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Effect of Ship Bow Overhang on Water Shipping for Ship Advancing in Regular Head Waves

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Abstract: This paper presents the results of an experimental investigation dealing with the effect of bow overhang extensions on the quantity of shipping water over the foredeck in case of ships advancing in regular head waves. To perform this investigation, a series of free-running tests was conducted in regular waves using an experimental model of a multipurpose cargo ship to quantify the amount of shipping water. The tests were performed on five bow overhang variants with several combinations of wavelength and ship speed conditions. It was observed that the quantity of shipping water was affected by some parameters such as wavelength, ship speed, and bow shape in terms of an overhang extension. The results show the significant influence of an overhang extension, which is associated with the bow flare shape, on the occurrence of water shipping. These results involve the combined incoming regular waves and model speed.

Keywords: water on deck, shipped water amount, ship model tests, bow overhang, green water, regular head waves

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1 Introduction

Water shipping and deck wetness are terms used to define a phenomenon that occurs when a ship, usually in harsh weather conditions, encounters waves that exceed the freeboard and wet the deck. Deck wetness refers not only to “white water” related to the spray from wave crests that encounter the ship bow or side but also to a solid bulk of sea water, the so-called “green water,”exceeding the freeboard and running over the forecastle or side of a ship. It is also used to distinguish between the spray splashed and real solid seawater on the deck. Ship safety is affected by freeboard and bow height parameters according to load line regulation, where a cause of sinking is the water shipping phenomenon essentially caused by strongly nonlinear relative motions between a ship and waves.

Many studies have been conducted on the water shipping phenomenon, but only a few provided quantitative information about the amount of shipping water trapped on the deck, which can be relevant to the dynamic behavior of ship motion in the presence of waves. When considering that the amount of shipping water trapped on the deck changes overtime because of water out-flow through openings and over the bulwark, the dynamic behavior of the ship is an important issue regarding ship stability, and the water on the deck may dramatically change the loading of the ship compared to its dry deck conditions.

To assess the effect of water shipping on ship stability, it is critical to estimate the amount of shipping water on the deck. In extreme cases, the ship might even capsize and sink because of the weight of water taken on board.

The effect of geometric parameters characterizing a ship bow is far from being understood. Moreover, sometimes, it is unclear whether they enhance or reduce water shipping. As an example, O'Dea and Walden (1984) reported that an increase in bow flare angle reduced the deck wetness; on the other hand, Lloyd *et al*. (1985) observed more frequent freeboard exceedance and deck wetness for heavily flared bows. Fundamental investigations are thus necessary to improve this lack of knowledge. In fact, Hamoudi (1993) quantified the deck wetness for a container ship by measuring the impact pressure due to the force in the longitudinal direction and the collected mass of green water on the deck. The main conclusion drawn from the results of the experimental investigation conducted by Hamoudi (1993) is that the mass of water shipping on the deck mainly depends on the vertical water-ship relative motion and vessel advancing speed.

Furthermore, several investigations of the effects of bow shape on water shipping were conducted by Watanabe *et al*. (1989), Buchner (1995; 1996), Buchner and Voogt (2000), Pham (2008), and Bellezi *et al*.(2013). It has been stated that green water can cause damage to sensitive equipment such as the fluid swivel, piping, turret structure, and chemical storesin the bow region. In fact, recent experiences with floating production, storage, and offloading vessels (FPSOs) in the North Sea confirmed that green water loading can cause serious damage in the bow region. This can result in repairs and downtime of vessels.

Although green water is an important design issue, not much is known about its complex and nonlinear phenomena. To design an FPSO against green water for harsh environments, it is important to identify influencing parameters on green water occurrence in the bow area. Buchner (1995) investigated ship motion, relative wave motion, and drift forces of FPSOs in harsh environments.

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These parameters are determined to be complex and considerably nonlinear in survival waves. Later, Rainey (2007) reported that drift forces have weakly nonlinear effects of second order caused by nonlinear wave potential effects. Moreover, Greco *et al*. (2012); Greco and Lugni (2012) performed a combined experimental and numerical study to investigate wave–ship interactions involving water shipping events. Therefore, a three-dimensional weakly nonlinear potential flow solver based on a developed weak-scatterer hypothesis and the physical aspects of global variables such as ship motions (heave and pitch) were analyzed. Moreover, local variables such as wave elevation and relative vertical motion were analyzed. As numerically predicted by the weakly nonlinear method, the results show that nonlinearities connected with global and local variables are retained up to the second order, with the exception of the statement made by Greco *et al*. (2012), Greco and Lugni (2012) relative to wave–ship interactions in a near-bow region where the fully nonlinear problem has to be solved to describe the run-up and predict green water. Thus, the understanding of this phenomenon is still arousing more attention for research on design issues, such as the effect of bow shape and efficiency of shielding breakwaters. Over a long period of time, observed water shipping resembles a dam-break-type phenomenon. Based on this theory, Greco *et al*. (2007) experimentally and numerically investigated the case of a fixed barge-shaped structure in a two-dimensional framework. In model tests, the occurrence of dam-breaking-type water was noticed. Moreover, a parametric analysis of the water-on-deck phenomenon has been performed in terms of local incoming waves and bow flow features.

After the loss of numerous bulk carriers at sea in the early 1990s, International Maritime Organization (IMO) (1999) focused on protecting foredeck fittings for bulk carriers against water shipping loads and minimizing the impact of such loads on forehatch covers. It was concluded that the deck wetness and water shipping loads were very sensitive to bow height and advancing speed of bulk carriers. However, bow shapes marginally change the deck wetness. Furthermore, Standing (1997) concluded that bow shape is important, but no clear trend emerged from model testing. It is generally beneficial to maximize the freeboard.

On the basis of justified conclusions made by Buchner (1998), with an increase in the bow flare angle, a decrease in the water height and an increase in the water velocity are observed. Impact pressures and global loads clearly decrease with an increasing bow flare angle. Ogawa *et al*. (2002) found that the occurrence of the deck wetness can be determined by comparing the water height with the maximum bow height. Moreover, they performed an experiment using a Japanese domestic tanker and a cargo ship model in regular head waves. A model test was conducted to determine the shipping water height distribution, load, and pressure due to the deck wetness. The most important conclusion shows that the effect of the local freeboard on the volume of shipping water, load, and pressure was more important than that of bow flare shape. Ogawa (2012) investigated the effect of the bow height and flare shape on the deck wetness using the long-term prediction method for an assessment of the load line. It is reported that using this method, an assessment of the bow height of domestic Japanese ships from the viewpoint of the deck wetness was performed, and it was found that unless the bow flare form is extremely varied, its effect on green water load is small. However, the conclusion regarding the effect of bow shape on the volume of green water was not considered.

Barcellona and Guedes Soares (2003) performed a series of experiments examining the water shipping problem at zero ship speed. In addition to pressure force measurements, video imaging of the flow field in the way of the deck was performed. An analysis of the data indicates that there are two peaks to the time evolution of loading on the deck house front. The first peak is associated with the initial impact of water, and the second peak is the result of a backward plunging impact force. In this investigation, the incoming wave steepness was varied, and its influence on both the global features of water shipping and loading on deck structures was investigated. Possible relevant factors in terms of deck and wall designs have been indicated. It has been deduced that the velocity along the centerline can be scaled with limited data scattering, regardless of the bow form and wave steepness.

Fonseca *et al*. (2005) performed an experimental investigation of water shipping on the bow of a container ship in head regular and irregular waves of large amplitude, and measurements of absolute vertical motions, relative motions on the bow, height of water, impact pressure on the deck, horizontal impact pressure, and total force on the first line of containers on the bow were taken. It was found that the impact pressures and forces increase almost linearly with height of water on deck in regular waves.

Recently, some numerical methods were developed and applied forthe analysis of water shipping prediction. For example, Kazuya *el al*. (2009) developed a numerical analysis method based on the moving-particle semi-implicit method for simulating water shipping on a moving ship with a realistic bow shape. This method aims at avoiding issues regarding the application of mathematical models while using various parameters such as ship speed, heading angle, bow shape, and superstructure.

Greco and Lugni (2012) conducted a numerical investigation of wave–ship interactions involving the water-on-deck and slamming phenomena. They concluded that the volume of shipping water nonlinearly increases with wave steepness. The amount of liquid left on the deck appears to be associated with a saturation phenomenon as the steepness approaches a threshold. Although there are many theoretical and computational studies on the bow effect on the occurrence of water shipping, model-scale testing is still considered as the most reliable approach for practical purposes. In fact, among previous studies dealing with bow overhang effects on water shipping, the work of Pham (2008) investigated novel modifications to a ship bow as bow knuckle and overhang extensions. Pham (2008) concluded that the purpose of conducting green water tests using generic bow sections is to assess the effects of bow features on water shipping. Despite positive achievements in the research on water shipping modeling, it is beleived that performing a more comprehensive test series with improved modifications to the above mentioned water bow shape will help justify benefits and disadvantages associated with a particular bow feature.

Since the increase of computer power, numerical methods are often employed to investigate water shipping over the deck in the general context of nonlinear three-dimensional problems. Although results of suchnumerical methods are generally satisfying, experimental methods with model tests are still a practical means to qualitatively and quantitatively study the above mentioned phenomenon, including the natural nonlinear behavior of water shipping. In this context, most investigations of the water shipping phenomenon through experimental methods and numerical simulations have been extensively performed for stationary ships such as FPSOs. This was a reasonable assumption because of the nature of the services of FPOSs. On the other hand, multipurpose cargo ships rely on their speed to keep up with the tight schedule. In fact, water shipping occurrence on FPSOs is influenced by many factors such as freeboard height, bow shape, ship motion, and wave parameters that were previously investigated by numerous researchers. However, when ships are moving with forward speed, more dynamic disturbance is encountered, and the characteristics of water shipping become more complex and are additionally influenced by the combination of the forward speed and geometric hull form, especially the bow flare. The present experiment focused on the effects of bow overhang extensions on the amount of shipping water. The results can also be extended to update the formula specified in the IMO Load Line Convention 1966; the formula was exclusively established for the determination of the minimum bow height and freeboard. The numerical simulation to predict the volume of water shipping is notably challenging and requires a mathematical model that considers bow overhang extensions. Such a demanding study has been left for future work.

2 Model presentation

The tested model was designed from the body plan of an existing multipurpose cargo ship shownin Fig. 1.

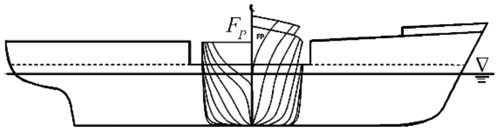


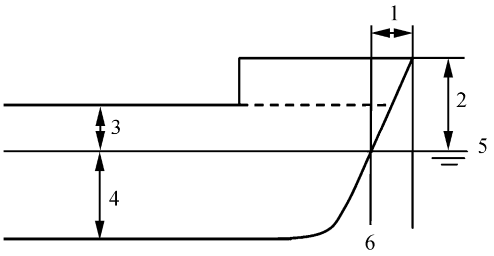
Fig. 1 Body plan and contours of multipurpose cargo ship

The model is made of glass-reinforced plastic and constructedata scale of 1:100. Model characteristics are presented in Table 1. Tests were performed using the same model provided with five bow overhang variants.

Table 1 Principal dimensions of the model ship

Type	Multipurpose cargo
Length between perpendiculars L /m	1.300
Breadth B /m	0.173
Depth D /m	0.085
Draught d /m	0.070
Freeboard F_d /m	0.015
Bow height F_b /m	0.078
Bow overhang B_o /m	0.048

A representation of bow overhang, which is an important parameter in the present study, is shown in Fig. 2.



1. Bow overhang B_o; 2. Bow height F_b; 3. Freeboard F_d; 4. Draught d; 5. Water line L_W; 6.Forward perpendicular F_P

Fig. 2 Representation of bow overhang B_o

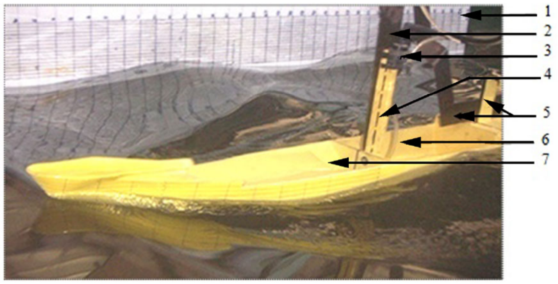
Bow overhang variants were obtained by increasing and decreasing bow overhang extensions, as presented in Table 2. The parent hull has a bow overhang extension of 0.048 m (model scale) for bow *B*. Note that the underwater hull shape was kept the same so as to obtain the same ship motion for all five bow variants and the same coefficient of fineness of a water plane area.

Table 2 Summary of tested bows

Bow	Overhang extension / m
Bow *A*	0.028
Bow *B*(Parent bow)	0.048
Bow *C*	0.063
Bow *D*	0.072
Bow *E*	0.083

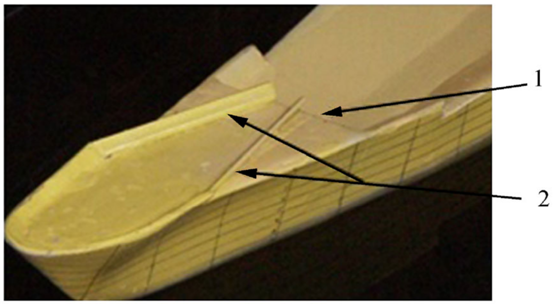
3 Model experiments

Model testing provides a useful means to quantify shipping water on the deck, including bow overhang effect, to investigate the influence of bow overhang extensions on the amount of shipping water on the deck. Therefore, a series of tests was performed on a model of a multipurpose cargo at the Seakeeping Basin of the Maritime Department at the University of Science and Technology of Oran "Mohamed Boudiaf". To conduct the tests according to recommended procedures and guide lines approved by the 26th Seakeeping Committee of the International Towing Tank Conference (ITTC), a special collecting tank, as shown in Fig.3, was centered approximately at the center of gravity of the model for gathering water that enters onto the foredeck, orienting it using two guide leaders toward the tank, and then trapping it inside the tank, as shown in Fig.4.



1. Rectangular ruler (Wave observatory); 2. Carrier blade; 3. Drain pump (to discharge the loaded water); 4. Coupled connection (see Fig.5); 5. Yaw elimination mechanism; 6. Suction and delivery straw; 7. Collecting tank

Fig. 3 Model description and experimental setup



1. Assembly position; 2. Guide leaders

Fig. 4 Bow and foredeck sections

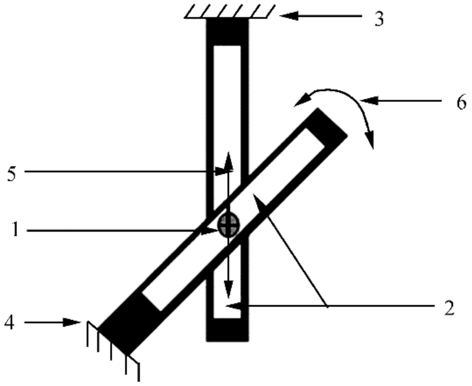
A small pump for discharging water is used to pump the instantaneous trapped water immediately out of the collecting tank. This prevents the model from sinking deeper and altering trim and inertia properties. Then, the amount of water collected is quantified.

Some different kits, as shown in Fig. 3, are fitted on the model deck only to keep a free pitch and heave motions of the vessel while advancing at a constant speed in regular waves. Rolling in water shipping would complicate the process, and thus, it was excluded from the tests.

The fore portion of the bow is presented in Fig. 4. The figure shows the assembly position for five interchangeable bow overhangs with an unchanged hull body of the model. It also shows guide leaders used for directing water flow to the collecting tank when water shipping occurs.

The connection between the model and carriage consisted of two guided blades: one is fixed to the model at its center of gravity and the other is fixed to the model carriage.

This would allow two degrees of freedom (pitch and heave); thus, other motions are eliminated to avoid complex interactions and mutual influences of each motion on others. These are the so-called cross-coupling effects.



1. Bolt; 2. Guide slot; 3. Blade fixed with the carriage; 4. Blade fixed with the model; 5. Heave; 6. Pitch

Fig. 5 Coupled connection description

The experiments were performed in a seakeeping basin (20 m length, 2 m width, and 1 m waterdepth). A plunger-type wavemaker was used to generate regular waves with different frequencies. The wavelength and height are controlled by varying the period of oscillation of the triangular plunger via a potentiometer. Although the vertical oscillation of the plunger can be considered strictly sinusoidal, the resulting wave differs in shape from a pure sine function, and thus, wave parameter determination was required. To determine wave parameters such as wavelength and wave height, a video camera and a vertical ruler were used. During the experimental setup, it was diffucult to keep the steepness (ratio of wave height to wavelength) fixed when changing the wavelength. This was because of a limitation in the digital controllability of the combination of the wave amplitude-to-stroke ratio and wave frequency of the plunger. This makes the current investigation more directed toward the study of the overhang extension effect on water shipping relating to the following parameters: wavelength-to-ship length ratio and forward speed.

The model was towed with a carriage at prescribed forward speeds. In the basin, waves were generated using a wavemaker on one side and damped at a beach on the opposite side to avoid wave reflection.

4 Test procedures and data measurement

Five head-sea regular waves were examined with heights, steepness, and lengths as presented in Table 3. Moreover, the ratio λ/L shown in Figs. 6−8 will be considered in further examinations.

To measure the wavelength, wave height, and wave steepness, a still digital video camera and rectangular ruler with 2 m length and 1 m height were used, as shown in

Fig.3. By observing frame-by-frame video images for wave crest and wave trough over the rectangular ruler of 10 mm mesh in the vertical direction, the wave height was obtained with an accuracy of about ±1mm. Moreover, the wavelength was obtained from photos of the wave motion, in which two consecutive crests were observable on the ruler of 50 mm meshed in the horizontal direction. The accuracy of the wavelength measurement was about ±2 mm. The quantity of shipping water on the deck of the model was quantified from water pumped out of the collecting tank. Different tests were performed to visualize the phenomenon of water shipping on the deck, and the test time was limited to a maximum of 26 s and consisted of a limited number of waves of 0.879–1.721 m in length.

Table 3 Incident wave parameters

Wavelength λ / m	Wave height H / m	Ratio/ λ/L	Wave steepness/ (H/λ)
0.879	0.076	0.676	0.086
1.020	0.056	0.784	0.054
1.290	0.046	0.992	0.035
1.600	0.044	1.230	0.027
1.721	0.030	1.323	0.017

First, a relationship between the model speed and water shipping on the deck is examined to determine the effect of speed on this phenomenon. Then, the influence of the five bow overhang extensions on water shipping on the deck of the model ship is investigated, and for each bow overhang, parameters such as the ratio λ/L and model speed were changed to quantitatively predict the behavior of water shipping. To extrapolate the quantity of shipping water on the model to full scale, the Froude scaling law is used according to recommended procedures and guidelines approved by the 26th Seakeeping Committee of the ITTC. The scaling factor of the quantity of shipping water is $1.025\alpha^3$, where the coefficient 1.025 represents the ratio between specific seawater density and fresh water density and α is the scale factor.

5 Results and discussion

5.1 Model speed effect on water shipping

For each bow overhang, a series of tests was conducted to quantify water loaded on the deck because of the model speed and incident wave on the bow region. It is confirmed that water shipping starts in the form of a plunging wave hitting the deck, often localized in the bow region. The obtained results, shown in Fig. 6, represent the relationship between shipping water and the model speed for five models with different bow overhang extensions.

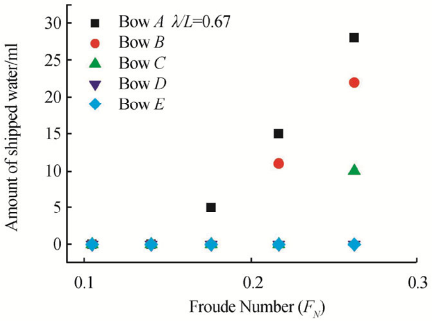
The results are also shown for five tested regular wavelengths λ. These results show that there is a link relating the speed of the model and volume of water loaded on the deck. The relationship is such that the water volume increases with continuously increasing speed. It was noted that bow overhang extension does not affect this relationship but affects the quantity of shipping water. In other words, the quantity of shipping water on the deck from the bow reduces as bow overhang increases.

As observed in reality and experiments, the amount of shipping water is very sensitive to forward speed. By considering the nonlinear ship geometry interaction with incoming wave parameters as coupled with ship speed, the relationship between the speed and amount of shipping water was determined to be an increasing function of the first, second, or third order. It was observed and reconfirmed through the results that water shipping occurrence is dependent on the wavelength-to-modellength ratio (λ/L). Moreover, for ships moving with forward speed, the most critical incoming wavelength in terms of the amount of shipping water is $\lambda = L$. The above mentioned dependence is very sensitive to bow overhang extension. This is clearly shown in Fig. 6; in case of a small extension of bow overhang (Bow *A*) when the ratio approaches the resonance frequency corresponding to $\lambda/L = 1$, there is a significant quantity of water flowing onto the deck.

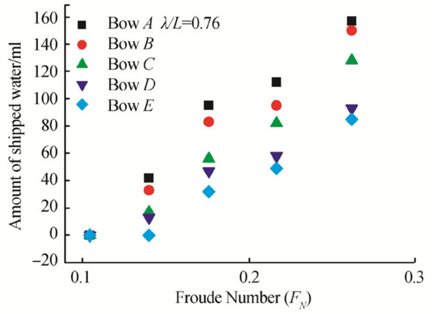
Furthermore, note that water shipping may only occur if and where the relative motion exceeds the local freeboard height around the bow region. The relationship between the forward speed and water quantity is presented in Fig. 7, where each bow overhang has been separately investigated. The results confirm the previous deduction about the influence of increasing model speed on shipping water on the fore deck. In this figure, it is evident that there was maximum quantity of shipping water when the ratio λ/L is around 1. Bow overhang extension coupled with the forward speed was found to cause greater vertical water–ship relative motions and hence more shipping water. On the other hand, this quantity depends also on other bow geometrical parameters such as bow flare, bow knuckle, and bow height. In summary, Figs. 6 and 7 represent the influence of the model speed on the amount of shipping water depending on wave parameters and bow overhang extension. Finally, it is well confirmed by plots in these figures that extended bow overhang reduces the relative quantity of shipping water. Thus, bow overhang represents an important factor in the water shipping phenomenon. Therefore, to optimize bow shape, it is necessary to introduce the bow overhang factor in ship design parameters.

5.2 Effect of wavelength on water shipping

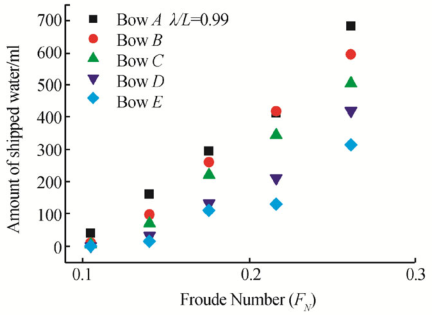
The results shown in Fig. 8 represent the relationship between the ratio λ/L and quantity of shipping water, which confirms in a more obvious manner that around the resonance frequency corresponding to the ratio between the wavelength and model length λ/L=1, the water shipping phenomenon becomes more severe, and the quantity of shipping water reaches its maximum. The reason for this can be found by considering the resonance between incident waves and ship vertical motions at the bow region.



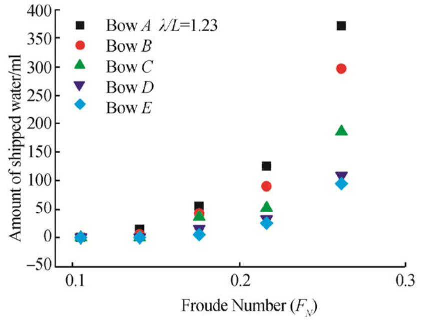
(a) λ/L=0.67



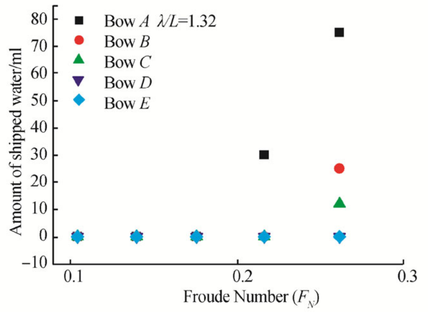
(b) λ/L=0.76



(c) λ/L=0.99

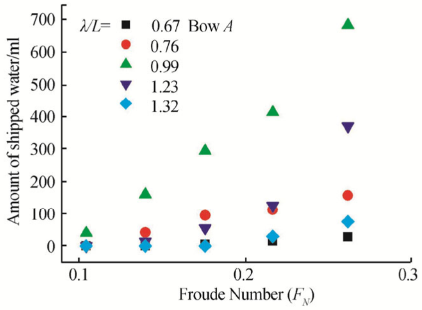


(d) λ/L=1.23

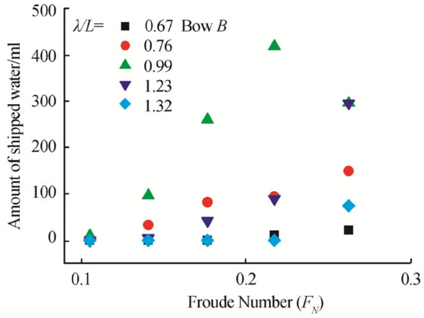


(e) λ/L=1.32

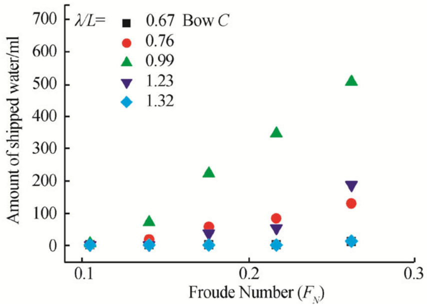
Fig.6 Amount of shipping water as a function of the Froude number for different λ/L values



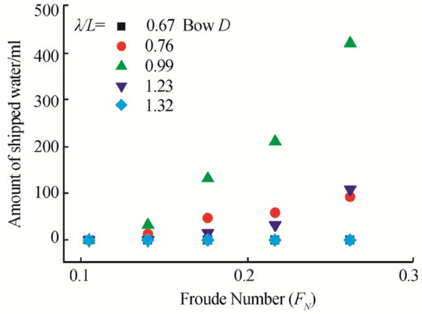
(a) Bow *A*



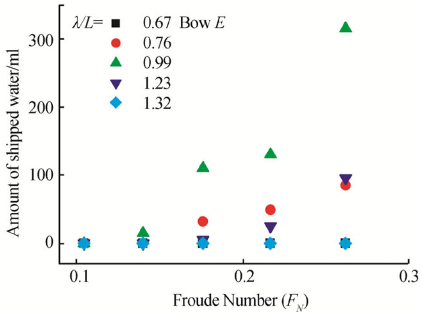
(b) Bow *B*



(c) Bow *C*

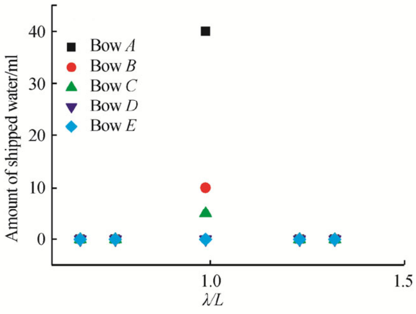


(d) Bow *D*

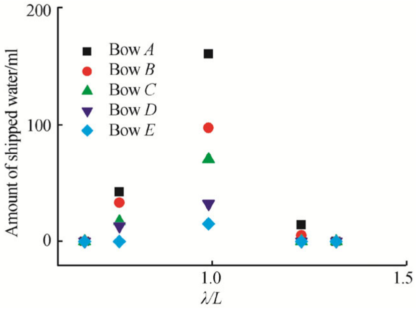


(e) Bow *E*

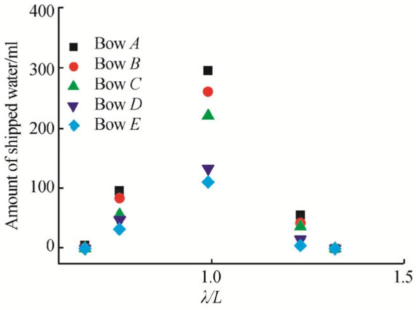
Fig.7 Amount of shipping water as a function of the Froude number for different bow overhangs



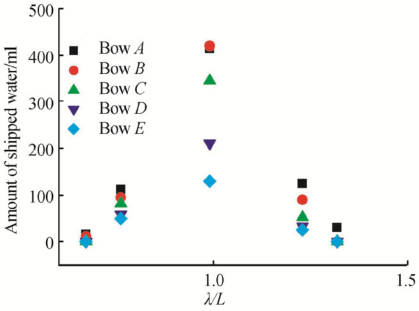
(a) *Fn*=0.104



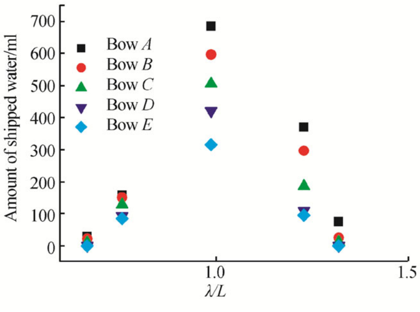
(b) *Fn*=0.140



(c) *Fn*=0.176



(d) *Fn*=0.216



(a) *Fn*=0.261

Fig. 8 Amount of shipping water versus *λ/L* ratio

The *λ*/*L* ratio was considered in all shown results as a very important parameter that affects the quantity of shipping water loaded on the deck. The results clearly indicate that the relationship between the quantity of shipping water and ratio *λ*/*L* is significant for each model speed and any bow overhang. Irrespective of the model speed, it is found and confirmed that the most critical incoming wavelength in terms of the quantity of shipping water is $\lambda = L$. However, bow overhang extension was confirmed to be an important geometric feature defining bow shape, such as bow flare and bow height.

The lowest values of shipping water occur for the shortest and longest wavelengths corresponding to *λ/L*=0.67 and 1.32, which match the wave steepness 0.173 and 0.035, respectively, as shown in Table 1. As plotted in Fig. 8, the shortest incident wave does not result in large amounts of shipping water on the deck. Nevertheless, for *λ*/*L*>1, water shipping appears to be less severe because the large wavelength-to-ship length ratio leads to a phasing between large incident waves and vertical motions of the bow, which tends to counteract the water-on-deck occurrence.

A similar analysis was conducted by Greco *et al*. (2012), Greco and Lugni (2012) on water shipping occurrence for the wavelength-to-ship length ratio *λ*/*L*=1.5 and Froude number *Fn*=0.189. It was expected that for longer waves, water shipping will decrease and tends to disappear.

5.3 Influence of bow overhang on water shipping

The main objective of the experimental work described above is to investigate water shipping on the model's deck, focusing on the influence of bow shape, particularly the bow overhang parameter. It appears that there is a large quantity of shipping water at the bow region and it increases even more at high speeds in head waves. The influence of bow overhang extension on the quantity of shipping water during the model tests is shown in Fig. 9. The effect of bow overhang extension is apparently significant in reducing the severity of water shipping. Hence, the bow overhang parameter cannot be neglected and should be included into the bow design through the bow height and bow flare.

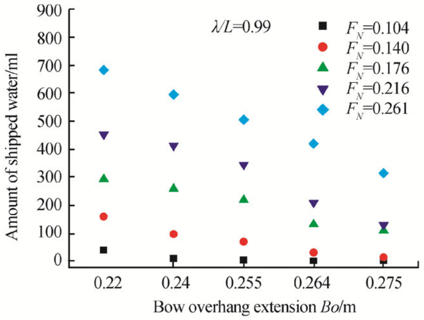


Fig. 9 Influence of bow overhang extension on shipping water

The experimental results showed that the modification of the bow by extending bow overhang improved the performance of the ship against water shipping flooding the forecastle around the bow region. Therefore, it is important to avoid large water flow induced by incoming waves on a moving ship's deck.

For this reason, the role of the shipping water measurement is significant. This phenomenon occurs when the free-surface motion exceeds the freeboard of the ship with the forward speed; this is considered to be significant. It is a notable challenge for ship safety because the amount and evolution of shipping water along the deck can damage deck structures in the bow region. Therefore, it can partly present a risk to stability if not drained in a timely manner.

6 Conclusions

Most previous research focused on water shipping height predictions and corresponding pressures, but bow overhang extension was not considered, not even in a CFD simulation because of its nontractable mathematical formulation.

Therefore, tests were performed in a seakeeping basin with regular head waves and different bow overhangs. A moving model of a multipurpose cargo ship was used to further investigate the relationship between bow overhang extension and water shipping. The main conclusions that can be drawn from the analysis of the experimental results are as follows:

It appears that water shipping strongly occurs when reducing bow overhang extension. Moreover, bow overhang features should be included among other factors such as freeboard height, wave steepness, and bow flarethat were investigated by previous studies. Abow overhang investigation is needed to improve the estimation of the amount of shipping water on the deck. This clearly implies that the extra hull volume caused by extended bow overhang reduces the area obtained on a ship's forecastle; therefore, the quantity of shipping water on the deck is reduced.

The relationship between the volume of shipping water on the deck and forward speed of the model has a certain trend, and the total volume of shipping water on the deck mainly depends on the model's forward speed. These results show a dynamic effect between the model speed and water flow onto the deck, whereby the amount of shipping water was mostly amplified. In this experiment, previous findings have been confirmed, and it has been found that water shipping is strongly related to the forward speed and λ/L ratio. Furthermore, bow overhang is found to be a significant contributing factor to water shipping.

The results found in the current investigation are in agreement with those of Pham (2008). The latter also showed that an increase in bow overhang extension reduces the quantity of water on the deck. In addition, an increase in the forward speed (Froude number) leads to an increase in the quantity of shipping water onto the deck. The experimental investigation of the quantity of shipping water is necessary for investigating the water flow rate over the bulwark. Contributing to bow design improvement, it is recommended that studies dealing with the deterioration of stability characteristics due to water on the deck should necessarily be performed in conjunction with associated IMO's works.

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