運輸省港湾技術研究所 (30th Anniversary Issue)

港湾技術研究所 報告

REPORT OF THE PORT AND HARBOUR RESEARCH INSTITUTE

MINISTRY OF TRANSPORT

VOL. 31 NO. 5 MAR. 1993

NAGASE, YOKOSUKA, JAPAN

港湾技術研究所報告 (REPORT OF P.H.R.I.)

第31巻　第5号 (Vol. 31, No. 5) 1993年　3月 (Mar. 1993)

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HARBOUR RESEARCH INSTITUTE
Vol. 31, No. 5 (Mar. 1993)

10. Applications of a Ship Maneuvering Simulator to Port and Harbor Planning

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Synopsis

Recently, a high and accurate ship handling simulator has become available for use in various fields. This paper reports some practical applications of the ship maneuvering simulator to port and harbor facilities as case studies, and a reasonable way of applying simulator to port and harbor planning. The paper also describes some simulation results of basic ship maneuvers under conditions of simplified water area.

Simulation experiments led to the following conclusions, i) The ship handling simulator is very effective for surveying marine traffic safety or evaluating marine traffic facilities in actual planning of water area. ii) Large number of experiments would be required to get accurate evaluations concerning traffic safety of facilities. The reason is that ship motion is dynamically changed by natural forces and a simulator is a man-and-machine system containing human factors. iii) In designing water area facilities, following items are now considered; ship size, geographic conditions and marine traffic conditions. The results of this study emphasize that the characteristics of ship motions especially in low speed areas should additionally be considered. iv) In planning a waterway where ships of poor maneuverability or ships strongly influenced by natural forces pass through, the vent part of waterway should not only be cut at corner but also be enlarged at both sides of curved area.

Key Words: Port and Harbor Planning, Ship Handling Simulator, Man-and-Machine System, Ship Maneuverability

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港湾技術研究所報告
第31巻　第5号　(1993. 3)

10.　操船シミュレーターの港湾計画への応用

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要　旨

近年，精度の高い操船シミュレーターが関連する多くの分野で利用可能となってきた。本報告では同装置を実際の港湾施設計画へ適用した事例を報告するとともに，操船シミュレーターの港湾計画への適用の方法及び単純化した水域での基本的な操船実験の結果について報告する。

事例研究及び実験の結果得られた主な結論は以下の通りである。

1）具体的な水域施設計画において，操船シミュレーターを利用する操船実験による検討方法は，船舶の航行上の安全性を検討するために施設の適切な評価を行うことが出来る有用な方法である。

2）船舶の操船は，実際上人間の判断により行われる。それゆえ，船舶運動には操船者の個人的な操縦特性が入り，この特性は個人間でかなり異なる。また，船舶運動を変動させる気海象条件等の外乱は空間的にも時間的にも変化するので，シミュレーション実験による水域施設についての安全上の定量的な評価を得るためには，統計的に処理するための十分な数の実験を行う必要がある。

3）水域施設の諸元の設計においては，対象船舶の船型（全長，全幅，喫水），地形条件及び航行条件等を考慮することにより求められているが，さらに船舶の種類に応じた港湾内特有の運動特性についても十分考慮に入れる必要があると考えられる。

4）運動性能のわるい船舶あるいは気象・海象条件の影響が大きい船舶が通航する航路では，屈曲部では安全性確保のために，隅切りだけでなく屈曲部付近の十分な拡幅が望まれる。

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Contents

1. Introduction

According to the Technical Standard of Port and Harbor Facilities and its explanations[1], in designing water area facilities such as waterways, anchorages and turning basins, emphasis should be given to marine traffic safety and smooth flow by considering ship size, using conditions of the facilities and natural characteristics. For example, in the case of a comparably long two directional waterway, width of waterway should be 1.5 times a ship's overall length where traffic volume is not large (**Fig. 1**). In principle, waterways should be planned in a straight direction and the crossing angle of curved part should be less than 30 degrees as far as possible. When the angle exceeds 30 degrees, corner cutting should be done (**Fig. 2**). The depth of waterways should be greater than 1.1 times the full laden draft of target ship in addition for space to pitching of the ship. Especially in planning waterways, the entrance of a harbor and turning basins, comments of ship owners and pilots should be taken into account. As such phrases as 'comparable long waterway' and 'traffic volume is great' are not so clear, many examinations may be needed before designing facilities to ensure safe and smooth traffic flow, the reasons why, however such fuzzy expressions are used might be that a uniform design method can not be applied to complex and various conditions. There also might be definite methodology of available design or little data stock concerning ship motions, maneuvering characteristics and natural conditions.

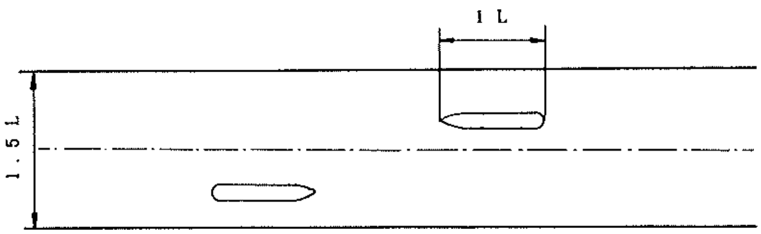


Fig. 1 Width of standard type waterway of 2 ways traffic where ships pass infrequently in relative long waterway

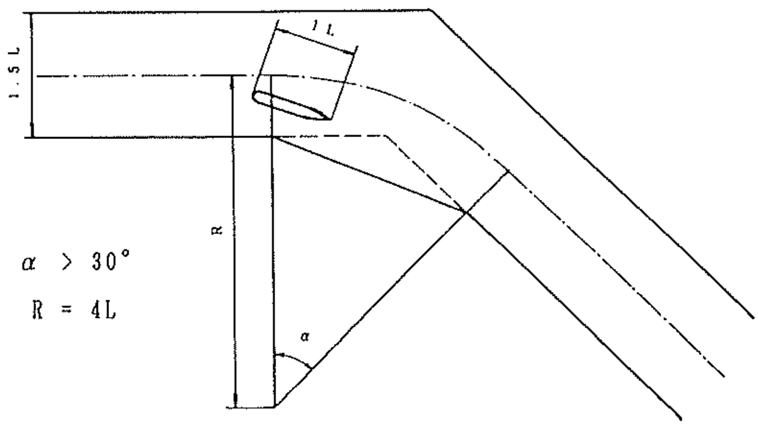


Fig. 2 Layout of waterway at curve where the intersection angle of center line of a waterway is more than 30 degrees (case of 1.5 L of width)

In the field of naval architecture, studies and researches on ship motions and their mathematical modeling have been carried out since about 1971. As a result, the Mathematical Modeling Group model which has high accuracy and flexibility was produced[2].

In a process of research and developing 500~1,000 thousand dead weight tonnages of ships in the same field to find the relationship between ship motions and maneuverability or controllability, a full scale ship maneuvering simulator was developed[3]. The bridge sizes are 8.4 m in width and 4.1 m in depth. For education and training, some ship handling simulators were developed and fully applied in mercantile marine colleges or seamanship college[4),5]. Among them the simulators of Ishikawajima-Harima Heavy Industries Co., Ltd. and seamanship college were derived from a highly accurate mathematical model and utilise a wide visual screen. Therefore shipping agents have used them for incumbent licensees to raise their technical skill (In case of IHI, it was used until simulator was taken to pieces). Well made simulators came to be acceptable for licensees such as captains or pilots because such simulators have almost same maneuvering feelings compared with actual ships. When a highly accurate ship motions models was introduced, new applications of simulators emerged. It came to be used for the studies of layout of port and harbor facilities[6], safe ship handling or standard ship handling method[7]. In this way, ship handling simulators have been used in many fields such as developing new type of ships, educational and training fields and also port and harbor planning.

The simulation system using ship maneuvering simulator consists of the following subsystems;

1) mathematical models which describe ship motions obtained by scale model tests

2) models of judgments and control done by pilots or captains. This system is called a man-and-machine system. Therefore this system is very complex. The methodology of evaluation of experimental results is not sufficiently established for it to be applied to facilities of port and harbor. A way to adequately utilize and apply the simulator to port and harbor planning is earnestly needed. In this paper, this is touched upon and three case studies were described that were applied to actual port and harbor planning using PHRI's ship maneuvering simulator. Additionally, some results of basic ship maneuvering experiments in a simplified imaginary port are also described.

2. PHRI's Ship Maneuvering Simulator

2.1 Outline of simulator

Some typical ship handling simulators that were made to study ship motions and safe navigation in port areas include the simulator of Hiroshima University[8], the simulator of Yusen Maritime Research Institute corporation[9] and the simulator of Port and Harbor Research Institute in Japan. These simulators were designed to reenact ship motions at slow speed, berthing and turning with the aid of tugboats with high accuracy.

PHRI's simulator was introduced in 1984, and has been improved in some points. Major points are expansion of external forces, setting method of environmental conditions and view part.

Simulator consists of 1) control part, 2) calculation part, 3) meter displaying part, 4) view part, 5) recording part, 6) analysis part. Part 1) and 2) are made with mini-computer PDP-11/model 24 system; here, calculation of mathematical model and real time control are performed. Part 3) is equipped with marine meters (engine revolution meter, velocity meter, gyro repeater, rate meter, rudder angle meter, engine telegraph, knob instead of steering wheel, anemometer and wind speed meter) which are generally attached in bridge of a ship. Part 4) is a view part of simulator made with a 20 inch color display that reproduces 3-dimensional figures seen from bridge every 2 seconds. Part 5) records many experimental conditions, parameters and results such as maneuver or control data and ship motions. Part 6) is analysis part made with analytical software and drafting machine which draws ship trajectory figures and ship maneuvering figures of time history.

A simple and cheap subsystem was built in as view part equipment instead of a full scale one although it directly concerns reliability and reproducibility. To generate a 3 dimensional picture, modified surface model is used. By using a personal computer whose calculative performance is nearly 1MIPS and 0.1MFLOPS, panoramic view of 70 objects is drawn in 1 second after processing geometrical transformation and clipping.

As a ship motions model, hydrodynamics model was used. Using Coordinate system shown in **Fig. 3**, ship motions will be described as follows;

surging $m\,(d\mathbf{u} / dt - \mathbf{v} \cdot \mathbf{r}) = X$

swaying $m\,(d\mathbf{v} / dt + \mathbf{u} \cdot \mathbf{r}) = Y$

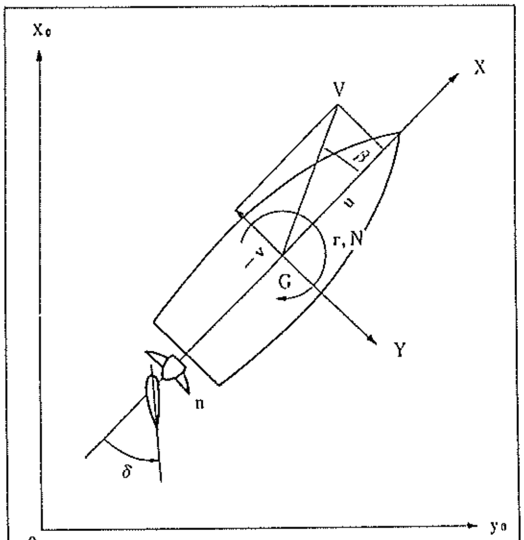
yawing $I_{zz} \cdot d\mathbf{r} / dt = N$

The right side variables X, Y and N contain not only hull force, rudder force and propulsive force but also following external forces;

1) wind forces
2) wave forces
3) current forces
4) shallow effect
5) bank effect
6) tugboat's push & pull forces

PHRI's simulator system allows plural navigating conditions on traffic route. This feature can be set up in a scenario in which ships circle around other ships.

Figure 4 is an exterior shot of PHRI's ship maneuvering simulator.



X : force in X-axis direction
Y : force in Y-axis direction
u : ship speed in x-axis direction
v : ship speed in y-axis direction
r : turning rate
N : roll damping moment
V : ship speed
n : number of propeller revolution
δ : rudder angle
β : lee way angle

Fig. 3 Coordinate system and ship motion

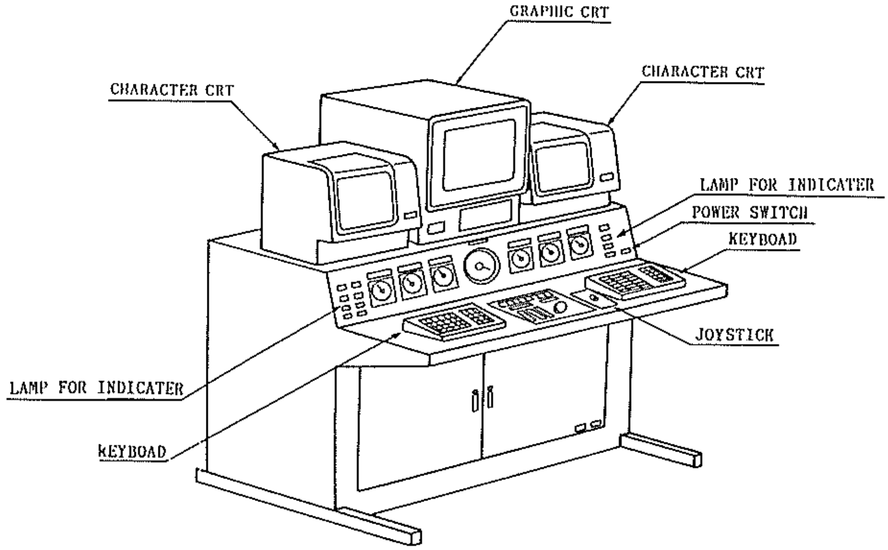


Fig. 4 Out look of PHRI ship maneuvering simulator

2.2 Validity of the Model Ship Motions

The mathematical model was introduced from the model of Ishikawajima harima Heavy industry corporation and Akishima Laboratory of Mitsui Ship Building corporation. The ship model was tested and calibrated in turning motions, zig-zag maneuver, spiral maneuver, stopping motion, turning motion in steady wind, turning motion in regular waves and turning motion in shallow water. **Figure 5** shows comparison of full scale trials and the results of simulation in various tests[10),11)].

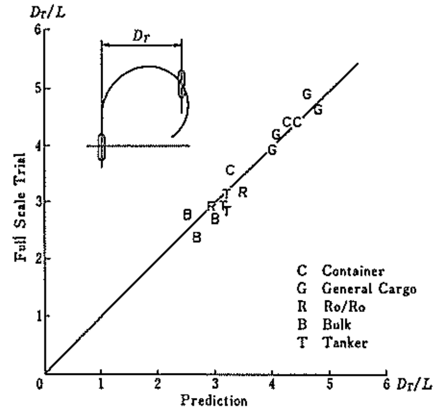
3. Procedure of Simulation

3.1 Clearing objects on experiments

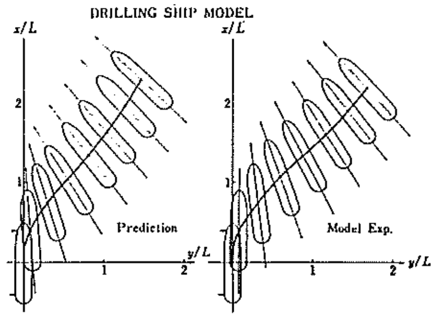
There are various factors related to safe navigation. In terms of ships, one must consider ship type, ship size (length, width, area of projection), engine (type, horse power), ship tonnage (displacement tonnage, dead weight tonnage), draught, trim and maneuvering characteristics. For Port and Harbor Facilities, waterway (width, length, bending angle, water depth and characteristics of bottom sand), break water (space at port entrance), buoy (distribution layout, distances between buoys), light house, maximum number of available tugboats must be considered. Traffic environment also concerns navigation; traffic control, traffic volume, 1 way or 2 way waterway, restricted conditions of port entrance. Additionally, natural conditions are very important for navigation. Depending on these conditions (calmness inside the port, current, wind conditions), a ship might not be able to enter the port. All these factors are closely related.

In setting up conditions, some of them are uncertain in that they could be considered both as input parameter and also as output results. On the other hand, few increased conditions would demand a large number of experiment combinations.

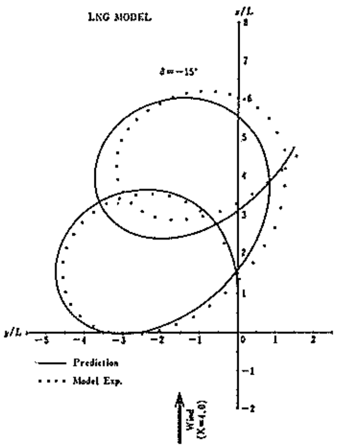
The first task in ensuring a successful experiment is to decide control variables and evaluation variables to make the number of cases minimum. For that purpose, it is very important to have meetings with shipping operators, captains and pilots,



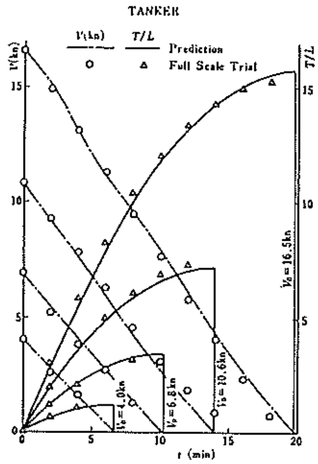
(a) Comparison of Tactical Diameter between Predictions and Full Scale Trials



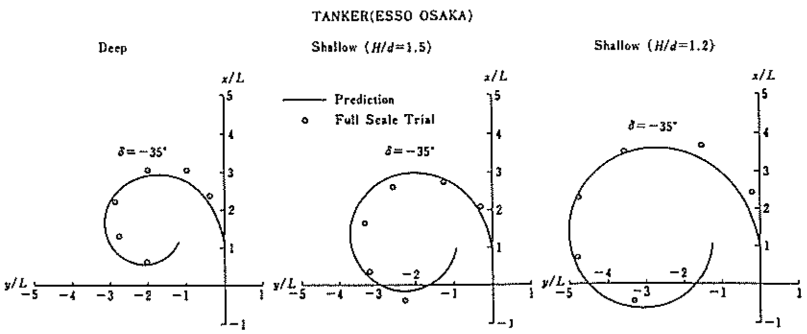
(b) Trajectory of Lateral Shifting Motion with Bow and Stern Thrusters (Drilling Ship Model)



(c) Turning Trajectory in Steady Wind (LNG Carrier Model)



(e) Time histories of Ship Speed and Travel Distance along Pass in Stopping Motion (270,000 Dead Weight Tonnages Tanker)



(d) Turning Trajectories in Shallow Water (ESSO OSAKA)

Fig. 5 Comparison of Full Scale Triales and Simulation Results authorities concerned and planner of port and harbor in order to decide input conditions and evaluating terms.

3.2 Setting conditions

The most effective way to set up and to build the conditions of water area and port facilities is to take pictures from a ship which actually enters the target port. If this way proved impossible for some reason, then data of facilities would be created by using surface plan.

Natural conditions are usually determined from observation data.

The ship type should be chosen to be the nearest type model as far as possible. If there is no model type which could substitute for the target ship, then new model of target ship should be introduced.

3.3 Execution of experiments

(1) Experiment team

The experiment team consists of an actual pilot or captain of ships for overseas services, navigation officer, engineer, representative captain of tugboats, tugboat maneuvering assistant and working service assistants of simulator system. In cases where experiments are done continuously, the captain or pilot would be replaced. Continuous strain could result in poor judgement. It takes 30~40 minutes to carry out one experiment from the position of outside the port to the position just in front of berth.

Impressions and feelings of substance concerning maneuvering should be memorized. Just after each experiment, comments and opinions of captains should be recorded.

(2) Efficiency of experiment

In PHRI, the number of experiments carried out per day was from 2~6. Much time was required for data inputting, condition setting and analyzing results of data. It also took a long time to make a schedule and negotiate with pilots, captains and officers to find a time when they were commonly available to perform experiments.

3.4 Evaluation of Simulation Results

It is said that maneuvering large ships is quite difficult. Changing rate is incommensurable with the human time scale because mass and size of ship are very large. For example, the distance between bridge and head of the ship is more than 200m. Usually height of deck is high, dead angle occurs in front side of a ship. Ships have to navigate with slow speed, especially in area of port and harbor. And slow speed makes maneuvering difficult due to the ship's susceptibility to relatively large external forces of wind, current, wave and shallows. Therefore, in most actual cases, only pilots who have deep experience in entering maneuvers are used.

Considering that ship maneuvering is performed by specialists with proficient skill and that ship motions are dynamically affected by natural random forces, maneuvering actions are characterized by randomness. The authors have formed a method which could evaluate facilities from the view point of safe navigation.

(1) The team who operates a ship maneuvering simulator should include plural captains or pilots who have experience in entering the objective port and water areas.

(2) By setting present status of all conditions, calibrations of simulator system should be done. Through these operations, captains or pilots would be able to grasp correspondence between actual ship maneuvering state and simulation experiments. After, experiments for many alternative cases would be carried out, alternative cases concerning

facilities would be evaluated relatively or absolutely from the view point of safety navigability and adequacy.

(3) On the other hand, static analysis should be done by finding out positions using ship trajectory map or time-history of maneuvering records.

(4) If evaluation results were different or maneuvering process was different among captains, meetings would be held by captains and opinions should be unified.

(5) Finally, considering all above opinions and analytical results, estimations and evaluations should be decided for facilities' plan from view point of ship maneuvering safety.

Figure 6 shows procedure of ship maneuvering simulation.

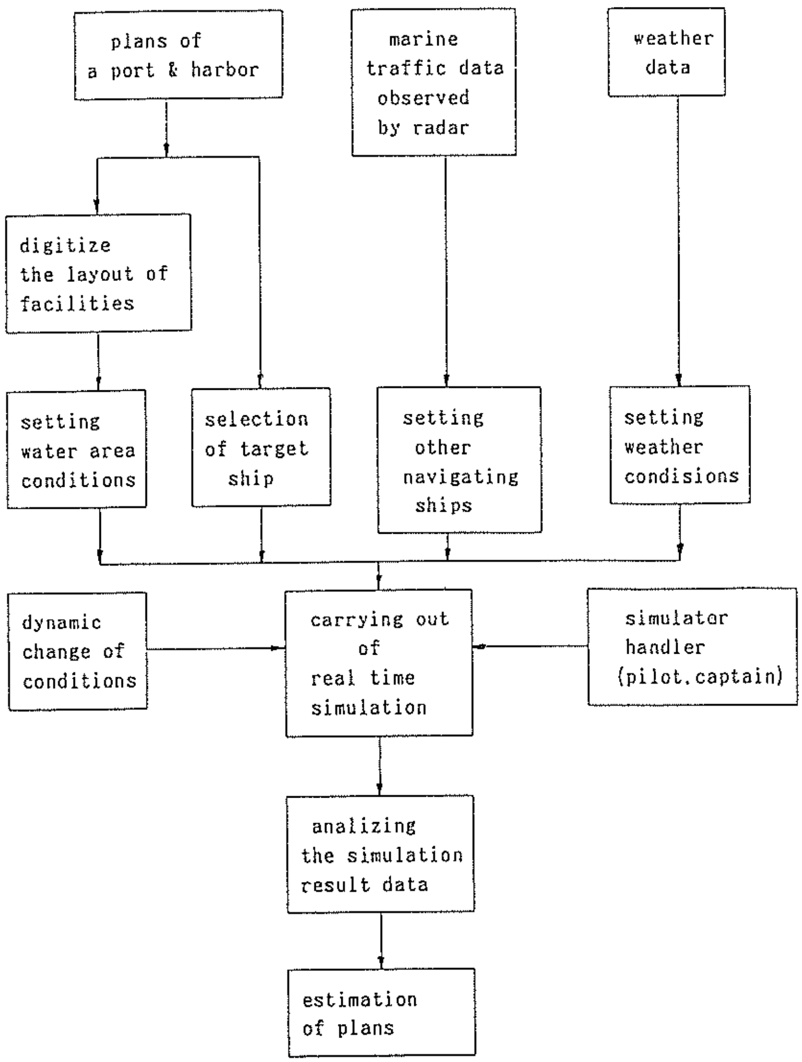


Fig. 6 Process and procedure to apply simulator for port & harbor planning

4. Case Study of Port and Harbor Planning

4.1 Case of Port of Kure

Kure port is situated at the east side entrance Hiroshima Bay. Iron and steel, ship building materials and machinery are the major cargoes in this port.

The object of the ship handling experiments at Kure port was to study and investigate whether ships would be able to enter and depart safely and whether there are any places where some troubles for ship handling occur under planned facilities and water areas on actual natural conditions.

(1) Target ship

The target ship was tip carrier with size of 46,000 dead weight tonnages. At that time PHRI did not have this type of ship model, thus new data of ship motions model were prepared for this experiment. Typical size and features of the target ship are shown in **Table 1**.

Table 1 Principal dimensions of target ship

ship type	tip carrier
ship size	46,000DWT
cargo conditions	full laden
length of perpendicular	187.0m
molded width	32.2m
draft	10.0m
trim	0.0m
displacement tonnage	49,500.0ton
diameter of propeller	6.6m
area of rudder	28.0m^2
area of ship front shadow	550.0m^2
area of ship side shadow	2,660.0m^2
type of main engine	diesel
engine power	8,150 HP
engine revolution	92 rpm

(2) Setting up conditions

Water area and navigating boundary conditions are shown in **Fig. 7**. The shape of waterway was almost straight and measured 150 m in width, 2,500 m in length and 11 m in depth. The depth of turning basin was 12 m and the depth of anchorage for quarantine was 13 m. Outside the boundary of the waterway, 4 buoys were set. These 4 buoys were moved from old position to new and hatched area was widened or deepened according to the plan.

Navigating scenario is through as follows. 1) The ship stays at anchorages and waits with her head to west direction until tide reaches a level that allows for navigation. 2) The ship starts and soon changes its course to entrance of the waterway. Ship speed is limited to 6 knots at the entrance of the waterway. 3) Passing through the waterway and turning basin, ship berths with the contact of her port side to the quay wall or her starboard side to the mooring dolphin. The maximum speed should be less than 1 knot in front of the quay or dolphin. 4) After the ship pulls away from the quay wall, ship moves astern to turning basin. 5) The ship turns 180 degrees at the basin. 6) Disengaging from tugboats at the basin, the ship goes forward and leaves the port through the waterway.

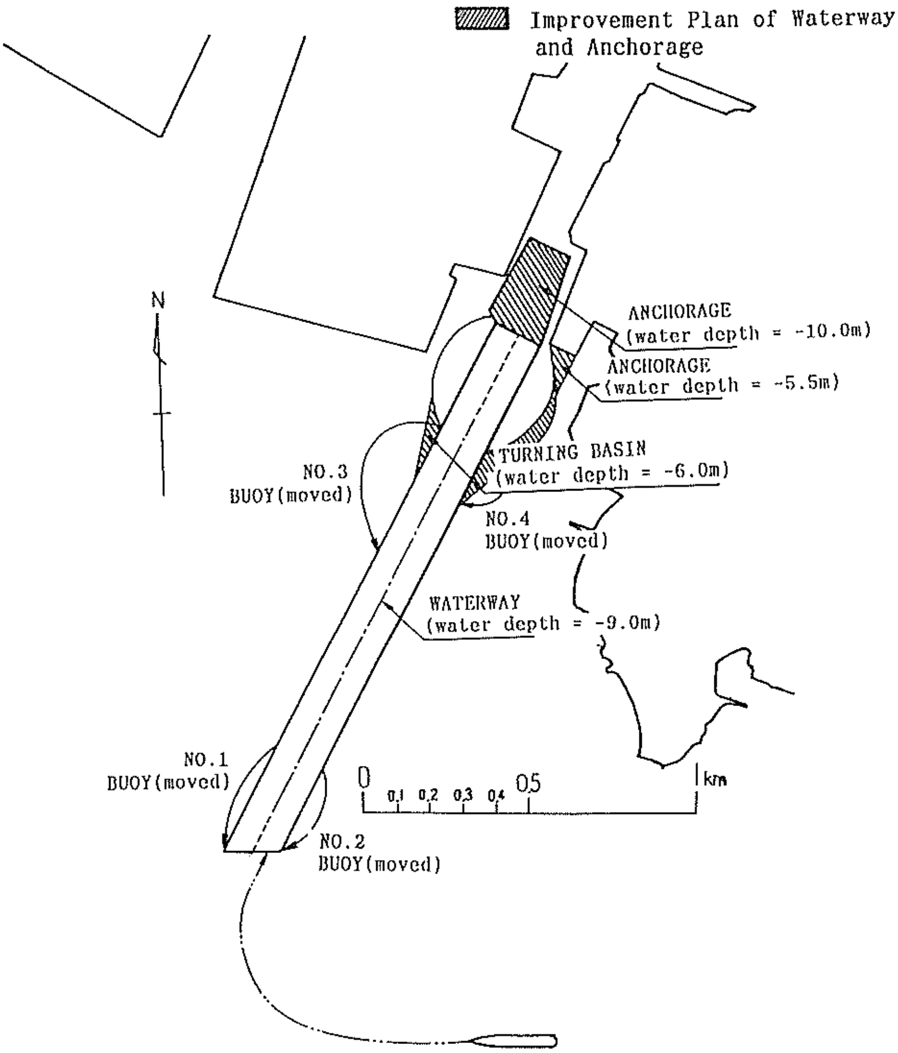


Fig. 7 Water area condition in Port of Kure (Hiro Division)

The target ship can use a maximum of 4 tugboats. Thrusts of tugboat were set at 5, 10, 20 and 25 tons for pushing and 4, 8, 15, 20 for pulling according to each tugboat's engine revolution. **Figure 8** shows actual tugboat's position around target ship.

For natural conditions, most severe states are chosen. (Maximum wind velocity for ships entering this port is 8 m/s.)

Because of time constraints, number of possible experiments was limited; 4 cases were finally chosen: 2 entry cases and 2 departure cases. The experiments were carried out by a team of 5 members. In these experiments, a tugboat captain did the work without maneuvering assistant.

(3) Results of experiments

Figure 9 shows ship trajectories in experiments and **Fig. 10** shows examples of ship handling records and time histories of ship motions. Case-1 and case-2 show entrance and case-3 and case-4 mean departure. According to the tracing of the ship motions in case-1, at first, the ship was anchored at a position where is east direction and 1,500 m distance from the position of latitude 34 degrees 12 minutes north, 132 degrees 36 minutes of East longitude. She started with her head to West direction and after 5 minutes she began to change her course to NNE and entered the waterway. After 20 minutes had passed, she reduced her speed to 0.6 knots keeping her head to 14 degrees and reached a point just in front of the dolphin.

In case-2, berthing object was quay located 150 m to the west of the dolphin. Wind condition was changed from 8 m/s to 12 m/s to examine ship navigating stability along a straight course, particularly in long waterway. Relative difficulty of berthing was another focus of the study. So, start position was set at a point which is on an extended line of the waterway. Ship Started with initial speed 7.4 knots and lowered her speed until 3.1 knots but could not succeed in reaching the quay. The reason for failure was data mistake. The current condition changed too late. New case-2-1 was added to the experiments and the result was that she could reach the quay with speed 0.1 knots under correct conditions.

In case-3 and case-4, wind conditions were respectively set up to 8 m/s and 12 m/s blowing both from Northeast direction. Referring to **Fig. 9**, turning area was fully used but trajectory showed that the ship could navigate safely.

The experimental results and time history were matter of above described. After this experiment, a meeting was held and feeling and opinions of pilots were discussed using trajectory maps and recorded data. Conclusions of this experiment were as follows;

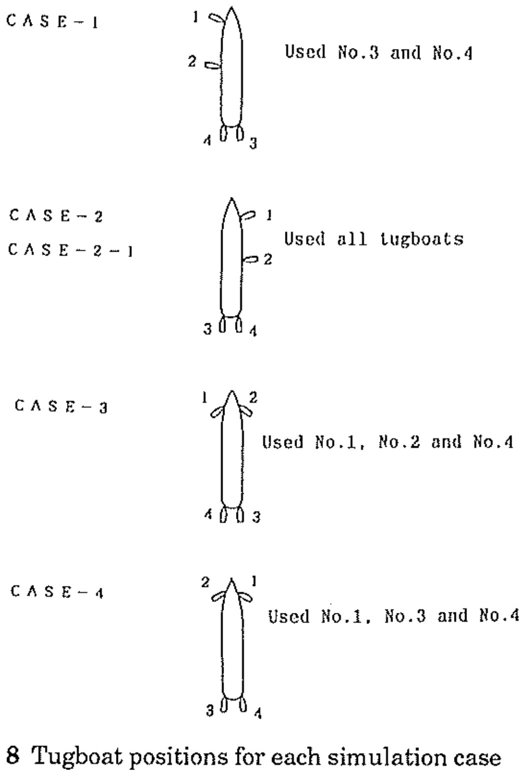


Fig. 8 Tugboat positions for each simulation case

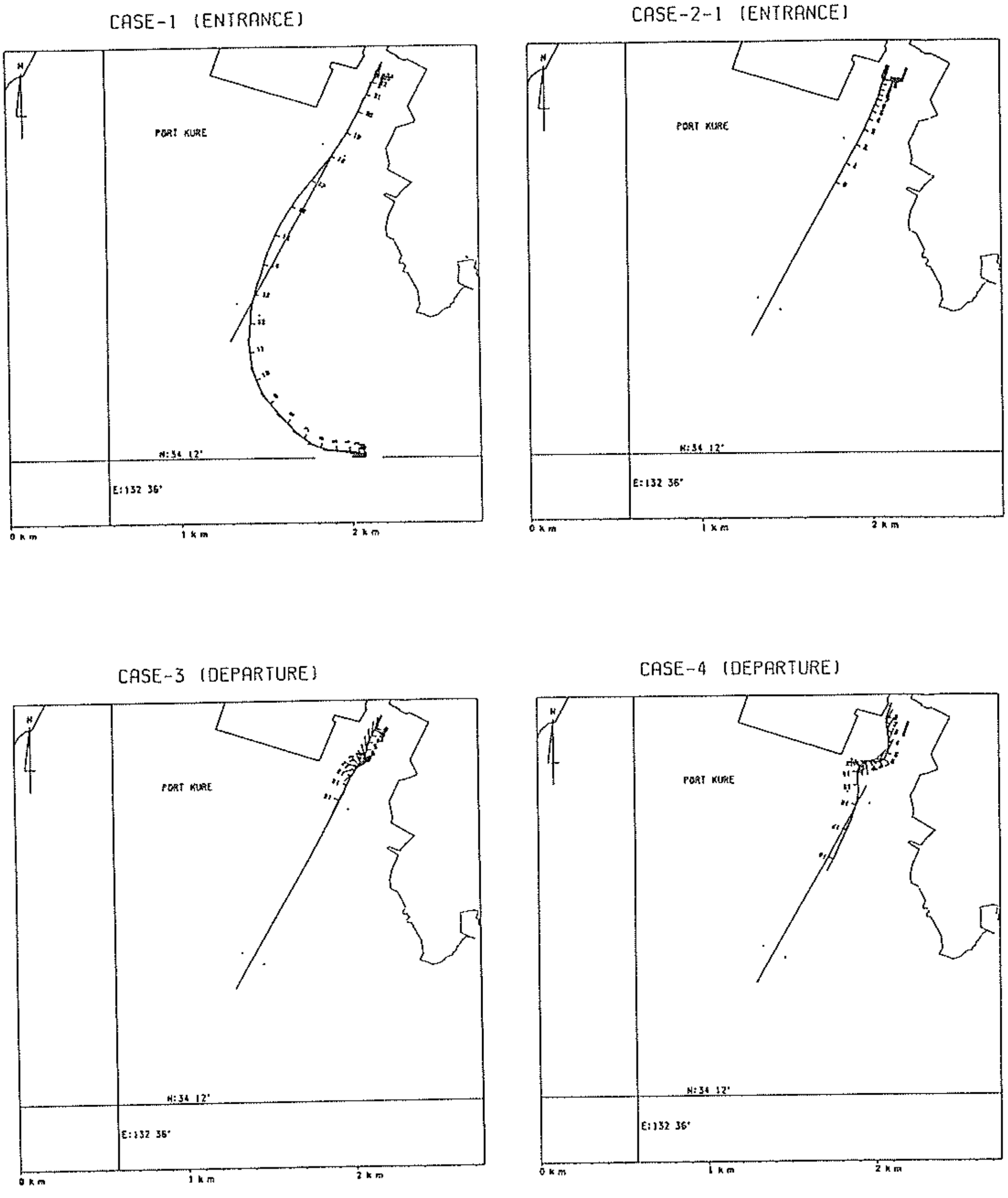
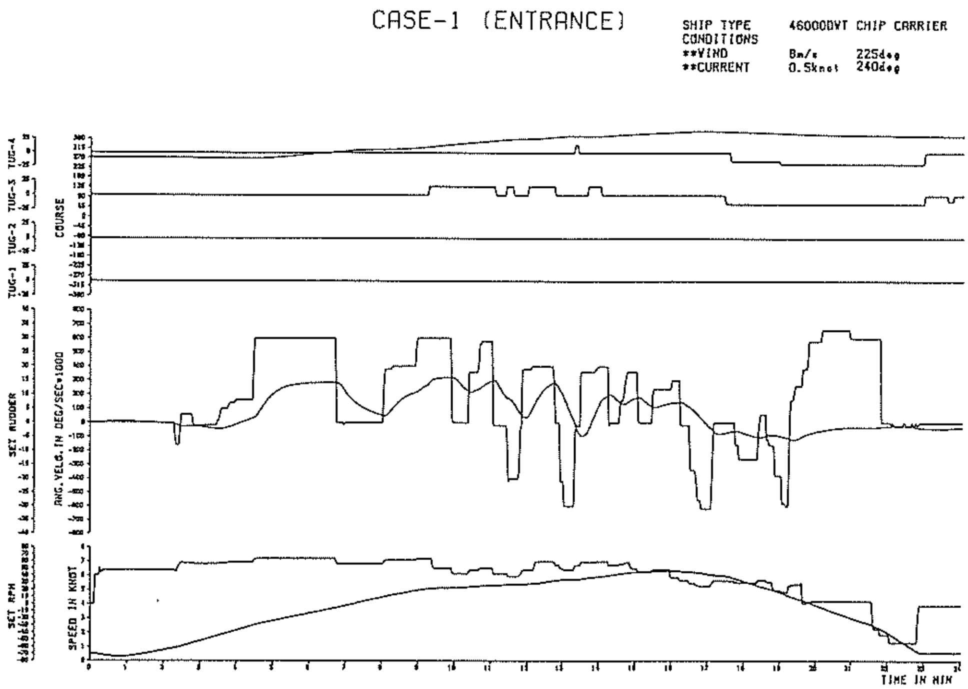


Fig. 9 Trajectories of experiment on Port of Kure



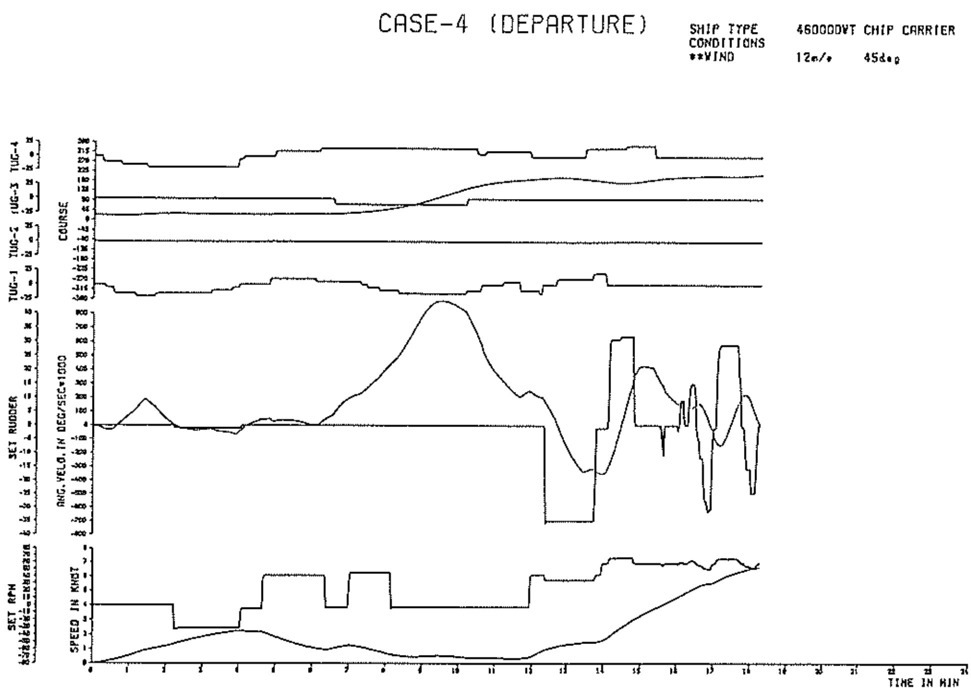


Fig. 10 Maneuvering records and time history of ship motion in Port of Kure

1) Natural conditions were set up to severe state that was equal to or exceeded the inhibited entrance condition.

2) Entrance ship maneuver could be possible under condition of 8 m/s of wind and 0.5 knots of currents if tugboats were available.

3) There might not be any problem in case of departure manuever.

4) The characteristics of target ship in plan would be more dull and bigger in turning circle compared with present ship. Ship maneuvering should be adjusted according.

5) To secure safe navigation, buoys and reading marks which were well recommended by ship handlers should be fully equipped.

4.2 Case of Port of Kawasaki

Kawasaki Port is very important and plays a large role in the economy of the metropolitan circle. Container berths in the Higashi Ohgishima area are planned to be expanded to cover increasing cargoes as cargo terminal.

The object of performing ship handling simulation was to make synthetic evaluations for safe ship entrance and berthing. The concrete aims were to decide shapes of water area facilities and ship entrance and departure root, to determine out the necessary number of tugboats and positions of nautical marks, and to examine ship navigating safety under actual natural conditions.

(1) Target ship

The objective ship type was largest container ship of 50,000 DWT class with size 280 m in length, 35 m in width, 13 m in full laden draught. Principal dimensions are shown in **Table 4**.

(2) Cases and its condition

The given water area for ship approaching and berthing is shown in **Fig. 11**. There were three water area parts: 1) Ohgishima 1st waterway, 2) Ohgishima 2nd waterway, 3) water area of berth front. Dimensions are 500 m · 1,300 m, 500 m · 1,800 m, 600 m · 4,500 m respectively. 1) and 3) cross with an angle of 45 degrees and 2) and 3) cross with an angle of 90 degrees. Water depth of Ohgishima 1st waterway was 17 m and 21 m, Ohgishima 2nd waterway was 21 m and water area of berth front was 15 m.

A meeting organized by specialists was held to discuss the basic maneuvering pattern and entrance course, critical points of experiments and the minimum number of cases necessary. There was a berth for pure car carrier near the container berths on the same quay line, traffic routes were in competitive state because berthing side of these ships are opposite. However, if traffic control would be done, the traffic route of container ship would be taken as right round. This means ships should enter passing through Ohgishima 2nd waterway and depart through Ohgishima 1st waterway. Otherwise it is feared that interference would occur between the entrance flow in Ohgishima 1st waterway and the departure flow in Kawasaki waterway that lied parallel to Ohgishima 1st water way. There remained another difficulty in choosing the right turning course. It would be difficult to turn 90 degrees after just passing the breakwater and continuously approach the berth while quickly reducing speed if natural conditions were severe.

The chosen number of cases for this experiment was 4:2 entrance cases and 2 departure cases. Water area environment and conditions for ship maneuvering were set up as follows. There were three container berths in same quay line and the center berth was selected for experimental target berth. And status of berths were that two container ships were berthing and under loading and unloading. In 2 cases, other navigating ships were set up. Captains needed to take care of only one other ship among plural nav-

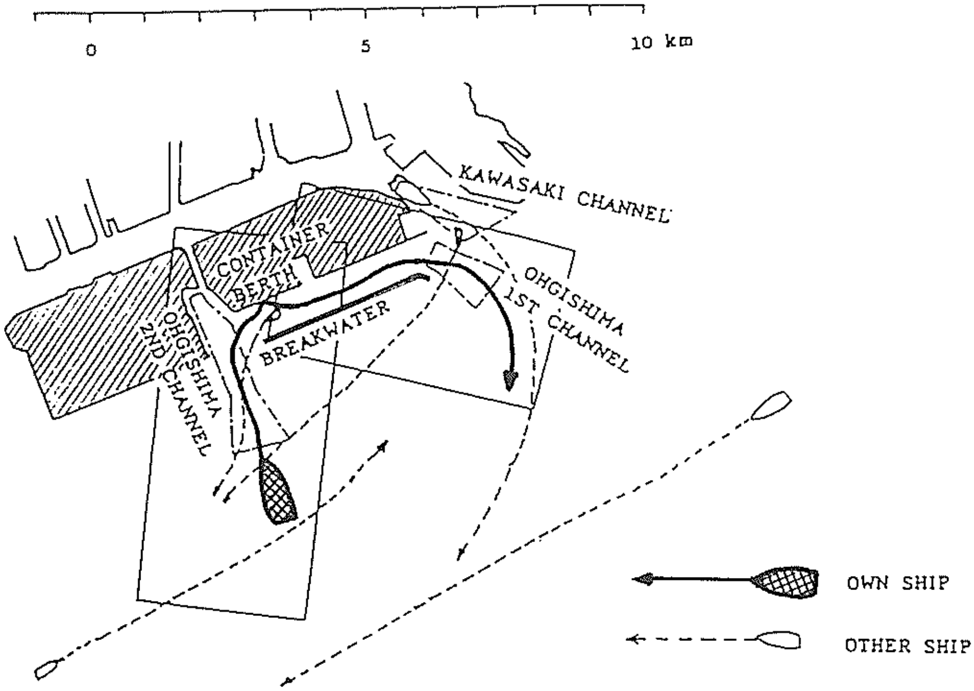


Fig. 11 Port of Kawasaki water area condition

igating ships. If collision was forecasted, one ship had to change its course. The traffic route and time were set up by considering opinions of specialists. Two types of traffic pattern of other ships were prepared and presented to captains by using map but concrete information such as velocity, the closest time and point were not given. Start position was set up 2,000 m from breakwater. Start position was randomly moved 200 m to lateral direction of waterway. Captains were not informed of position data.

As for natural conditions, wind of 8 m/s from Southeast and current of 0.5 knots to east-northeast outside of breakwater in case of entrance, wind of 8m/s from South and current of 0.5 knots to west-southwest outside of breakwater in case of departure were simulated. These conditions are most severe for ship handlers in actual ship maneuvering.

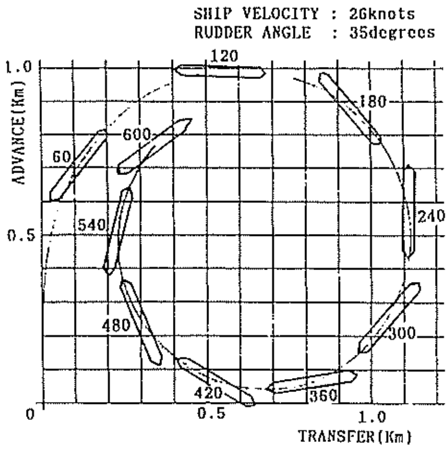
Captains and pilots grasped the navigating environment and ship maneuverability and made ship entrance plans in long time allowance. Ship characteristics shown in **Table 2** and **Fig. 12**, were presented to captains to aid their preparation.

(3) Carrying out experiments

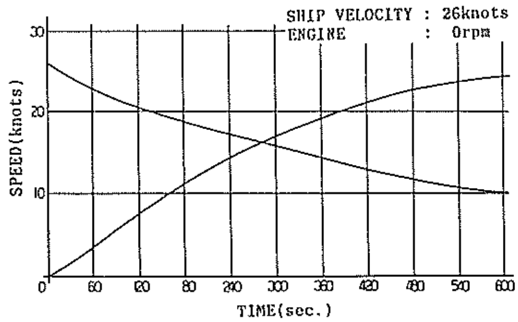
Five captains were invited and asked to operate the ship maneuvering simulator. Each captain carried out the experiments in the order from case-1 to case-4. Every experiment was carried out by a simulation handling team which consisted of seven members. **Photo. 1** shows one ship captain (an actual pilot), helmsman and engineer at the state of experiment, **Photo. 2** shows tugboat captain who was communicating with container ship captain and assistant officer. Impressions and opinions of maneuvering were memorized and recorded in the same form.

(4) Result of experiments

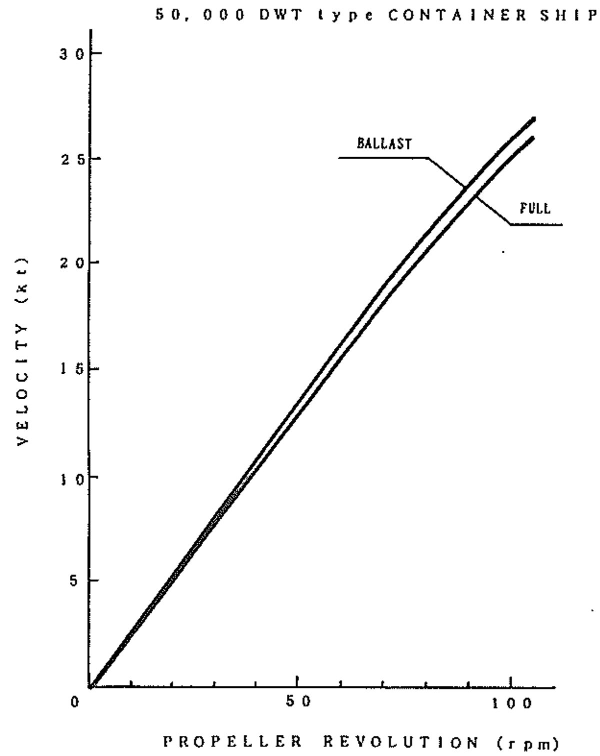
Ship trajectory maps and also time history figures of ship motions were made from simulation records (**Fig. 13** and **Fig. 14**). Total number of experiments was 20,



(a) Turning test



(b) Acceleration and deceleration test



(c) Relation between velocity and engine revolution

Fig. 12 The characteristics of maneuverability of the target ship

Table 2 Principal dimensions of 50,000 DWT (dead weight tonnages)

		cargo condition	
		full laden	ballast
length of over all	(m)	280.0	
molded width	(m)	35.0	
molded depth	(m)	22.5	
draft	(m)	13.0	9.65
trim	(m)	0.0	1.0
displacement tonnage	(ton)	76,000	52,000
area of ship front shadow	(m^2)	1,100	1,220
area of ship side shadow	(m^2)	6,500	7,400
diameter of propeller	(m)	8.60	
area of rudder	(m^2)	68.2	62.3
height of rudder	(m)	11.3	10.0
power of engine	(HP)	55,400	
revolution of engine	(rpm)	104	
navigating velocity	(kts)	26.0	26.8

Photo. 1 Operating Captain (Pillot), Officer and Engineer in Simulation Room

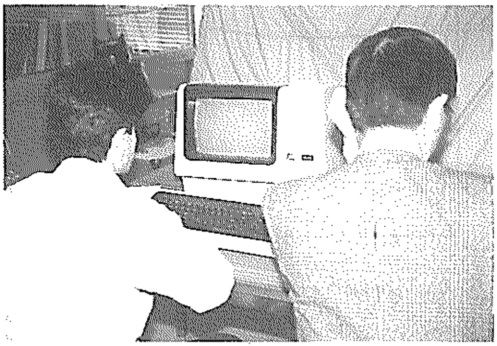
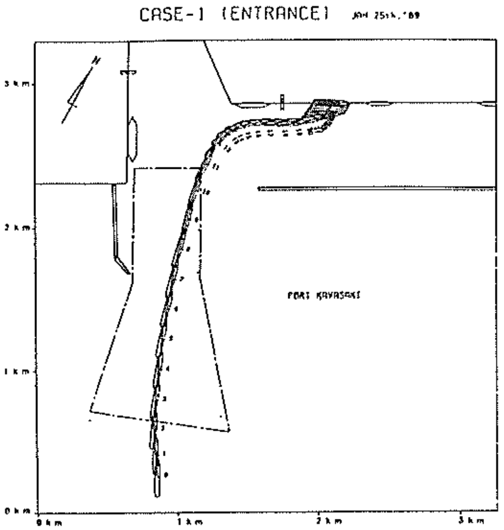
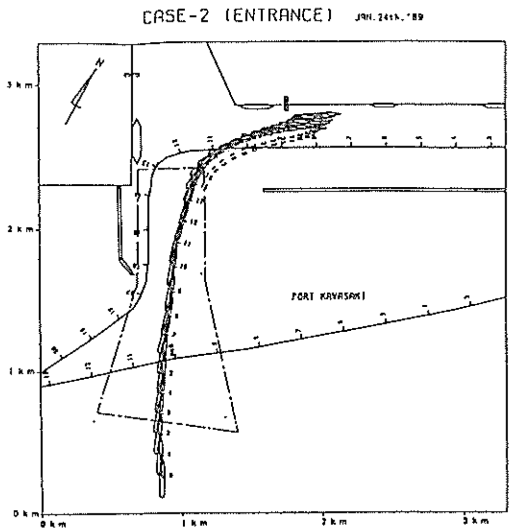


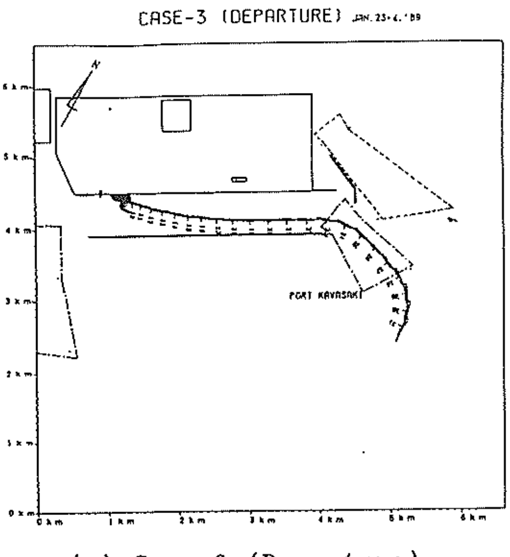
Photo. 2 Operating assistant (the left side man) and Captain of Tugboat (the right side man) who is receiving maneuvering order of tugboat from Mother Ship Captain



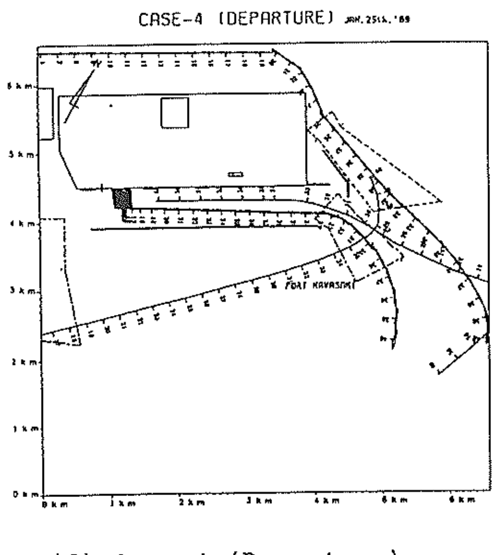
(a) Case-1 (Entrance)



(b) Case-2 (Entrance)

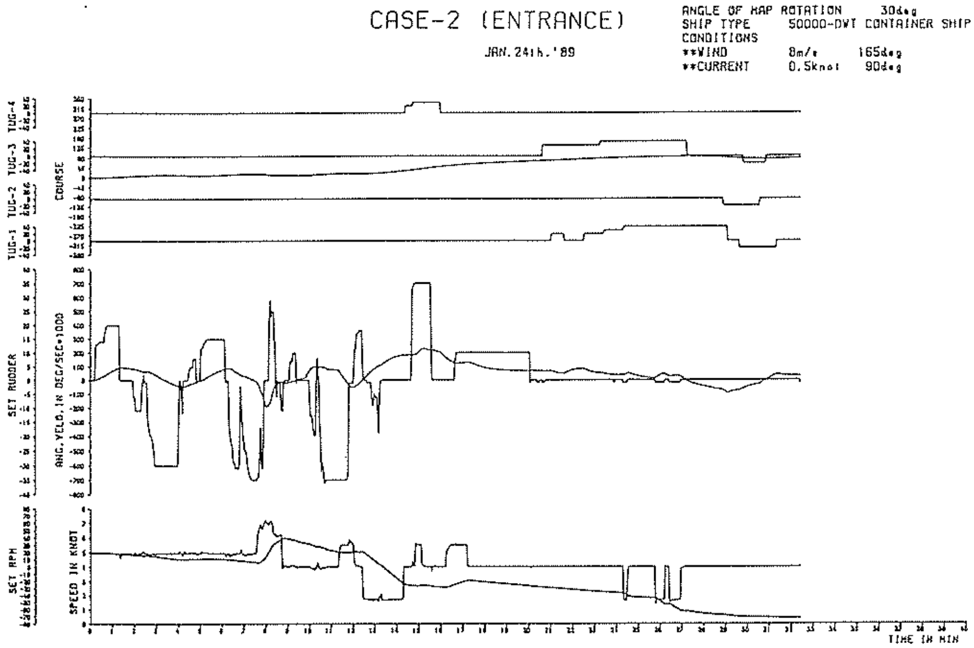


(c) Case-3 (Departure)

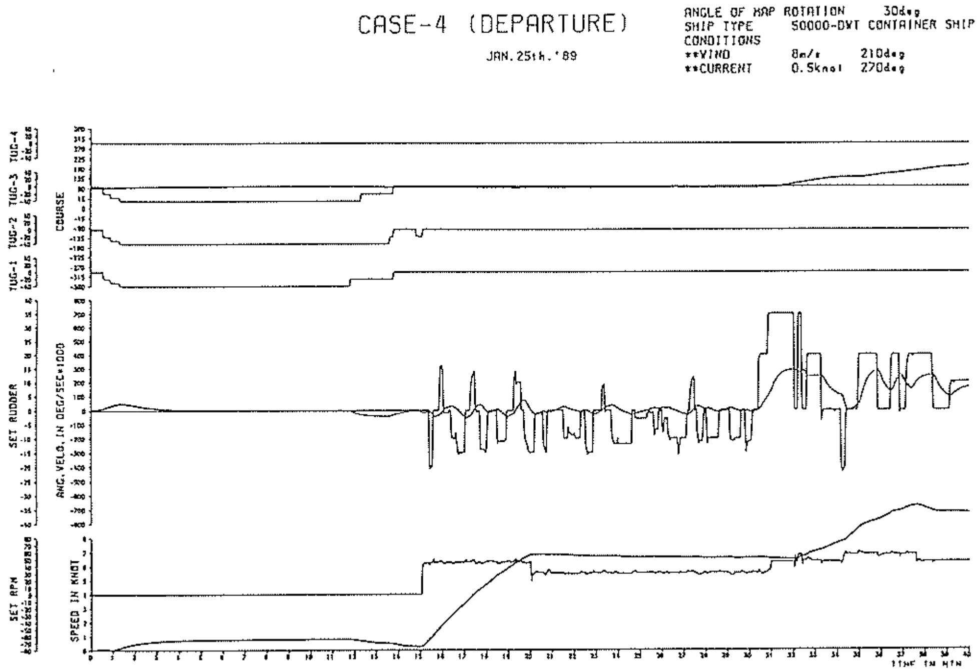


(d) Case-4 (Departure)

Fig. 13 Ship trajectories of simulation results on Port of Kawasaki



(a) Case-2 (Entrance)



(b) Case-4 (Departure)

Fig. 14 Ship handling records and time histories of ship motions on Port of Kawasaki and 40 figures and 20 time history tables of ship maneuvering were output. Though the number of experiments was not big, authors tried to pick up some characteristics by comparing and analyzing only these figures and tables. Because of above reasons, general results were not obtained but some particular characteristics were found. There were two types of ship maneuvering. One group was headed by captains who maintained the initial speed until passing through the breakwater and then quickly reduced their speed to perform berthing. Another group of captains commerced speed reduction at an earlier time. Against external forces which became relatively large given the slow ship speed, captains frequently used may tugboats at an early stage and also used them for big turning course. One captain reduced his ship's speed by using a rudder in the maximum position (35 degrees). Comparing 1st time and 2nd time trajectories, there was little difference among them. Perhaps, during 2nd time captains modified there operation considering the results of 1st time. In total for case-1 and case-2 (entrance), number of failures was 4 at 1st time experiment and 1 at 2nd time. Similarly comparing departure case, there were three failures the 1st time and one failure the 2nd time.

Total evaluations were done by holding a meeting with all concerned members. Members recommended the following:

1) Basically, traffic route and the facilities plan of waterway concerning container berths at Port Kawasaki have no problems in present plan from view point of ship maneuvering safety.

2) Considering natural conditions, when external forces were severe, ship handling would be rather difficult. Therefore Ohgishima 2nd waterway should be cut at the corner and widened toward breakwater. No. 1, No. 2 and No. 4 buoys in Ohgishima 1st waterway should be moved so that 1st waterway might be widened and expanded.

3) Concerning marine navigating aids, buoys of Ohgishima 1st waterway should be easily distinguished from the buoys of Kawasaki waterway.

4) In addition, light house should be built at the end of Ohgishima east breakwater.

5) Concerning traffic administration, Ohgishima 1st and 2nd waterways should be under control of harbor regulations law. By so doing, traffic administration could consider the contact between traffic flow of Ohgishima 1st waterway and traffic flow of Kawasaki waterway.

6) Traffic route should be taken so that container ships might enter through Ohgishima 2nd waterway and depart through 1st waterway. In case of pure car carrier, opposite route should be taken.

4.3 Case of Port of Colombo

Colombo Port handled not only domestic cargoes but also many other countries' cargoes and is expected to be a transit port. Based on the increase in cargoes, it was forecasted that more large tankers and container ships would enter.

Following problems were identified at that time for large ships; 1) The width of waterway was too narrow. 2) The length of stopping distance was not enough. 3) The water area was too small and depth of water area was not enough. Therefore pertinent plan of improvement for water area facilities was expected.

Under above background, experiments for examination of port planning were held for cases in which big ships would enter the port.

(1) Target ship

The target ships were 50,000 DWT container ship and 46,000 DWT bulk carrier. Tip carrier was alternated instead of latter type ship. Dimensions of these ships were already described in **4.1** and **4.2**.

(2) Conditions of experiments

The existing state of water area of Port Colombo was shown in **Fig. 15**. Physical width of break water was 200 m but projection width of breakwater was only 160 m. Course changing angle of main waterway outside of breakwater was 40 degrees. On the other hand, the distance between breakwater and container berth was only 750 m, therefore ship had to turn 145 degrees for berthing after passing the beakwater. And the depth of water area in front of container berth was only 10~12 m, although depth of main waterway was 13 m.

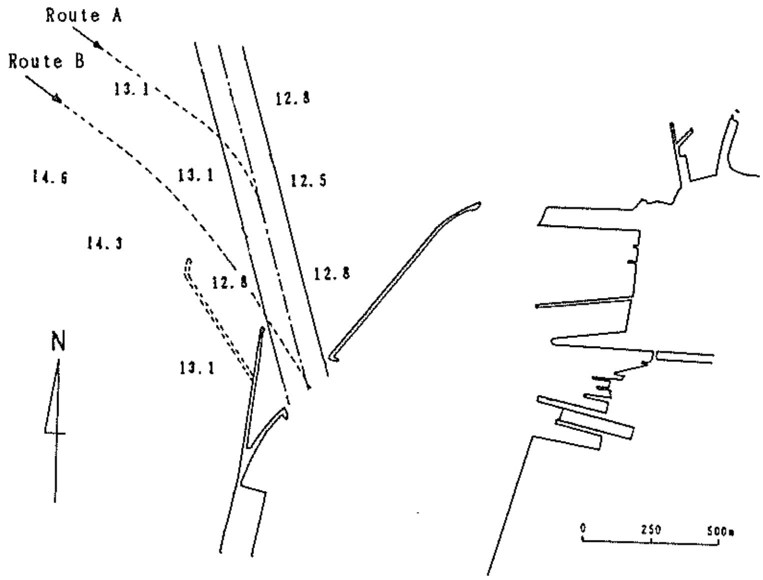


Fig. 15 Water area conditions of Port of Colombo

For these experiments, two ship entrance routes were chosen. Route A was the present course and the route B was the new course based on the plan. Route B had two improvements. The first involved the course in which changing angle in main waterway was decreased from 40 degrees to 20 degrees. The second saw the width of entrance part of breakwater widened by at least 17% by changing path angle at breakwater. According to these cases, alternative data of breakwater and waterway were set up.

As to water depth, the same data as present depth were set up.

Using meteorological observation data, following natural conditions were set up. Three wind types were 7.5 m/s from WSW, 7.5 m/s from NNE and nil. Significant wave height was 2 m from WSW or nil.

There were 11 selected cases as shown in **Table 3**.

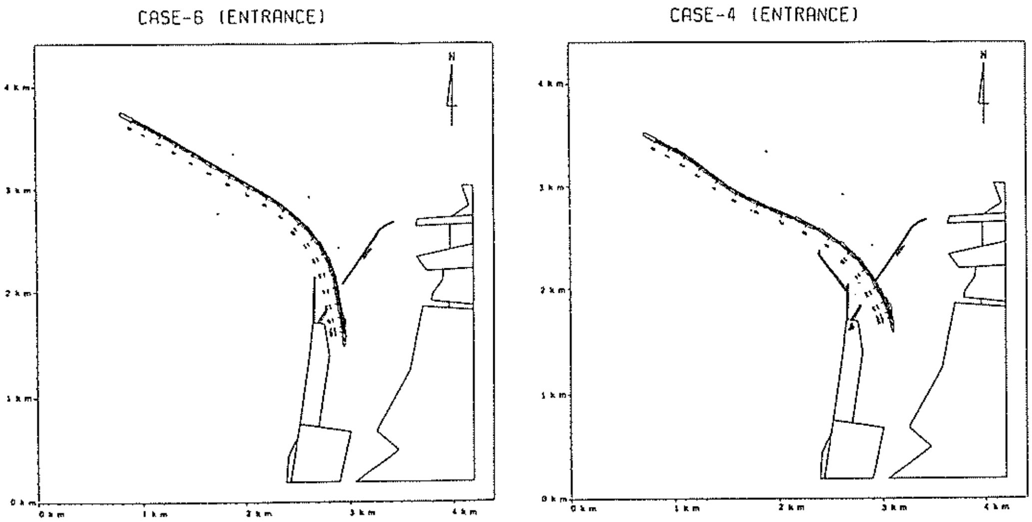
Concerning tugboats, no captain used assistance of tugboat. The reason was that usually tugboats were called only after passing breakwater, having entered the turning basin in Port Colombo. In these experiments, the examination area was from outside of breakwater to turning basin inside of breakwater.

(3) Results of experiments

Eleven experiments were carried out by four captains. Examples of map of ship trajectories and ship handling histories are shown in **Fig. 16** and **Fig. 17**. (a) is for the

Table 3 Simulation case and its conditions on Port of Colombo

no	capt.	ship type	route	wind(m/s)	wave(WSW)
1	A	container	A	WSW, 7.5	NIL
2	B	container	A	NNE, 7.5	NIL
3	C	container	A	NIL	NIL
4	A	container	A	WSW, 7.5	H1/3=2
5	B	container	A	WSW, 7.5	H1/3=2
6	C	container	B	NIL	NIL
7	D	container	B	NNE, 7.5	NIL
8	A	container	B	WSW, 7.5	NIL
9	D	tip carri	B	NIL	H1/3=2
10	C	container	A	WSW, 7.5	H1/3=2
11	A	tip carri	A	WSW, 7.5	H1/3=2



(a) present condition (b) on condition of plan

Fig. 16 Examples of ship trajectory of simulation results on Port of Colombo

case of present condition and (b) is for the planned case.

Finally using both impressions of ship handling and results of these experimental records, following conclusions were obtained.

1) General

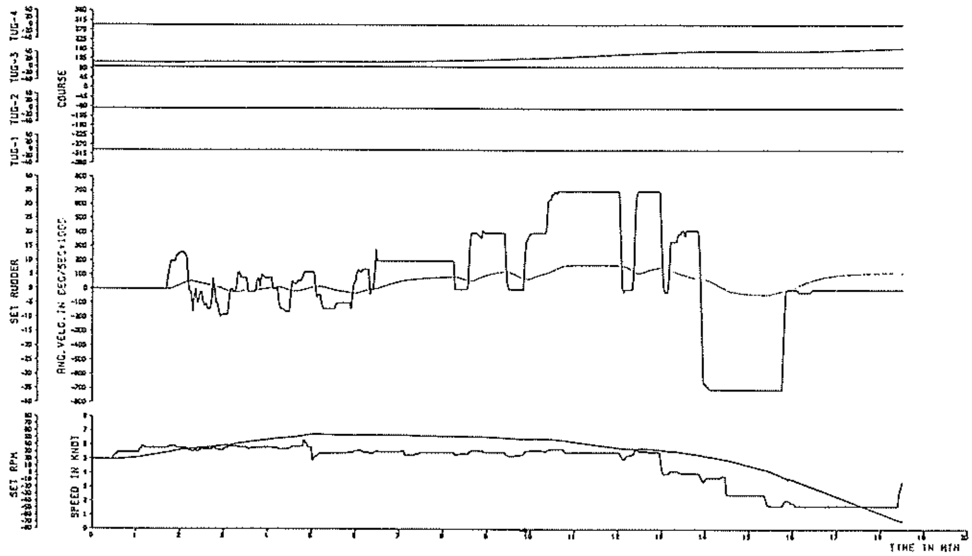
Why the rudder effect became poor and ship control became difficult because the clearance between keel and seabed was too small and because of the effect of relatively strong external forces while keeping slow speed.

The stopping distance was from 1 to 2 times length of ship in container case and from 3 to 3.5 times length of ship in tip carrier case. (L means one length of ship. In following descriptions, L is used.)

2) Results of present state conditions

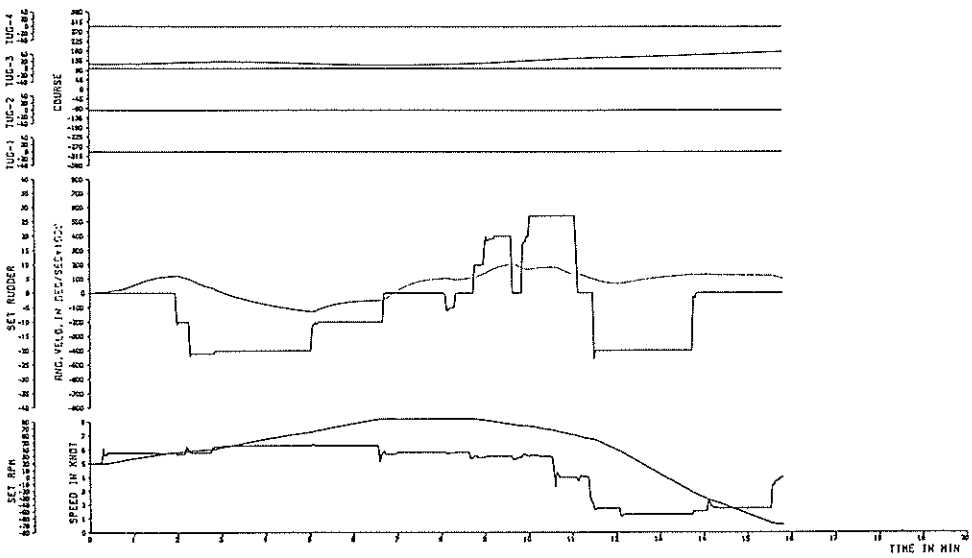
If external force was only 7.5 m/s wind from NNE, then the influence was small and there was no problem for ship handling. When wind of 7.5 m/s blew from WSW di-

CASE-6 (ENTRANCE)



(a) present condition

CASE-4 (ENTRANCE)



(b) on condition of plan

Fig. 17 Ship handling records of experiment on Port of Colombo rection and wave of 2 m height entered from WSW direction simultaneously, course keeping was difficult for ship maneuvering. This fact would lead to the conclusion that it would be dangerous for a container ship of 280 m in length to enter the port under such natural conditions without tugboat.

3) Comments on new entry route and facility plan

The extreme point of the new beeakwater was an obstacle for ship navigation. When ship dodged this point,she came to northeast breakwater. As an alternative route, she tried to enter the straight part of waterway at the position 1L to 2L from this side of the new breakwater at an early stage, but was unsuccessful.

In conclusion, if container ship of 50,000 DWT is supposed to enter the Port Colombo in future, following conditions should be satisfied and planned as port improvement plan from the standpoint of safe ship navigation.

It should be a straight waterway with length of about 2,000 m from ship start point to entrance part of the port.

The extreme point of the northeast breakwater should be cut so that the entrance part of port might be widened. (Exact size of width of entrance part requires examination by considering conditions of degree of sheltering.)

5. Study Using Imaginary Special Port

In the previous chapter, it was described how the authors carried out evaluatious for three case studies by using ship maneuvering simulator system. Through the case studies, much information was obtained such as requireded cost or term, accuracy of pass or ship handling quantity, conditions and evaluating method of results of experiments. These results were accepted by not only planning section of charged but also all related maritime sections.

On the other hand,there might be another application to direct designing of facilities using ship maneuvering simulator. However, it is required to clear many unknown factors contained in simulation experiments in this application. For instance, maneuvering characteristics of handlers, accuracy of ship motion model, state of environmental conditions concerning navigation and relations between running conditions and natural conditions might be some of the important and unknown factors.

Among unknown factors, following three items were identified and experiments for obtaining rough estimates of their effects were carried out.

1) Differences of maneuverability between typical ship types
2) Ship motions in basic (elemental) ship handling
3) Characteristics of ship handler

5.1 Elemental ship handling

(1) Conditions for experiments

It is said that the procedure of ship handling is divided into two parts when a big ship arrives at a port and enters. The first is called approach maneuver and second is berthing[12]. Kose and others analyzed data involving 95 cases of maneuvering plan data for ship entrance at typical ports in the Inland Sea of Japan, and concluded that most ship handling at port entrance could be summarized into four basic procedures: course keeping, course changing, turning and lateral movement[13]. Based on these, five elementary ship handling techniques were chosen: course keeping, course changing, reducing speed, reducing speed and course changing and turning short round. Each ship handling scenario for experiment is as follows;

1) Course keeping

A ship goes straight to inside of waterway bounded by buoys without tugboats. The ship speed is set to 6 knots.

2) Course changing

Conditions are almost same as above except that waterway has bending part of 30 degrees.

3) Reducing speed

A ship reduces her speed from 6 knots to 2 knots while keeping straight course by main engine astern. Tugboats are available.

4) Reducing speed and course changing

Along bent waterway, a ship changes its course 90 degrees from original course and reduces speed to 2 knots at designated final position. It was permitted to change main engine astern when necessary. Tugboats are available.

5) Turning short round

A ship leaves from a berth using tugboats and turns 180 degrees. After that she starts to move outside the port through waterway. Ship handler could choose any turning direction.

The general conditions of water area are such that the width of the waterway is equal to one ship length of the target ship. In case of 90 degrees course changing, waterway was widened so that radius of curvature made by center line of waterway might be 4L. The turning basin was given as a regular square with a side of 2L length of target ship. The distance between buoys was 1,000 m in principle. The water depth was set up 1.4 times of draught outside of breakwater and 1.2 times within breakwater.

As for natural conditions, the most difficult direction was chosen. In course changing, the direction in which influences were largest after changing course was selected. Bulk carriers were permitted to use tugboats of 3,000 HP while other ships could use tugboats of 4,000 HP. In **Fig. 18**, conditions of water areas are shown and in **Table 4**, natural conditions are described for each ship type and elementary ship handling.

(2) Results of experiment

Four captains were asked to handle the equipment. Each captain carried out fifteen cases (three ship types multiplied by five kinds of ship handling cases); total number of experiments was sixty. Example of ship trajectory is shown in **Fig. 19**.

Analyzing these figures and arranging captains' impressions and comments, the general impressions of each elementary ship handling are as follows;

1) Course keeping

Some captains estimated that in the most difficult case, ship maneuvering seemed impossible because of danger under given conditions. Actually according to experimental record, the canceler rudder angle against external forces was over 20 degrees and the

Table 4 Natural conditions for 5 maneuver cases by ship type

kind of ship operation	wind		wave		current		depth
	m/s	deg	m	deg	knt	deg	H/d
course keeping	15	120	1.5	270	0.5	270	1.4
course changing	15	270	1.5	120	0.5	120	1.4
speed down	15	120	1.0	270	-	-	1.2
course change & speed down	15	330	1.0	180	-	-	1.2
turning short round	10	270	1.0	270	-	-	1.2

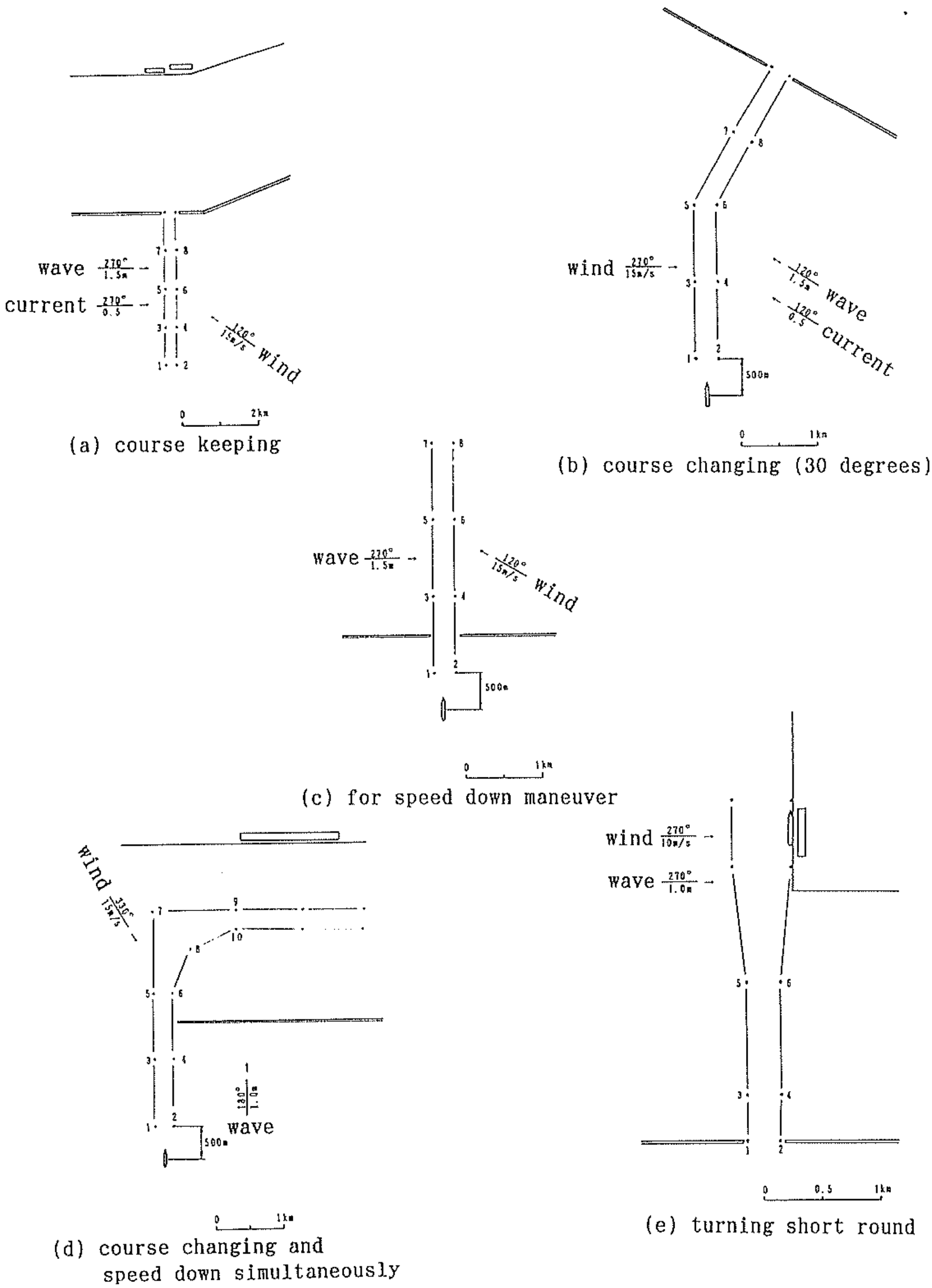
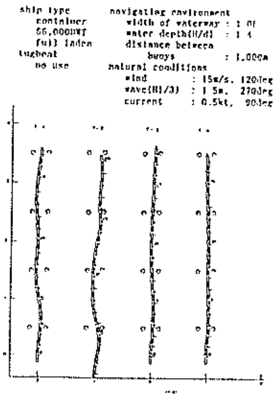
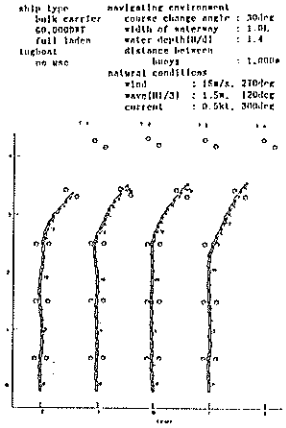


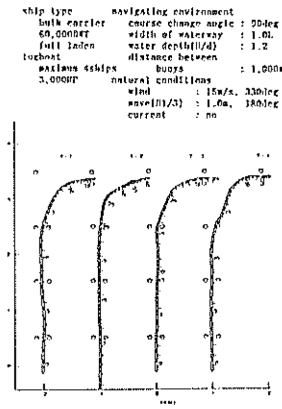
Fig. 18 Water area conditions



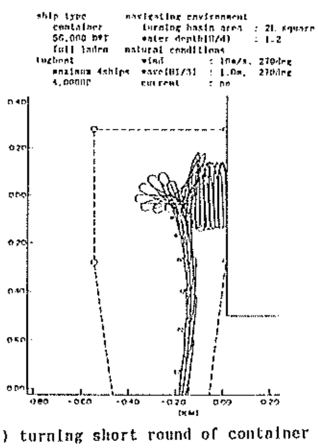
(a) course keeping of container ship
by four captains



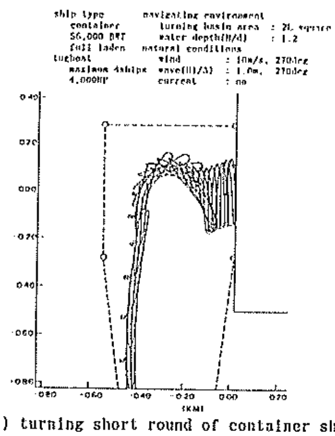
(b) course changing of bulk carrier
by four captains



(c) course changing and speed down of bulk carrier
by four captains



(d) turning short round of container ship
to right direction rotation



(e) turning short round of container ship
to left direction rotation

Fig. 19 Ship trajectories of simulation results time share rate was 19% when maximum rudder angle (35 degrees) was taken during whole execution time in case of PCC (pure car carrier). It was easier to maneuver container ship than PCC. In this case, limitation of ship speed was higher from 6 knots to 7 knots and traffic control was held to the minimum necessary condition. About bulk carriers, three out of four captains evaluated that it was possible to maneuver safely under given conditions.

2) Course changing

This maneuver comprised a 30 degree course change at the position of 2,000 m offing from breakwater. It is said that course changing is hard because external force and its direction would change with ship motions and if large rudder angle was taken, effect of rudder would be dull from speed reduction and ship would drift in a lateral direction. In case of PCC, three out of four captains failed to navigate within boundary of waterway. Therefore, three captains were able to navigate safely in the container case. For the case of bulk carrier, there were not any problems for safe navigation and all captains successfully passed through inside of waterway.

3) Reducing speed

In this ship maneuvering scenario, after passing breakwater, ship reduces its speed at position of buoy No. 5~6, finally reaching a speed of 2 knots at buoy No. 7~8. Ordinarily, ships reduce their speed to 2 knots for berthing, anchoring or turning short round. In this water area, usually widening or area expansion were done. If ship was handled, three type of ships could successfully decelerate under condition of using tugboats.

4) Reducing speed and course changing

Typical examples of this kind of ship maneuver in Japan are in case of berthing to Tohyoh Wharf at Kawasaki Port and Honmoku Wharf's D pier of Yokohama Port[14]. It was said that tugboats were absolutely necessary when making widen turns under both conditions of low speed and strong external forces.

Time rates of maximum rudder position (35 degrees) were respectively 36.4%, 51.0% and 27.4% for each ship type but there were no clear differences among ship handlers' impression.

5) Turning short round

It was supposed by manual calculation that container ship would not be able to leave the berth safely under condition of wind of 15 m/s because of the strong influence of it blowing from lateral direction even if four tugboats would assist. Therefore wind velocity was set up to 10 m/s in this case for all three type of ship. As a result, four captains were able to negotiate their turning rather easily. There were no comments such that maneuvering was dangerous or water area was narrow in condition of 2L square area as a turning basin.

Ship handlers' comments concerning layout of water area were: even in case of 30 degrees bending part of waterway, corner cutting or widening should be done for PCC navigation; in case of reducing speed and course changing, layout of this ship maneuver should be divided into two areas, turning area and reducing speed area; Width of water area from turning basin to buoy No. 5 and No. 6 should be maintained at more than 2L.

Figure 19 shows each ship handlers' trajectories lined up in one figure. There might be some differences among each ship handler but it was impossible to discern characteristics of ship handling or individual characteristics.

As to the difference in ship maneuvering among ship types, other than **Table 5**, no quantitative evaluations or results were obtained from want of numbers of experiments. In **Table 5**, time rate of maximum rudder angle (35 degrees) suggests these might be difficult if other indices were same.

Table 5 Some indices of handling and ship motions by elemental maneuver

course keeping		PCC	CONTAINER	BULK
average rudder angle	(deg)	-21.7	-16.3	-1.3
S.D. of rudder angle	(deg)	22.6	18.8	7.2
time rate of hard rudder	(%)	19.1	13.5	0.0
interval time of rudder changing	(sec)	37.0	42.0	29.0
lee way	(deg)	-1.8	-2.9	-4.6
maximum lateral displacement from center of waterway	(m)	68.6	71.4	52.4
course changing		**PCC**	**CONTAINER**	**BULK**
average rudder angle	(deg)	22.1	23.2	5.1
S.D. of rudder angle	(deg)	24.8	26.4	17.0
time rate of hard rudder	(%)	28.3	37.0	6.4
course changing & speed down		**PCC**	**CONTAINER**	**BULK**
time rate of hard rudder	(%)	36.4	51.0	27.4
maximum used number of tugboat		2.5	3.3	2.3
average used thrust of tugboat	(ton)	48.0	63.4	29.1
turning short round		**PCC**	**CONTAINER**	**BULK**
time rate of hard rudder	(%)	26.7	30.6	23.7
maximum used number of tugboat		2.0	2.0	2.0
average used thrust of tugboat	(ton)	82.7	122.7	88.8

5.2 Curved Waterway

Based on experiments concerning elemental ship maneuvering, the waterway with changing course should be well considered compared with other water areas. Bent part of waterway required widening for large ships especially PCC type ship in severe condition.

In this section, other experiments carried out to analyze and clear details in bent part of waterway are described.

(1) Target ships

Two different types of ships were selected for these experiments, PCC and bulk carrier. The former ship is easily influenced by wind forces and latter ship has dullness in ship motion.

(2) Environmental conditions and natural conditions

The bent part of waterway is the main point of this experiment relating to limited speed or tugboats condition. In this experiment, the target bent part of water area was set up inside the breakwater. The cross angles of waterway were chosen to be both 30 degrees and 60 degrees. In both cases, tugboats were not prepared. The reason for not using tugboats was that the distance from bent part to berth was long enough and ship did not need to reduce its speed quickly, therefore ship maneuverability would remain good. The navigation area was set up so that the width of waterway may be 1L and interval distance of buoys be 1,000 m. Corner cutting was done so that radius of curvature may be 4L in case of 60 degrees of bent waterway. Water depth was set up to 1.2 times of draft outside of breakwater and 1.1 times otherwise. The environmental conditions are shown in **Fig. 20**.

Wind blowing from 240 degrees with velocity of 15 meters per second was set up. Both velocity and direction were set as time varying wind referencing observation data. Current of 0.5 knots drifting to west direction was set up outside of breakwater. As for wave (significant wave), height and direction were set up to 1.5m and 240 degrees outside of breakwater, and 1.0 m and 180 degrees within breakwater. Concerning wind direction, influence was most severe for navigating ship before passing turning point. After changing course, the influence of wind remained partially in case of 30 degrees, and little in case of 60 degrees of course changing. There were some differences between wind conditions of chapter 5.1 and this condition in spite of the same 30 degrees course changing.

(3) Ship maneuvering plan before experiments

It is said that usually ship handlers investigate and study ship maneuvering characteristics, water area, facilities condition and weather conditions, then make course and procedure plan for ship entrance and berthing. In these experiments, following items were noted for establishing port entry plan.

1) There was no other navigating ship, and overall width of 1L was available area for navigation.

2) Shallow effects would strongly appear inside the breakwater.

3) In case of PCC navigation, engine boosting maneuver would be needed and space angle of rudder would be small.

4) Ship handler would grasp the lateral force and momentary force affected by external forces during pre-running time of navigation. Ship handler should take care that external forces would change according to ship position and ship head direction.

(4) Results

Ten captains carried out navigational experiments and each captain carried out four cases in random order of four cases. Each case was numbered from 1~4. Case-1 and case-2 are for bulk carrier tests and case-3 and case-4 are for PCC. Odd numbered cases are cases of course changing of 30 degrees and even numbered cases correspond to course changing of 60 degrees.

At first, ship handlers classified ship trajectories into 5 groups as follows;

A : ship navigated close to center of waterway corresponding to navigating plan

B : ship leaned to one side of waterway, but was within normal range

C : ship navigated a little beyond boundary of waterway

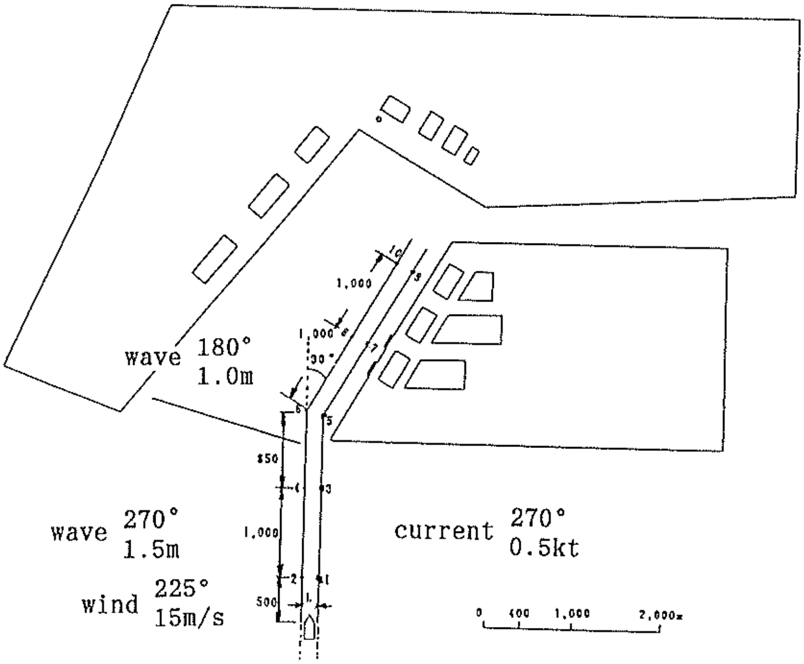
D : ship touched buoy or boundary of waterway

E : ship deviated far from waterway and failed test of safe navigation

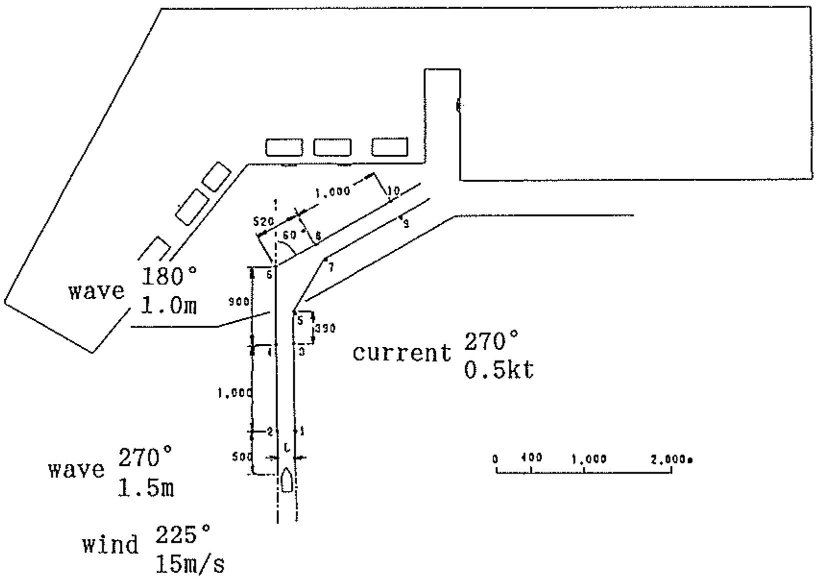
Share rates of rank A, B and C were respectively 80%, 70%, 50% and 40% from case-1 to case-4. This number shows that difficulty of maneuver of PCC is 1.7 times in comparison with bulk carrier, and turning 60 degrees is 1.2 times in comparison with 30 degrees.

Ship handlers estimated the trajectories and commented. In case of PCC, even course keeping would be impossible, regardless of the width of waterway under severe natural conditions. Straight course maneuver of bulk carrier would be no problem if width was 1L, and one way traffic was kept. At vent part of waterway with width of 1L, widening by corner cutting or by other way should be done.

Under given navigating and natural conditions, authors tried to calculate how much the waterway should be widened using above trajectories.



(a) 30 degrees course changing



(b) 60 degrees course changing

Fig. 20 Water area condition for course changing

1) The boundary of waterway was adjusted on the trajectory map so that all passes may be within the rank A or B or C. Accordingly, the width of vent part of waterway were respectively 1.3L, 1.5L, 2.3L and 1.8L from case-1 to case-4. In case-4, one experiment was excluded because the trajectory traced far off course.

2) In vent part and straight part of waterway, maximum absolute values of displacement from center were identified. In cross section of 60 degrees bent of waterway, the arc with 4L of curvature diameter was regarded as center. Mean value and standard deviation of maximum displacement were calculated for each case. And if the variable of maximum displacement of trajectory depended on a normal distribution, then width of waterway with 97.7% probability would be respectively 1.3L, 1.7L, 2.8L and 3.7L for each case. For reference, those values were 1.2L (bulk carrier) and 1.8L (PCC) in straight part of waterway.

In case of 60 degrees vent curve, corner is cut. When waterway's width of straight part is 1L, expanded width by corner cut corresponds to 2.2L.

Upper values are adopted for few rough trial examples, but many more simulation tests should be made to obtain meaningful values.

Furthermore, in both **5.1.2** and these experiments, the positions of maximum displacement were far away from cross section point. Some captains suggested that vent part should be expanded until the position where ship motion became stable. It was also suggested that widening areas, not only inside part but also both side of corner, should be considered. In part of curvature, smooth lined expansion should be taken as far as possible so that ship maneuvering may be easy because ship motions are affected by unsymmetrical hydraulic forces according to head direction changing[15].

6. Fast Time Simulation

It takes a long time to carry out ship maneuvering experiments because ship maneuvering simulator is a real time simulation system. In chapter five, authors carefully selected cases concerning navigational conditions for experiment, yet, number of experiments was not enough to obtain quantitative evaluations.

If simulator was used as fast time simulator system without human handling, many cases would be done in a very short term. This would make macro evaluation and would lead to clear critical point for facility's plan of water area before real time simulation. In real time simulation, some pointed out cases would be taken. Actually, the first time simulation was done by outside facility of PHRI as preliminary experiment, and real time simulation was done in PHRI concerning port and harbor planning of MAP TA PHUT in Thailand at 1985.

As another application, there are some fields of studies such as standard maneuver, design of maneuver, berthing maneuver[7] and standardization of maneuverability[16]. Application to real time design in port entry situation is proposed by using on-board fast time simulator[17]. Study of limits in course keeping under strong wind is also presented[18].

Here, relations between turning maneuverability and engine revolution changing, and relations between turning characteristics and some natural conditions are investigated for container ship (50,000 DWT class), PCC (50,000 GT class) and bulk carrier (50,000 DWT class).

6.1 Typical Ship Motion

Turning maneuverability and acceleration or deceleration characteristics would be important information for ship handling.

When sailing ship takes its rudder to starboard (right angle), ship motion and trajectory would be as **Fig. 21**[2]. As the results of turning test, the final diameters at a helm of 35 degrees for three ship types were respectively 3.1L, 2.8L and 2.0L. When helm was at 5 degrees, diameters were 13.3L, 12.3L and 5.9L. These results seem to suggest that a bulk carrier has better turning ability in comparison with container ship or PCC, but many captains have opposite impressions. It might be related to threshold rudder angle (hysteresis characteristics of rudder effect) or ability of short time engine boosting for rudder effect. Final diameter kept almost the same values for even changing engine revolution from dead slow to standby full. Its variations were within 5%.

Turning tests on changing speed are shown in **Table 6**. In case of acceleration, tactical diameter and max advance decrease from 80%~67% in comparison with the same constant speed condition. When engine revolution was changed from slow to stop, max advance increases by 1.9 times in case of container ship or PCC and 1.5 times in case of bulk carrier ship.

Stopping characteristics of ships were as follows. If ships with initial speed of 6 knots stopped their engines, they would advance from 14L~23L of distance according to ship type until ships' speed reduced to 2 knots. And if decreasing way of speed was taken by engine position of dead slow astern, then the distance would be respectively 2.6L, 4.9L and 5.2L for the three types of ship. However, final ship' head direction of container ship and PCC were 70 degrees and 41 degrees respectively, with lateral displacement from 1L to 2L. This means that stopping maneuver by engine astern would be difficult without tugboats assistance in case of unstable ship.

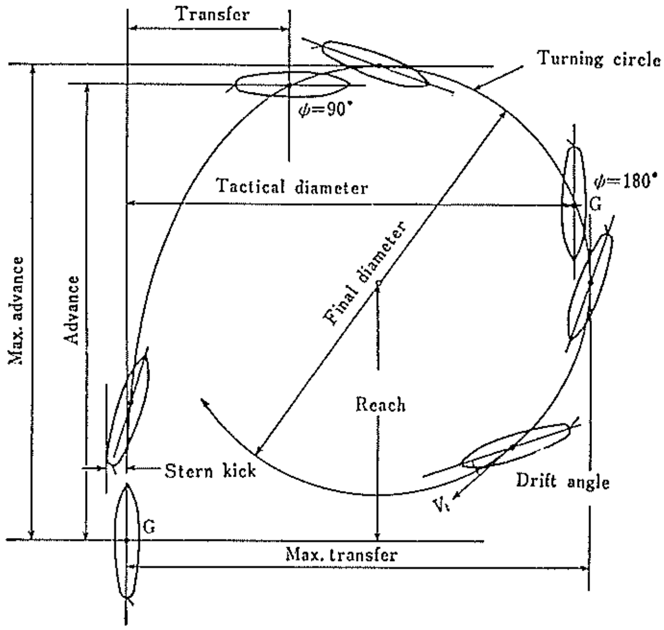


Fig. 21 Turning trajectory and its declarations

Table 6 Max advance and Max transfer on changing speed
(unit : Length of Over All)

ship type	item	slow stop	slow d.slow	slow slow	d.slow full
container	max-advance	6.2	4.2	3.3	2.3
	max-transfer	8.7	4.4	3.9	3.1
PCC	max-advance	6.2	4.0	3.2	2.1
	max-transfer	8.8	4.5	3.7	2.9
BULK	max-advance	4.3	3.2	2.9	2.1
	max-transfer	4.6	3.3	3.0	2.4

6.2 Influences of External Forces

Here, turning tests were carried out under conditions of shallow effect and wind force.

As to shallow effect, when engine position was slow and ratio of water depth by draught was 1.2, max advance and tactical diameter increased to 1.1 times in case of only bulk carrier, unexpectedly. Further experiments on this point might be necessary.

The simulation tests of turning were done with condition of 6 knots as initial speed and wind of 15 m/s. Results are shown in **Fig. 22** and **Table 7**. Maximum change rate of tactical diameter was 15% increase in case of PCC and 11% in bulk carrier. Maximum advance increased 7% in both ship type.

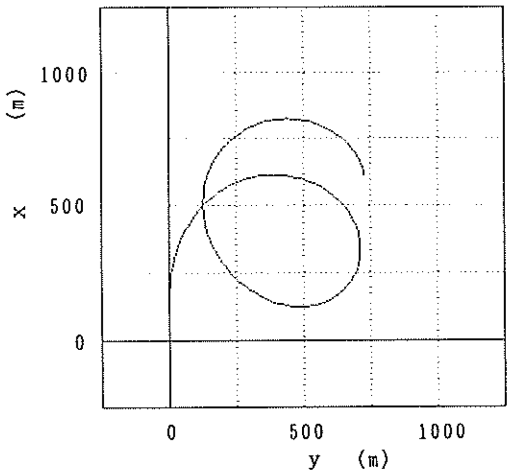


Fig. 22 An example of ship trajectory under strong wind condition (ship type is PCC, engine position is slow, rudder angle is 35 degrees, wind velocity is 15m/s and wind direction is from south)

Table 7 Turning characteristics of low speed ship under strong wind (15 m/s)

(LOA : Length of Over All)
(cargo : ballast condition)

	wind direction	max-advance (LOA)	max-transfer (LOA)	rate of (%)	changing (%)
PCC	NIL	2.9	3.4	-	-
	N	2.7	3.6	7	6
	NE	2.9	2.9	0	15
	E	3.1	2.9	7	15
	SE	3.1	3.3	7	3
	S	3.1	3.6	7	6
BULK	NIL	2.7	2.8	-	-
	N	2.7	2.8	0	0
	NE	2.7	2.6	0	7
	E	2.9	2.5	7	11
	SE	2.8	2.7	4	4
	S	2.8	2.9	4	4

7. Conclusions

In applying ship maneuvering simulator for planning or designing of port and facilities, many kinds of investigation and studying were carried out and many things were cleared. For instance, utility and service condition of facilities, employment of marine traffic condition, architecture of ship building and safe navigation and ergonomics or psychology might be related to the experiments and their evaluations. Each factor should be not only cleared individually but also be grasped as a component of the system.

In this paper, about matters of synthetic studies are not discussed. Three case studies of application of ship handling simulator are reported, and some experiments for elementary ship handling in simple water area conditions as subsystem. Major results obtained by experiments are as follows;

1) Experimental procedure was cleared applying ship maneuvering simulator (It is a man and machine system.) for examinations of port and harbor planning. Particularly, when examination theme was clear and conditions were limited to small number, adequate conclusions would be obtained by carrying out scores of cases of experiments using ship maneuvering simulator.

2) To obtain general designing conditions for water area facilities, further studies and investigations were needed because of the many unknown factors contained in simulator system.

3) Motion characteristics are remarkably different among ship type under severe natural conditions. Therefore water area should be sufficiently widened for safe navigation, or inhibited conditions of ship entrance might be changed to accommodate large ships (50,000 DWT class) that strongly affected by natural conditions.

4) Ship maneuvering to some extent depends on human choice. Therefore, evaluation of safety of navigation might be sometimes different among ship handlers in the same navigating conditions.

5) In straight waterway, 1L width might be sufficient for safe navigation under con-

dition of one way traffic, 6~6.5 knots speed and no other crossing ship even in severe natural conditions.

6) In bent part of waterway with width of 1L, safe maneuvering is rather difficult for large ships where cross section angle was even 30 degrees when external forces were very strong. Especially for PCC, ship handler should have many experiences in maneuvering this type of ship and widening of bent part is eagerly expected.

7) In situations involving by turning angle like 90 degrees, layout of water area should be designed to be large enough or water area should be divided so that elemental ship maneuver may be possible.

8) For PCC and container ship of 50,000 DWT class, the turning area of 2L diameter would not be a problem if enough tugboats were available.

As to further studies and applications, it is expected that comprehensive examinations will be made of port shape and layout related to limited conditions of cargo handling affected by long-period wave and safe ship entrance. It also might be expected that a study to increase the navigational safety of dangerous cargo ships such as liquid natural gas carriers or crude oil tankers under actual natural conditions will carried out. Moreover, for the appearance of ultra high speed ships, it might be applied to study new port layout, maximum speed in port and examination of full time opened ports.

Acknowledgement

This research was carried out with the cooperation of many relational organizations. Naikai Licensed Pilots Association, Tokyo Bay Licensed Pilot Association, Yokosuka Licensed Pilots Association participated in each simulation experiment. Planning of alternative facilities and analysis of experimental results were executed with the aids of The Japan Association for Preventing Marine Accidents, Coastal Development Institute of Technology, and The Overseas Coastal Development Institute of Japan.

Authors express our sincere thanks to them.

(Received on August 31, 1992)

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