CAPSIZING DUE TO BOW-DIVING

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Abstract

Recent model experiments by the authors indicated that bow-diving is one of the crucial capsizing modes for a ship traveling in following and quartering seas with high forward velocity, while only a few research attempts on this phenomenon have been reported so far [1]. In this paper, basic features of bow-diving are discussed with measured time series. It is concluded that bow-diving is associated with surf-riding and triggered with submergence of bow bulwark top. Statistic calculating of vertical distance between bulwark top and wave surface by Froude-Krylov assumption well explained the possibility of bow-diving.

1. INTRODUCTION

Even now small ships, such as fishing vessels, occasionally capsize when they run in heavy following and quartering seas with high speed. To resolve capsizing phenomena, we conducted capsizing free running model experiments in following and quartering seas using 9 models in Marine Dynamics Basin at National Research Institute of Fisheries Engineering (NRIFE). The main causes of capsizing in following and quartering seas are pure-loss of stability, broaching-to, parametric resonance and bow-diving. Broaching-to, pure loss of stability and parametric resonance could be theoretically well explained, but knowledge on bow-diving was very limited [2], [3]. Bow-diving is a phenomena that the bow plows into the water. It occurs from surf-riding without broaching-to in following and quartering seas and then she capsized with large negative pitch angle, sometime exceeding –20 degrees.

The effect of bow form on this phenomenon was discussed by Jullumstroee [4]. Renilson et al., compared experiments with a theory, but there are not enough agreements[5]. Taguchi et al. explained the phenomena by calculating water level at bow, but did not compare with experiments [6].

In this paper, firstly, we show free running model experiments of 3 types fishing vessels about bow-diving [7]. Secondary we discuss the relationship between bow-diving and water level at bow under the assumption that heave and pitch motions can be approximated by simply tracing their static equilibrium. Finally the effect of wave length is discussed with free running capsizing model experiments of a Japanese trawler.

2. EXPERIMENTAL OBSERVATION

Free running capsizing model experiments were carried out in the Marine Dynamics Basin at NRIFE using three types of fishing vessels, which are 80 gross tonnage-type Japanese purse seiner (Ship A), North European purse seiner (Ship B) and fishing vessel for set nets (Ship C). The general arrangements of Ship A, B and C are shown in Figs.1, 2 and 3. Principal particulars of these ships are also shown in Table 1. Ship A is one of the typical Japanese purse seiners, which suffered some capsizing accidents. Ship B engages in purse seine like Ship A, but is much deeper than Ship A. Ship C is a semi-planing boat and has large beam to depth ratio.

The bird's-eye view of the basin is shown in Fig.4. The dimensions of the tank are 60 meters in length 25 meters in wide 3.2 meters in depth. The wave maker consists of 80 plungers. The free-running models were propelled with an electromotor, whose power was supplied by batteries onboard. The propeller revolution was controlled by a feed back control. They were steered by an autopilot whose rudder gain is one. The maximum rudder angles were 35 degrees. Roll, pitch and yaw angles were measured by optical gyroscopes. These measured signals were recorded in an onboard computer in digital form. The measured yaw angle was also used for the auto pilot control. Each model was tested with more than 200 runs by changing speeds, directions and wave lengths.

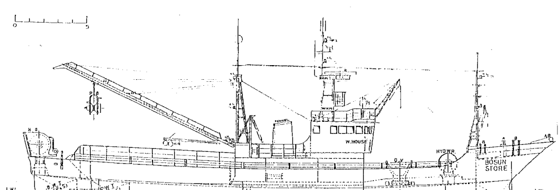

Fig.1 General arrangement of Ship A

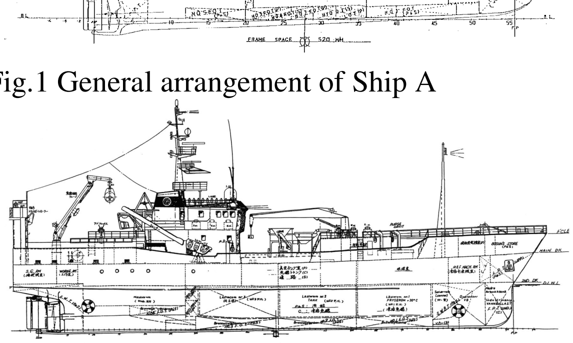

Fig.2 General arrangement of Ship B

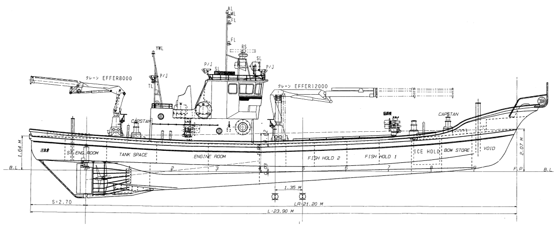

Fig.3 General arrangement of Ship C

Table 1. Principal particulars of the ships

Ship	A	B	C
Length between perpendiculars:L_{pp}	29.0m	55.0m	21.2m
Bredth:B	6.80m	12.0m	4.82m
Depth:D	2.60m	7.60m	1.26m
Mean draught:d_m	2.30m	5.25m	0.99m
Block coefficient: C_b	0.577	0.657	0.657
Model scale	1/12.6	1/25	1/8

3. EXPERIMENTAL RESULTS

Ship A and Ship C were capsized by bow-diving. The time series are shown in Figures 5-6. In Fig.5, the negative pitch angle exceeded 20 degrees at 40 seconds. Then Ship A capsized. At that time, her bow dived into the forward wave up-slope. And Ship C was capsized at 37 seconds after starting with exceeding 10 degrees of negative pitch angle. On the other hand, Ship B was not capsized by bow-diving. Ship B was running with either stable surf-riding or broaching when she was running such high speeds in following and quartering seas. Especially, Ship B showed a stable surf-riding in following condition; wave to ship length ratio, λ/L, of 1.4, ship speed, Fn, of 0.4-0.45 and autopilot directions, χ, -15 degrees to -0 degrees. Under this condition, Ship A and Ship C were capsized by bow-diving. One example in such condition for Ship B is shown in Fig.7. She runs with a wave on its up-slope, as pitch angle was positive and constant. At this time, the water level at bow was nearly equal to bulwark top but the bow did never dive into water.

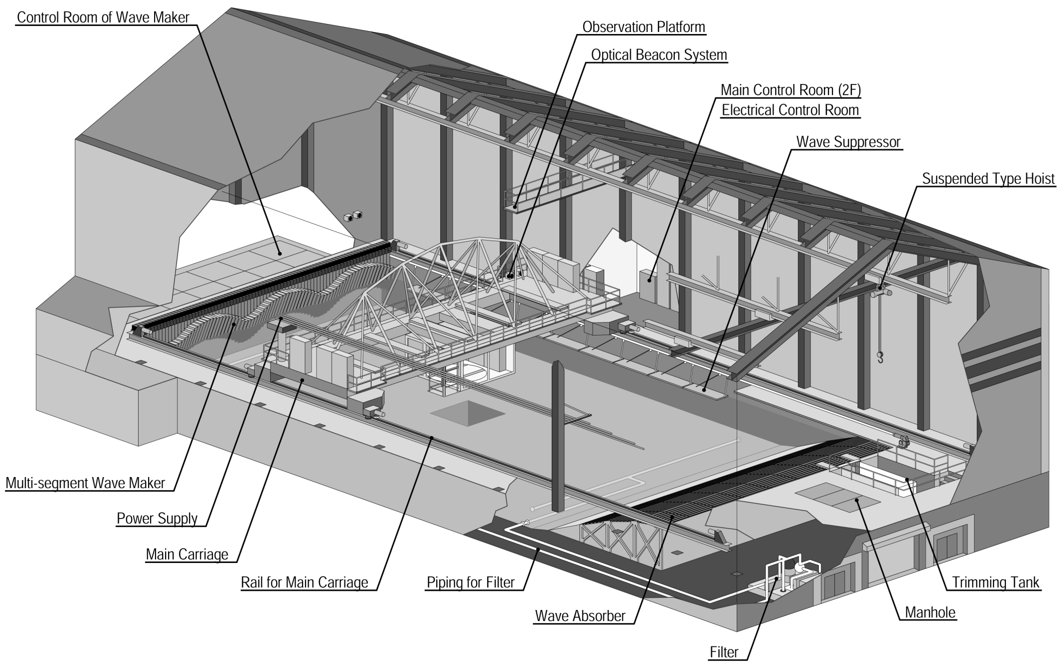

Fig.4 Marine Dynamics Basin

These experimental results show the characteristics of bow-diving as follows:

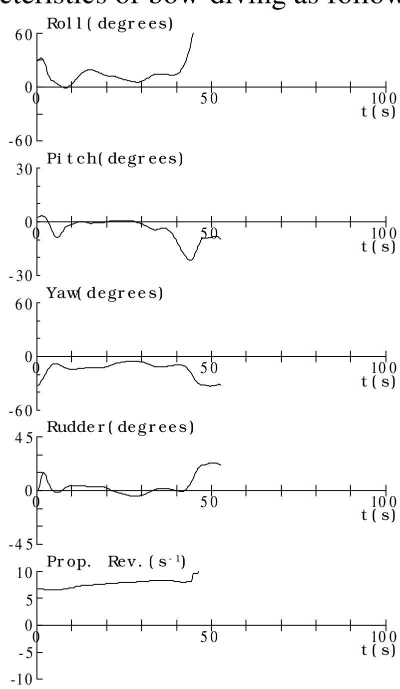

Fig.5 Measured time series of Ship A (λ /L=1.41, χ=-10degrees, Fn=0.46, GM=1.36m)

- λ Bow-diving occurs with surf-riding
- λ Bulwark top at bow is into water

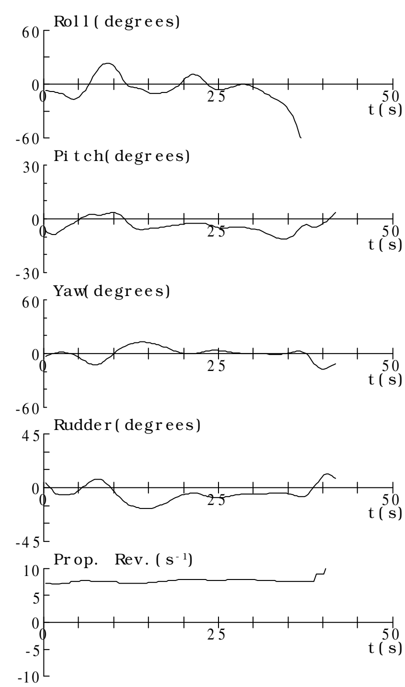

Fig.6 Measured time series of Ship C (λ /L=1.38, χ =-5degrees, Fn=0.43, GM=1.10m)

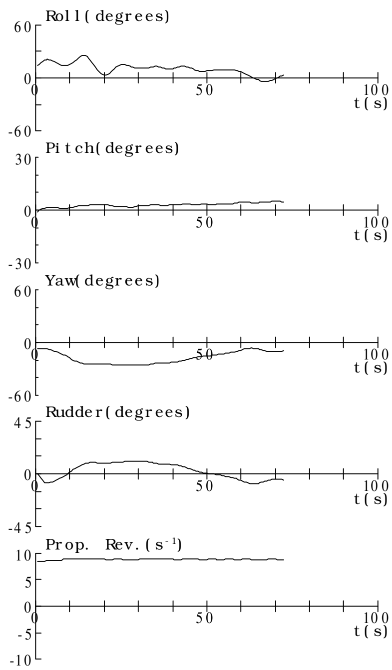

Fig.7 Measured time series of Ship B (λ /L=1.39, χ =-15degrees, Fn=0.45, GM=0.544m)

4. THEORETICAL CALCULATION

Bow-diving happened when the bow bulwark top dived into water during surf-riding for Ship A and Ship C. On the other hand, the bow bulwark top of Ship B under stable surf-riding, did not dive into water. Since the encounter frequency of a ship to waves was low, heave and pitch motions can be regarded as tracing a static balance[8]. Therefore, we calculated a relative distance between bow bulwark top end and water level using the static balance to determine whether the bow bulwark top sinks into water.

We calculated heave and pitch motions in waves using the static balance of the Froude-Krylov assumption with the running attitude. The coordinate systems used here are shown in Fig.8.

The relationship between the bow bulwark top and the wave surface, ζ_r, is calculated as follows:

$$\zeta_r = \zeta_G - x_{bow} \sin\theta - \zeta_{W\,bow} \qquad (1)$$

$$\zeta_{W\,bow} = \zeta_a \cos k(x_{bow} \cos\theta + \xi_G) - \frac{1}{2} k \zeta_a{}^2 \cos 2k(x_{bow} \cos\theta + \xi_G)$$

(2)

Here ζ_G is heave, $\zeta_{W\,bow}$ is the wave height at the bow edge, ζ_a is the wave amplitude, x_{bow} is the horizontal distance between the bow edge and the centre of gravity, θ is the pitch angle, k is the wave number and ξ_G is the longitudinal position of centre of gravity from a wave trough.

If ζ_r is larger than bull work top height in still water, ζ_{still} , bow submergence is occurred.

Therefore the relative water level of the bulwark top, ζ_{bow}, is calculated as follows:

$$\zeta_{bow} = \zeta_r - \zeta_{still}$$

(3)

If ζ_{bow} is less than 0, the bulwark top is below the wave surface.

Fig.9 shows the calculated results of Ships A,B and C. ζ_{bow}' is the non dimensional value of ζ_{bow} using the wave height (=2ζ_a).

ζ_{bow}' of Ship A which capsized by bow-diving is slightly lower than zero at a relative position of the midship to wave, ξ_G / λ, of 0.85. The calculated result shows that bow bulwark top of Ship A submerges when the relative position of the ship to wave is 0.85. As shown in Fig.10, the bow submergence occurred when ξ_G / λ is nearly equal to 0.8. On the other hand, the

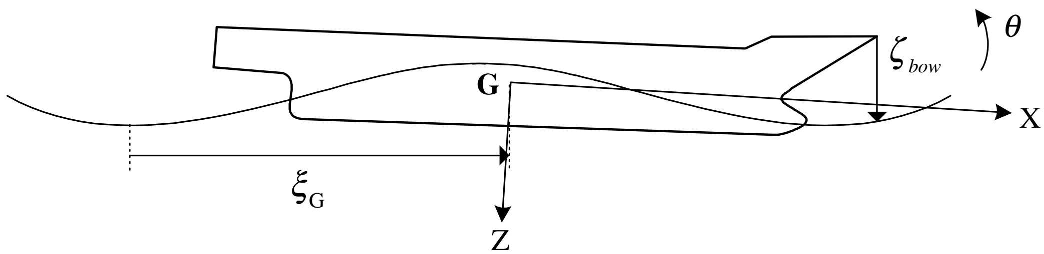

Fig.8 Coordinate Systems

minimum ζ_{bow}' of Ship B is 0.32. The

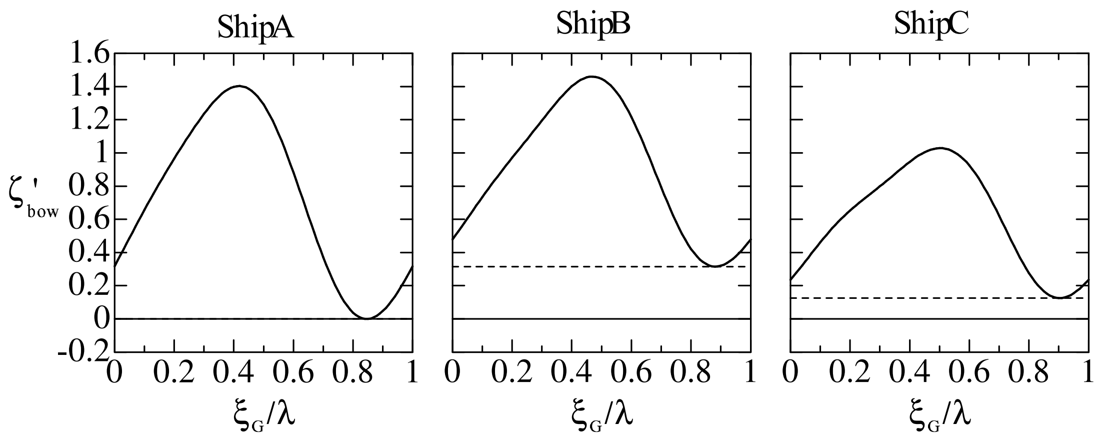

Fig.9 Relative height between bulwark top to wave surface

calculated result shows the bow edge is fairy above the water surface. In free running model experiments, Ship B was running with stable surf-riding without bow-diving. Thus it is possible to conclude that the results of calculation and free running model experiments show reasonable agreements.

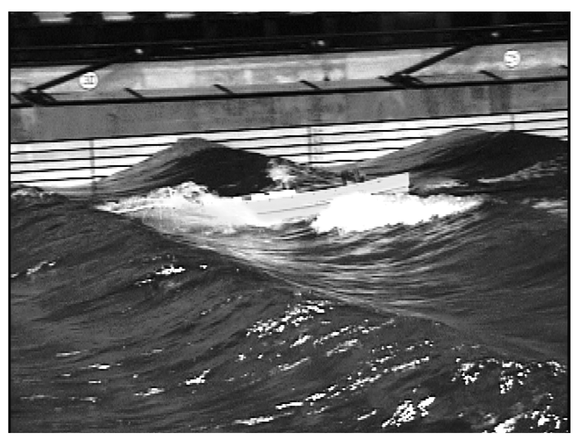

Fig.10 Photo of Ship A

However, Ship C that was capsized by bow-diving in free running model experiments does not occur bow-diving in the calculation, but the minimum ζ_{bow}'=0.12 is very small. In the calculation we did not take the effects of waves generated by bow itself and the fender into account. This could be a possible reason of the disagreement. In addition the bow submergence occurs at ξ_G/λ =0.9 in the calculation while at ξ_G/λ =0.8 in the experiment. A hydrodynamic study is required for more precise estimation of the hull attitude for such a semi-planing vessel.

In general, when the calculated minimum vertical distance between the bow bulwark top and the wave surface is smaller, the possibility of bow diving is larger.

5. EFFECT OF WAVE LENGTH

The above experimental and theoretical procedure, were applied to a Japanese trawler (Ship D). The general arrangement and principal particulars of Ship D are shown in Fig.11 and Table 2, respectively. The calculated results were also shown in Fig.12. Table 3 is overview of the results of calculation and free running model experiments.

For the case of λ/L=1.613, the relative bow height can be negative in the calculation and the capsizing due to bow-diving was observed in the experiments. Its time series of bow-diving is shown in Fig.13. After 20 seconds elapsed, the negative pitch angles exceeded 10 degrees and capsized. This is bow-diving. For the case of λ/L=1.127, the relative bow height is always positive in the calculation and no bow-diving was observed in the experiments. As shown in Fig.14, stable surf-riding was observed in the experiments. These two cases show reasonable agreements between experiments and theory and the theoretical calculation could explain the effect of wave length in bow-diving.

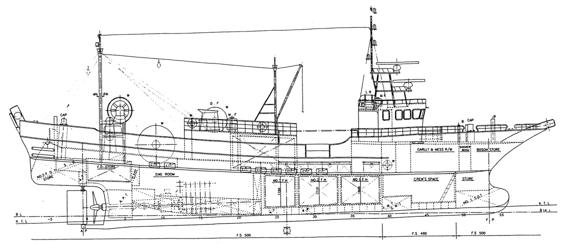

Fig.11 General arrangement of Ship D

Table 2. Principal particulars of Ship D

Length between perpendiculars:L_{pp}	26.9m
Bredth:B	5.90m
Depth:D	2.60m
Mean draught:d_m	2.18m
Block coefficient: C_b	0.789
Model scale	1/12.2

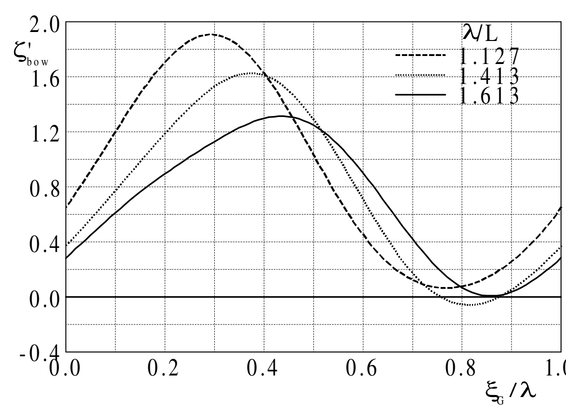

Fig.12 Relative position between bulwark top to wave surface

Table 3. Calculating and Experimental Results

λ/L	1.127	1.413	1.613
Calculating	No bow-diving	Bow-diving	Bow-diving
Experiments	No bow-diving	No bow-diving	Bow-diving

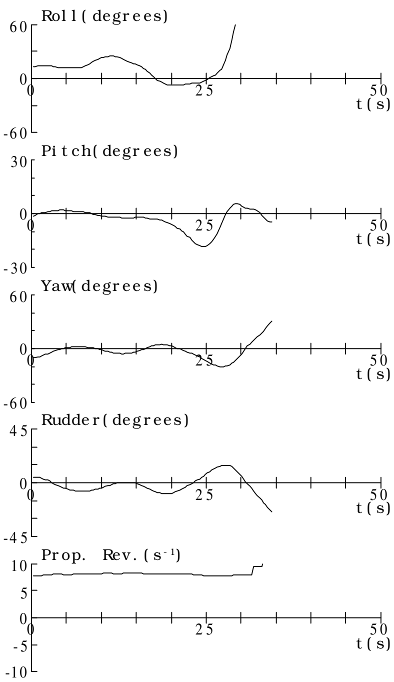

Fig.13 Measured time series of Ship D
(λ /L=1.613, χ =-5degrees, Fn=0.442, GM=0.586m)

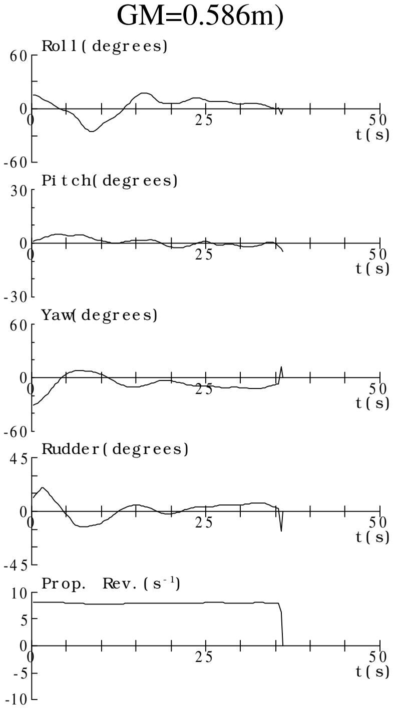

Fig.14 Measured time series of Ship D
(λ /L=1.127, χ =-5degrees, Fn=0.442, GM=0.586m)

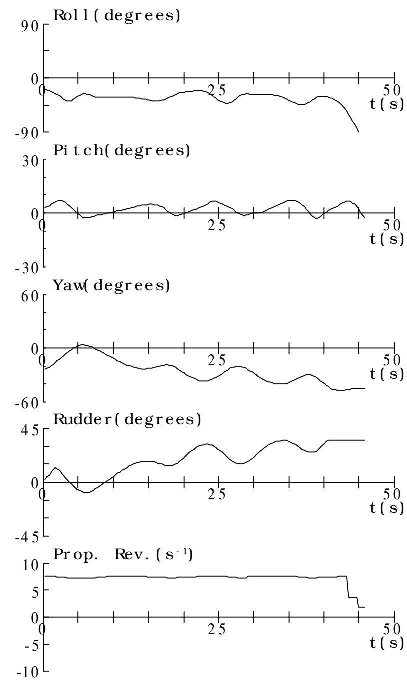

Fig.15 Measured time series of Ship D
(λ /L=1.413, χ =-5degrees, Fn=0.442, GM=0.586m)

On the other hand, for the case of λ/L=1.413, the calculated bow height can be negative but the ship model capsized by pure loss of stability in stead of bow-diving. An example of the time series is shown in Fig.15. All capsizing in λ/L=1.413 were occurred before surf-riding. This is the reason why bow-diving was not recorded in λ/L=1.413 in the experiments.

6. CONCLUSION

We obtained the conclusion from this research as follows:

1) There is the possibility of capsizing by bow-diving in following and quartering seas with high forward speed for a 80 tonnage type Japanese purse seiner and a fishing vessel for set nets.
2) The Northern European purse seiner could run with stable surf-riding and does not occur bow-diving in such high forward speed in following and quartering seas.

3) The simple calculation of static balance of heave and pitch in waves could roughly estimate occurrence of bow-diving.
4) The calculation procedure is applicable to a Japanese trawler, and could explain the effect of wave length.

7. ACKNOWLEDGMENTS

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