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A Study on Berth Maneuvering Using Ship Handling Simulator

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***Abstract*— In this study, training data of berth maneuvering using ship handling simulator was analyzed from the viewpoint of the minimum time berth maneuvering problem. The safety margin of the minimum time berthing problem was derived from the minimum value and the maximum value of the simulator training data of the first class pilot trainee.**

***Keywords*— ship berthing, ship handling simulator**

I. Introduction

Berthing a ship at a harbor is one of difficult missions for ship operators. The ship requires long distance and lot of time to stop at the harbor, because the braking force is small compared with its huge mass. Since the rudder of the ocean vessel is designed for navigational full speed, the maneuverability worsens remarkably when the speed is decreased for the berthing. Therefore, the ship operators make the plane for ship operation while considering the distance that the ship requires to stop and the maneuverability at the low-speed. And then, they execute the ship berthing operation. When the ship operators make the plane for the ship berthing operation, it is important to understand the ship's maneuverability adequately. In generally, the ship operators learn the ship's maneuverability through a lot of ship operations experiences. The berthing method of well experienced ship operator is a rational and effective maneuvering method that derived the maximum maneuverability of the ship. However, it is predicted that the ship operator who has not enough experience of ship operation will face to ship berthing operation in the near future in Japan. There are a lot of ratios of senior crew in Japan. Therefore if the senior generation retires, the ratio of young crew will increase. Then, there are needs of the berthing operation support system which supports the young crew.

In the previous work [1], we have focused to the method of well experienced ship operator, and developed the ship berthing support system based on rational and effective maneuvering method that derived the maximum maneuverability of the ship. Then, we have adopted the minimum time berthing method which is the limit of the maneuverability as a plan of the berthing operation. The solutions of minimum time berthing problem has been obtained by solving nonlinear two-point boundary value problems (TPBVP) by the authors [2]. In this method, for the sake of obtaining reliable solutions, the equations of motions in berth maneuvering are represented by sophisticated nonlinear mathematical model. The rationality of the minimum time berthing method is shown by systematical solutions which are analyzed from viewpoint of geographical condition [3]. However, there is a possibility that the ship operator feels danger [4] compared with the ship operator's maneuvering method because the minimum time maneuvering method is limit of ship's maneuverability. In the previous research, from the viewpoint of ship operator's maneuvering method, the setting of ship berthing problem was divided into two phases which were an approaching phase and a berthing phase. And more, it is necessary to set an appropriate safety margin in the setting of ship berthing problem to obtain the solution which suits the ship operator's sense.

Therefore, in this study, training data of berth maneuvering using ship handling simulator is analyzed from the viewpoint of the minimum time berth maneuvering problem. Then, it will be tried to obtain the safety margin from the training data and to set the safety margin as constraints in the minimum time berthing problem. In this paper, first of all, setting of the minimum time berthing problem and method of solving the problem are described. Next, the detail of the training for berth maneuvering which used ship handling simulator is described, then some results of analyzed data are shown.

II. Outline of The Minimum Time Berthing Problem

A. Setting of the problem

In general, the ship operators executed the ship berthing operation as following procedures. At first, they are entering the port while reducing the ship speed by controlling main engine (M/E) revolution per minute (rpm) or controllable pitch propeller (CPP) angle. Next, the ship was guided to the front of the berth by operating the rudder while decelerating. Finally, the ship was moved into the berth while the ship's attitude was controlled by ship's side thruster or tugboats and stopped on berthing point. The minimum time berthing problem was to execute this series of operation by minimum time. Therefore, the minimum time berthing problem was formulated to guide a

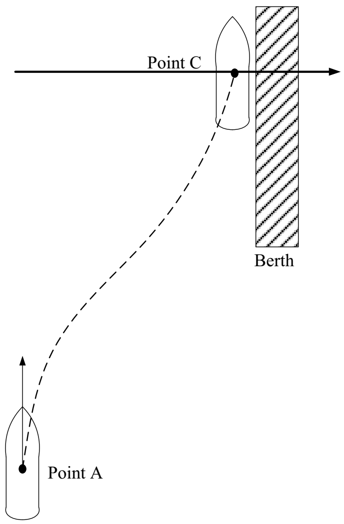

Figure 1. Berthing problem

ship from a certain point (point A in Fig.1) to another berthing one (point C in Fig.1) in a minimum time. This kind of problem was considered as a two-point boundary value problem, which set the point A as an initial point and the point C as a terminal point.

Such berthing problem might be solved using the theory of calculus of variations [5]. Thus the minimum time berthing problem is formulated as follows. A performance index of this problem is defined by a functional

$$I = \int_0^1 f(\mathbf{x}, \mathbf{u}, \tau, t)dt = \int_0^1 \tau dt = \tau \qquad (1)$$

where, I is a scalar value, $\mathbf{x}$ is the state vector, $\mathbf{u}$ is the control vector, t is the actual final time value and τ is the normalized time value. And the solution of the problem is minimized the performance index with constrains as follows. The differential constraints,

$$\dot{\mathbf{x}} - \boldsymbol{\varphi}(\mathbf{x}, \mathbf{u}, \tau, t) = 0, \quad 0 \le \mathrm{t} \le 1 \qquad (2)$$

where the function denotes a nonlinear ship's motions model, and the boundary conditions:

The initial ship's state, specified by the functional

$$[\boldsymbol{\omega}(\mathbf{x})]_0 = 0 \qquad (3)$$

The terminal state of ship, specified by the functional

$$[\boldsymbol{\psi}(\mathbf{x}, \tau)]_1 = 0 \qquad (4)$$

where $\boldsymbol{\omega}$ denotes initial constrain and $\boldsymbol{\psi}$ denotes terminal constrain. The non-differential constraints,

$$\mathbf{S}(\mathbf{x}, \mathbf{u}, \tau, t) = 0, \quad 0 \le t \le 1 \qquad (5)$$

where the function $\mathbf{S}$ is useful to set the safety margin such as the constraint of state vectors and limit of the control inputs.

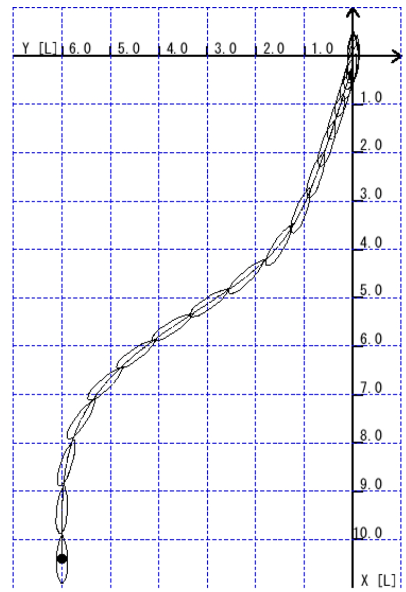

Figure 2. Track of minimum time berthing solution

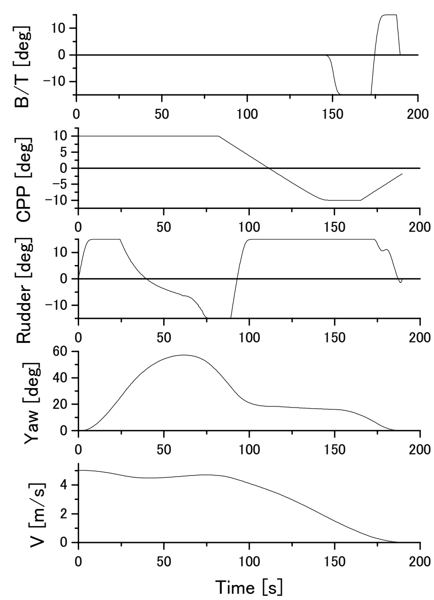

Figure 3. Time series of minimum time berthing solution

Therefore, the one of the purpose of this study is to obtain the value of state vector for this constraint function.

B. Solution of Minimum Time Berthing Problem

If the safety margin was not set to the minimum time berthing problem, there are possibility that the solution of the problem made ship's operator feel stress, because the solution of minimum time berthing problem required ship to keep high speed at near the berth. For instance, the solution of the

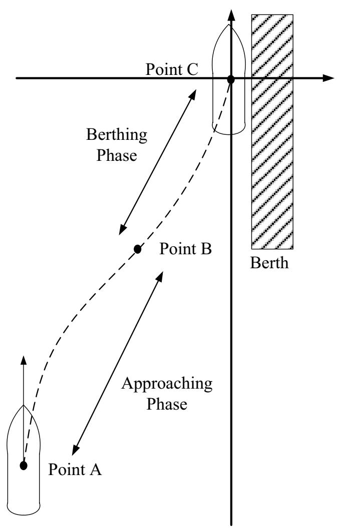

Figure 4. Setting of berthing problem

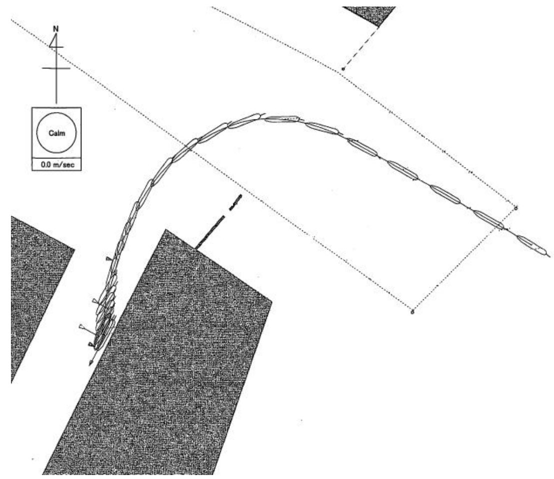

Figure 5. Outline of the scenario

minimum time berthing problem which was not set the safety margin was indicated in Fig.2 and Fig.3. The solution of the track was indicated in Fig.2 and the time series of state vectors were indicated in Fig.3. From these figures, it was clear that the ship speed was 1.54 m/s (3 knots) at the position where 25m from the berth. It could give the ship operator a strong stress, that the ship was approaching the berth at the speed which couldn't be stopped at once. Then, to set the safety margin at the ship's speed around the berth, the minimum time berthing problem was divided into two phases, namely approaching phase and berthing one like showing in Fig.4. In this figure, point A was assumed to a starting position, point B was assumed to the front of the berth position, and point C was assumed to the berth. And, the section where the ship was guided from point A to point B while decelerating was assumed to approaching phase, and the section where the ship was moved from point B and stopped into point C was assumed to berthing phase. If ship operator set the position of point B and the speed at point B, as a result, the safety margin was set at beginning of the berthing phase. Then, one of the targets of this research was to derive the data of starting point of berthing phase from the training data of ship handling simulator.

III. Ship Handling Simulator for Pilot Trainees

In Japan, the training school of pilot uses the ship handling simulator for trainee's training. Therefore, in this study, to obtain the safety margin of the berthing problem, their training data in the ship handling simulator was analyzed. The ship handling simulator which was used for their training consists of a bridge system, a visual system, and a control system. The bridge system was installed all equipments necessary for navigation. The visual system produces a seascape of 240 degrees in horizontal view and 40 degrees in vertical view. The control system was for creating and editing of scenarios and for operation of simulation runs. During simulation runs, tugboats, anchors, and moorings are controlled by an operator of the control system.

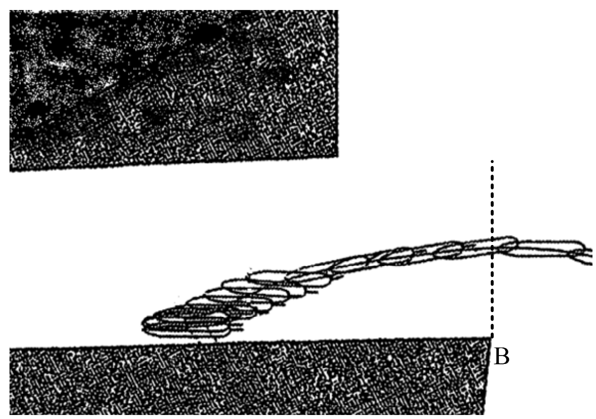

Figure 6. Outline of Berthing phase

In this study, the scenario for entering Yokohama port was used. Target ships were a container ship with 10,000 Gross Tonnage and a container ship with 70,000 Gross Tonnage. Fig.5 shows the outline of the scenario. The starting position of this scenario is entrance of the sea route for entering the Yokohama port. At first, there is a breakwater in both sides of the sea route, the ship operator was required that keep the ship on the right side of sea route. After the breakwater is passed they have to make the ship turn to the left. Next, they should have the ship toward to the Honmoku D4 berth while decreasing the ship's speed. Since the ship's speed become slowly, the effect of the rudder worsens. Therefore, they could use two tugboats with 3000ps. The tug boats are used for controlling the position of the ship by pushing or pulling. In this scenario, other ships other than the tugboats did not arrange, because this scenario was used for an initial stage of the training. Subjects were the first class pilot trainees of 13 people. They are the man of 55 to 65 years, and they have experience of ship's captain.

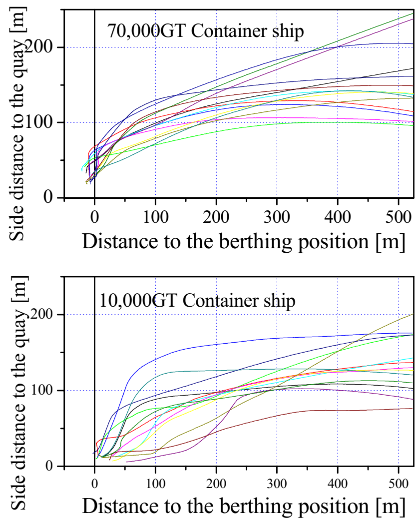

Figure 7. Tracks of berthing phase

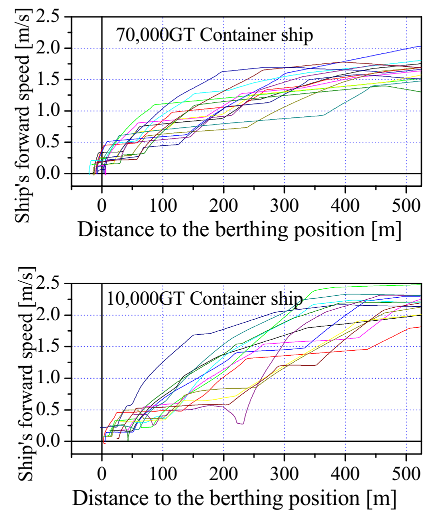

Figure 8. Ship's forward speed during berthing phase

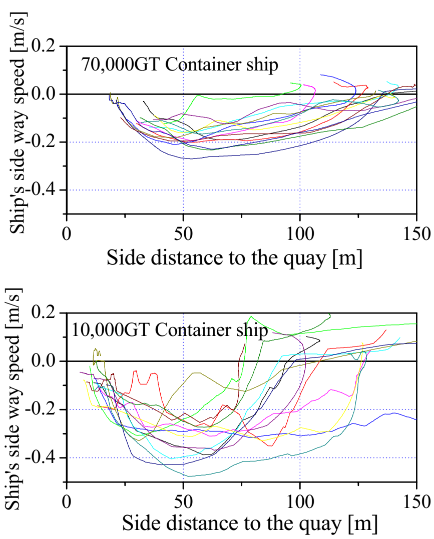

Figure 9. Ship's side way speed during berthing phase

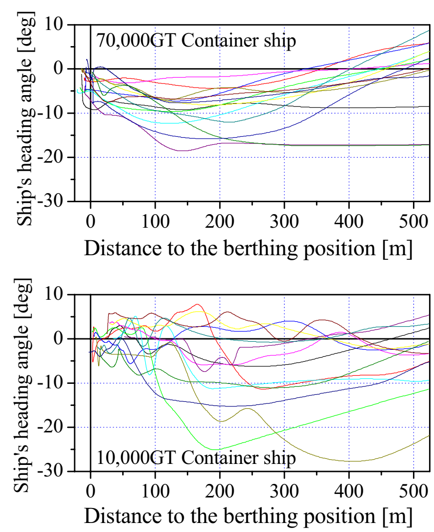

Figure 10. Ship's heading angle during berthing phase

IV. Results of The Simulator Training

From the viewpoint of minimum time berthing problem, training data of first class pilot trainee were analyzed in this section. At first, berthing problem was divided into the approaching phase and the berthing phase as explained in section 2. In this simulation, after the ship turned to the Honmoku wharf, the tugboats were used for berth maneuvering. Then, the position to which the ship had lined up in the quay corner in Honmoku shown in Fig.6 was assumed to be a starting point of the berthing phase. The state vector of the ship in the berthing phase was analyzed to obtain the safety margin of the minimum time berthing problem. The state vector of the ship in the berthing phase of the simulator training that the first class pilot trainee had done with the container ship of 10,000GT and 70,000GT was indicated in the following figures. The track of the ship, the ship's forward speed, the ship's side way speed, the ship's heading angles and the ship's turn rate were shown in Fig.7-Fig.11 respectively.

In Fig.7, the origin indicated the berthing position, the horizontal axis indicated the distance to the berthing position, and the vertical axis indicated the side distance to the quay. Therefore, the position of 525m of a horizontal axis showed the position of the quay corner in Fig.6. From Fig.7, it was read that in the case with the ship of 10,000GT, minimum value of

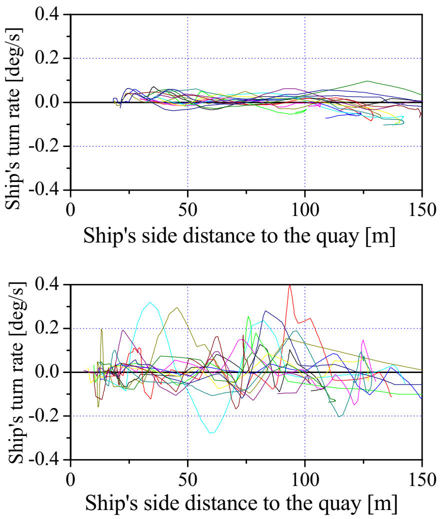

Figure 11. Ship's turn rate during berthing phase

side distance to the quay when the ship lines up in the quay corner was 76m. In the case with the ship of 70,000GT, minimum value was 100m. Therefore, it was thought that the minimum value of side distance to the quay of beginning of the berthing phase could be set for the minimum limit of ship's side distance to the quay of beginning of the berthing phase in the minimum time berthing problem as the safety margin.

In Fig.8, the horizontal axis indicated the distance to the berthing position and the vertical axis indicated ship's forward speed. From Fig.8, it was read that, in the case with the ship of 10,000GT, maximum value of the ship's forward speed at beginning of the berthing phase was 2.5m/s. In the case with the ship of 70,000GT, maximum value was 2.0m/s. Therefore, it was thought that the maximum value of ship's forward speed at the beginning of berthing phase could be set for the maximum limit of ship's forward speed at the beginning of berthing phase in the minimum time berthing problem as the safety margin.

In Fig9, the horizontal axis indicated the side distance to the quay, and the vertical axis indicated the ship's side way speed. From Fig.9, it was read that in the case with the ship of 10,000GT, maximum value of the ship's side way speed which approached the quay was 0.47m/s. In the case with the ship of the 70,000GT, the maximum value was 0.27m/s. Therefore, it was thought that these maximum values of ship's side way speed which approached the quay could be set for the maximum limit of ship's side way speed in the minimum time berthing problem as the safety margin.

In Fig.10, the horizontal axis indicated the distance to the berthing position, and the vertical axis indicated the ship's heading angle. Since the ship's heading angle becomes parallel to the quay, it was set as zero. If the ship's heading angle was point to the quay, it was set as minus angle. During the berthing phase, maximum approaching angle toward the quay was 28 degrees for the ship of 10,000GT. In the case with the ship of 70,000GT, it was 18degrees. Therefore, it was thought that these maximum approaching angles could be set for the maximum limit of ship' s heading angle in the minimum time berthing problem as the safety margin.

In Fig 11, the horizontal axis indicated ship's side distance to the quay, and the vertical axis indicated the ship's turn rate. From Fig11, it was read that maximum value of turn rate was 0.4 deg/s for the ship of 10,000GT. In the case with the ship of 70,000GT, maximum value was 0.1 deg/s. Therefore, it was thought that these maximum values could be set for the maximum limit of ship' turn rate in the minimum time berthing problem as the safety margin.

V. Discussion

In this research, it was tried to derive the safety margin of the minimum time berthing problem from the minimum value and the maximum value of the simulator training data of the first class pilot trainee. In this section, instructor's demonstration data was analyzed as well as the case of the first class trainee. The minimum value and the maximum value of the state vector of the ship in the berthing phase were derived, and it was shown in Table I. From Table I, it was clear that the instructor's value were smaller than first class pilot trainee's value. This shows that the instructor was controlling ships more smoothly than the first class pilot trainee. The instructor has more than 15years pilot's experience, and he has a high ship maneuvering skill. This shows that there is a possibility to evaluate the result of the ship handling simulation by analyzing the value of the safety margin of the minimum time berthing problem. Moreover, it is thought that there is a possibility that the optimum solution corresponding to the skill can be derived by solving the problem of setting the safety margin with a different skill.

TABLE I. Maximum or Minimu vale of Ship's state Vector

Ship's state vector	**10,000GT**		**70,000GT**	
	Instructor	Trainee	Instructor	Trainee
Minimum value of ship's side distance to the quay at the biginning of the berthing phase	100 [m]	76 [m]	115 [m]	100 [m]
Maximum value of ship's forward speed at the biginning of the berthing phase	2.0 [m/s]	2.5 [m/s]	1.6 [m/s]	2.0 [m/s]
Maximum value of ship's side way speed during the berthing phase	0.41 [m/s]	0.47 [m/s]	0.11 [m/s]	0.27 [m/s]
Maximum value of ship's heading angle during the berthing phase	17 [deg]	28 [deg]	13 [deg]	18 [deg]
Maximum value of ship's turn rate during the berthing phase	0.25 [deg/s]	0.4 [deg/s]	0.06 [deg/s]	0.1 [deg/s]

VI. Conclusion

In this study, training data of berth maneuvering using ship handling simulator was analyzed from the viewpoint of the minimum time berth maneuvering problem. Then the following safety margins which were able to be used for the constraint in the minimum time berthing problem were obtained from the ship handling simulation training data of the first class pilot trainees. As the constraint of the condition at the beginning of berthing phase, the minimum value of ship's side distance to the quay and the maximum value of ship's forward speed were obtained. As the limitation value during the berthing phase, the maximum value of ship's side way speed, the maximum value of ship's heading angle, and the maximum value of ship's turn rate were obtained.

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