Gravitational acceleration (m/s^2)
H	Initial water height inside the tank (m)
Hg	Height of the opening (for water discharge) (m)
Hr	Water height at the rear end of the tank (m)

h	Average water height inside the tank (for water collection experiments) (m)
hw	Nondimensional average water height inside the tank (for water collection experiments)
L	Flooded length of the tank (m)
Q	Volume flow rate (m^3/s)
R^2	Correlation coefficient
sqrt	Square root
T_{nw}	Non-dimensional time (2Lf/C)
T_S	Surface tension for water (N/m)
T_w	Wave period (1 / f) (s)
t_n	Non-dimensional time (t*sqrt(g/Hr))
λ	Wave length (m)
ρ	Density of water (kg/m^3)

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