Model Experiment of an Offshore Supply Vessel Running in Astern Waves

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ABSTRACT

At the IMO (International Maritime Organization), the second generation intact stability criteria for pure loss of stability are now under development. In its latest draft, vessels with extended low weather deck such as offshore supply vessels (OSVs) are exempted from this application but its backgrounds have not yet been explained other than sample calculation reports of inconsistencies between different levelled criteria. To solve this problem, we executed model experiments for a typical OSV in astern waves and then identified that the OSV is not relevant to the phenomenon that the pure loss of stability criteria assume but is relevant to the phenomenon due to trapped water on deck. Further, effect of low weather deck length is investigated by systematically modifying hull forms with help of a CAD software.

Keywords: *IMO, Second generation intact stability criteria, pure loss of stability, water on deck, OSV*

1. INTRODUCTION

The second generation intact stability criteria to be developed by the IMO are requested to cover stability failure due to pure loss of stability in following and stern quartering waves (Umeda & Francescutto, 2016). For this failure mode, the direct stability assessment and two-layered vulnerability criteria should be developed. As a possible tool for the direct stability assessment, a coupled surge-sway-yaw-roll numerical model in irregular waves was developed and validated with model experiments using a containership (Kubo et al., 2012).

Based on the knowledge obtained from this numerical model, the level 1 and 2 vulnerability criteria were developed. Here the level 1 and 2 criteria utilize GM and GZ in longitudinal waves, respectively. The standards of these criteria were tentatively determined to avoid the “false negative” problem between the two levels in many sample calculation results except for offshore supply vessels (IMO, 2015). The sample calculations executed by two delegations indicate that offshore supply vessels easily comply with the level 1 but do not so with the level 2. This is a so-called “false negative” problem, which should be avoided in regulatory applications. Thus, the current vulnerability criteria are allowed not to be applied to “a vessel with extended low weather deck due to increased likelihood of water on deck or deck-in-water”.

However, its definition of the extended low weather deck, based on a model experiment or equivalent, was not yet established by 2015. In fact, even a published free-running model experiment of an offshore supply vessel in astern waves had not been available so far. Therefore, the authors newly executed a model experiment using a scaled model of typical offshore supply vessel in stern quartering waves and compared the obtained results with the second generation criteria. As a result, the reasons why OSVs should be exempted from the application of the pure loss of stability criteria are revealed. Furthermore, for investigating the effect of weather deck length, calculations of the vulnerability criteria were also conducted by systematically modifying above-water hull forms of the offshore supply vessel using a CAD software, i.e. the NAPA software.

2. SUBJECT SHIP AND MODEL EXPERIMENT

Free-running model experiments of the 60 m long offshore supply vessel (OSV), as shown in Fig. 1-2, in stern quartering waves were conducted at a seakeeping and manoeuvring basin of the National Research Institute of Fisheries Engineering of Japan. The vessel has a deck house in its fore part and a low weather deck situated from its midship to its stern with bulwarks and freeing ports. The length of the low weather deck is 35 m in full scale. Its service Froude number is 0.3 with twin propellers and twin rudders. Its principal particulars and righting arm curve are shown in Table 1 and Fig. 3, respectively. The metacentric height is set to marginally comply with level 2 criteria for pure loss of stability, which is lower than the designed one. The vessel under the experimental condition is judged not vulnerable to pure loss of stability with the level 1 criterion because the GM with the wave steepness of 0.334 is 1.32 m, which is much larger than 0.05m. However, it critically complies with the level 2 criterion with CR value of 0.06. Thus an inconsistency between the two levels could appear if the calm-water GM is smaller than 1.45m.

The vessel model ran with a constant propeller revolution and attempted to keep its specified course with a PD autopilot in stern quartering waves. The translational and rotary motions of the vessel model were measured by an optical tracking system, consisting of two theodolites and two prisms, an optical-fibre gyroscope, respectively. The model was rereleased when water waves were sufficiently propagated in the water area of the basin. These experimental procedures are based on the ITTC (International Towing Tank Conference) recommended procedures for intact stability model test (ITTC, 2008).

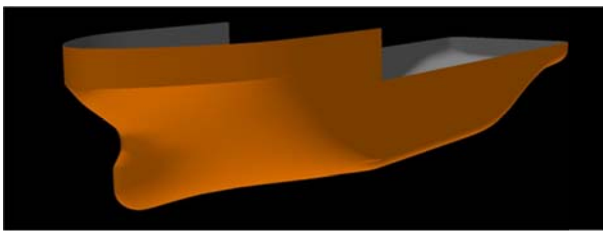

Fig.1 3D view of the hull form of the used OSV

Fig.2 Free-running model experiment of the OSV in astern quartering waves

Table 1 Principal particulars of the OSV

Items	Ship	Model
L_{bp}	60.00m	2.00m
Moulded Breadth	16.40m	0.546m
Moulded Depth	7.20m	0.24m
Moulded draught	6.00m	0.20m
Metacentric height (GM)	1.45m	0.0482m
Natural roll period	11.50s	2.10 s

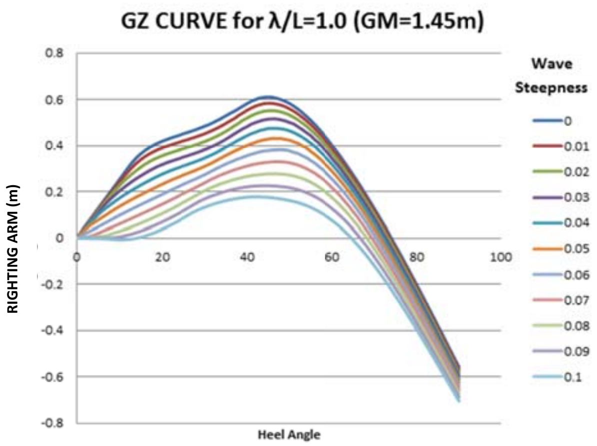

Fig. 3 GZ curve of the OSV at a wave crest amidship in longitudinal waves. Here the wavelength is equal to the ship length and the wave steepness ranges from 0 to 0.1

3. EXPERIMENTAL RESULTS AND DISCUSSION

The maximum roll angles measured during each model run in astern waves are shown in Fig. 4. Here the wavelength is equal to the ship length, as the worst case assumed in the criteria for pure loss of stability and the nominal Froude number ranges from 0.24 to 0.37 as also specified by the criteria. The used wave steepness H/λ, are 0.03, 0.05 and

0.1. The results indicate that roll angles under these wave and operational conditions are smaller than 15 degrees so that no real danger can be expected.

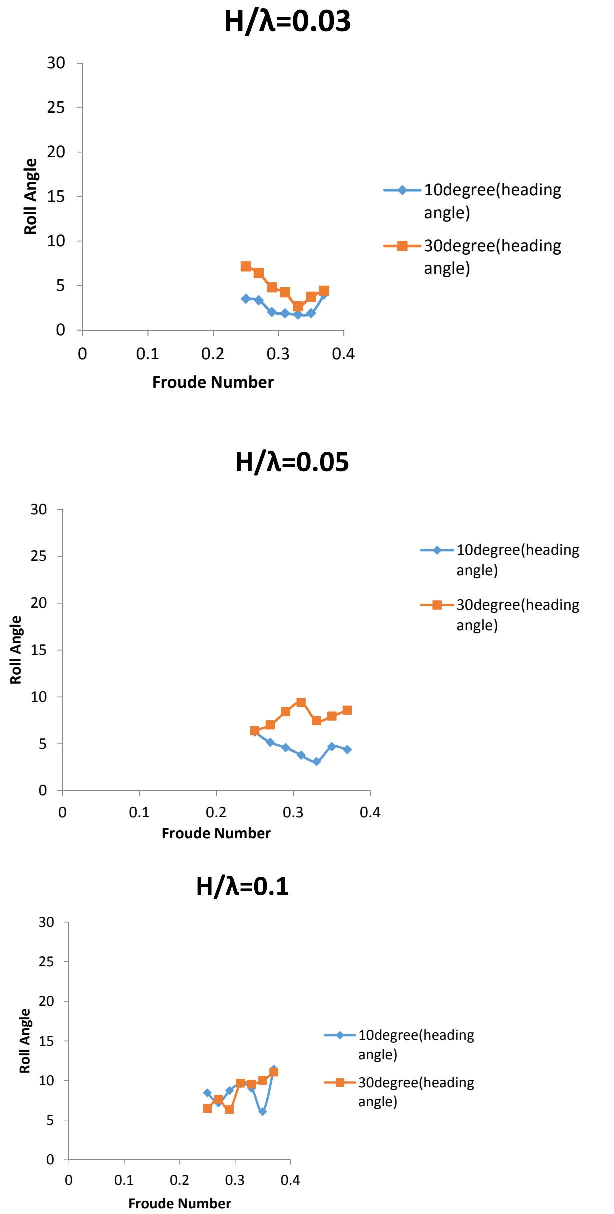

Fig. 4 Maximum roll angles (degrees) recorded in the experiment for the wavelength to ship length ratio of 1.0 and the wave steepness of 0.03, 0.05 and 0.1 with the auto pilot courses of 10 and 30 degrees from the wave direction.

This would be because the trapped water-on-deck acted as a kind of anti-rolling tank. This is because that the estimated natural period of possible trapped water on deck, which ranges between 1.8 s and 2.4s in model scale as shown in Fig. 5, is comparable to the natural roll period of 2.1s. The roll decay test of this model in calm water with large instantaneous initial roll angle was rapidly damped as shown in Fig.6. Thus, we can presume that this large roll damping is due to resonance of ship roll motion and the trapped water on deck. This is similar to a mechanism of an anti-rolling tank.

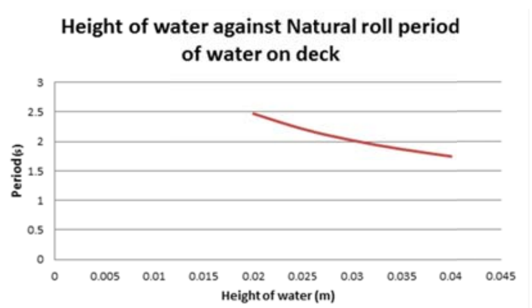

Fig. 5 Estimated natural period of trapped water on deck as a function of water depth.

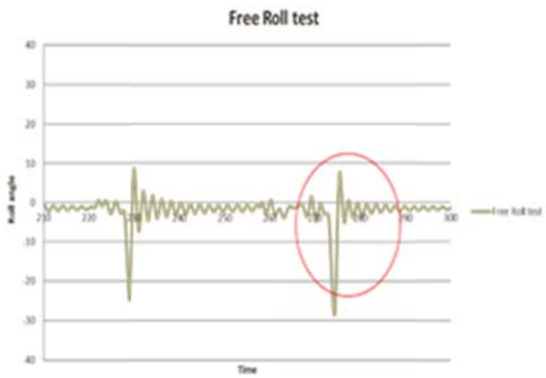

Fig. 6 Time series of roll decay test with the large instantaneous initial roll angle in degrees.

As a next step, model runs were conducted under longer waves. Here the ratio of wavelength to ship length, λ/L, was 1.5 and the wave steepness is 0.1. In this case larger water volume was trapped on deck because water ingress across the bulwarks exceeds egress though the freeing ports. The results shown in Fig. 7 indicate that larger roll angles such as about 50 degrees were recorded. When the speed decreases, the roll angle increases. This tendency is completely different from pure loss of stability.

The reason of the larger roll could be the heeling moment of trapped water-on-deck, which could depend on the height of bulwarks. In the case of this OSV, if the roll angle exceeds about 21 degrees, the relative water level exceeds the bulwark. As shown in the GZ curve for this wavelength as shown in Fig. 8, the loll angle is larger than 20 degrees and the angle of vanishing stability is slightly larger than 50 degrees. Thus, the bulwark submergence cannot be avoided at a wave crest amidship and then the maximum roll angle could be 50 degrees. This suggests that the reason of large roll seems to be hydrostatic heel moment due to water on deck.

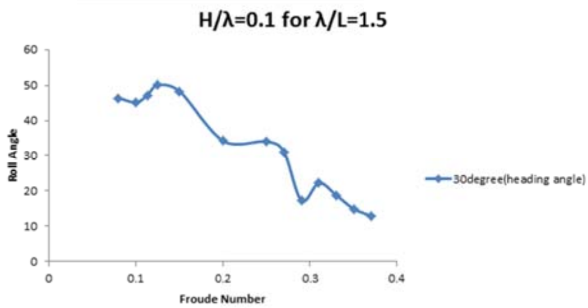

Fig. 7 Maximum roll angles (degrees) recorded each free running test for the wavelength to ship length of 1.5 with the wave steepness of 0.1.

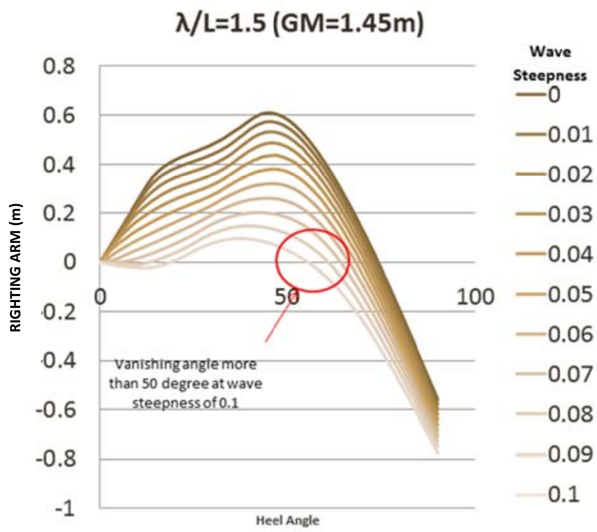

Fig. 8 GZ curve of the OSV at a wave crest amidship in longitudinal waves for the wavelength to ship length of 1.5 and the wave steepness ranges from 0 to 0.1.

For investigating mechanism of this dangerous phenomenon further, the coupled surge-sway-yaw-roll numerical model proposed by Kubo et al. (2012) was used for simulating the dynamic ship behaviour under the wave conditions used in the experiment. This is a manoeuvring-type model with linear wave exciting forces and restoring variation focusing on low frequency phenomena but the effect of trapped water on deck is not taken into account. All propulsion and manoeuvring coefficients as the input for the simulation model are estimated with conventional captive model experiments. The linear wave exciting forces and restoring variation were calculated by a slender body theory with low encounter frequency assumption and a direct pressure integral of incident wave pressure up to instantaneous water level, respectively.

The comparisons between the experiments and the simulations are shown in Figs. 9-10. For the higher speed case shown in Fig. 9, both the measured and calculated roll periods are twice the encounter wave period and different from the natural roll period. The maximum roll angle occurs whenever the ship centre meets a wave crest. Thus this could be a period doubling phenomenon due to restoring variation experimentally identified for containerships by Kan et al. (1990). The measured roll amplitude is much smaller than the calculated one so that the trapped water that is not included in the numerical model has a role to damp the roll motion as a kind of anti-rolling tank.

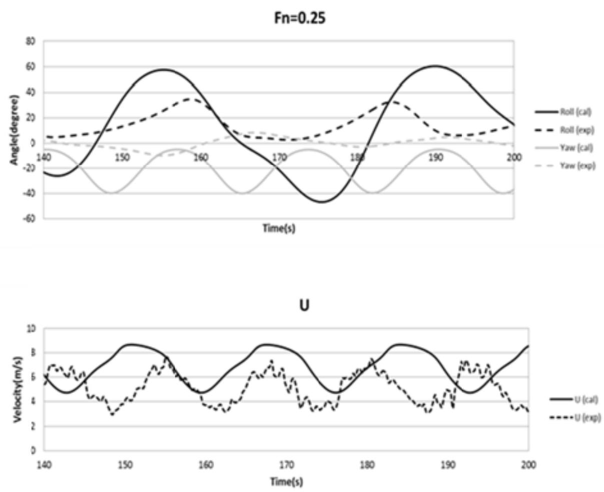

Fig. 9 Comparison between the simulation and the experiment for the wave steepness of 1/10, the wavelength to ship length of 1.5, the nominal Froude number is 0.25, the specific heading angle from the wave direction of 30 degrees and the rudder gain of 3.0. Here the positive roll means starboard side down and the positive yaw does starboard turn.

For the lower speed case shown in Fig. 10, the period doubling phenomenon were again found in both the experiment and the simulation. The measured roll amplitude is much larger than the simulated one. Furthermore, the mean of the measured roll angle is also larger than that of the calculated roll angle. This suggests that hydrostatic heel moment due to trapped water on deck, which is not included in the numerical model, has a crucial role for inducing the extremely large roll angle in the experiment.

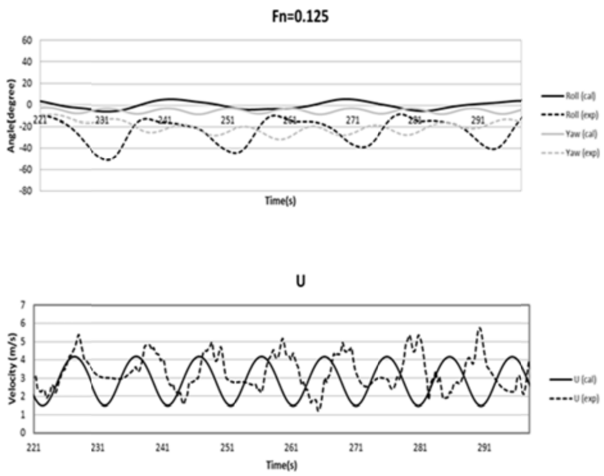

Fig. 10 Comparison between the simulation and the experiment for the wave steepness of 1/10, the wavelength to ship length of 1.5, the nominal Froude number is 0.125, the specific heading angle from the wave direction of 30 degrees and the rudder gain of 3.0.

4. EFFECT OF WEATHER DECK LENGTH

To create a proper definition for a vessel with extended low weather deck, the NAPA system was used to make systematically modified hulls of our offshore supply vessel (OSV) model.

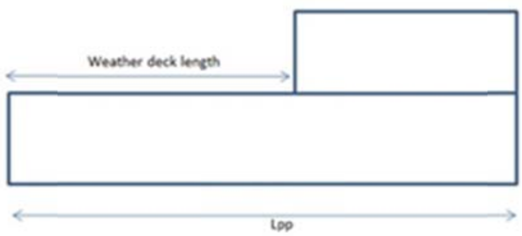

Fig.11 Simplified OSV with weather deck length definition.

The weather deck length, as defined in Fig. 11, was systematically modified with keeping other dimensions constant. Then the level 1 and 2 criteria were applied to the generated hulls. All modified hulls comply with the level 1 with directly calculated GM in waves because the required value is 0.05m. The level 2 criteria consist of two requirements: CR1 is based on the angle of vanishing stability and CR2 is based on the angle of heel under action of the speed-dependent heeling lever. The standard for these values are 0.06. Here the Froude number is set to be 0.25. The results are shown in Fig. 12. Thus, when the weather deck length is larger than half the ship length between perpendiculars, the CR2 value rapidly increases so that the vessel is judged as vulnerable to pure loss of stability. To avoid such “false negative” case, it can be recommended to include the low weather deck length in the definition of a vessel with extended low weather deck.

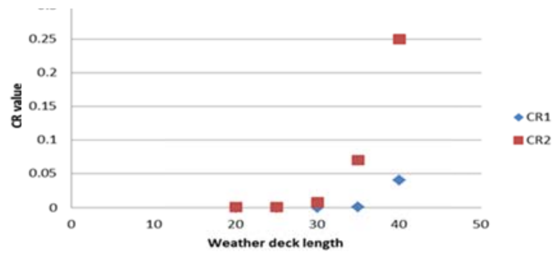

Fig.12 Weather deck length and CR values from Level 2 program results.

5. CONCLUSIONS

From this study, it can be concluded that pure loss of stability at higher speed in astern waves is not relevant to this OSV. However, large heel could occur due to trapped water on deck at very slow speed.

Based on the systematic hull modification survey, it also can be conclude here that, if the length of low weather deck is less than 0.5Lpp, it is not appropriate to apply the level 2 pure loss criterion to this type of ships.

6. ACKNOWLEDGEMENTS

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