

## Experimental Study on Braking Force Characteristics of Tugboats in Shallow Water

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### ABSTRACT

The braking force characteristics of tugboats are presented in this paper relying on the analysis of the results measured by Model experiments. In addition, it is confirmed that the braking force of the tugboats is affected by towed speed, propeller revolution speed as well as water depth. Furthermore, it is pointed out that the characteristics of the braking force differ in braking methods and its difference becomes more violent in shallow water. The knowledge on the braking force characteristics of tugboats is useful for pilots and tugboat's operators to handle tugboats safely and effectively.

**KEY WORDS:** Tugboat; propeller thrust; braking force; shallow water; braking method.

### INTRODUCTION

Nowadays, consequently more and more vessels require coming in and out a harbour. Due to the limitation of ship's maneuver, some collisions happened occasionally between ship--ship or ship--bank. Then, the tugboat becomes more and more important to cooperate with the entrance of large vessels. Hence, it is significantly essential to comprehend the assisting capabilities of tugboats. Moreover, the effect of shallow water on the braking capabilities of a tugboat has to be taken into account, especially in the port area.

At present, researchers have, thus far, mainly focused on the bollard pull of a tugboat (the Japan Workvessel Association 1979 and H. Hansen 2003) and its towing capabilities (Sadakane H. et al., 2002 and LEE S.S. et al., 2004). Although some reports on the investigation to brake a Large Vessel with support of tugboats had been conducted by Japan Workvessel Association (1967 & 1972), the researchers only paid attention to the bollard pull of the tugboat, whereas the braking force characteristics of the tugboat have not received much attention yet. In addition, the effect of shallow water on the braking force of tugboats wasn't taken into account yet. We are sure that the knowledge on the braking force characteristics of tugboats is useful for shiphandling in port area.

The difference of the braking force characteristics between tow types of tugboats was presented in the previous paper (Yang L.J. et al., 2007), but the shallow water effect on the braking force wasn't examined. This paper reports some experimental results with respect to the effect of water depth on the braking force of a tugboat under both braking methods, namely ahead thrust method and astern thrust method. These experiments were conducted using a representative ASD-tugboat model with twin Azimuth Stern Drive propeller. On the basic of the braking force measured by means of model experiments, the braking force characteristics of the tugboat were analyzed systematically and became clear. In addition, the effect of shallow water on the braking force of the tugboats was also presented.

### BRAKING FORCE

The **braking force** is termed as the resultant force of propeller thrust and resistance acting on the tugboat's hull. Generally, it is affected by towed speed, propeller revolution speed and braking methods as well as water depth. The direction of the braking force is opposite to the moving direction of the assisted ship.

In order to understand and analyze the assistance forces of a tugboat clearly, the co-ordinate system of tugboat's assisting forces is built up and shown in **Fig.1**. The assisting forces  $F_x$  of a tugboat, such as braking force  $F_b$ , or towing force  $F_t$ , are indicated with the axis of ordinates while the axis of abscissas indicates the advance coefficient  $J$ . Furthermore, we define it as positive when tugboat has head thrust or headway. In accordance with the definition of the braking force, the 2<sup>nd</sup> and 3<sup>rd</sup> quadrants in which the force directions opposite to the moving directions are named as braking force quadrants, in the contrast, the 1<sup>st</sup> and 4<sup>th</sup> quadrants are named as towing force area. In the 2<sup>nd</sup> quadrant, the thrust of propeller is in ahead condition and the tugboat has sternway, therefore, it is named as the ahead thrust method (Ahead TM). In the 3<sup>rd</sup> quadrant, the thrust of propeller is in astern condition and the tugboat has headway, therefore, it is named as the astern thrust method (Astern TM).