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Research Paper
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Experimental Study on the Towing Stability of Barges Based on Bow Shape

Sang Lee* · Sang-Min Lee**†
* Graduate school of Kunsan National University, Kunsan 54150, Korea
** Dept. of Marine Science and Production, Kunsan National University, Kunsan 54150, Korea

선수형상이 다른 부선의 예인안정성에 관한 실험 연구

이상* · 이상민**†
* 군산대학교 대학원, ** 군산대학교 해양생산학과

Abstract : *The maneuverability of a tugboat is affected by the slewing motion of a barge while the tug is navigating with the barge in water. Therefore, it is necessary to reduce the slewing motion of the barge to allow for safe towing work. In this study, a water tank experiment was performed to examine the factors affecting the slewing motion of a barge and improve course stability. The characteristics of slewing motion vary according to bow shape. Three barge models, each with a different bow shape, were selected as experimental subjects. A comprehensive analysis was performed to study the effects of various factors on the slewing motion of a barge such as the presence of a skeg and bridle, towing speed, and the length of the towline. The effect of the location of the skeg varied according to bow-hull form. The slewing motion of the barge decreased as the length of the towline increased, and this decrease was even greater when a bridle was connected to the towline. In addition, the slewing motion decreased significantly as the length of the bridle increased. The slewing angles did not show significant change with respect to towing speed.*

Key Words : *Barge, Slewing motion, Course stability, Skeg, Bridle, Towline*

요 약 : 예부선이 항행할 경우 부선의 회두운동으로 인하여 예선은 조종성능에 제한을 받기 때문에 부선의 회두운동을 감소시켜야 안전한 예항업무를 이행할 수 있다. 본 연구에서는 부선의 침로안정성을 향상시키기 위한 방안으로 부선의 회두운동에 영향을 미치는 항목들을 조사하기 위하여 수조실험을 실행하였다. 선수 형상에 따라 회두운동 특성이 다르게 나타나기 때문에 서로 다른 선수 형상을 지닌 부선 모델을 대상으로 스케그의 영향, 예인선속의 영향, 예인삭 길이의 영향, 브라이들의 영향에 대하여 종합적으로 분석하였다. 실험결과 스케그의 설치 위치에 의한 효과는 선수형상에 따라서 다르게 나타나고 있는 모습을 보여주고 있다. 부선의 회두운동은 부선에 연결된 예인삭의 길이가 길수록 부선의 회두가 작아짐을 알 수 있었다. 또한 예인삭만 연결한 상태보다 예인삭에 브라이들을 연결하는 것이 부선의 회두가 작아지며, 브라이들의 길이가 길어질수록 부선의 회두운동이 크게 작아짐을 알 수 있었다.

핵심용어 : 부선, 회두운동, 침로안정성, 스케그, 브라이들, 예인삭

1. Introduction

The maneuverability of a tug is affected by the slewing motion of a barge during the navigation of a tug-barge in water. Therefore, it is necessary to reduce the slewing motion of the barge for safe towing work. Generally, two empirical criteria are used to evaluate the course stability of tug-barges. These criteria are as follows: the amplitude of the slewing motion should be less than 50 % of the width of the barge; when external forces are applied to the barge in a direction away from the center line, the barge's movement amplitude should lie within the movement amplitude range defined by the first criterion within two cycles (Lee and Lee, 1997).

Inoue et al. (1977) and Takekawa et al. (1975) have clarified the effect of skeg lift on the course stability of barge. Latorre and Ashcroft (1981) discussed the research and development on the towing resistance of simple hull forms, skeg design, and the relationship between skeg lift and towed barges' course stability.

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* First Author : officersang@kunsan.ac.kr, 063-469-1724
† Corresponding Author : smlee@kunsan.ac.kr, 063-469-1814
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Im et al. (2015) used CFD to compute the sway force and yaw moment and analyzed the effects of nonlinearity on barges. Tanaka et al. (2014) investigated the effects of stern skeg on hydrodynamic force characteristics of a ship with twin azimuthing podded propellers. Kwon et al. (2014) studied the practical prediction methods on the course stability of towed FPSOs with single skeg and twin skegs using CFD.

The characteristics of the slewing motion of the barge models were similar to those of the slewing motion of actual barges. Devices developed to prevent the excessive slewing motion of barge models showed a comparable performance when used in the actual barge (Latorre and Ashcroft, 1981). Therefore, the safest towing method developed using the water tank experiment can also be applied to the actual towing work.

In this paper, a water tank experiment was performed to study the factors affecting the slewing motion of a barge and to improve its course stability. The characteristics of the slewing motion vary according to the bow shape. Therefore, three barge models, each with a different bow shape, were selected as experimental targets. A comprehensive analysis was performed to study the effects of various factors such as the presence of the skeg and bridle, towing speed, and length of the towline, on the slewing motion of a barge. The safest towing method for application during stern towing was determined by using the results of a water tank experiment. The results were obtained through the analysis of the effects of the aforementioned factors on the slewing motion and tow tension of a barge.

2. Experimental tank test

Three barge models, each with a different but widely used bow shape, were selected 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. Fig. 1 and Table 1 describe the basic shapes and specifications of the barge models. The size of each barge model was 1/50 of a full-scale ship. Fig. 2 shows the stern of the barge. The fully loaded condition was selected as the experimental condition in this study.

A wire rope was used as a towline for connecting the barge. The wire rope was 1 mm in diameter, and had the number of steel wire and the direction of lay similar to that of the actual rope used in practice. Two types of connection methods were applied. In one method, a towline was directly connected to the barge. In the other, the towline was connected to the barge through a bridle. The bridle used was a towing rope of triangular shape connected to the towline. During towing, the bridle distributed the load applied to the towline and tows at a certain angle.

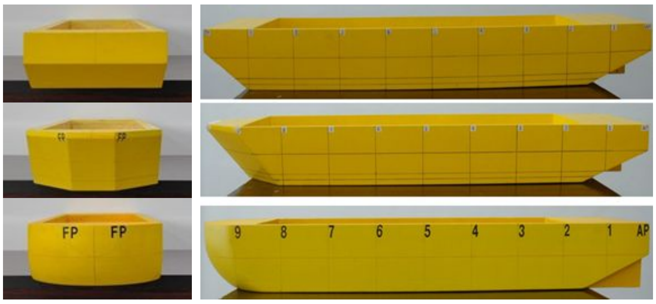

Fig. 1. Front and side views for KNU-001 (top), KNU-002 (middle) and KNU-003 (bottom) model ship.

Table 1. Principal particulars of model ship (1/50 scale)

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

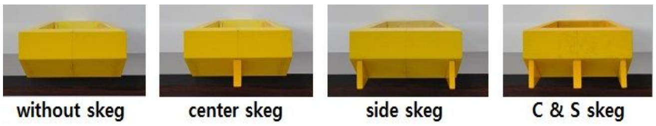

Fig. 2. Skeg arrangement on the model.

The experiment was performed in the circulating water tank (8.0 × 2.8 × 1.4 m). The sidewalls were assumed to have no effect on the slewing motion because the barge models were not allowed to approach the vicinity of the water tank walls during the experiment. The most stable stern towing method was determined through the analysis of the slewing motion of the three barge models. The analysis was based on the bow shape, presence of the skeg and its location, length of the towline, ship speed, and the presence of the bridle and its length.

A tensiometer was installed at the towing point to measure the towing tension, and a towline was connected at this point. The experiment was performed by setting the speed of barge models to 0.367, 0.513, and 0.659 m/s, which corresponded to speeds of 5, 7, and 9 knot, respectively, of a full-scale ship. Fig. 3 shows the stern towing method. In addition, it clarifies the concept of bridles and the method for measuring the towing tension and slewing angle of the towline (amplitude of slewing motion).

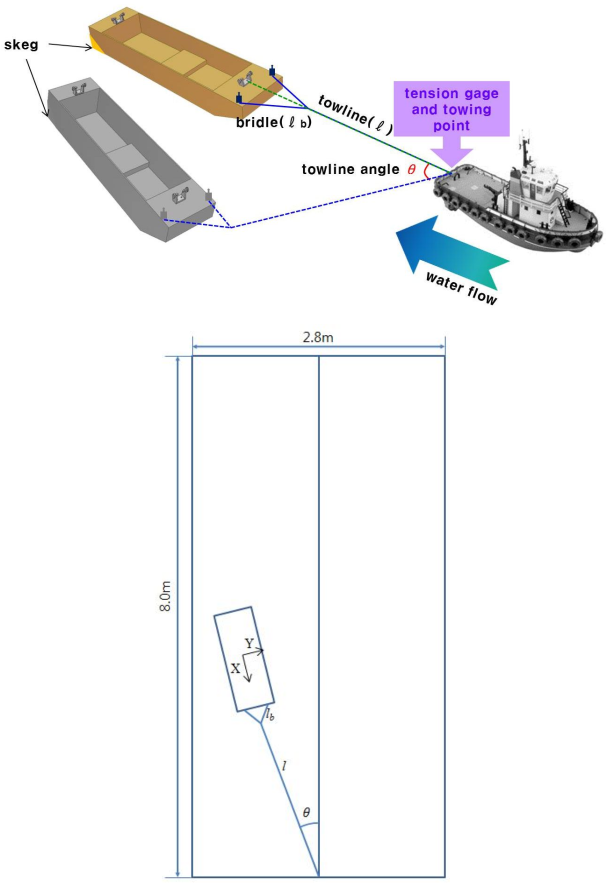

Fig. 3. Tug and barge system.

3. Analysis of the experimental results

3.1 Analysis of the effects of skeg

The water tank experiment was performed under four conditions: the absence of a skeg, presence of only the center skeg, presence of only the side skegs, and presence of both the center and side skeg. This was done to determine the effects of the skeg and its location on the slewing motion of the barge models.

The maximum slewing angle of KNU-001 (Fig. 4) measured 28° under the speed of 7 knot, it was not installed with a skeg. The slewing angle of KNU-001 was approximately 1.5° in the presence of the center skeg. KNU-001 can be satisfactorily ensured through the installation of only the center skeg.

The maximum slewing angle of KNU-002 (Fig. 6) measured 31° under the speed of 7 knot, it was not installed with a skeg. The slewing angle was < 1° in the presence of only the side skegs. KNU-002 can be satisfactorily ensured through the installation of the side skegs. The experimental results (Fig. 4 and Fig. 6) of KNU-001 and KNU-002 have been presented in the other paper to show the effects of skegs on barges (Im et al., 2015).

In the final case, the maximum slewing angle of KNU-003 (Fig. 8) measured 43° toward the left and right directions. This occurred under the following conditions: the speed of KNU-003 was 7 knot, it was connected with only a towline, and it was not installed with a skeg. The slewing angle of KNU-003 was approximately 30° in the presence of only the center skeg. The slewing angle was < 1° in the presence of only the side skegs, as well as in the presence of both the center and side skegs. In other words, when the barge models were not installed with a skeg, the slewing motion of KNU-003 was greater compared to those of the other barge models. Further, the effect of the center skeg on the slewing motion of KNU-003 was not as significant as in the case of KNU-002. In other words, the course stability of the KNU-003 barge can be satisfactorily ensured through the installation of the side skegs.

The variation analysis of towing tension shows that KNU-001 exhibits significant reduction in towing tension as a result of the installation of a center skeg (Fig. 5). KNU-002 exhibits a reduced slewing angle of 8°, but shows comparatively greater reduction in towing tension as a result of the installation of a center skeg (Fig. 7). The installation of the skeg, irrespective of the difference in bow shape, comparatively reduces the towing tension to a manageable level.

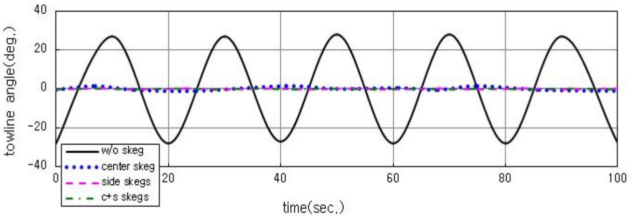

Fig. 4. Comparison of towline angle for KNU-001.
($l = 1\,L$, $V_s = 7.0$ kts)

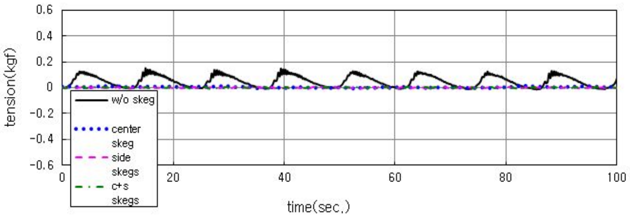

Fig. 5. Comparison of towline tension for KNU-001. ($l = 1\,L$, $V_s = 7.0$ kts)

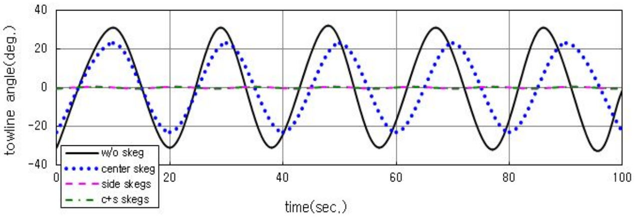

Fig. 6. Comparison of towline angle for KNU-002. ($l = 1\,L$, $V_s = 7.0$ kts)

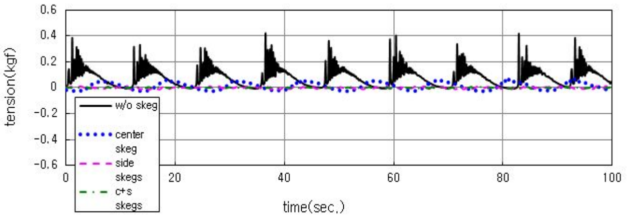

Fig. 7. Comparison of towline tension for KNU-002. ($l = 1\,L$, $V_s = 7.0$ kts)

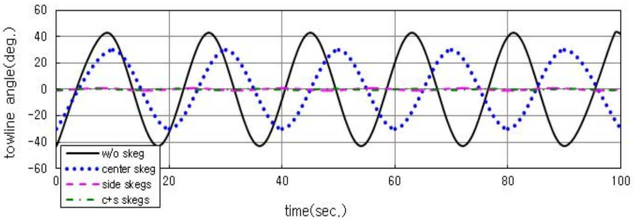

Fig. 8. Comparison of towline angle for KNU-003. ($l = 1\,L$, $V_s = 7.0$ kts)

3.2 Analysis of the effects of bridle

The experiment was also performed under the following conditions: in the presence of only the towline (without the bridle) and in the presence of bridles of lengths $0.3\,L$ and $0.5\,L$ (where L is the length of the towline). This was done to determine the effects of the presence of the bridle and its length on the slewing motion of the barge models.

The maximum slewing angle of KNU-001 (Fig. 9) measured approximately 28° toward the left and right directions when the barge was connected with only the towline. The slewing angle of KNU-001 were approximately 20° in the presence of a bridle of length $0.3\,L$, and it was only 2°～5° in the presence of a bridle of length $0.5\,L$. The slewing motion was smaller in the presence of the bridle as compared to that in the presence of only the towline. The slewing motion also decreased with increase in the bridle length. In particular, the slewing angle was reduced significantly when the bridle length was half of the towline length. Therefore, bridles can ensure course stability for a barge.

The maximum slewing angle of KNU-002 (Fig. 11) measured approximately 31° toward the left and right directions when the barge was connected with only the towline. The slewing angles of KNU-002 were approximately 24° and 16° in the presence of bridles of length $0.3\,L$ and $0.5\,L$, respectively. The slewing motion decreased with increase in the bridle length. The effect of the bridle length on the slewing motion of KNU-002 was not as significant compared to that on the slewing motion of KNU-001. However, the bridle of length $0.5\,L$ reduced the amplitude of the slewing motion by approximately 50 %.

In the final case, the maximum slewing angle of KNU-003 (Fig. 13) measured approximately 43° toward the left and right directions when the barge was connected with only the towline. The slewing angles of KNU-003 were approximately 33° and 24° in the presence of bridles of length $0.3\,L$ and $0.5\,L$, respectively. The slewing motion decreased with increase in the bridle length. The effect of the bridle length on the slewing motion of KNU-003 was also not as significant compared to that on the slewing motion of KNU-001. However, the bridle of length $0.5\,L$ reduced the amplitude of the slewing motion by approximately 44 %.

It was inferred from the experiment that, irrespective of the shape of the barge, the towing tension reduced with decrease in the slewing motion (Fig. 10 and Fig. 12). Therefore, it can be predicted that undertaking towing work after the installation of a bridle, for reducing the towing tension, is a safer towing method.

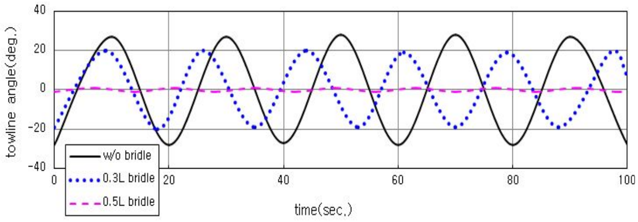

Fig. 9. Comparison of towline angle for KNU-001. (without skeg, $V_s = 7.0$ kts)

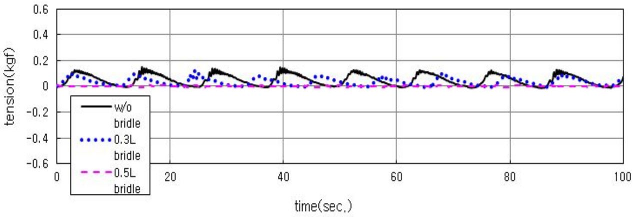

Fig. 10. Comparison of towline tension for KNU-001. (without skeg, $V_s = 7.0$ kts)

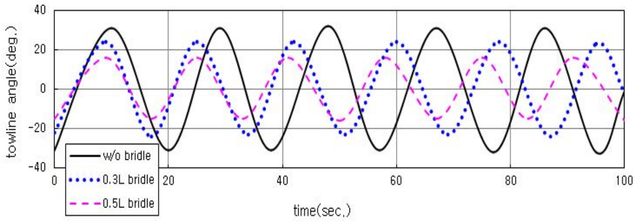

Fig. 11. Comparison of towline angle for KNU-002. (without skeg, $V_s = 7.0$ kts)

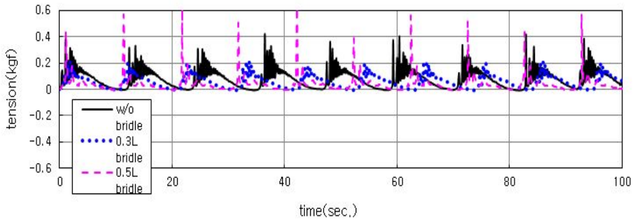

Fig. 12. Comparison of towline tension for KNU-002. (without skeg, $V_s = 7.0$ kts)

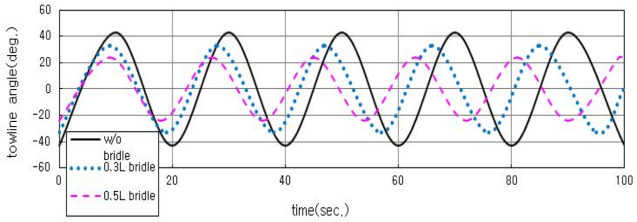

Fig. 13. Comparison of towline angle for KNU-003. (without skeg, $V_s = 7.0$ kts)

3.3 Analysis based on ship speed

Figs. 14 - 18 show the experimental results of the barge models KNU-001, KNU-002, and KNU-003, where the experiments were based on ship speed. These experiments were performed to determine the effects of towing speed.

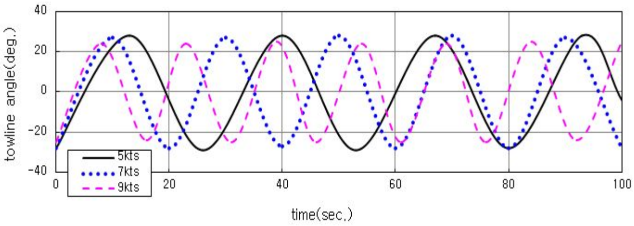

Fig. 14. Comparison of towline angle for KNU-001. (without skeg, $l = 1\,L$)

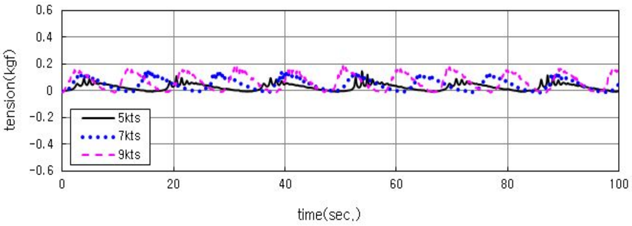

Fig. 15. Comparison of towline tension for KNU-001. (without skeg, $l = 1\,L$)

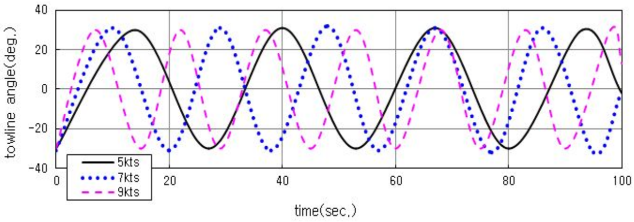

Fig. 16. Comparison of towline angle for KNU-002. (without skeg, $l = 1\,L$)

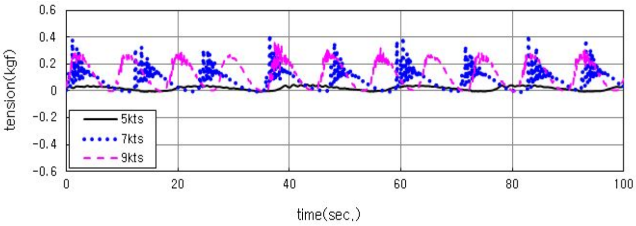

Fig. 17. Comparison of towline tension for KNU-002. (without skeg, $l = 1\,L$)

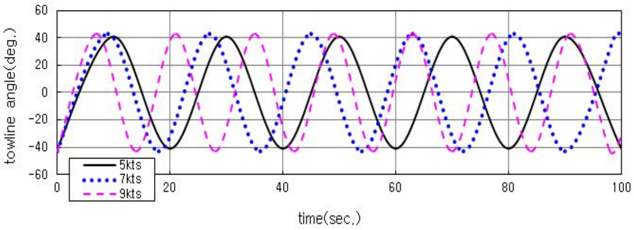

Fig. 18. Comparison of towline angle for KNU-003. (without skeg, $l = 1\,L$)

Fig. 14 shows the experimental results of KNU-001 based on ship speed, when the barge was connected with only a towline of length 1 *L*. The slewing angles of KNU-001 were approximately 29°, 28°, and 25° corresponding to ship speeds of 5, 7, and 9 knot, respectively. Thus, the slewing angles of KNU-001 did not vary significantly with changes in the ship speed. The comparison of the slewing cycles showed that they were approximately 26, 20, and 16 s in duration corresponding to ship speeds of 5, 7, and 9 knot, respectively. Thus, it was determined that the slewing cycles became shorter with increase in the ship speed.

Fig. 16 shows the experimental results of KNU-002 based on ship speed, when the barge was connected with only a towline of length 1 *L*. The slewing angles of KNU-002 were approximately 30°, 31°, and 31° corresponding to ship speeds of 5, 7, and 9 knot, respectively. Thus, the slewing angles of KNU-002 differed by < 1°~2° at different ship speeds. The comparison of the slewing cycles showed that they were approximately 27, 20, and 15 s in duration corresponding to ship speeds of 5, 7, and 9 knot, respectively. Thus, it was determined that the slewing cycles became shorter with increase in the ship speed.

Fig. 18 shows the experimental results of KNU-003 based on ship speed, when the barge was connected with only a towline of length 1 *L*. The slewing angles of KNU-003 were approximately 41°, 43°, and 43° corresponding to ship speeds of 5, 7, and 9 knot, respectively. Thus, the slewing angles of KNU-003 differed by < 2° at different ship speeds. The comparison of the slewing cycles showed that they were approximately 20, 18, and 14 s in duration corresponding to ship speeds of 5, 7, and 9 knot, respectively. Thus, it was determined that the slewing cycles became shorter with increase in the ship speed.

It was also determined that, irrespective of the shape of the barge models, ship speeds had an effect on the changes in the slewing cycles. However, they did not have a significant effect on the changes in the slewing angle.

The towing tension reduced significantly with decrease in the ship speed. Therefore, reducing the towing speed, when a barge and tug are subjected to excessive towing tension, is an effective towing operation method.

3.4 Analysis based on the length of towline

Figs. 19 - 23 show the experimental results of KNU-001, KNU-002, and KNU-003, which were performed at a ship speed of 7 knot. The experiments were performed by connecting the barges using towlines of length 1 *L* and 2 *L* to investigate the slewing motion with respect to the towline length.

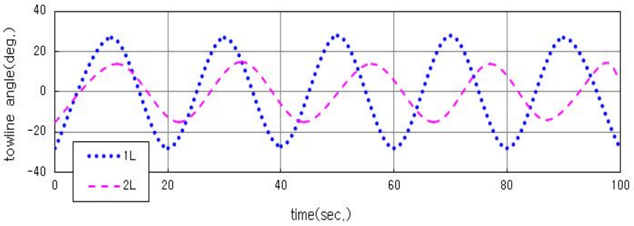

Fig. 19. Comparison of towline angle for KNU-001. (without skeg, $V_s = 7.0$ kts)

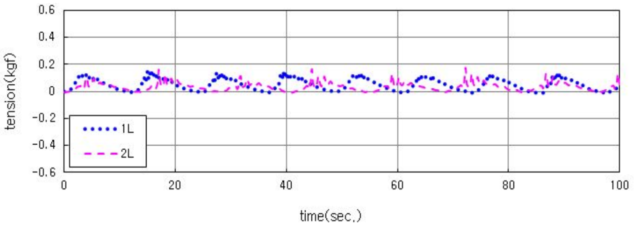

Fig. 20. Comparison of towline tension for KNU-001. (without skeg, $V_s = 7.0$ kts)

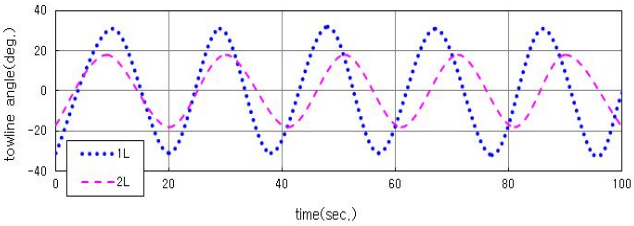

Fig. 21. Comparison of towline angle for KNU-002. (without skeg, $V_s = 7.0$ kts)

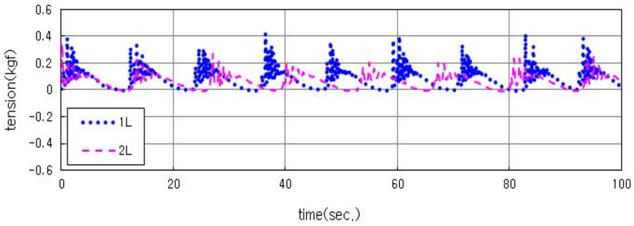

Fig. 22. Comparison of towline tension for KNU-002. (without skeg, $V_s = 7.0$ kts)

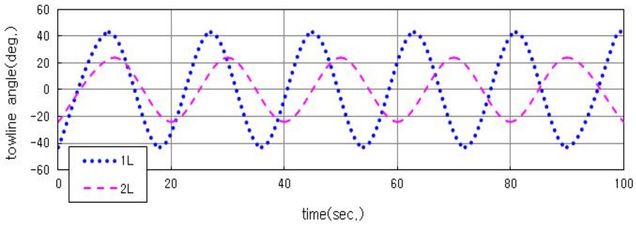

Fig. 23. Comparison of towline angle for KNU-003. (without skeg, $V_s = 7.0$ kts)

Fig. 19 shows that the slewing angles of KNU-001 were approximately 28° and 15° toward the left and right directions when the towline lengths were $1L$ and $2L$, respectively. Thus, it can be observed that the slewing angle decreases by approximately 46 % with increase in the towline length.

Fig. 21 shows that the slewing angles of KNU-002 were approximately 31° and 17° toward the left and right directions when the towline lengths were $1L$ and $2L$, respectively. Thus, it can be observed that the slewing angle decreases by approximately 45 % with increase in the towline length.

Fig. 23 shows that the slewing angles of KNU-003 were approximately 43° and 24° toward the left and right directions when the towline lengths were $1L$ and $2L$, respectively. Thus, it can be observed that the slewing angle decreases by approximately 44 % with increase in the towline length.

It can be observed that the slewing angle decreased by the same factor when the length of towline was doubled and when the length of the bridle was $0.5L$ in case of KNU-002 and KNU-003 barge models.

The analysis of the characteristics of the towing tension shows that the amplitude of the slewing motions of KNU-001 and KNU-002 decreased, and even the towing tension showed a decreasing trend. It was inferred from the experiment that the amplitude of the slewing motion and towing tension were proportional under certain conditions. However, these conditions did not include the changes in the amplitude of the slewing motion and towing tension owing to the ship speed.

4. Conclusions

In this study, the characteristics of the slewing motion of a barge, during the navigation of a tug-barge, were investigated. The investigations were based on the presence and location of the skeg, presence of a bridle and its length, difference in ship speeds, and length of a towline. The results are as follows.

The effects of the location of the skeg varied according to bow-hull form. For the box-type KNU-001 barge model, course stability can be ensured through the installation of only the center skeg. However, course stability could only be ensured through the installation of the side skegs in case of KNU-002 and KNU-003 barge models. The slewing motion of the barge decreased with increase in the length of a towline connected to the barge, and the decrease in slewing motion was greater when a bridle was connected to the towline. In addition, the slewing motion decreased significantly with increase in the length of the bridle.

The slewing angles did not show significant changes with respect to the ship speeds of 5, 7, and 9 knot, but the cycles of the slewing angle became shorter. However, the towing tension significantly decreased with decrease in the towing speed.

Due to the fluctuations in the sway force and yaw moment affecting the slewing motion by skegs, the course stability of barge can be influenced. A future study is considered necessary to investigate the effects of skegs according to the vessel length and width by CFD on barges in which the stern flow field can be substantially varied by skegs.

References

[1] Im, N. K., S. M. Lee and C. K. Lee(2015), The influence of skegs on course stability of a barge with a different configuration, Ocean Engineering, Vol. 97, pp. 165-174.

[2] Inoue, S., K. Kijima and M. Doi(1977), On the course stability of a barge. Transactions of the West-Japan Society of Naval Architects, Vol. 54, pp. 193-201.

[3] Kwon, C. S., O. J. Kwon, S. W. Lee and H. T. Kim(2014), Prediction on course stability of towed offshore structures by computational fluid dynamics. Proceeding of the Twenty-fourth International Offshore and Polar Engineering Conference, Busan, 15-20 June 2014, pp. 478-485.

[4] Latorre, R. and F. Ashcroft(1981), Recent developments in barge design, towing, and pushing. Marine Technology, Vol. 18, No. 1, pp. 10-21.

[5] Lee, K. J. and K. C. Lee(1997), A study on the appropriate shape and size of skeg for the incinerator mounted circular barge. Journal of Ocean Engineering and Technology, Vol. 11, No. 3, pp. 100-106.

[6] Takekawa, M., S. Nagamatus and S. Motora(1975), Course stability of towed large barge, Journal of the Society of Naval Architects of Japan, Vol. 137, pp. 186-195.

[7] Tanaka, S., T. Fukushima, N. Hirata and H. Yasukawa(2014), Stern skeg effects on course stability of a ship with azimuthing propellers, Proceeding of the Twenty-fourth International Offshore and Polar Engineering Conference, Busan, 15-20 June 2014, pp. 948-955.

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