An Examination of the Safety of #2 Berth of the 'HPC' Pier using Port Design Simulator

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항만 설계 시뮬레이터를 이용한 대산항 HPC 부두의 안전성 조사

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요약문

본논문은 대산항의 HPC 제2번 부두의 안전성을 조사하기 위한 것이다. 항만설계목적으로 개발된 항만 설계 시뮬레이터(Port Design Simulator)를 이용하여, HPC 제2번 부두에서 10,000 DWT 엘엔지(LNG) 탱커가 이안할 때의 안전성을, 조종상 어려움이 많고 위험한 입선자세에서 이안하는 시뮬레이션을 거쳐 평가하였다. 환경 조건으로서는 창조류인 북동 3노트의 조류와 탁월풍인 북동풍 30노트의 바람을 사용하였다. 3,600 마력이 넘는 2척의 예선을 이용하여 이안하였다.

본 시뮬레이션의 분석 결과 HPC 부두의 수역은 10,000 DWT 엘엔지 탱커가 이안하기에 좁고 안전하지 못한 것으로 판명되었다.

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1. Introduction

The purpose of this study is to investigate the safety of the HPC(Hyundai Petrochemical Company) pier at the Port of Daesan by simulation. The safety of the HPC pier is examined through the unberthing simulation of a 10,000 DWT vessel from the 'bow-in' posture, using the port design simulator, which was developed for port design purpose.

For this purpose we appreciate the safety of the berth in view point of berthing and unberthing, under the worst conditions of environment such as weather, sea state and current, and the vessel's pose, as is generally applied in the design of port and waterway. Therefore, the following conditions were applied in this case:

① As the environmental conditions the wind is assumed to blow at 30 *kts* port-athwart, ie. northwesterly, and the flood tidal current to flow at 3 *kts* northeasterly.

② Under the above conditions the berthing operations in 'bow out' are more difficult than those in 'bow in' and the unberthing operations in 'bow in' are harder than those in 'bow out'.
On the other hand the berthing operations in 'bow out' are more difficult than the unberthing operations in 'bow in'. In addition, where there are any restrictions in the unberthing operations, there will be more restrictions in the berthing operations. Therefore in this investigation the unberthing operations in 'bow in' are examined instead of the berthing operations in 'bow out'.

③ When the unberthing operations are carried out, it is assumed that there is no wave effect and the tugs use their engines as soon as the order is given.

④ The initial stern direction of the experimental vessel is considered to be 243°.

2. Experimental methodology and Method of Evaluation

The simulation consists of the data base development of the topography, the fairway, the artificial structure, the current, the wind and so on, the development of dynamic characteristics of a model ship, the conning of the model ship, and the analysis of the results of conning. In this section the simulation experiment and the method of evaluation will be described.

2.1 Experimental methodology

2.1.1 The process of shiphandling simulation

The simulation in this investigation is aimed at appreciating the safety of unberthing operation of a 10,000 DWT tanker, and is composed of the repetitive manoeuvres by many shipmasters under the special environment using a port design simulator, the analysis and the appreciation of the run results.

When a shipmaster cons the model ship according to the scenario, a deck officer and a quartermaster are arranged to help him as is in a real ship, in order to make the simulation as real as possible.

The simulation was carried out as the following sequence.

1) The development of database

Databases for the simulation consist of 4 databases of image database, radar database, depth database and current database. These databases were constructed based on the navigational charts, current charts, estimation of the current changes of the Environmental Effect Evaluation Report, photographs of the HPC pier.

(1) Image database

Image database was constructed in such a way that the whole view of the HPC pier is visible. Piers, nearby mountains and buildings were represented together with the buoys in front of the pier. Photographs were taken at the pier in order to represent the view at the scene as really as possible.

(2) Radar database

Radar database was constructed on the basis of the image database. Shade effect, fading effect, blind area effect were implemented in order to produce the same image as the real radar.

(3) Depth database

Depth databse was constructed based on the newly published navigational chart.

(4) Current database

Current database was constructed based on the existing survey data, current chart and current data of the Korean Hydrographic Office.

2) The development of the mathematical ship model

A model ship was a 10,000 DWT LNG tanker, the specification of which is as ⟨Table 1⟩. The mathematical model of this ship was developed and installed in the simulator before simulation.

The heuristic type mathematical model was chosen for this simulation. This type of model is written directly from actual data of the ship's manoeuvring behavior, by means of simple equations, developed from first principles, rather than by using hydrodynamic derivatives to model the forces. This model has the advantage in that a best fit is obtained in terms of actual manoeuvring behavior, and a very high level of user acceptance is achieved. The validity of the model has been proved already in many studies.

⟨Table 1⟩ Specification of the Model Ship (10,000DWT)

Item	Spec.	Item	Spec.
LOA	130m	propeller type	fixed
breadth(B)	20.1m	number of shaft	1
draft(d)	8.0m	speed(full ahead)	16.5kts
Displacement	14,800Ton	acceleration time(2/3 of max. speed)	200sec
windage(lateral)	1,200㎡		
windage(front)	350㎡	deceleration time(1/3 of max. speed)	225sec
		circle diameter	360m

3) The standard model of ship's manoeuvre

The standard model of ship's manoeuvre until the ship moves upto the target point is established. It varies according to the tidal current, the wind, and the ship's unberthing posture, and is established referring to the opinion of the shipmasters or pilots who have enough experiences on board for years. In this investigation, the ship was arranged to be unberthed from the 'bow-in' posture.

4) The real-time simulation

The shiphandler cons the ship according to the modified standard model, and verifies and corrects the model again. At this time the model is modified according to the opinions of the pilots or shipmasters who attend the experimental maneuvers.

5) The establishment of safety margin

To secure solider safety in the transit of a ship, the allowance of deviation and the margin of ship's manoeuvre is determined according to the type of water area, the obstacles and so on, and is added to the standard value obtained from the theory and the experience.

6) The second real time simulation

The proximity and the controllability of the model ship are recorded. In addition shiphandler's subjective evaluation such as the mental burden, the difficulty of the manoeuvre and so on, is analyzed.

7) The evaluation

All the data collected from simulation are analyzed and evaluated statistically.

2.1.2 The determination of the standard model of the ship's maneuver

The way to examine the safety of a ship's maneuver by analyzing the simulated runs after the ship operator cons a ship under a certain environmental condition is very useful. However it takes plenty of time to draw reliable conclusion, as many simulated runs are required.

If the external forces such as the wind or the tidal current and the factors such as the position and the controllability of the ship can be indicated in the common index in appreciating the safety of ship's maneuver in the narrow channel or harbour area, they will become effective data.

In the meantime the external forces have a great influence on the method of maneuver and the method varies according to the situation or individual differences. A general model of the ship's maneuver which can be taken by an ordinary ship operator under the specific circumstance, however, was introduced. This model is made on the basis of the opinion of shipmasters or pilots who have much experience on board, and is corrected through some fast time simulations and real time simulations. This is called the standard model of the ship's maneuver.[1] This model is used frequently because it has advantages of reducing the number of the test maneuver for the statistical analysis.

2.2 The evaluation method of simulation

The method to evaluate the result of simulation consists of ship's proximity, ship's controllability, and the shiphandler's subjective evaluation. Three or two of them are appreciated according to the contents of the safety evaluation of the ship's transit.

2.2.1 Evaluation of the ship's proximity

In this investigation, the evaluation of the ship's proximity is made as follows.[2] When the ship is moving astern, the closest distance from the ship's starboard side to the line connected between buoy "C" and "D", the closest distance from the starboard side to the line connected between buoy "D" and "E", and the closest distance from the ship's starboard side to the dolphin are measured. The probability distribution of each closest distance is obtained, and the probability of ship's intrusion to the line of interest is obtained. Here, the closest distance is the nearest distance between the ship's end and the point of interest or the line of interest.

Meanwhile the probability distribution of the closest distance is assumed to be the normal distribution, using the formula(1) we can obtain the reference value ξ from the probability variable.

$$\xi = \frac{\mu}{\sigma} \quad \cdots\cdots (1)$$

Here μ is the average of the closest distances between the ship's end and the reference line, σ is the standard deviation of the closest distances between the ship's end and the reference line.

By using the formula (1), ξ is obtained. And then the probability of the intrusion to the reference line, P can be obtained by the formula (2).

$$P = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\xi} \frac{e^{-x^2}}{2} dx \quad \cdots\cdots (2)$$

According to TNO's report, in case of an LNG tanker the probability of the intrusion to the border of a channel is 0.001, and that of the intrusion to the entrance of break water or in the harbour is 0.0001.[3] This is the probability by which a ship invade into the reference point or the reference line when passing it. Because the simulation area is inside the harbour and the safe transit and berthing is of great importance in this investigation, 0.0001 was chosen as the probability of the intrusion, with which the safety is evaluated.

When the reference value with which this probability becomes 0.0001 is ξ0.0001, and the original width of the water area is cwo, the new width of the water area cw is expressed in the formula (3).

$$cw = cw_o + \sigma \xi_{0.0001} - \mu \quad \cdots\cdots (3)$$

2.2.2 Evaluation of the ship's controllability

The evaluation of the ship's controllability is the appreciation of the maneuverability of the model ship in the specific water area, and it is carried out where difficulties in the ship's maneuver are expected.[4] The items of appreciation are the variability of heading, the yaw rate, the swept-path, the rudder angle, the engine usage, ship's speed, and ship's deviation etc.. However in this investigation they are omitted because the safety of the ship's maneuver in this case can be judged by the evaluation of the ship's proximity only.

2.2.3 Shiphandler's subjective evaluation

The shiphandler is a final actor of a synthetic control system of the ship's maneuver. In the system he should acknowledge and integrate the inputs such as the topography, the navigational aids, the dynamic characteristics of the ship, the traffic environment, the environmental conditions and so on to determine the appropriate method of control. The integration is a process of response through the perception, the nerve, the mental fatigue and the will. This response is indicated in the ship's proximity to the target and the ship's controllability.

Here the process the shiphandler integrates the factors differs according to each individual. For example, the perceptibility of the ship's speed and the tidal current differs according to each individual, and the technique, strategy, and the ability to make a decision differs from each person.[5]

In appreciating the safety of ship's transit through simulation the objective appreciation factors previously mentioned are very important. But the ship is conned by a human who judges and controls it. Though it is difficult to quantify, the shiphandler's subjective evaluation should also be considered.

The main contents of this appreciation are the mental burden, the work load, and the difficulties each shiphandler feels through simulation under the influence of ship's characteristics, maneuvering model, waters and topography, navigational aids, tidal current and wind.

3. Experimental Design and Description

This section carries out the simulation to investigate the safety of the unberthing of 10,000 DWT LNG tanker from #2 berth of the 'HPC' pier. For this purpose the standard model of the ship's maneuver is established and the scenario is made.

Each of six shipmasters conned a laden 10,000 DWT LNG tanker outbound from #2 berth of the 'HPC' pier. Each shipmaster made two familiarization runs and two experimental runs. A mate and helmsman were present on the bridge for each run to assist the shipmaster and make the simulation more realistic.

3.1 Design of maneuvering scenario

1) Independent variables and scenario

The direction and maximum speed of the wind used in simulation are those of the prevailing wind in the port of Daesan in the meteorological report published by the Office of National Meteorology. The environmental conditions of the unberthing maneuver are indicated in ⟨Table 2⟩. The prevailing wind of maximum speed is northwest 30 *kts* . The northeast 3 *kts* flood current is used as the tidal current referring to the tidal chart.

⟨Table 2⟩ The environmental conditions of simulation

	Wind	Current
Direction	Northwest	Northeast
Speed	30 *kts*	3 *kts*

Six shipmasters participate in the simulation. They carry out the familiarization simulation twice and then the experimental simulation.

2) Dependent variables

In this investigation, as the understanding of the unberthing maneuver is the purpose of the simulation the proximity is appreciated as a dependent variable as is shown in ⟨Table 3⟩. Firstly the closest distance from the ship's starboard side to the line connected between buoy "C" and "D", the closest distance from her starboard side to the line connected between buoy "D" and " E", and the distance from her starboard side to the dolphin are measured and analyzed.

3.2 The standard model of maneuver for unberthing

The way how the 10,000 DWT LNG tanker is unberthing from #2 berth of the 'HPC' pier is divided into the 'bow-in' posture and the 'bow-out' posture. But in this investigation the unberthing from the 'bow-in' posture is established as the standard model of the ship's maneuver.

Because the ship is berthed on her portside as is indicated in Fig. 1, two tugs of 3,600 bhp are taken to the starboard bow and stern. By the assistance of the tugs the ship moves apart from the berth as wide as her breadth. Then she

⟨Table 3⟩ The dependent variable in case of the unberthing from the berth in accident

Dependent variable	Contents	
Ship's proximity	Closest distance from the end of ship's starboard to the line connected between buoy "C and "D" Closest distance from the end of ship's starboard to the line connected between buoy "D and "E" Closest distance from the end of ship's starboard to the dolphin	Probability of intrusion

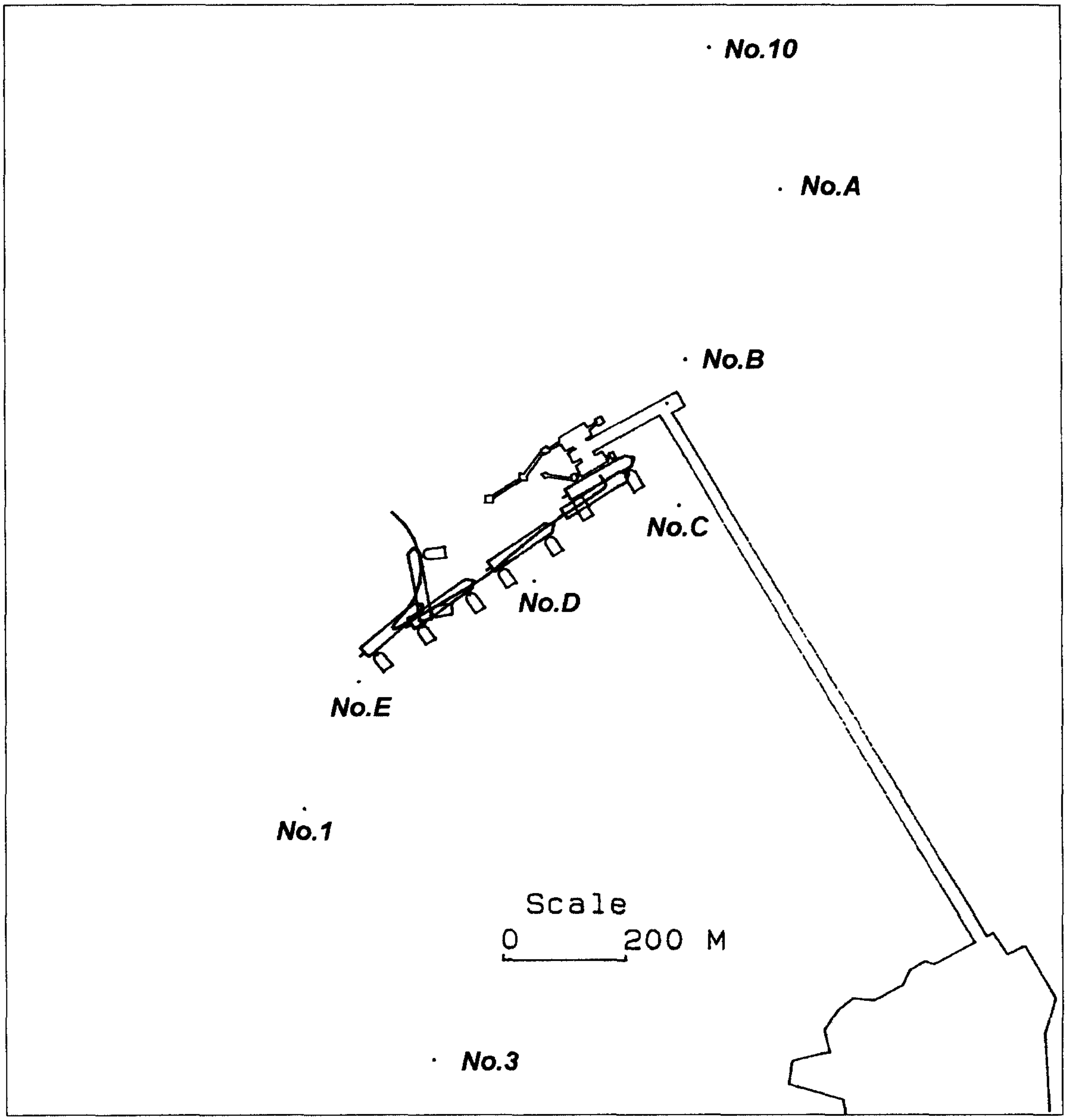

Fig. 1 Standard model of the ship's maneuver for unberthing

moves astern at a slow speed. At this time the stern tugs are ordered to pull her to the direction of 243°. The bow tug pushes her bow to the right angle in order to reduce the ship's clockwise rotation.

This operation is repeated until she approaches buoy "E". When she approaches near buoy "E", she swings to port with the 'hard port' rudder, the use of ahead engine at a slow speed, and the assistance of the two tugs. When her heading becomes 315°, she let go tugs and passes away the dolphin on her starboard.

4. Data Analysis and Results

In this section the analysis of data for this study will be described. The evaluation of the safety will be done by the ship's proximity and the subjective evaluation.

4.1 Evaluation of the ship's proximity

In case of #2 berth of the 'HPC' pier the descriptive statistics and the probability of the intrusion to the reference lines about the variables of the proximity to them are indicated respectively in ⟨Table 4⟩.

The probability of the intrusion as indicated in the closest distance of the transit ship ranges 0.0078~0.1762 in ⟨Table 4⟩. This value is much bigger than TNO's recommendation value of 0.0001. Therefore in case of the unberthing from #2 berth of the 'HPC' pier it is considered that the ship's transit in terms of the ship's proximity is unsafe under the environmental conditions of the northwest 30 *kts* wind and the northeast 3 *kts* tidal current.

This is indicated in the composite plots of Fig. 2. In Fig. 2, the width of the ships' tracks is 64m near the buoy " D", 112m near the buoy "E" , and 136m near the dolphin.

Meanwhile when the probability of the intrusion to the line connected between buoy "C" and buoy "D" is less than 0.0001, $\xi_{0.0001}$ is more than 3.72. On the basis of the value we can calculate the minimum width from the dolphin to the line connected between buoy "C" and buoy "D", ie. the width of the water area cw as follows.

$$cw = 125 + 18.84 \times 3.72 - 45.57$$
$$= 149.5(m)$$

Therefore the width of the water area of #2 berth of the 'HPC' pier should be over 149.5m, which is 24.5m bigger than the present width.

And the width from the extension line of the dolphin to the line connected between buoy "D" and buoy "E" becomes 175.1m when calculated in the same manner, which is 50.1m bigger than the present width.

⟨Table 4⟩ Descriptive statistics and probability of ship's proximity in case of unberthing from the berth in accident.

Dependent variable		Descriptive statistics	Probability of intrusion
Closest distance to line between buoy "C" and "D"	M SD	45.57 18.84	0.0078
Closest distance to line between buoy "C" and "D"	M SD	16.67 17.96	0.1762
Closest distance to dolphin	M SD	56.67 23.52	0.0080

4.2 Shiphandler's subjective evaluation

Because the width of the water area of #2 berth of the 'HPC' pier is only 125m, ship's maneuverability is restricted severely and therefore, two tugs were taken to assist her maneuver. When the ship moved astern the bow turned to the right. Then the bow tug pushed her and then it came to turn to the left. Due to the use of her engine ahead and astern and the assistance of the tugs, she could not keep her course steady and the bow was yawing. At that time the stern tug was ordered to pull her and she was able to keep her course with difficulty. And due to the influence of tidal current, her

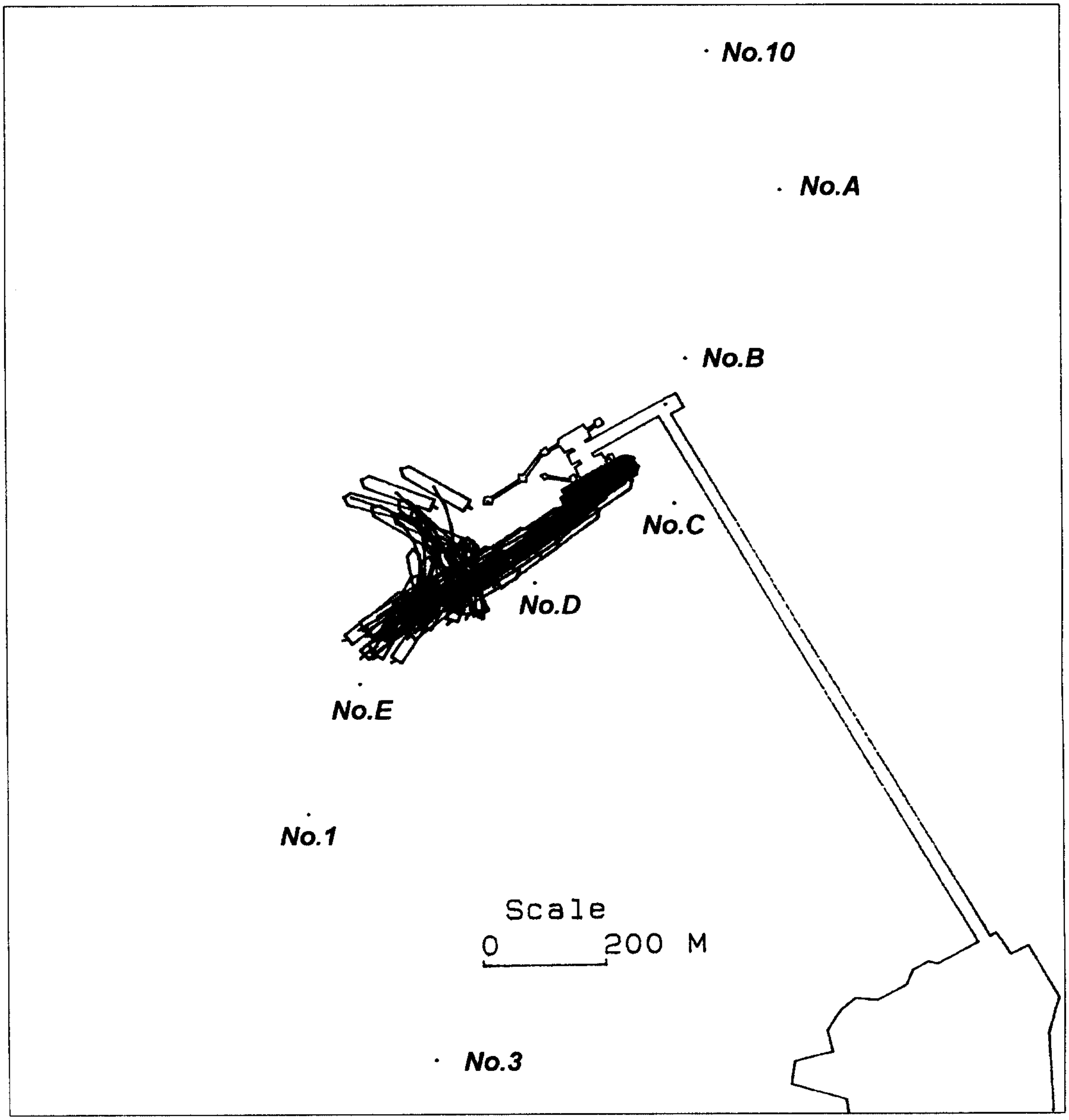

Fig. 2 Composite track plot of simulation

backward speed was reduced to 2 *kts*. In addition, the bow tended to approach buoy " C". Therefore the mental burden, the maneuvering work load and difficulties were very heavy.

5. Conclusion

The appreciation of the unberthing safety of the 10,000 DWT LNG tanker from #2 berth of the

'HPC' pier at Daesan port was made through unberthing simulation from the bow-in posture which had much difficulty in maneuvering and was dangerous. The northeast 3 *kts* flood current and the northwest 30 *kts* wind, which is the prevailing wind at Daesan port, were given as the environmental condition. And the ship was unberthed with the assistance of two tugs of over 3,600 bhp. From the simulation results, the following conclusions are obtained.

① In the appreciation of the ship's proximity in case of unberthing, the closest distance to the line connected between buoy "C" and buoy "D" was 45.57 m, that to the line connected between buoy "D" and "E" was 16.67 m, and that to the dolphin was 56.67 m. The probability of the intrusion for these ranged 0.0078~0.1762, which was much bigger than TNO's reference of 0.0001. The unberthing maneuver from the berth, therefore, is judged as unsafe.

② In case of #2 berth of the 'HPC' pier the width of the water area, that is, the distance from the dolphin to the line connected between buoy "C" and "D" should be more than 149.5m and the distance from the extension line of the dolphin to the line connected between buoy "D" and buoy "E" should be more than 175.1m. Because these values were calculated under the assumption that the tugs operate without the effect of the wave and the ship's engine is used instantly when requested, they should be bigger in practice.

③ In order to get the ship unberthed, the stern tug had to pull her while the bow tug was pushing to prevent her from turning to the right.

④ The subjective evaluation showed that the mental burden, maneuvering work load and difficulties were very high.

As was explained above, the unberthing maneuver of the 10,000 DWT LNG tanker from #2 berth of the 'HPC' pier was found to be unsafe from the simulation. Meanwhile, according to the opinion of pilots and masters of tugs it is very difficult for tugs to pull or push when the wave height is over 1 m. The upward and downward movement of a tug due to the swell was not taken into consideration in the simulator, and therefore, the safety level of the unberthing maneuver will be worse than experienced through the simulation.

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