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The Effects of Skegs and Length of Towline on Trajectory Characteristics of Barge

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스케그의 유무와 예인삭의 길이가 부선의 궤적 특성에 미치는 영향

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Abstract : *This research presents the results of a study on the trajectory characteristics of barges with different configurations. A towing experiment was carried out in a water tank with three types of barges in two cases: with and without skegs. The effects of towline length on trajectory were also observed. This study analyzed and compared the length and amplitude of trajectory shapes for each barge in various combinations. It revealed that the trajectory of a barge is influenced not only by skegs but also by the length of the towline. As a result of this work, it can be clearly seen that skegs significantly improve the course stability of a towed barge regardless of differences in bow shape or towline length. Water tank test results also indicated that the length of a towline plays a key role in affecting the trajectory characteristics of a barge-towing system. The length and amplitude of the slewing motion of a barge increased with an increase in the length of the towline connected to the barge. Validation of the present research results should be carried out by further experiments and computational comparisons in the near future.*

Key Words : *Barge, Skeg, Length of towline, Course stability, Slewing motion*

요 약 : 본 연구는 다양한 유형으로 구성된 부선의 궤적의 특성의 결과를 제시하는 것을 그 목적으로 하였다. 스케그의 유무에 따른 3가지 조합의 부선 모델을 대상으로 수조실험을 실행하였고, 예인삭의 길이가 궤적에 미치는 영향을 관찰하였다. 본 연구는 다양한 조합의 바지선에서의 각각의 궤적 형태의 길이와 진폭을 비교분석하였으며, 그 결과 부선의 궤적은 스케그 뿐만 아니라 예인삭의 길이에도 영향을 받고 있음이 드러났다. 스케그는 선수형상 및 예인삭 길이의 차이에 관계없이 부선의 코스 안정성을 크게 향상 시킨다는 것을 명확히 나타내고 있다. 또한, 예인삭의 길이는 부선 시스템의 궤적 특성에 영향을 미치는 핵심적인 역할을 한다는 것이 밝혀졌다. 부선의 회두운동의 길이와 진폭은 부선 연결된 예인삭의 길이가 길수록 증가되었다. 향후 추가 실험 및 결과 분석을 통하여 본 연구의 타당성을 입증할 것으로 기대된다.

핵심용어 : 부선, 스케그, 예인삭 길이, 코스안정성, 회두운동

1. Introduction

The prediction of the course stability of towed barges strongly depends on the model tests in marine industries. The characteristics of the slewing motion of the barge models are similar to those of the slewing motion of actual barges. Therefore, the model test is widely used for its reliability and the safest towing method developed using the water tank experiment can also be applied to the actual towing work.

The prediction of the course stability is one of the most important aspects of the design and engineering of offshore projects. Much research has been done on the prediction of the course stability.

Takekawa et al. (1975) and Inoue et al. (1977) showed that the

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course stability of barge is greatly influenced by the skeg and configuration. Preliminary resistance for barge with stern notches of various sizes was estimated by summarizing data from numerous tank tests of ocean barge models (Lattore et al., 1981). Course keeping tests for four different size of skegs, resistance tests for three different shapes of skeg were performed in (Lee and Lee, 1997) and the effect of angle of skegs on resistance was studied at final stage. Kim presented the skeg design for stabilization of the barge for the 75 m class barge (Kim, 2003) and for the 64 m barge (Kim, 2005). A parametric study was performed a parametric study to determine the correlation parameters between the designed stern skeg size and barge dimensions (Chun et al., 2011). The effects of stern skeg on course stability for three ships which were without stern skeg and equipped with two types of flat plate skeg were investigated experimentally and numerically (Miyazaki et al., 2011). Their publish findings showed that course stability is greatly influenced by the skeg type and configuration. Captive model tests were carried out to investigate the effect of stern skeg area on the hydrodynamic force characteristics of a ship with PODs in pusher mode during maneuvering motions (Tanaka et al., 2014). The sway force and yaw moment w valere computed by CFD and the effects of nonlinearity on barges were also analyzed (Im et al., 2015). The effects of various factors such as the presence of the skeg and bridle, towing speed, and towline length 1 L and 2 L, on the slewing motion of a barge were investigated by performing tests in a water tank (Lee and Lee, 2016).

As described above, previous studies have primarily focused on particular types of vessels to identify the optimal shapes and arrangements of skegs for those vessels.

The present paper deals with the correlation between the shape of the barge, the absence of skeg and the length of towline. It was found that the slewing motions differ according to the bow shape of barge. In order to improve the course stability of the towed barge, barges are often equipped with stern skegs. Effects of stern skeg on course stability are still worth considering. However, due action should be paid to determine the differing effects of skegs in accordance with the bow shape and correlation with the length of towline. The purpose of this study is to present the results of experiments on trajectory characteristics of barges with different configurations. The results were obtained through the analysis of the effects of skegs and lengths of towline on the slewing motion of barges. Based on the experimental data, the optimum combinations were successfully derived. It is expected that the validation of the present study will be carried out by further experiments and computational comp-arisons in the near future.

2. Towing experiment system

The towing experiment was carried out in the water tank at Mokpo National Maritime University to determine the characteristics of the slewing motion of the barge models. The total length of the water tank is 50 m, width 20 m. In this experiment, the towing vessel was Free Running Model Ship of a 300 K crude oil tanker KVLCC1. The scale of this model is 1/100 and its details can be referred to (Im and Seo., 2010). The particulars and overview are shown in Table 1.

Table 1. Principal particulars of model ship

Classification	Actual	Model
Scale ratio	1	1/100
Type	Tanker	Tanker
Froude number	0.142	0.142
Design speed (m/s)	7.9739	0.79739
Lpp (m)	320	3.2
Breadth (m)	58	0.58
Depth (m)	30	0.3
Draft (m)	20.8	0.2
Displacement (m^3)	312737.5	0.3127

Whole system was installed with high accuracy of 1 cm R5 Trimble GPS Receiver and wireless radio communication device that can perform Real Time Kinematics (RTK) positioning system for the record of ship trajectory, referred to (Choi and Im, 2016). This system consisted of a shore base on land and a mobile station mounted on the barge during experiment, the former gets the precision position, compares and transmits the correction via radio transmitter to the mobile station. In this experiment, 10 Hz data was continuously saved by Topo Method. The installation of GPS system is shown in Fig. 1 and 2.

Three barge models, each with a different but widely used bow shape, were chosen as test specimens in a water tank experiment. The three barge models were as follows: a box-type model KNU-001, hexagon-type model KNU-002, and a spoon-type model KNU-003, and can be referred to (Lee and Lee, 2016). The size of each barge model was 1/50 of a full-scale ship. The main specifications of the barges are shown in Fig. 3 and Table 2.

Fig. 1. Mobile Base GPS Receiver.

Fig. 2. Shore base GPS Receiver.

Barge was connected to Free running model ship by a wire rope. The towing model ship sailed steady with stable velocity and the fully loaded condition was selected as the experimental condition. The towing speed was based on the design speed of the target barge. The wire rope was 1 mm in diameter considering the convenience of the model test and directly connected to the barge.

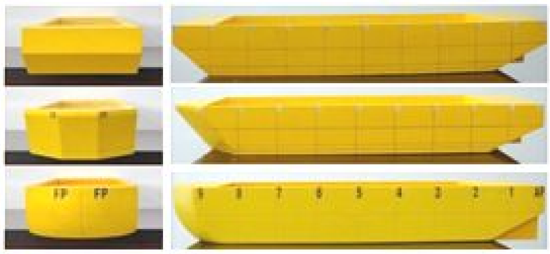

Fig. 3. Front and side views for KNU-001 (top), KNU-002 (middle) and KNU-003 (bottom) model barge.

Table 2. Principal dimension of barges

Classification	KNU-001		KNU-002		KNU-003	
	Actual	Model	Actual	Model	Actual	model
LBP (m)	50.0	1.0	50.0	1.0	50.0	1.0
Breadth (m)	12.0	0.24	12.0	0.24	12.0	0.24
Draft (m)	2.8	0.056	2.8	0.056	2.8	0.056
Volume (m^3)	1474.0	0.01179	1389.0	0.01111	1430.0	0.01144
Cb	0.8772	0.8772	0.8267	0.8267	0.8512	0.8512

This experiment was performed to investigate the factors affecting the slewing motions of a barge through quantitative analysis and to improve course stability. In the experimental scenario, each barge was conducted in 6 cases, with and without skeg, and was installed with three lengths of towline 2 L, 4 L and 5 L (L is length of barge model). These lengths which are often used in actual towing operation were utilized to observe their effects to slewing motions of barge models. Totally, 18 cases of towing experiment which were carried out are listed in Table 3.

Table 3. Towing test scenarios

		Senario No.①~⑱								
Model No.		KNU-001			KNU-002			KNU-003		
Length of towline		2L	4L	5L	2L	4L	5L	2L	4L	5L
Skeg*	with	①	②	③	④	⑤	⑥	⑦	⑧	⑨
	without	⑩	⑪	⑫	⑬	⑭	⑮	⑯	⑰	⑱

* see Fig. 5

Fig. 4 is the appearance of the towing experiment in the water tank.

Fig. 4. Tug and barge system.

The analysis below was based on the bow shape, presence of the skeg, and length of the towline.

3. Analysis and comparison of the experimental results

3.1 Analysis of the effects of skeg

The water tank experiment was performed under two conditions: the absence of a skeg, presence of the side skegs (as can be seen in Fig. 5). This was done to determine the effects of the skeg on the slewing motion of the barge models.

Fig. 5. Skeg arrangement on the model.

Figs. 6-8 compare the trajectories of barge model KNU-001 when the barge was towed in the straight direction, with and without skeg, and was installed with three lengths of towline 2 L, 4 L and 5 L. With skegs, in case 2 L and 5 L towline, the trajectories were unstable at first but becames more stable later. Nevertheless, without skeg, the trajectories remained unstable from beginning.

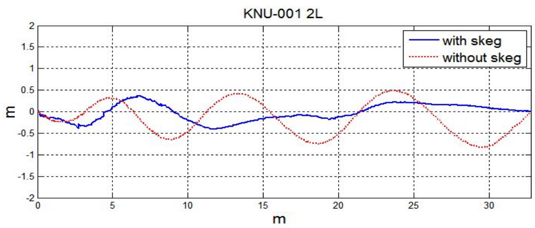

Fig. 6. Comparison of trajectories of KNU-001 (with and without skeg, 2 L towline).

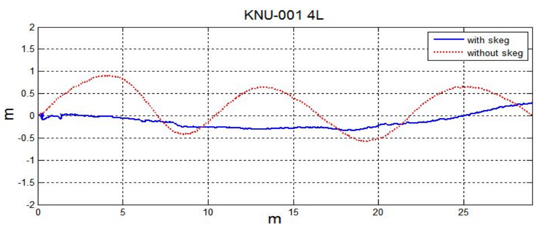

Fig. 7. Comparison of trajectories of KNU-001 (with and without skeg, 4 L towline).

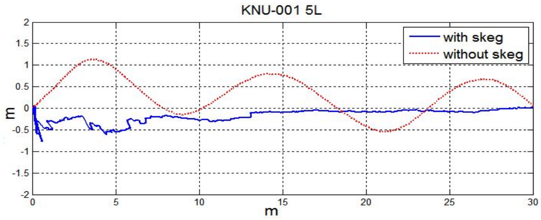

Fig. 8. Comparison of trajectories of KNU-001 (with and without skeg, 5 L towline).

Figs. 9-11 compare the trajectories of barge model KNU-002 when the barge was towed in the straight direction, with and without skeg, and was installed with three lengths of towline 2 L, 4 L and 5 L. With skegs, KNU-002 showed the more stable courses incomparison with those without skegs.

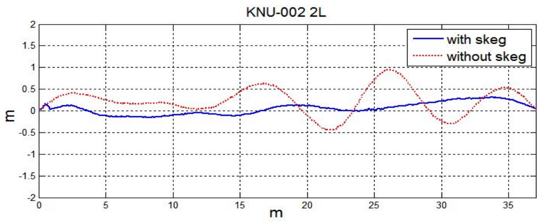

Fig. 9. Comparison of trajectories of KNU-002 (with and without skeg, 2 L towline).

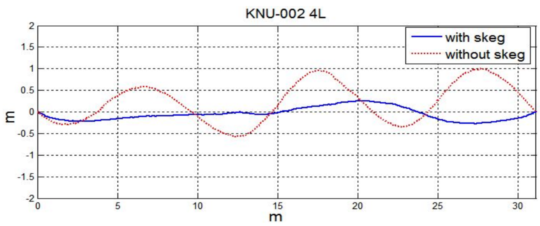

Fig. 10. Comparison of trajectories of KNU-002 (with and without skeg, 4 L towline).

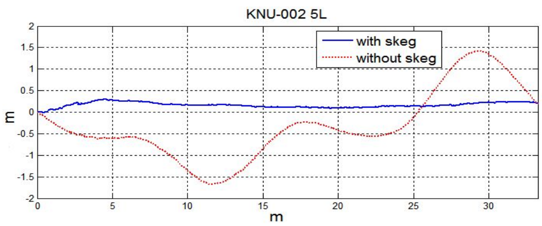

Fig. 11. Comparison of trajectories of KNU-002 (with and without skeg, 5 L towline).

Figs. 12-14 compare the trajectories of barge model KNU-003 when the barge was towed in the straight direction, with and without skeg, and was installed with three lengths of towline 2 L, 4 L and 5 L. With skegs, in case 2 L, the trajectory was very unstable but becames more stable when the barge was equipped with 4 L and 5 L towline. However, without skeg, the trajectories remained unstable with great amplitudes.

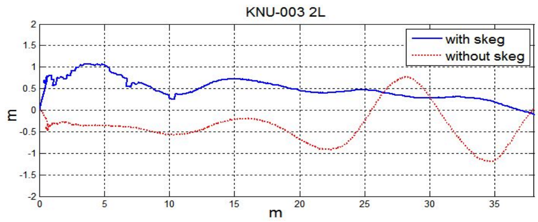

Fig. 12. Comparison of trajectories of KNU-003 (with and without skeg, 2 L towline).

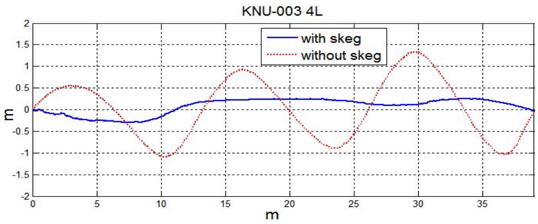

Fig. 13. Comparison of trajectories of KNU-003 (with and without skeg, 4 L towline).

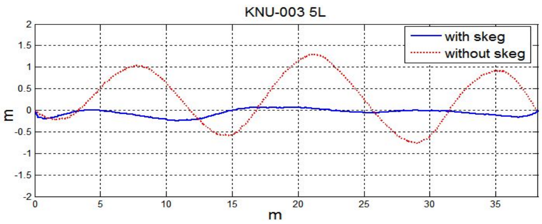

Fig. 14. Comparison of trajectories of KNU-003 (with and without skeg, 5 L towline).

According to above figures, the trajectories of all three barges equipped with skegs were around center line with very small amplitudes (the maximum value was only approximate 0.5), while in case of absence of skeg, the trajectories were appeared as wave-shape with comparatively greater amplitudes. It is confirmed that the installation of the skeg, irrespective of the difference in bow shape, comparatively maintains the course stability to a manageable level.

3.2 Analysis of the effects of length of towline

Figs. 15-17 compare the slewing motions of KNU-001, KNU-002, and KNU-003, in case with skeg. The experiments were carried out by connecting the barges using towlines of length 2 L, 4 L and 5 L to investigate the characteristics of slewing motion with respect to the length of towline. As can be seen in these figures, three models of barges could maintain straightness when skegs were installed.

It has been confirmed that, irrespective of the shape of the barge models, different length of towlines did not have a significant influence on the changes in the trajectories of barges, which are more dependent on the skeg as described in the previous section, the skeg was designed to maintain the stability of the barge during the operation of the barge. It also can be seen clearly in three figures that, when equipped with skegs, the trajectories of barge KNU-002 were most stable.

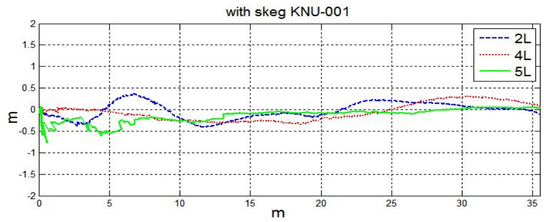

Fig. 15. Comparison of trajectories of KNU-001 (with skeg).

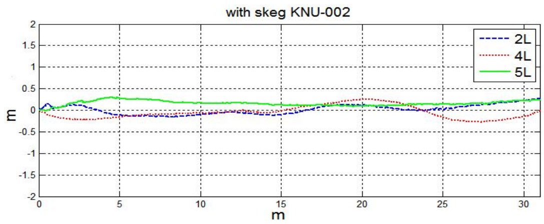

Fig. 16. Comparison of trajectories of KNU-002 (with skeg).

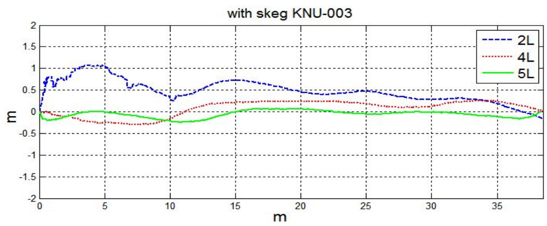

Fig. 17. Comparison of trajectories of KNU-003 (with skeg).

Same conditions of experiments were performed in case without skeg. To compare the slewing motions of barges, in this section, two non-dimensional paremeters which are L_{SM} (length of slewing motion) and A_{SM} (amplitude of slewing motion) were used. Firstly, average length and amplitude of slewing motion of each barge were calculated by dividing sum of lengths (and amplitudes) by number of motions. Finally, L_{SM} and A_{SM} are the result of average length of slewing motion divided by length of barge and average amplitude of slewing motion divided by breadth of barge, respectively. The method of observing these parameters in one motion is as shown in Fig. 18.

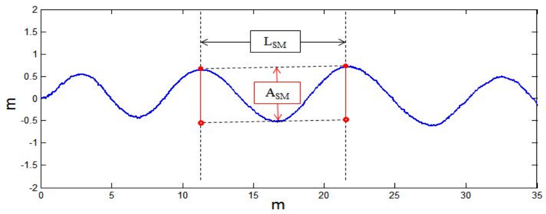

Fig. 18. Method of observing length and amplitude of slewing motion.

Fig. 19 shows the trajectories of barge KNU-001 when it was connected with towline of length 2 L, 4 L and 5 L, respectively. The values of L_{SM} were 11.47, 12.33 and 13.34 while the values of A_{SM} were 5.342, 5.821 and 5.883 corresponding to towline length of 2 L, 4 L and 5 L. Therefore, it can be seen clearly that the longer the towline was, the longer lengths and amplitudes of slewing motions became.

The trajectories of barge KNU-002 when it was connected with towline of length 2 L, 4 L and 5 L were showed in Fig. 20. The values of L_{SM} were 10.34, 10.87 and 11.67 while the values of A_{SM} were 5.375, 5.500 and 5.550 corresponding to towline length of 2 L, 4 L and 5 L, respectively. Therefore, same result with case of KNU-001, the longer the towline was, the longer lengths and amplitude of slewing motions became.

In the case of barge KNU-003 (as can be shown in Fig. 21) The lengths of slewing motions were 10.16, 13.33 and 10.60 while the amplitudes of slewing motions were 7.235, 8.075 and 8.217 corresponding to towline length of 2 L, 4 L and 5 L, respectively. During test 17 (with towline length 4L and without skeg), due to sudden strong wind, the value of L_{SM} of this case was greater than expected (it should be between 10.16 and 10.60). Only the amplitudes of slewing motions became longer with increase of towline length.

Furthermore, according to these figures, among three barges, trajectories of barge KNU-001 were stable and lengths and amplitudes of slewing motions did not show significant changes during the test.

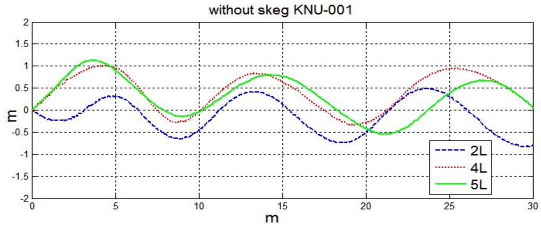

Fig. 19. Comparison of trajectories of KNU-001 (without skeg).

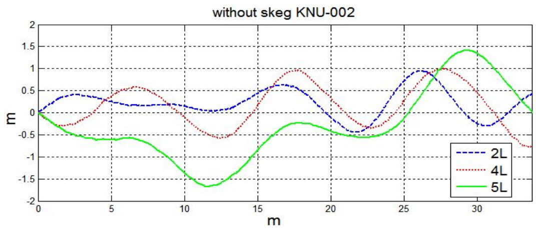

Fig. 20. Comparison of trajectories of KNU-002 (without skeg).

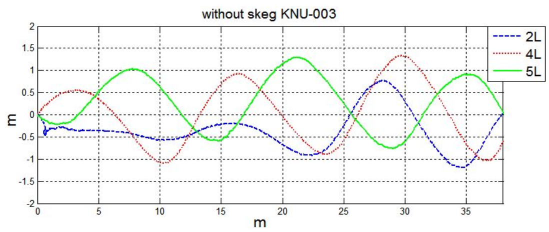

Fig. 21. Comparison of trajectories of KNU-003 (without skeg).

Tables 4-5 and Figs. 22-23 are showing and comparing the values of L_{SM} and A_{SM} of barges in 9 cases of absence of skeg.

Table 4. Values of L_{SM} of three types of barges (without skeg) with 3 lengths of towline

Classification	Length of towline		
	2L	4L	5L
KNU-001	11.47	12.33	13.34
KNU-002	10.34	10.87	11.67
KNU-003	10.16	13.33	10.60

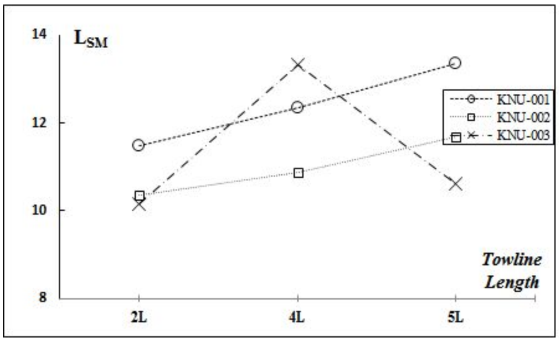

Fig. 22. Comparison of L_{SM} of 3 barges (without skeg) with 3 lengths of towline.

Table 5. Values of A_{SM} of three types of barges (without skeg) with 3 lengths of towline

Classification	Length of towline		
	2L	4L	5L
KNU-001	5.342	5.821	5.883
KNU-002	5.375	5.500	5.550
KNU-003	7.235	8.075	8.217

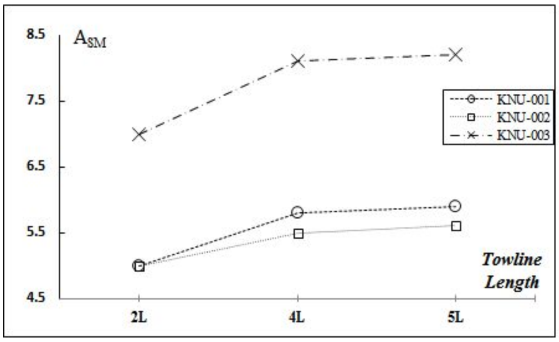

Fig. 23. Comparison of A_{SM} of barges (without skeg) with 3 lengths of towline.

Table 4-5 list the values of L_{SM} and A_{SM} of three barges with different lengths of towline. As can be indicated from these tables, when connected to towline length of 2 L, slewing motions of barge KNU-001 showed the longest L_{SM} and the shortest A_{SM}. It means that the box-type barge has the most stable course among three barges in this case. In case with towline length of 4 L, it is unclear to assess the course stability of three barges. In the final case, the slewing motion of KNU-003 had smaller L_{SM} and greater A_{SM} in comparison with those of the other barge models. In other words, the course stability of the KNU-003 barge cannot be satisfactorily ensured through the installation of 5 L towline.

Figs. 22 and 23 show an upward tendency that the values of L_{SM} and A_{SM} of the three barges increased with increase in the length of a towline connected to the barge. However, L_{SM} of KNU-003 without skeg, 4 L towline did not follow the trend and was unexpectedly greater. The reason for this is that during the test 17, there was suddenly strong wind in a short time.

Furthermore, also according to Figs. 22 and 23, among three types of model barge, the values of A_{SM} of KNU-003 were comparatively greater than those of KNU-001 and KNU-002 in all three cases with towlength 2 L, 4 L and 5 L. The same result can be referred to (Lee and Lee, 2016), from the experiment with towlength 1 L and 2 L in a water tank that also showed that slewing motions of KNU-003 had biggest angles to the left and right directions. Thus, it was found that spoon-type model KNU-003 has the worst stability in case absence of skeg among three types of barge. The values of A_{SM} of KNU-002 were smaller than those of two others. It means that without skeg, KNU-002 were most stable.

4. Conclusions

In this study, the characteristics of the slewing motion of a barge, during the navigation of a tug-barge, were investigated. The relationship between the barges' stability and the skeg and the length of towline was derived and the following results were obtained.

(1) It was verified that skeg contributed to the improvement of the course stability. Irrespective of the difference in bow shape and length of towline, the installation of skegs significantly reduced the slewing motion of barge to a manageable level. When equipped with skegs, the trajectories of the hexagon-type KNU-002 had the best stability.

(2) Also regardless to the bow shape, the length and amplitude of slewing motion of the barge increased with increase in the length of a towline connected to the barge.

(3) In case of barge without skeg, the spoon-type KNU-003 presented the worst course stability with all three lengths of towline and the hexagon-type KNU-002 showed the most stable trajectory.

(4) Based on more test results in the future, we will carry out continuous verification and also comparative study by calculation.

Acknowledgements

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