

## A Study on Proposed New Consideration Factors in Channel Design Process

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**Abstract** : There are certain guidelines on the channel design such as domestic guidelines(Korean and Japanese, etc.) and international guideline known as PIANC Rules(Permanent International Association of Navigation Congresses Rules), in the world. These rules have considered many factors such as natural conditions, ship maneuverability and geographical features etc. But it is contented that the area of these rules that are meant to facilitate the ease of ship-handling is insufficient. To satisfy this point in design process, it is necessary to take into account the difficulties encountered in ship-handling within these inland waterways. Because many vessels are navigating at the same time within these waterways, the specific navigable traffic volume should be considered with regard to the standard process of route designing. It must also be considered with regard to the volume of navigable traffic because of ship-handling difficulty that arises within the same waterway with varying amounts of traffic volume because that ship-handling/manueverability is directly influenced by these factors.

This paper aims to propose a new approach to the design of standard inland water route considering the traffic volume and the shape of waterway. Also consider the relationship among these factors may affect to the ship-handling difficulties.

**Key words** : Channel, Design, Safetv, Ship-handling Difficulty, Traffic Volume

### 1. Introduction

Marine traffic plays an important role in human life and is a system that contributes to both international and domestic commerce. The marine traffic system consists of relationships between ship-human-environment. In order to enhance the safety of marine traffic, important measures are taken to provide a well-arranged system of marine traffic environment as well as improving the seafarers competence and ships capability. The enhancement of seafarers competence and ships capability is based on laws and conventions of the international maritime society. Although they have become standardized, but the part of marine traffic environment with regard to the channel design of inland waterway has not yet been standardized. Each channel route design remains strictly site specific.

Ordinarily, a channel can be defined as a waterway with a designated depth, width and length. When the route is designed within that waterway, it must take into account those factors affecting safe navigation, such as ease of ship-handling, natural conditions and such physical aids to navigation(buoys, channel markers, signal lights, etc).

Until now, certain route design guidelines have been applied to congested waterways and ports with narrow channels. There are route design guidelines for each of the many domestic waterways, route guidelines such as (Korean Rules, Japanese Rules etc), and international PIANC

Rules(Permanent International Association of Navigation Congresses Rules) in the world. These rules have considered many factors such as geographical features as well as maneuverability of ship, etc.

And, in almost all cases channels are constructed to facilitate two-way traffic and their guidelines are dominated by the largest and the deepest-draft vessel expected to use that particular waterway. However these route design guidelines of inland waterway channels do not take into account the navigable traffic volume in detail. This particular factor must be more closely considered ship-handling difficulties that are imposed within the same channel shape varies in proportion to the changes in traffic volume. Also, ship-handling difficulties encountered with consistent traffic volume but within a different shaped channel must also be considered.

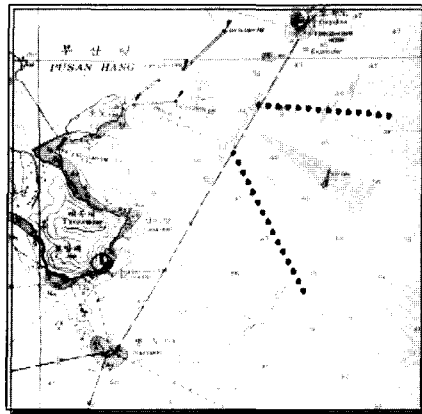
This paper proposes a new approach to route design standards to include traffic volume and the relationship between channel shapes and the ship-handling difficulties imposed by applying the Environmental Stress model(INOUE Kinzo, 2000).

### 2. A Kind of Channel Shape

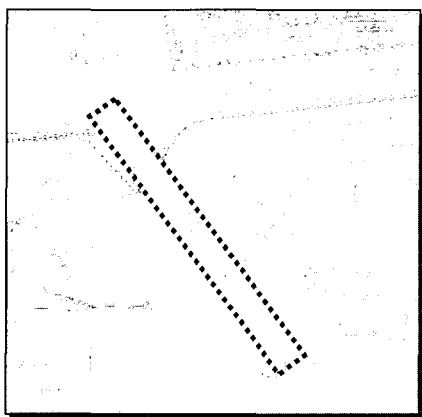
Channel shapes of inland waterway routes can be divided into two general types throughout the world. Fig.1 shows a sectorial route of an entrance channel in the outer harbour

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(a) Sectorial Route(Busan, R.O.K)



(b) Straight Route(Kobe, JAPAN)

Fig. 1 Two Kinds of Channel Shape

(Fig.1(a)). The other is a straight route in the inner harbour or narrow channel(Fig.1(b)).

### 2.1 Establishment of Waterway Shape and Navigable Vessel Number

This paper assumed a sectorial route with an angle(parameter  $0^\circ \sim 45^\circ$ ) between route entrance and restricted section(navigable middle part in the established channel) to reproduce simply two types of channels. In these channels, channel with a parameter angle of  $0^\circ$  is considered to be a straight channel.

As shown in Fig.2, the width of restricted section consists of five varying widths such as 1 mile, 1000m, 656m, 610m and 400m. The range of marine traffic simulation area was 14 miles $\times$ 24 miles and the assessment target area was 3 miles $\times$ 7 miles with the restricted section serving as the central figure. The following conditions were set for marine traffic simulation to consider the proposed new factors(traffic volume and channel shape) presented in this paper. First, all ships' navigation was in a northerly direction. One-way traffic passing, and ships that had been occurring depending

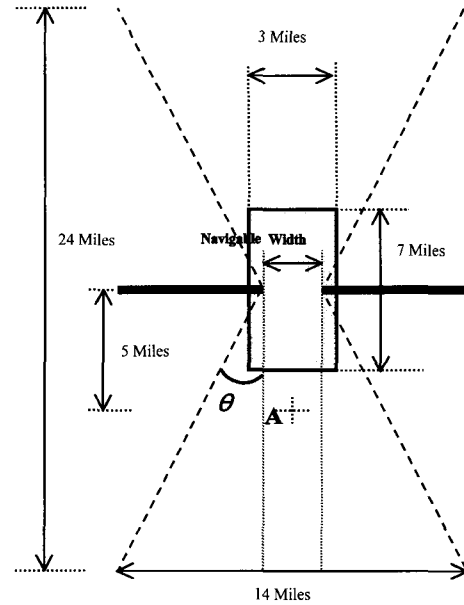


Fig. 2 Area Condition and Channel Shape in Marine Traffic Simulation

on uniform distribution established on a circumference with a radius of 7 miles centered at point "A" of Fig.2.

Ships sizes were divided into three types, small size (GT20~1,000), medium size(GT1,000~10,000) and large size vessels(more than GT10,000) at the ratio of 4, 5 and 1. The occurrence volume of ship was 10, 25 and 40 ships per hour. Ship's speed was applied by using a normal distribution curve of 12 knots as an average speed with standard deviations measured in 5 knot values.

Additionally, in the case of a straight channel, two-way traffic passage was added in the part of ships navigation.

### 2.2 Marine Traffic Flow Simulation without Avoidance ship-handling

Marine traffic flow simulation was carried out without taking into account of avoidance maneuvers. The intention of this research is to clarify the potential size of the load that is latent in each encounter. Latent load will be explained in detail in section 3.2 of this paper.

## 3. Application of Environment Stress Model

The Environmental Stress Model used to assess ship-handling difficulties will be introduced in this chapter.

### 3.1 The Environmental Stress Model(ES model)

#### 1) Environmental Conditions

The elements of environmental conditions that can be taken into account in the model are as follows:

- (1) Topographical conditions such as land, shoals, shore protection, breakwaters, buoys, fishing nets, moored ships and other fixed or floating obstacles.
- (2) Traffic conditions such as the density of other ships and traffic flow.
- (3) External disturbances such as winds and currents.

2) Model Structure

The proposed model, which expresses in quantitative terms the degree of stress imposed by topographical and traffic environments on a mariner, is called the Environmental Stress Model (ES model). The ES model is composed of the following three parts:

- (1) Evaluation of ship-handling difficulty arising from restrictions on the water area available for maneuvering. A quantitative index expressing the degree of stress forced on the mariner by topographical restrictions (ES<sub>L</sub> value: Environmental Stress value for Land) is calculated on the basis of the time to collision (TTC) with any obstacles.
- (2) Evaluation of ship-handling difficulty arising from restrictions on the freedom to make collision-avoidance manoeuvres. A quantitative index expressing the degree of stress forced on the mariner by traffic congestion (ES<sub>S</sub> value: Environmental Stress value for Ship) is calculated on the basis of the time to collision (TTC) with ships.
- (3) Aggregate evaluation of ship-handling difficulty forced by both topographical and traffic environments, in which the stress value (ES<sub>A</sub> Value: Environmental Stress value for Aggregation) is derived by superimposing the value ES<sub>L</sub> and the value ES<sub>S</sub>.

In the respective calculations of the values ES<sub>L</sub> and ES<sub>S</sub>, a common index was used and the same algorithm was introduced to perform simultaneous aggregate evaluations of ship-handling difficulty as experienced in encounters with other ships in ports and narrow waterways.

3) Calculation of Stress Value

When, as in ocean sailing, there are no restrictions on the water area available for maneuvering and there is sufficient TTC, regardless of the direction in which the ship proceeds, no stress is imposed on the mariner and he feels no difficulty in ship-handling. In narrow waterways, the water area available for maneuvering is restricted, and there is little TTC, regardless of the ships direction; therefore, the topographical environment causes the mariner considerable stress and creates difficulty in ship-handling. When other ships are present in the vicinity, and there is a danger of

collision with other ships according to the direction of sailing, the mariner is put under additional stress. This stress becomes particularly great when there is little TTC, regardless of the direction of the ship.

Based on this concept, the value ES<sub>L</sub> and value ES<sub>S</sub> are calculated under the common procedure shown below.

- (1) Consider the ships course in the range of 180° .
- (2) Calculate the TTC for each one degree gradation in the range of ±90° centered on the present course.
- (3) Convert the TTC into the mariners perception of safety for each one degree.

The conversion formulae shown in Equation (3.1) are given by regression equations found through ship-handling simulator experiments (31-subjects) and questionnaire (573-answers) (INOUE Kinzo, 1998).

$$S_{JL}, S_{JS} = \alpha \cdot TTC + \beta \tag{3.1}$$

Where, S<sub>JL</sub> is the subjective judgment of mariners in relation to TTC with obstacles and S<sub>JS</sub> is the subjective judgment of mariners in relation to TTC with ships. The scales of the subjective judgment consist of numeric values with seven steps from 0 (extremely safe) to 6 (extremely dangerous).  $\alpha$  and  $\beta$  are coefficients determined by the size of own ship (in case of S<sub>JL</sub> value) or by the combination of the size of own ship and target ship (in case of S<sub>JS</sub> value).

The values S<sub>JL</sub>, S<sub>JS</sub> within the range of courses ±90° are summed to find the stress values as follows:

$$ES_L = \sum_{i=-90^\circ \sim +90^\circ} (S_{JL})_i \tag{3.2}$$

$$ES_S = \sum_{i=-90^\circ \sim +90^\circ} (S_{JS})_i \tag{3.3}$$

4) Calculation of Stress Ranking

If there is no danger in all directions, the SJ value of 0 extends over 180° , so 0×180=0 is assigned as the minimum stress value. If there is an immediate danger, regardless of the ship's direction, the SJ value of 6 extends over 180° , so 6×180=1,080 is assigned as the maximum stress value. The

Table 1 Stress Ranking and Acceptance Criteria

SJ: MARINERS' JUDGEMENT	ES value $\sum (S_{J})_i$	STRESS RANKING	ACCEPTANCE CRITERIA
0: Extremely safe	{ 0 }	NEGLECTIBLE	ACCEPTABLE
1: Fairly safe	{ 500 }		
2: Somewhat safe		{ 750 }	MARGINAL
3: Neither safe nor dangerous	{ 900 }		CRITICAL
4: Somewhat dangerous		{ 1000 }	CATASTROPHIC
5: Fairly dangerous			
6: Extremely dangerous			

stress ranking is set up by classifying the range of stress values as 0 to 1,000, as shown in Table 1.

The rank of stress can be classified according to the extent to which a dangerous situation causes a particular SJ value in the range of  $\pm 90^\circ$  around the present ships course. In the model, a situation giving the same SJ value, regardless of direction, was taken as the standard situation. The relationship between each stress ranking and the acceptable level was found through ship-handling simulator experiments and a questionnaire.

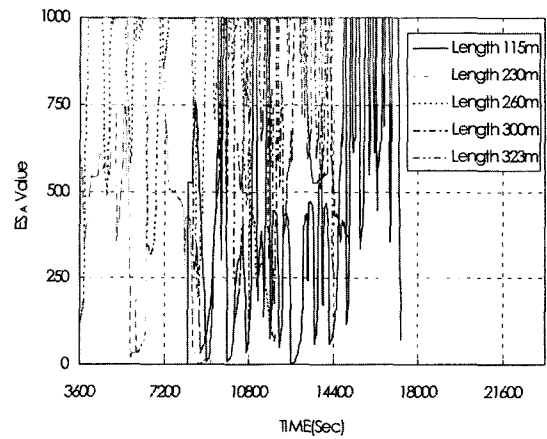
The ES model, therefore, allows us to judge how great a stress value will be when it is no longer acceptable and to point out the disadvantages of the topographical and traffic situation in ports and waterways.

### 3.2 Latent Environmental Stress Value

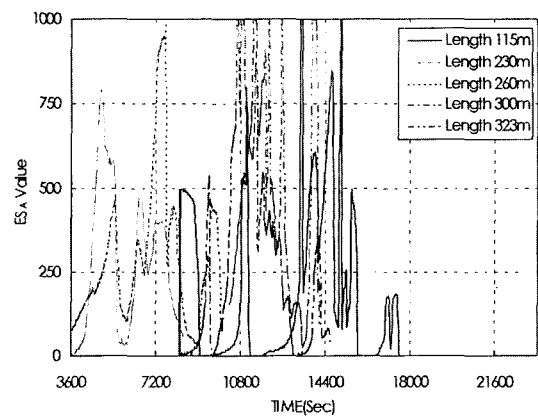
Individual uncertainty due to different skills or personalities of mariners is inevitably included in the manoeuvring process, such as the decision making on the timing and the action when taking a collision avoidance manoeuvre. To clarify the ship-handling difficulty of ports and waterways, human factors such as the skill or the personality of a mariner must be excluded from the evaluation process.

The L-ES value is, therefore, introduced to avoid the influence of individual differences in skills and personalities among mariners, and to guarantee the universality of the results when evaluating ship-handling difficulty. L-ES values are obtained by calculating the stress value, assuming that own ship sails at a fixed speed along a fixed route without making any collision avoidance manoeuvres against encountering ships. This is intended to avoid concealing information on stress levels that each encounter would naturally impose on the mariner by taking collision avoidance actions against other ships.

This paper was gotten L-ES<sub>A</sub> value of navigating ships within the assessment area (3×7 miles). In detail, first of all, it was accumulated that the time scale data of L-ES<sub>A</sub> value imposed each ship on an object of all ships which was passing target area within simulation time. And, it was calculated a percentage of unacceptable condition imposed more than L-ES<sub>A</sub> value 750 for mariner on the passage route. And this paper pays attention to L-ES<sub>A</sub> value that expresses the aggregate evaluation result of ship-handling difficulty forced by both topographical and traffic environments.



(a) Straight Route ( $\theta = 0^\circ$ )



(b) Sectorial Route ( $\theta = 45^\circ$ )

Fig. 3 ESA Values of Each Waterway Shape

## 4. Ship-handling Difficulty of Traffic Volume and Channel Shape Change

### 4.1 Assessment Process

Fig.3 shows the calculated time-scale L-ES<sub>A</sub> values for the two types of channel. L-ES<sub>A</sub> values were calculated on the assumption that the own ship sails at a fixed speed along the fixed route without making any collision avoidance maneuvers. L-ES<sub>A</sub> values were calculated by applying the ES model to the ship-handling process in each case of navigation, and L-ES<sub>A</sub> values representing the ship-handling difficulties in the channel were obtained by taking mean values of these output results on a time basis.

Fig.3(a) shows L-ES<sub>A</sub> value that expresses the degree of ship-handling difficulty in a straight channel, and Fig.3 (b) shows L-ES<sub>A</sub> value in a sectorial channel. Regarding with the L-ES<sub>A</sub> values, it can be seen that great stress is imposed over the entire area of straight channel compared to sectorial channel, and the stress is greater in the case of larger vessels.

#### 4.2 Channel Shape Change and Traffic Volume Change

Encounters with other vessels in a topographically restricted narrow channel would impose great stress on mariners. Accordingly,  $L-ES_A$  values are significant when the degrees of ship-handling difficulty in different channels with different traffic conditions are contrasted. Figure 4 shows the percentages of unacceptable stress rank for each case based on the calculated  $L-ES_A$  values.

The degree of ship-handling difficulty can be judged from the percentage of unacceptable ( $L-ES_A \geq 750$ ) found from the calculations of  $L-ES_A$  values. The higher the percentage of unacceptable ( $L-ES_A \geq 750$ ) is the greater the ship-handling difficulty is.

As shown in Fig.4, horizontal axis shows length conversion traffic volume based on standard length 70m and vertical shows unacceptable load for mariner in passage route. It shows relationship between the change of traffic volume and ship-handling difficulty. There are three kinds of target occurrence vessel volume such as 10, 25 and 40 ships per hour in traffic flow simulation at length conversion traffic volume. As can be seen in this figure, under the same channel condition, the degree of ship-handling difficulty is higher in the channel of large traffic volume than small traffic volume. And, under the same traffic volume condition, ship-handling difficulty is more imposed over a straight channel compared to a sectorial channel. That is to say, because traffic flow of a sectorial channel and small volume channel is separated, the navigable area for each ship is widened. As a result, ship-handling difficulty imposed each ship is reduced.

To identify the quality of the each channel from the viewpoint of ship-handling difficulty, the results were represented on the equation shown in formulae (1)~(3), paying attention to the percentage of unacceptable ( $P(L-ES_A \geq 750)$ ), the navigation width( $W$ ) and the ship traffic volume( $Q$ ).

$$\text{Case of the Sectorial Channel with } \theta = 45^\circ \\ P(ES_A \geq 750) = 0.32Q - (2.0 \log_e W - 12) \quad (1)$$

$$\text{Case of the Sectorial Channel with } \theta = 25^\circ \\ P(ES_A \geq 750) = 0.41Q - (3.1 \log_e W - 21) \quad (2)$$

$$\text{Case of the straight Channel with } \theta = 0^\circ \\ P(ES_A \geq 750) = 0.54Q - (6.8 \log_e W - 47) \quad (3)$$

$W$ : Navigable Width(m)

$Q$ : L-conversion traffic volume(ships/hour)

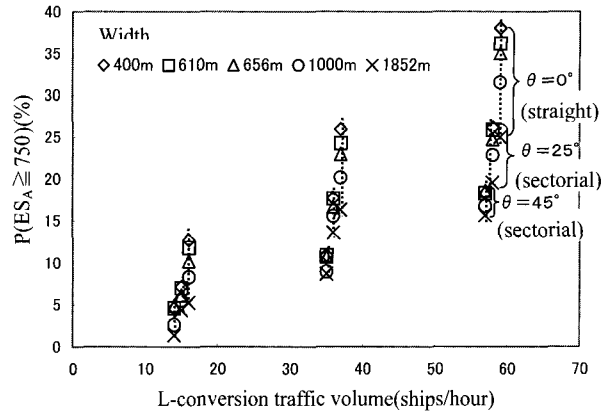


Fig. 4 The relationship between ship-handling difficulty and passage traffic volume and channel shape

### 5. New Consideration Factors and Design Diagrams

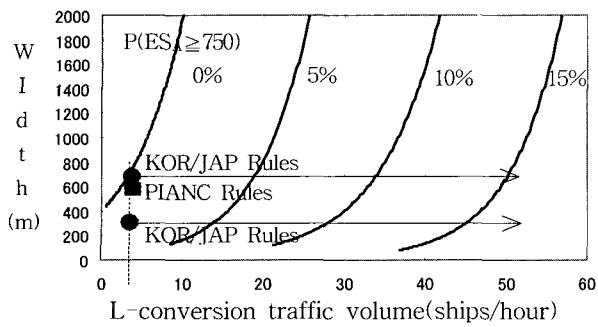
#### 5.1 One-way Channel

This paper proposes diagrams to enable the design level of each channel shape to be designed so that a channel can be passed without ship-handling difficulty. Fig.5 shows diagrams to find from the relationship between navigable width and target traffic volume. This diagrams are based on equations (1)~(3). In these diagrams, if the present channel shape, navigable width and traffic volume are given, the present ship-handling difficulty in the channel can be estimated.

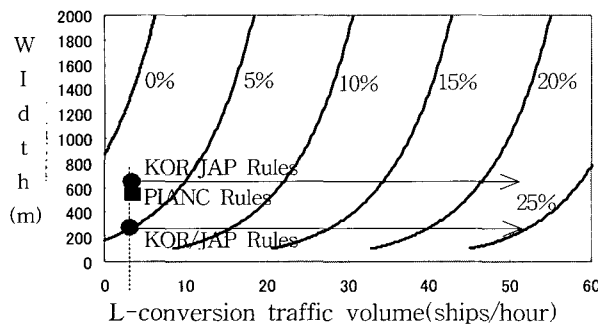
The channel widths based on the PIANC and KOREA/JAPAN Rules were plotted on the diagrams. As can be seen in this Figure, ship-handling difficulty for each traffic volume is different about 20% under the condition that the designed navigable width is 328m~656m. And ship-handling difficulty in the viewpoint of the channel shape difference is about 5%. If the present channel width is 500m in the straight channel with 10 ships per hour, this 5% difference is meant navigable width about 500m or traffic volume about 7 ships.

#### 5.2 Two-way Channel

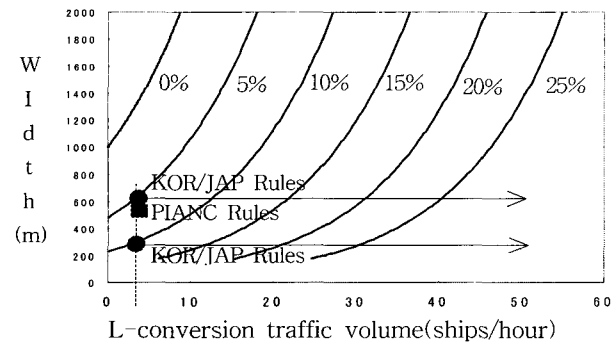
Until now, this paper examined about the ship-handling difficulty of the one-way channel. Then what will happen to in a two-way channel. Fig.6 shows the ship-handling difficulty of two-way straight channel with navigable width of 400m and 1000m. The horizontal axis shows the passage mode of channel, the vertical axis shows the unacceptable percentage imposed each ship in the assessment area. As



a)  $\theta = 45^\circ$  Sectorial Channel



b)  $\theta = 25^\circ$  Sectorial Channel



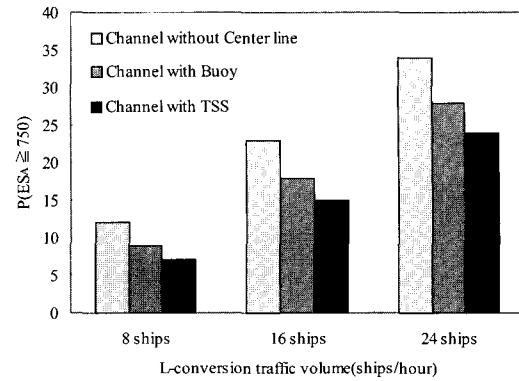
c)  $\theta = 2^\circ$  Sectorial Channel

Fig. 5 Design Diagram of One-way Channel

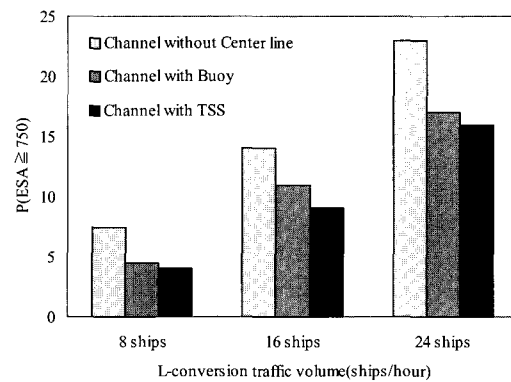
can be seen in this figure, under the same navigable channel width, degree of ship-handling difficulty for 3 kinds of two-way channel was different from 5% to 10%.

## 6. Conclusion

Until now, there is no standard of channel design taking into account traffic volumes and channel shapes in detail. This paper suggests traffic volumes and channel shapes as new consideration factors in channel design process because the ship-handling difficulty of each ship navigated under the same channel shapes width is different according to traffic volumes, and ship-handling difficulty under the same passage traffic volume in channel is different



(a) Channel Width 400m



(b) Channel Width 1000m

Fig. 6 ship-handling Difficulty of Two Way Channel

according to channels shape by employing the ES model which can evaluate the difficulty of ship-handling due to geographical restrictions and traffic congestion.

In this paper, it is proposed new thinking of approach channel design standards including the traffic volume, channel shape, and the relationship diagram between each waterway shape and imposed ship-handling difficulty. The relationship between the contribution to the easing of ship-handling difficulty and the design of shape and width of waterways and traffic volume is quantitatively clarified by employing the ES model which can evaluate the difficulty of ship-handling due to geographical restrictions and traffic congestion. This paper also proposes channel design diagrams that can be passed through without ship-handling difficulties.

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