A trial experiment on the IMO draft guidelines for alternative assessment of the weather criterion

Harukuni Taguchi, Shigesuke Ishida and Hiroshi Sawada
National Maritime Research Institute (Japan)

ABSTRACT

This paper describes a trial model experiment following the draft guidelines for alternative assessment of the weather criterion, which the IMO/SLF intersessional correspondence group has developed. The objective of the experiment was to clarify the feasibility and reliability of the draft guidelines and examine their equivalency to the current weather criterion.

In the experiment, using a scaled model of a Ro-Pax ferry, a drifting test for evaluating wind heeling lever, l_{w1}, a roll decay test and a roll test in beam waves, both for evaluating roll angle, ϕ_1, were conducted. In the drifting test the estimated centre of drift force exists higher than half draft, which is the assumption in the current weather criterion, and almost locates even higher than the waterline. As a result, the l_{w1} is evaluated to be smaller than the one with the current weather criterion by about 30%. As for the roll angle, ϕ_1, the angle evaluated with measured data is about 19 degrees and larger than the one with the current weather criterion by about 4 degrees.

Using these experimental results, the weather criterion was assessed and compared to the current assessment. As a result, it is recognised that the alternative assessment with model experiments may lead to a significant change of safety level of the criterion. Besides beam wind and waves effects the current weather criterion implicitly includes some safety margin for other factors of danger. Therefore this experimental result might indicate that in alternative assessment some measure should be taken to limit the change of safety level of the criterion.

1. INTRODUCTION

In 2002 the IMO Sub-Committee on Stability, Load Lines and Fishing Vessels Safety (SLF) decided to review the weather criterion, defined in 3.2 of the Intact Stability Code (IS Code), as a matter of priority in the revision process of the IS Code. In the course of discussion, some drawbacks of relevant parameters to evaluate wind heeling lever and roll angle used in the weather criterion were pointed out and the applicability of the criterion to some types of ships (e.g. modern large passenger ships), which was not existed at the time of development of the criterion, was questioned [1,2]. However it was also recognised that the weather criterion was intended to ensure ship stability safety with its entire application and partial modification of relevant parameters might lead an unpredictable variation of the implied level of safety [2].

As the result of discussion, the SLF Sub-Committee agreed that the weather criterion should be revised to allow alternative assessment with model experiments. And to ensure uniform applicability of model experiments, the intersessional correspondence group, which was setup at the 47th session of SLF Sub-Committee, has developed draft guidelines for alternative assessment of the weather criterion, which specifies detailed procedures of model experiments.

However, feasibility, reliability, equivalence to the current weather criterion and equivalence among the options of the draft guidelines are not fully clarified.

With this background we conducted a scaled model experiment of a Ro-Pax ferry following the draft guidelines and examined the above mentioned items. This paper reports the outline of this investigation.

2. ALTERNATIVE ASSESSMENT OF THE WEATHER CRITERION

The weather criterion evaluates the ability of a ship to withstand the combined effects of beam wind and waves. Fig. 1 is a figure used in assessing the weather criterion and the criterion requires that area "b" should be equal to or greater than area "a". The levers and angles in Fig. 1 are defined as follows:

l_{w1}: steady wind heeling lever at wind speed of 26 m/s,

l_{w2}: gust wind heeling lever (l_{w2} = 1.5 l_{w1}),

ϕ_0: heel angle under action of steady wind,

ϕ_1: roll angle to windward due to wave action,

ϕ_2: downflooding angle (ϕ_f) or 50 degrees or angle of second intercept between gust wind heeling lever (l_{w2}) and GZ curves, whichever is less.

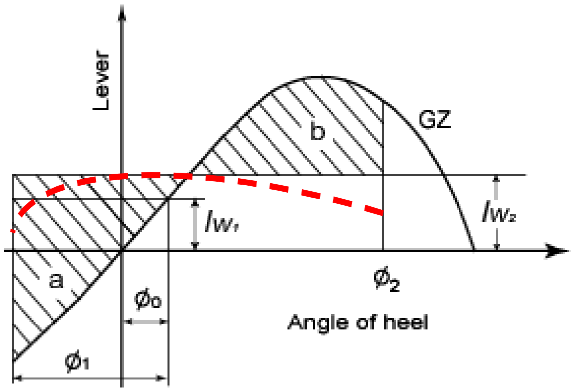

Fig.1 Assessment of the weather criterion

In the alternative assessment [3], both the steady wind heeling lever, l_{w1}, and the roll angle, ϕ_1, evaluated with measured data in scaled model experiments can be used. And it is allowed in the alternative assessment to consider the heeling levers as dependent on the heeling angle like the broken line in Fig. 1. The draft guideline for alternative assessment specifies detailed procedures of wind tunnel tests and drifting tests, both for evaluating wind heeling lever, and roll decay tests and roll tests in beam regular waves, both for evaluating roll angle.

3. MODEL EXPERIMENT

3.1 Outline of the Experiment

In this investigation a scale model of a Japanese Ro-Pax ferry was used. Table 1 shows the principal dimensions of the ferry. And its general arrangement and rough body plan are shown in Fig. 2 and Fig. 3 respectively. Compared to general European Ro-Pax ferries the tested ferry has finer shape. Fig. 4 shows the GZ curve at the tested condition. It is found that up to about 40 degrees the GZ curve has a very small nonlinearity to heel angle.

Table 1 Principal dimensions

Length: Lpp	170.0m
Breadth: B	25.0m
Depth: D	14.8m
Draft: d	6.6m
Displacement: W	14,983t
Blockage coefficient: Cb	0.521
Metacentric height: G_0M	1.41m
Rolling period: Tr	17.9s
Downflooding angle: ϕ_f	39.5deg.

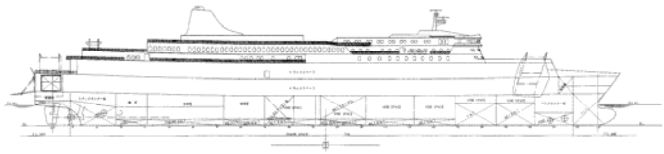

Fig. 2 General Arrangement

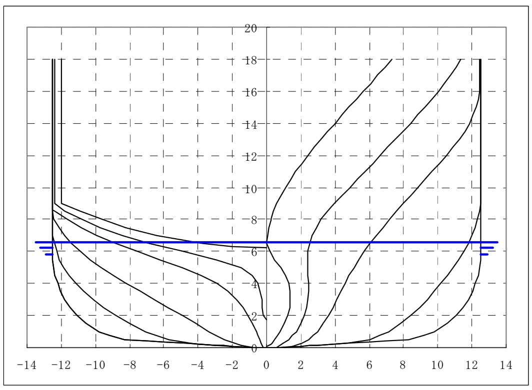

Fig. 3 Body Plan

Using the scale model (Lpp = 2 m) of the ferry, a drifting test, a roll decay test and a roll test in beam regular waves were conducted in the seakeeping wave tank at National Maritime Research Institute (length: 50.0m, width: 8.0m, depth: 4.5m). A wind tunnel test for measuring drag coefficient, Cd, was not carried out this time but it is scheduled to be conducted in this October. Instead in the drifting test the drift speed was varied for cover the expected range of Cd. In the roll test in beam regular waves guide ropes were attached to the model in free floating to adjust the change of heading angle.

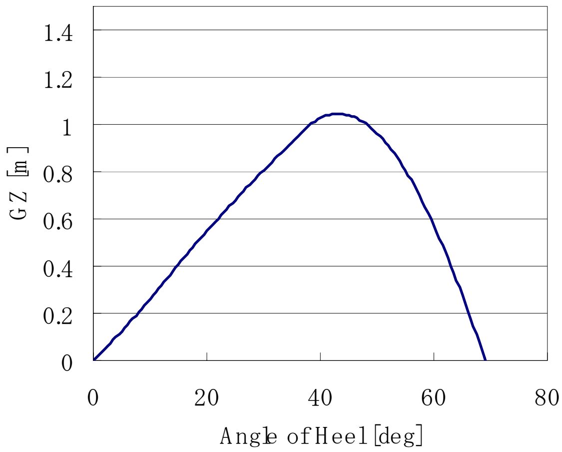

Fig. 4 GZ Curve at the tested condition

3.2 Result of Drifting Test

In the drifting test the heeling moment and the drift force were measured with a load cell, which was attached to a guidance system on the towing carriage (Fig. 5). The drifting test was carried out in upright condition and at heeled conditions ranging from 15 degrees to wind side to 30 degrees to lee side with 5 degrees increment. And the drift speed (towing speed) was decided and varied to make the measured drift force equal to the wind force with assumed wind drag coefficients, C_d, ranging from 0.5 to 1.1 and the wind speed of 26 m/s in ship scale. For upright condition and C_d = 0.8 the drift speed was 0.195 m/s, which corresponds to 1.80 m/s in ship scale.

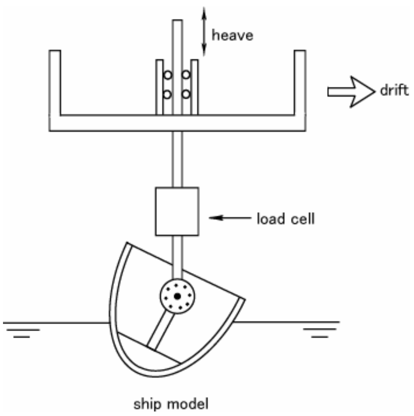

Fig. 5 Arrangement for the drifting test

In Fig. 6 the result is shown as the height of the centre of drift force above the waterline, which was estimated with the measured heeling moment divided by measured drift force. The horizontal axis is the heel angle and the vertical axis is the height of the centre of drift force normalised by the draft. It is found that the centre of drift force exists higher than half draft, which is the assumption in IS Code, and almost locates even higher than the waterline. This phenomenon can be explained by the pressure distribution on the bottom [4]. Local separation flow stating from the bilge corner or the centreline keel induces low-pressure part on the opposite side of the bottom to the drifting direction. On the other hand there is high-pressure part on the face side of the bottom. Due to this pressure distribution, the moment lever defined with the measured heeling moment divided by measured drift force locates higher than the waterline.

The effect of the ratio of breadth/draft was also investigated by changing the draft of this Ro-Pax ferry model in upright condition. The drift speed was set at 0.188 m/s.

The result is shown as the normalised height of the centre of drift force with each tested draft in Fig. 7. It is recognised that a ship with larger breadth/draft ratio tends to have a higher virtual position of the centre of drift force.

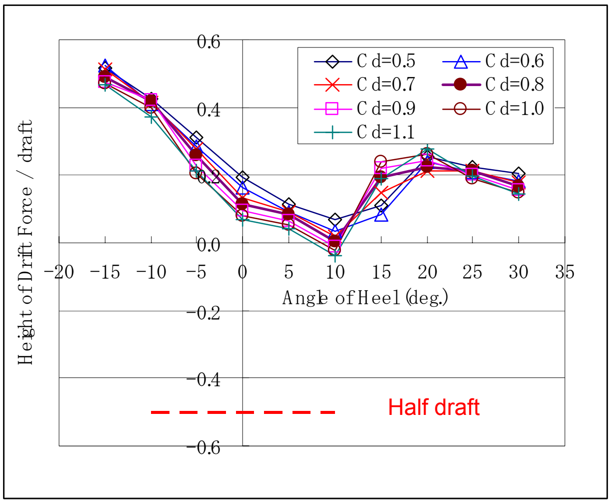

Fig. 6 Height of the centre of drift force above the waterline for assumed wind drag coefficients

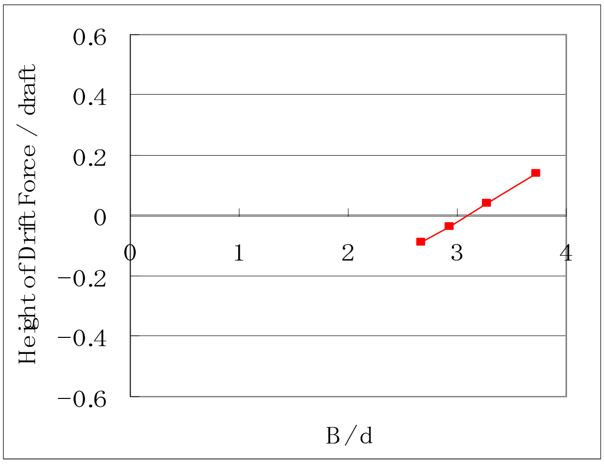

Fig. 7 Effect of draft on the centre of drift force

3.3 Result of Roll Decay Test

To obtain the roll damping characteristics a series of roll decay tests were carried out in calm water.

The measured nonlinear roll damping coefficient, N, as a function of roll amplitude is shown in Table 2. The damping coefficient of this ship at roll amplitude of 20 degrees, N(20), is about 0.01, which is half of the assumed standard value, N(20) = 0.02. The dependency of N coefficient on roll amplitude is small because the linear component (wave making damping) is small for this ship.

Table 3 shows measured period from peaks to peaks in roll decay test as a function of roll amplitude. As the nonlinearity of GZ curve of this ship is quite small (Fig. 4), effect of roll amplitude on the natural roll period is recognised to be not so large.

Table 2 Roll damping coefficient N

Roll Amplitude (deg.)	N
10.0	0.0122
12.5	0.0116
15.0	0.0113
17.5	0.0110
20.0	0.0109
22.5	0.0107
25.0	0.0106

Table 3 Effect of roll amplitude on the natural roll period

Roll Amplitude (deg.)	Natural Roll Period (sec.)
10.0	1.910
12.5	1.901
15.0	1.893
17.5	1.886
20.0	1.881
22.5	1.876
25.0	1.873

3.4 Result of Roll Test in Beam Regular Waves

From the table of wave steepness as a function of the natural roll period in the draft guidelines, the assumed wave steepness, s, for this ship is 0.0383 (1/26.1). To obtain data for estimating the resonant roll amplitude, rolling motion of the model was measured in beam regular waves with s = 1/26.1, 1/40 and 1/60. In this test the maximum wave height was 27.8 cm, which is close to the limitation of the test basin.

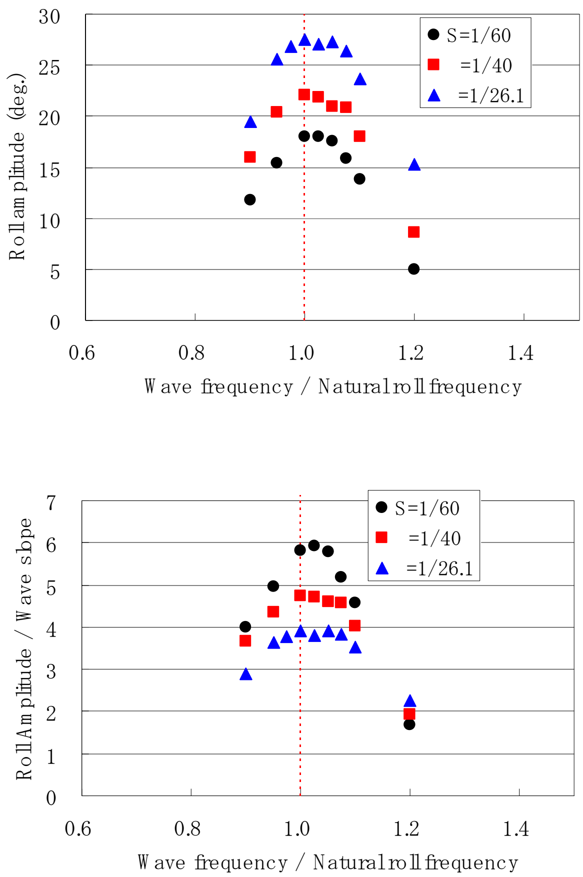

Fig. 8 Roll amplitude in beam regular waves (upper: in degrees, lower: non-dimensional)

The measured roll responses are shown in Fig. 8. The upper figure shows the measured peak roll amplitude in degrees, while the normalised amplitude with wave slope is shown in the lower figure. The horizontal axis in both figures is the ratio between wave frequency and natural roll frequency.

It is found that in the tested wave steepness range the difference between the frequencies of the peak of the roll responses and the roll natural frequency is not large, as the nonlinearity of GZ curve of this ship is quite small. And because of the nonlinearity of damping the normalised roll amplitudes are larger in smaller steepness.

4. ALTERNATIVE ASSESSMENT OF THE WEATHWR CRITERION

4.1 Alternative Assessment of l_{w1}

As the wind tunnel test for this ship has not conducted yet, the wind heeling lever, l_{w1}, could not be evaluated with the method in the draft guidelines. In this investigation l_{w1} was evaluated from the following equation in the IS Code.

$$l_{wl} = \frac{P \cdot A \cdot Z}{1000 \cdot g \cdot \Delta} \qquad (1)$$

where P is the wind pressure, A is the projected lateral area above the waterline, Z is the vertical distance from the centre of A to the centre of the underwater lateral area, Δ is the displacement, and g is the gravitational acceleration.

Using the test result, Z in the equation (1), heeling moment lever, was changed to the vertical distance from the centre of lateral projected area to the measured centre of drift force (Fig. 6). This method is not included in the draft guidelines, but it helps to understand the effect of using the test result to l_{w1}. The evaluated l_{w1} with the test result for Cd = 0.8 is shown in Fig. 9. It is recognised that the calculated heeling moment lever is smaller than the current assessment by about 30%.

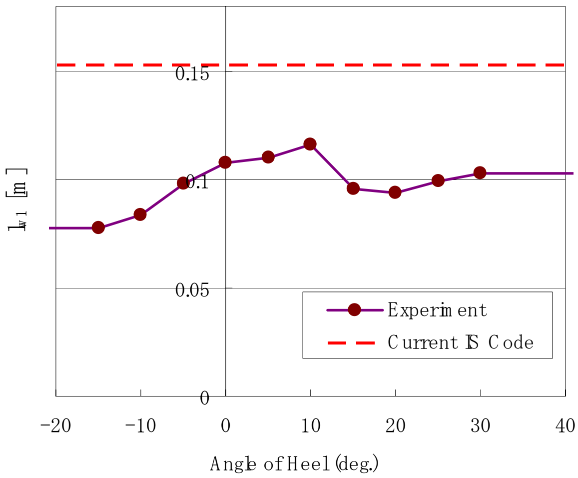

Fig. 9 Wind heeling lever, l_{w1}, evaluated by the drifting test

4.2 Alternative Assessment of ϕ_1

In the weather criterion ϕ_1 is defined as follows:

$$\phi_1 = 0.7\phi_{1r} \qquad (2)$$

where ϕ_{1r} is the resonant roll amplitude in beam regular waves of a steepness specified in the criterion.

The draft guideline specifies three procedures for evaluating ϕ_{1r}, namely the direct measurement procedure, the three steps procedure and the procedure with parameter identification technique. In this investigation the direct measurement procedure and the three steps method were adopted.

Direct measurement procedure

As shown by the symbols of s = 1/26.1 in Fig. 8 the directly measured peak roll amplitude in regular waves is 27.5 degrees. With the equation (2) ϕ_1 is evaluated as 19.3 degrees, while it is 15.4 degrees in the current assessment.

<u>Three steps procedure</u>

The three steps procedure calculates ϕ_{1r} with the following equation:

$$\phi_{1r} = \sqrt{\frac{90\pi rs}{N(\phi_{1r})}} \qquad (3).$$

The roll damping coefficient, N, is already estimated in paragraph 3. The effective wave slope coefficient, r, is calculated by the roll amplitude measured in waves of natural roll period of the ship. In this procedure the measure data in small wave steepness is used. From the result in waves of s = 1/60, r is evaluated as 0.759. Using these values in equations (2) and (3) the resultant ϕ_1 becomes 19.5 degrees, which is very close to the direct measurement.

4.3 Alternative Assessment of The Weather Criterion

The comparison of assessed weather criteria using experimental results along with the current assessment is summarized in Table 4. Here dependency of l_{w1} on heel angle is ignored for simplicity (l_{w1} = 0.1 m).

It is recognised from Table 4 that the alternative assessment with model experiment can change the value of "b/a" significantly (ranging from 2.02 to 4.03) and it is also different from the current assessment ("b/a" = 3.00). For this ship, enlarged ϕ_1 by experiment makes "b/a" smaller and the evaluated l_{w1} by drifting test makes "b/a" larger than the current assessment.

Table 4 Assessment of the weather criterion

	Current Weather Criterion	l_{w1}:Current + ϕ_1:Direct	l_{w1}:Current + ϕ_1:3Steps	l_{w1}:Drift test + ϕ_1:3Steps	l_{w1}:Drift test + ϕ_1:Current
l_{w1} [m]	0.153			0.100	
r [-]	1.096	−	0.759		1.096
Tr [sec]	16.3	17.9			16.3
s [-]	0.0431	0.0383			0.0431
ϕ_1 [deg]	15.4	19.3	19.5		15.4
ϕ_0 [deg]	6.1			4.0	
$\phi_0-\phi_1$ [deg]	-9.3	-13.2	-13.4	-15.5	-11.4
ϕ_f [deg]	39.5				
Area a [rad-m]	0.075	0.111	0.113	0.103	0.067
Area b [rad-m]	0.224			0.268	
b/a [-]	3.00	2.02	1.98	2.60	4.03

5. DISCUSSION

As mentioned in the previous section, the alternative assessment with model experiments may lead to a significant change of safety level of the criterion. If a wind tunnel test is carried out and its result is used together with the one of drifting test, it is expected that "b/a" becomes much larger than current assessment [1,5]. This implies that the alternative assessment with results of total experiments may lead to a drastic decrease of the resultant required metacentric height and a wide range of freedom to design ships.

On the other hand, the proposed assessment with model experiments is physics based and assumes beam wind and waves condition, however the current weather criterion implicitly includes some safety margin for other factors of danger. With this reason it seems appropriate that there should be a certain limit for the change of safety level in alternative assessment.

In the revised IS Code prepared by the intersessional correspondence group [6], the determinations of l_{w1} and ϕ_1 by model tests are prescribed separately and independently. This may allow any combination of current and alternative assessment for l_{w1} and ϕ_1. In that case variation of safety level of the criterion is expected to become larger than that in Table 4. To keep a certain safety level as an international standard, the number of alternatives and combinations should be minimised.

6. CONCLUSIONS

Using a Ro-Pax ferry model, a trial experiment following the draft guidelines for alternative assessment of the weather criterion was carried out to clarify the feasibility and reliability of the draft guidelines and examine their equivalency to the current weather criterion.

As a result it is found that the alternative assessment with model experiment can change the safety level of the criterion significantly. Taking some implicit safety margin secured by the weather criterion into account, it is considered appropriate that there should be a certain limit for the change of safety level in alternative assessment. To set out reasonable allowance for the change of safety level in alternative assessment, further investigation including evaluation of capsizing probability, which may be related to "the long-term approach" in IMO, is necessary.

The draft guidelines for alternative assessment of the weather criterion will be finalised at the 48th session of SLF Sub-Committee in this September. To examine the finalised guidelines thoroughly, investigation including a wind tunnel test with the same ferry model for exact evaluation of the wind heeling lever and alternative evaluation of the roll angle with the parameter identification technique will be carried out.

ACKNOWLEDGEMENTS

Part of this investigation was carried out as a research activity of the SPL research panel of the Japan Ship Technology Research Association, funded by the Nippon Foundation. The authors express their sincere gratitude to the both organizations.

REFERENCES

1. Francescutto, A., Umeda, N., Serra, A., Bulian, G. and Paroka, D., "Experiment-Supported Weather Criterion and its

Design Impact on Large Passenger Ships”, Proc. 2nd International Maritime Conference on Design for Safety, pp.125-135, 2004.

2. Bulian, G., Francescutto, A., Serra, A. and Umeda, N., “The Development of a Standardized Experimental Approach to the Assessment of Ship Stability in the Frame of Weather Criterion” Proc. 7th International Ship Stability Workshop, pp. 118-126, 2004.
3. SLF 48/4/3 “Report of the Intersessional Correspondence Group (part 3) “ Submitted by Germany, 2005.
4. Ishida, S. and Fujiwara, T., “ On the Capsizing Mechanism of Small Craft in Beam Breaking Waves “ , Proc. 7th International Conference on Stability of Ships and Ocean Vehicles (STAB2000), Vol. B, pp.868-877, 2000.
5. Bertaglia, G., Serra, A. Francescutto, A. and Bulian, G., “Experimental Evaluation of the Parameters for the Weather Criterion”, Proc. 8th International Conference on Stability of Ships and Ocean Vehicles (STAB2003), pp.253-263, 2003.
6. SLF 48/4/1 “Report of the Intersessional Correspondence Group (part 1) “ Submitted by Germany, 2005.