DEVELOPMENT OF BOW SHAPE TO REDUCE THE ADDED RESISTANCE DUE TO WAVES AND VERIFICATION ON FULL SCALE MEASUREMENT

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SUMMARY

The added resistance due to waves on full hull form ships is mainly generated by the diffraction of the incident waves at the blunt bow. In order to reduce the diffraction of waves at the blunt bow, new concepts of bow shape were developed. The results of model tests showed that the added resistance due to waves on these bows is reduced by 20%～30% in comparison with that for ordinary bow.

Among these bow shapes, Ax-Bow was first applied on the actual ship. In order to verify the effect of Ax-Bow to reduce the added resistance due to waves at actual sea, the ship monitoring system with wave height meters was installed both on Ax-Bow vessel and on the sister vessel of ordinary bow. The hull performance measurement in actual sea has been carried out. The results show the advantage of Ax-Bow also at actual sea.

1. INTRODUCTION

After the oil crisis of 1970's, considerable effort has been spent to reduce the fuel oil consumption of ships and the horsepower necessary to the ship has been reduced by almost half in the last two decades. Such horsepower reduction on ships has been based on improving the hull shape, energy saving devices fitted on the ship and the performance of the main engine.

Recently, however, it has been pointed out that the ratio of horsepower increase or speed loss in waves has become larger in spite of their better performance in still water. Development of ship hull shape has been focused on the power reduction in still water, but it is also necessary to take that in waves into consideration.

The purpose of the present study, therefore, is to develop new hull shapes to reduce the added resistance due to waves in order to achieve lower sea margin. Here, the sea margin is defined by the ratio between necessary horsepower increase in waves and that in still water on a same ship speed.

In this paper, some ideas to reduce the added resistance due to waves are studied and evaluated by model tests. Then, the performance of the first vessel applied one of these bow shapes at actual sea is evaluated by the full-scale measurement.

2. CONCEPT OF NEW BOW SHAPE

The added resistance due to waves can be described as sum of two components, one is caused by the diffraction at the bow and the other is caused by the radiation wave due to ship motions.

As shown in Fig.1, the radiation component is dominant mainly in the range of longer wavelength and the diffraction component is in shorter wavelength range where the ship motion is small. The added wave resistance acting on a large full hull form ship, such as tankers or bulk carriers, is mainly due to the diffraction and breaking of waves at its blunt bow.

Fig.2 schematically shows the waterline shapes of the bow. In Fig.2, incident wave is reflected and broken at the blunt bow. Such wave diffraction or breaking generates the reaction force acting in the backward on the ship's bow.

Therefore, a simple idea to reduce the added resistance due to waves is to sharpen the waterline shape of the bow. The sharpened bow can reduce such reaction force because the reflected waves in forward direction component are decreased.

When a ship is sailing at sea, the water surface is elevated at the bow that is called dynamic swell up and incident wave motion is occurred around this swell upped water level. Therefore, to sharpen the bow shape above the load waterline causes the reduction of the added resistance due to waves. It means that there is room for further modifications of hull shape above the load waterline and it does not influence the hull propulsive performance in still water. Based on this consideration, a new concept of bow shapes was developed.

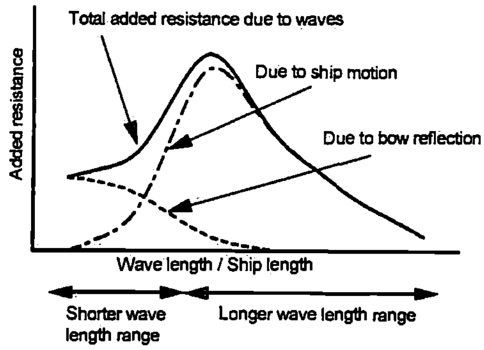

Fig.1 Components of Added Resistance due to Waves

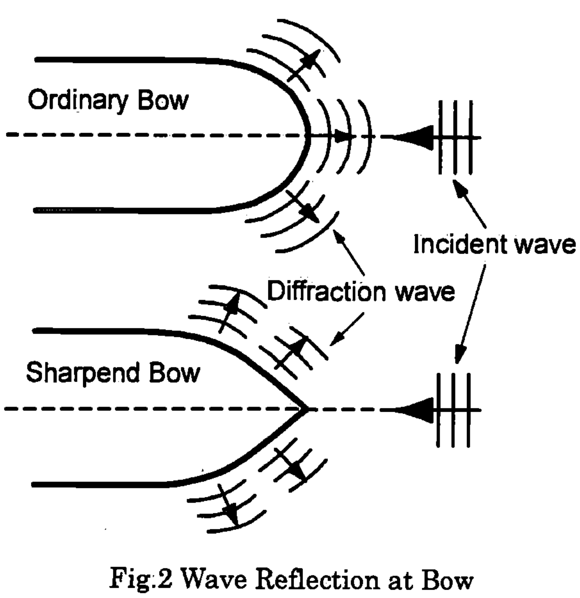

Fig.2 Wave Reflection at Bow

2.1. BEAK-BOW

In order to sharpen the bow shape above the load waterline, stem line is lengthened forward as shown in Fig.3. It shows a comparison between the ordinary bow and a new concept of bow shape applied on a bulk carrier. This bow is named Beak-Bow, because its shape looks like the beak of a bird. The full load draft is 16.5m for this ship. Comparing the waterlines between the ordinary bow and the Beak-Bow, the hull shape below the load waterline is completely the same. But the waterline shape above the load waterline, the shape of Beak-Bow is sharper than that of the ordinary bow.

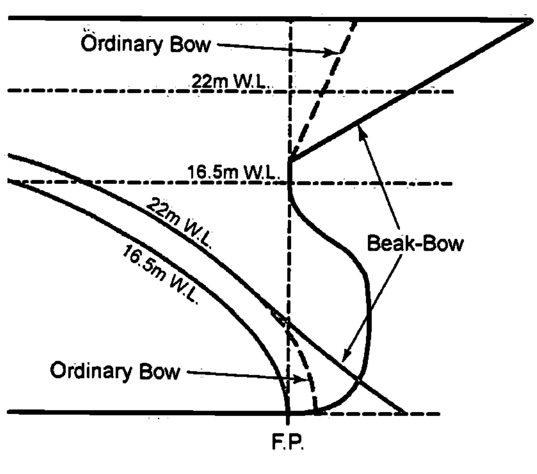

Fig.3 Beak-Bow

2.2. AX-BOW

The total ship length with Beak-Bow becomes longer as shown in Fig.3, because the bow is lengthened forward. From the practical viewpoint, the ship length is limited by some port regulations. In the case of Cape Size Bulk Carrier, the ship length becomes about 300m by adopting Beak-Bow. The ship cannot lengthen her length up to 300m, if she enters some port in Europe, because the allowable ship length under its port regulation is set to be under 289m.

Cutting off the tip of the bow shape as described by the solid line shown in Fig.4 is necessary for satisfying this port regulation. But only such cutting off the bow may increase the added wave resistance because of its triangle section's remaining at the bow front.

Therefore, the bow shape is modified to shape the waterline as sharp as possible under keeping the profile of the bow as the solid line in Fig.4 under the condition of the maximum ship length. The above modified bow shape is named Ax-Bow, because of its profile shape's looking like the ax but no more the beak.

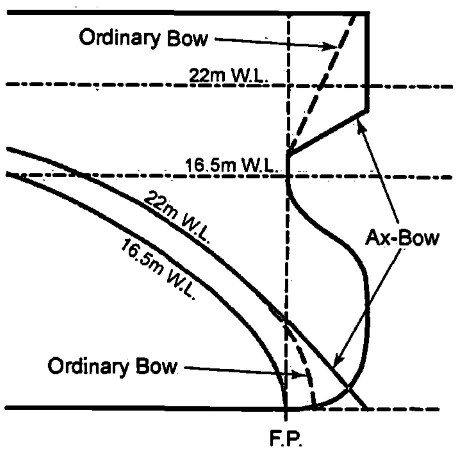

Fig.4 Ax-Bow

2.3. LEADGE-BOW

Beak-Bow and Ax-Bow are sharpened the bow shape above the load waterline and the hull form below the load waterline is completely the same as the hull with ordinary bow shapes to avoid the deterioration of the hull performance in still water.

Generally, the bow shapes of hull with bulbous bow affects the wave making resistance characteristics. But the full hull form ship sails with comparatively slow speed and its wave making resistance itself is small in the total resistance.

From the viewpoint to reduce the added resistance in waves, it would be more effective to sharpen the whole part of stem line. A new bow shape, shown in Fig.5, is developed based on this idea. The bow shape is named LEADGE-Bow from meaning "Leading-Edge".

When the ship sails in ballast condition, the sea surface is below the load waterline. LEADGE-Bow has a sharpened part below the load waterline. It can also reduce the added resistance not only in full load condition but also in ballast condition.

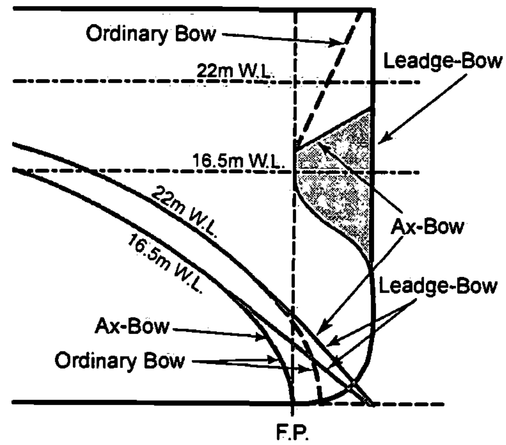

Fig.5 LEADGE-Bow

3. MODEL TEST RESULTS

Model tests for the measurement of added resistance due to waves for these bow shapes have been preformed. The results showed advantages of these new bow shapes over the ordinary bow shape.

3.1. MODEL TEST RESULTS OF BEAK-BOW

4.0m-length model of a bulk carrier, shown in Fig.6, was used for the model test in regular head waves and measured the resistance and ship motions. The principal dimensions in real ship scale are, ship length (Lpp) = 279.0m, breadth = 45.0m and design draft = 16.5m. The model was towed in regular head waves at 13.0knot in ship scale. The wave height was 3.0m in ship scale and the range of wavelength are between 0.4Lpp～1.6Lpp.

Fig.7 shows the results of measured added resistance coefficient in regular head waves. as a function of wavelength to ship length ratio. Beak-Bow gives smaller added resistance due to waves than that of the ordinary bow by the ratio of 20～30%. There was no difference on the resistance in still water between two bow shapes.

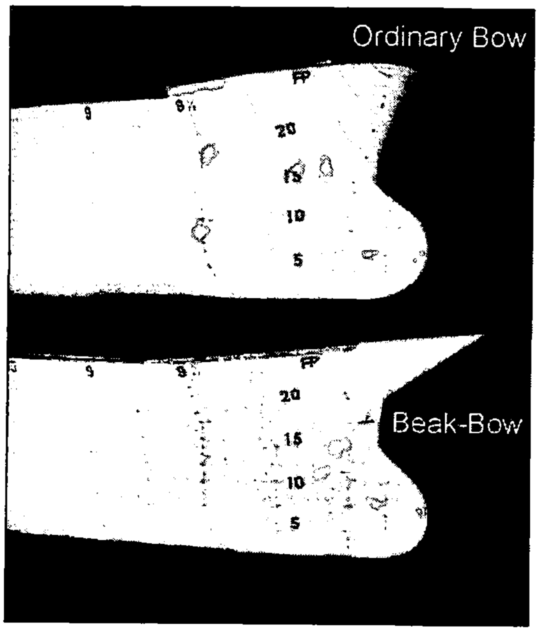

Fig.6 Model Ship of Beak-Bow

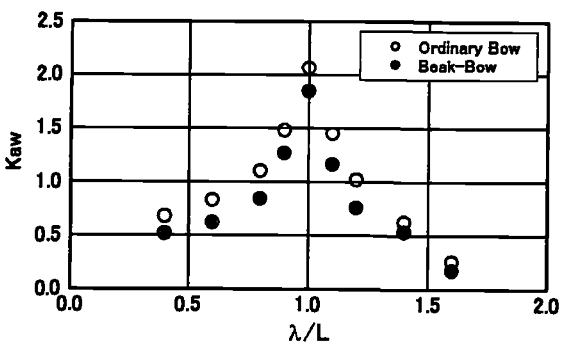

Fig.7 Added Resistance Coefficient for Beak-Bow from Model Test

3.2. MODEL TEST RESULTS OF AX-BOW

3.5m-length model of a Bulk Carrier, shown in Fig.8, was used for the model test. The tests were in regular waves with their direction of every 30° from 180°(head wave) to 0°(follow wave). The wave height was 3m in ship scale. The model was towed in regular waves at 13.0knot in ship scale and measured resistance and 6-components of motions. Fig.9 shows the results of added resistance due to waves in regular head wave and oblique wave.

Ax-Bow gives smaller added resistance due to waves than that of the ordinary bow by the ratio of about 20～30% in head and oblique waves

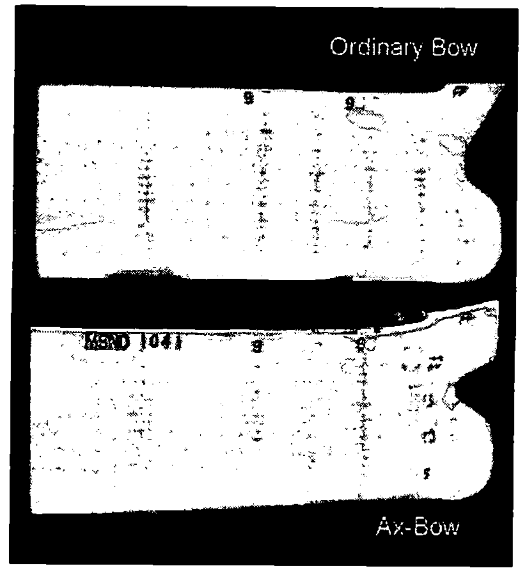

Fig.8 Model Ship of Ax-Bow

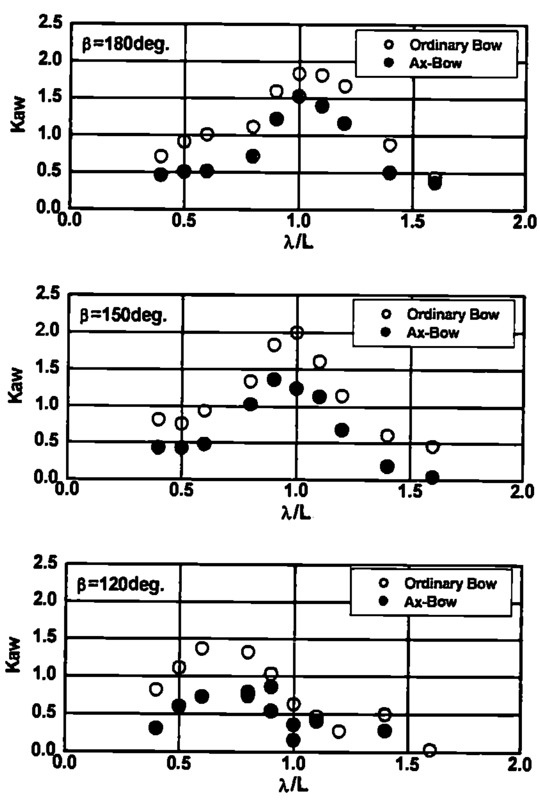

Fig.9 Added Resistance Coefficient for Ax-Bow from Model Test

3.3. MODEL TEST RESULTS OF LEADGE-BOW

LEADGE-Bow has a sharpened shape at whole part of stem line. The effect of LEADGE-Bow to reduce the added resistance due to waves is expected in both full load and ballast condition. 4.7m-length models of a tanker, shown in Fig.10, were used for the model test in regular head wave. The bow shapes were ordinary bow, Ax-Bow and LEADGE-Bow. Test conditions were full load and ballast condition

Fig.11 shows the result of full load condition. Ax-Bow gives smaller added resistance due to waves than that of the ordinary bow by the ratio of about 12%. LEADGE-Bow gives more effective results for added resistance due to waves by the ratio of about 19% in comparison with the ordinary bow.

Fig.12 shows the result of ballast condition. In this case the added resistance due to waves for the ordinary bow is assumes the same as Ax-Bow because Ax-Bow has complete the same hull form as ordinary bow below the full load waterline. LEADGE-Bow gives smaller added resistance due to waves than that of Ax-Bow by about 5%. LEADGE-Bow has a sharpened bow shape also near the waterline in ballast condition. Therefore, LEADGE-bow has an advantage over ordinary bow or Ax-Bow.

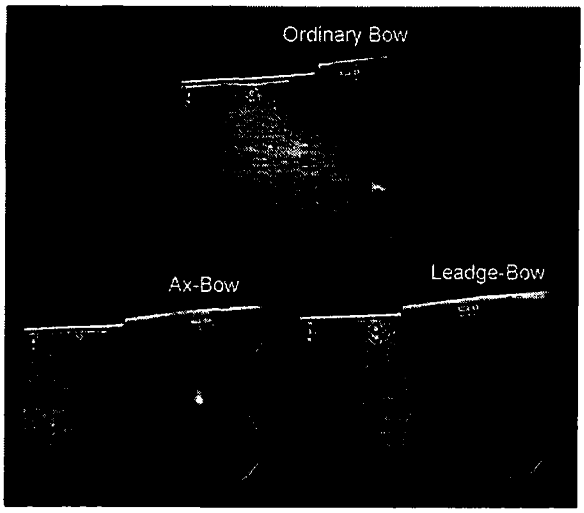

Fig.10 Model Ship of LEADGE-Bow

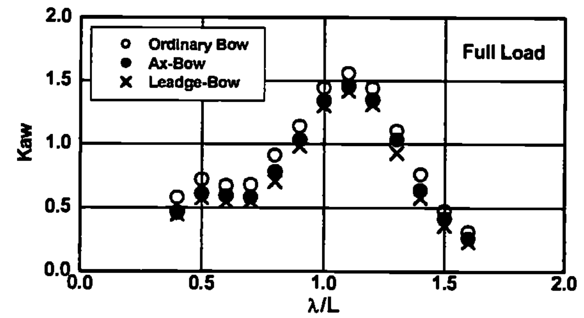

Fig.11 Added Resistance Coefficient for LEADGE-Bow from Model Test (Full Load)

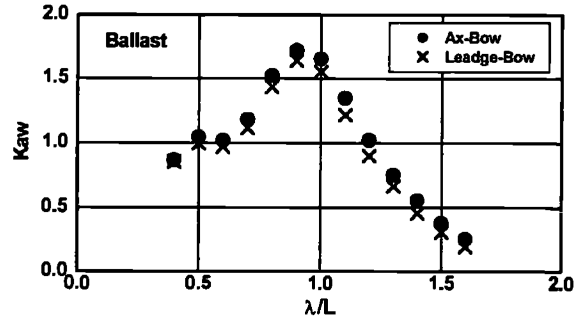

Fig.12 Added Resistance Coefficient for LEADGE-Bow from Model Test (Ballast)

4. FULL-SCALE MEASUREMENT

The first bow shape among the above fitted to the actual ship was Ax-Bow and the first vessel with Ax-Bow was Cape-Size Bulk Carrier "M/V KOHYOHSAN" (Fig.13) delivered in 2001. In order to verify the effect of Ax-Bow to reduce the added resistance due to waves at actual sea, the full-scale hull performance measurement was performed. M/V KOHYOHSAN has a sister vessel with ordinary bow delivered in almost the same period. The hull performance monitoring system was installed to these two vessels and full-scale measurement was started from their maiden voyage.

4.1. MONITORING SYSTEM

Fig.14 shows a diagram of monitoring equipments and items. The monitoring system unit was installed in the electric equipment room at the back of wheelhouse. Most of the monitoring items were obtained by branching from

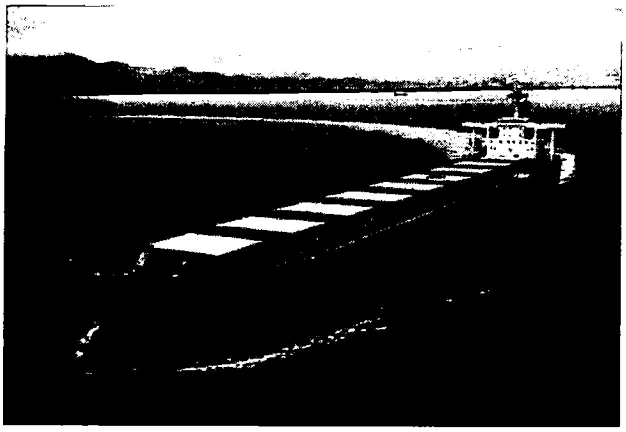

Fig.13 M/V KOHYOHSAN

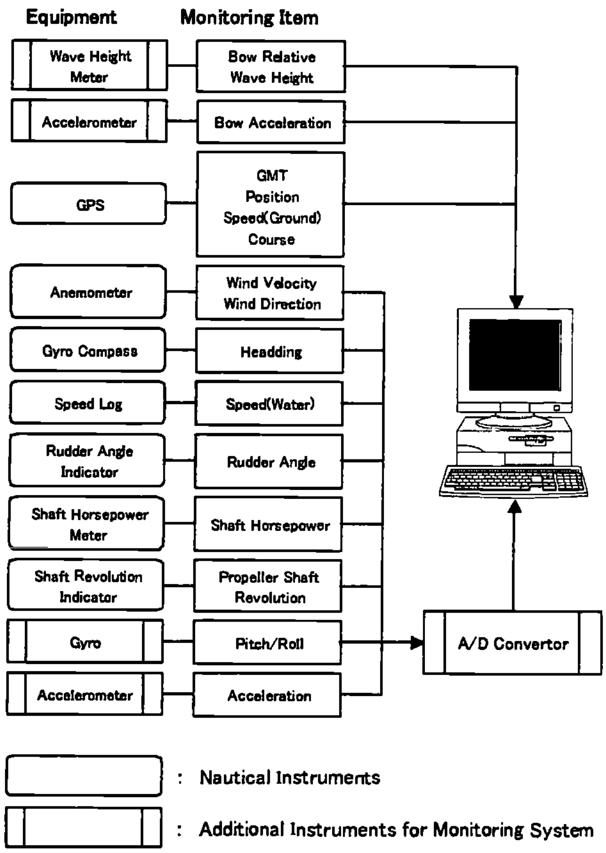

Fig.14 Hull Performance Monitoring System

navigation equipment. In addition to these items, some instruments were installed for the hull performance monitoring.

(1) Wave Height Meter

Three sets of the electromagnetic-wave type wave height meter were installed at the tip of the bow deck and 7m backward from the tip of the bow deck on both port and starboard side deck. The wave height meter measures the relative wave height at bow. In order to obtain the absolute wave height, heaving motion at the bow has to be taken into account. An accelerometer was installed in the bosun's store for correction of heaving motion of the bow.

(2) Motion Sensor Unit

A motion sensor unit including two sets of gyroscope and one accelerometer was installed in the wheelhouse. It monitors the rolling motion, pitching motion and vertical acceleration.

4.2. MEASURING SEQUENCE

The hull performance data were measured fully automatically by the monitoring system. The one measuring unit is consisted of 20minutes for measuring and 10 minutes for data storing and statistical analyzing. This measuring unit was repeated in every 30 minutes. Therefore, 48 sets of measured time histories and statistical analysis can be obtained per a day.

4.3. SEPARATION OF RESISTANCE COMPONENTS

The components of the external disturbance acting on a ship in actual sea are mainly due to wind, wave and current. These external disturbances cause the added resistance, an encounter rudder and a drifting. The encounter rudder or drifting also causes the added resistance. In order to verify the effect of Ax-Bow, these components of added resistance are divided and the speed loss or horsepower increase only due to waves are analyzed for every voyage.

5. THE EFFECT OF AX-BOW AT ACTUAL SEA

The speed loss due to waves for M/V KOHYOHSAN and her sister vessel are analyzed from the monitoring data for about 2 years from their maiden voyage.

5.1. SAMPLING OF THE MONITORING DATA

M/V KOHYOHSAN and the sister vessel sails in different route each other. Therefore, they have encountered different external disturbances and with different loading conditions. In order to improve the precision of verification, a certain number of the data are selected under almost the same condition as follows.

(1) Full load condition

(2) Propeller revolution is greater than the normal service output

(3) Wave encounter angle is within 60degree (head sea)

(4) Encounter rudder is within 2 degree

(5) Absolute wind velocity is under 10m/s

(6) Absolute wind direction is from head to side

5.2. SPEED LOSS DUE TO WAVE

Fig.15 shows the speed loss due to waves analyzed from the monitoring data. In this figure, the speed loss from the calm sea condition is shown as a function of the significant wave height. The markers show the analyzed speed loss of Ax-Bow and ordinary bow. The solid line and dashed line shows the mean line of speed loss for Ax-Bow and ordinary bow. There seems no difference between two bows in the lower wave height region, but the difference of speed loss becomes significant in the higher wave height region. This result shows the effectiveness of Ax-Bow to reduce the speed loss in actual sea.

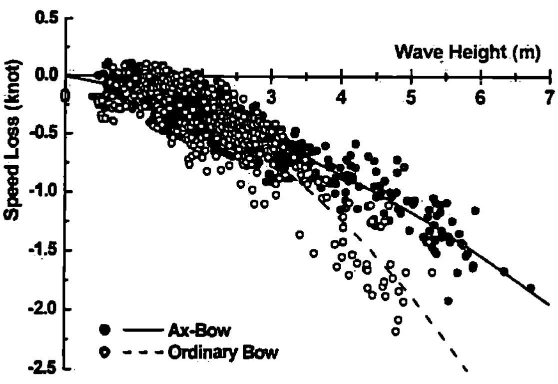

Fig.15 Comparison of Speed Loss

Table.1 shows the reduction ratio of speed loss by Ax-bow. Table 1-(a) shows a result of short-term prediction obtained by using model test results. Table 1-(b) shows mean value of the full-scale measurement, which is shown in solid and dashed line in Fig.15.

The absolute values of speed loss for Ax-Bow and ordinary bow are different between Table 1-(a) and Table 1-(b), but the reduction ratio of speed loss shows a good agreement.

Table 1 Reduction Ratio of Speed Loss

(a) Short Term Prediction by Tank Test

H(m)	3	4	5	6
Te(sec.)	6.5	7.8	8.5	8.8
Ax-Bow(knot)	-0.75	-1.29	-1.80	-2.38
Ord. Bow(knot)	-1.16	-1.93	-2.67	-3.48
Reduction(%)	*64%*	*67%*	*68%*	*68%*

(b) Result of Full Scale Measurement

H(m)	3	4	5	6
Te(sec.)	6.5	7.8	8.5	8.8
Ax-Bow(knot)	-0.57	-0.87	-1.20	-1.50
Ord. Bow(knot)	-0.68	-1.20	-1.88	-2.63
Reduction(%)	*84%*	*73%*	*64%*	*57%*

6. CONCLUSIONS

The conclusions in the present study are as follows:

1. In order to reduce the diffraction component of added wave resistance, new bow shapes, Beak-Bow, Ax-Bow and LEADGE-Bow are developed.

2. Model tests in regular waves show the reduction of added resistance due to waves by adopting these bow shapes.

3. The first vessel adopted Ax-Bow was Cape Size Bulk Carrier. The full-scale measurement has been carried out by using the first Ax-Bow vessel and her sister vessel with the ordinary bow.

4. The full-scale measurement result of speed loss due to waves shows the advantage of Ax-Bow to reduce the speed loss also at sea.

5. The full-scale measurement result shows good agreement with the results of short-term prediction by the model test.

A development of hull form design had long been carried out by focusing on the improvement the hull performance in the calm water. Ax-Bow is the first full form to improve the hull performance at actual sea by modifying the hull form above the load waterline to reduce the added resistance due to wave. Ax-Bow has already been applied to more than 50 vessels.

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