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The influence of skegs on course stability of a barge with a different configuration

N.K. Im [a], S.M. Lee [b,*], C.K. Lee [c]

[a] Division of Marine Transportation System, Mokpo Maritime University, Jeonnam 530-729, Republic of Korea
[b] Department of Marine Science and Production, Kunsan National University, Jeonbuk 573-701, Republic of Korea
[c] Division of Navigation Science, Korea Maritime and Ocean University, Busan 606-791, Republic of Korea

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ABSTRACT

In a water tank experiment, it was found that slewing motions differ according to the bow shape of a barge. Due attention should be paid to the differing effects of skegs in accordance with the bow shape, and it is necessary to estimate the course stability of each barge by identifying the hydrodynamic forces acting on it. This study analyzed the skeg-induced characteristics of course stability of different types of barges. To this end, we used CFD to analyze the effects of nonlinearity, such as the generation of three-dimensional vortices; computed the sway force and yaw moment during drift and steady yaw motions of barges with different bow shapes; and analyzed the flow fields around the barges. As a result, it was verified that skeg contributed to the improvement of the course stability and the shape of a vortex generated in the stern section was found to be significantly influenced by skeg position and number.

1. Introduction

It is difficult to ensure the course stability of a barge while it is towed offshore. In order to improve course stability, skegs have been traditionally used on the basis of experience rather than scientifically analyzed data for the different configurations of barges.

In case of vessels with a box stern, the yaw motion of the barge itself can be kept within a safe range without skegs owing to sufficient lateral drag. However, the downside to this is the increased resistance compared to vessels with a raked stern on which skegs are mounted (Lee and Lee, 1997). Therefore, most barges are designed to reduce resistance by providing a rake angle to the lower part of the stern to ensure a smooth flow under the aft end of the hull (Chun et al., 2011).

Researchers have verified the efficiency of skegs in improving the course stability of a barge (Takekawa et al., 1975), and Yasukawa et al. (2006b) conducted the experiments and simulations to analyze the effects of skeg and bridle for a barge. Miyazaki et al. (2011) have studied about interaction between hull and stern skeg such as ratio of additional lateral force induced by stern skeg. Yang et al. (2004) carried out the study to investigate the effects of the skeg on the directional stability of the FPSO. Inoue et al. (1977) performed various experiments on barge with a spoon bow, thereby varying the shapes and types of skegs, such as a laterally symmetrical wing cross-section skeg, a cambered wing cross-section skeg, and a skeg with two slots mounted on the tip of a wing cross-section. Their published findings showed that course stability is greatly influenced by the skeg type and configuration.

Experiments showed that course stability could be improved by installing a knuckle-type skeg to a bare-hull barge without skeg having a yaw amplitude that was 10 times the vessel width (Chun et al., 1997). More recently, research was conducted on the correlation between the hull coefficient of a barge and knuckle-type skeg. However, installing the knuckle-type skegs to a bare-hull barge increases drag by as much as 33% (Chun et al., 2011). Because changes in hull coefficient are reflected only in the changes in vessel width and length without any changes in bow and stern shapes, a knuckle-type skeg cannot be applied in the same manner to all shapes of barges currently in use.

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. In order to estimate the maneuvering performance of a vessel, hydrodynamic derivatives should be determined using parameters such as the angular velocity and drift angle. Most existing studies have used the principal particulars of a vessel for numerical calculation or experimentally obtained values of the coefficients. A numerical calculation based on potential theory has a limitation in accurately reflecting the effects of interference between the hull and a hull appendage and those of viscosity that affect course stability. Researchers are currently attempting to estimate the maneuvering performance of vessels

* Corresponding author. Tel.: +82 63 469 1814; fax: +82 63 469 1811.
E-mail address: smlee@kunsan.ac.kr (S.M. Lee).

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using computational fluid dynamics (CFD) (Oers and Toxopeus, 2006; Miyazaki et al., 2008; Broglia et al., 2012).

Nonaka et al. (1986) conducted experiments to determine the fluid motion around the hull of a vessel and the hydrodynamic force exerted on a drifting vessel. They reported strong nonlinearity and a very complex flow field, including the formation of three-dimensional vortices.

A study comparatively investigated the models of very large crude carriers (VLCCs) with U- and V-shape sterns by developing a computation method for viscous flow around a vessel in drift motion (Kim and Kim, 2001). Another study performed numerical fluid dynamics calculations during drift and pure yaw motions in order to assess the directional stability of the AFRAMAX model applicable to its initial design stage (Hong and Yang, 2008). In a more recent study, vortical structures, instabilities, and turbulent structures in drift motions of a KVLCC2 tanker were analyzed using CFD (Xing et al., 2012).

In a water tank experiment, it was found that slewing motions differ according to the bow shape of a barge. The best method for reducing yaw is mounting skegs on the stern. However, due attention should be paid to the differing effects of skegs in accordance with the bow shape, and it is necessary to estimate the course stability of each barge by identifying the hydrodynamic forces acting on it.

Against this backdrop, this study analyzed the skeg-induced characteristics of course stability of different types of vessels. To this end, we used CFD to analyze the effects of nonlinearity, such as the generation of three-dimensional vortices; computed the sway force and yaw moment during drift and steady yaw motions of barges with different bow shapes; and analyzed the flow fields around the barges.

2. Water tank experiment

Two barge models, each with a different but widely used bow shape, were selected as test specimens in a water tank experiment. The two barge models were as follows: a box-type model KNU-001, and hexagon-type model KNU-002. Fig. 1 and Table 1 describe the experiments and specifications of the barge models.

The effects of a skeg on the course stability of a barge were investigated in four cases: 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 skegs. The breadth of center skeg is 0.024 m, which is a tenth of the width of barge. The breadth of side skeg is half of the center skeg. The side skeg is mounted on the inside as much as the width of side skeg. The barge models with different bow shapes were manufactured with same stern shapes for comparing the models' course stability.

The experiment was performed in the circulating water tank to determine the characteristics of the slewing motion of the barge models. The dimensions of the water tank were 8.0 m × 2.8 m × 1.4 m (length × width × depth). The operational characteristics of the barge were analyzed by performing the experiment using the aforementioned models assuming the absence of external factors such as wave, wind and current. A virtual towing point was identified at the entrance to the water flow, after positioning a stationary barge model at the center of the circulating water tank. The barge model was connected with only a towline of length 1 L. When the water flow velocity in the tank was gradually increased to a desired speed 7 knots, the slewing motion was repeated in a certain cycle. This cycle was based on the course stability characteristics of each barge model. Next, the slewing angle of the barge was observed directly.

The maximum slewing angle of KNU-001 (Fig. 2a) measured 28° toward the left and right directions. This occurred under the following conditions: the speed of KNU-001 was 7 knots, it was connected with only a towline, and it was not installed with a skeg. The slewing angle of KNU-001 was approximately 1.5° 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, the course stability of KNU-001 can be satisfactorily ensured through the installation of only the center skeg.

The maximum slewing angle of KNU-002 (Fig. 2b) measured 31° toward the left and right directions. This occurred under the following conditions: the speed of KNU-002 was 7 knots, it was connected with only a towline, and it was not installed with a skeg. The slewing angle of KNU-002 was approximately 23° 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, the course stability of KNU-002 can be significantly improved through the installation of the side skegs.

3. Numerical calculation

In this study, numerical calculation was performed using the commercial analysis program FLUENT v.12.1, and the grid system was generated by Gridgen.

Fig. 3 shows the coordinate system used in this study. As shown in Fig. 4, the numerical calculations were performed for eight cases in which four calculation conditions, which varied according to the

Table 1
Principal dimensions of the barge.

Particulars	KNU-001		KNU-002	
	Full-scale	Model	Full-scale	Model
Length overall, LOA (m)	50.0	1.0	50.0	1.0
Length between perpendicular, LBP (m)	50.0	1.0	50.0	1.0
Breadth, *B* (m)	12.0	0.24	12.0	0.24
Draft, *d* (m)	2.8	0.056	2.8	0.056
Volume, ∇ (m^3)	1474.0	0.01179	1389.0	0.01111
Block coefficient, *Cb*	0.8772	0.8772	0.8267	0.8267
LCG from AP (m)	25.177	0.504	24.007	0.480
KG (m)	2.622	0.0524	2.623	0.0524

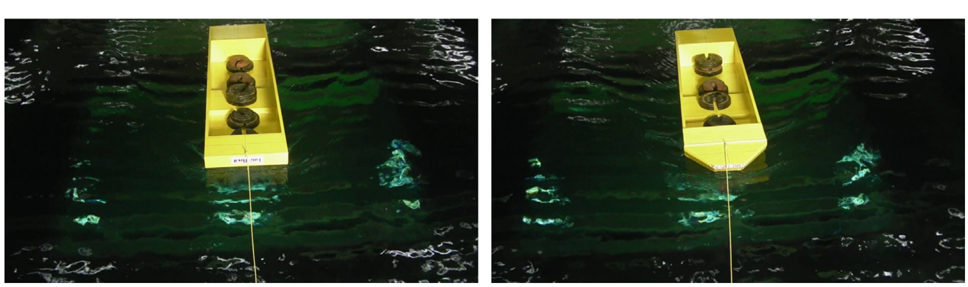

Fig. 1. Experimental barge model KNU-001 (left) and KNU-002 (right).