NAVIGATIONAL EFFICIENCY IN MARINE TRAFFIC OPERATIONS IN THE PORT OF KEELUNG

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NAVIGATIONAL EFFICIENCY IN MARINE TRAFFIC OPERATIONS IN THE PORT OF KEELUNG

by

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ABSTRACT

The rapid economic growth of Taiwan has been paralleled by an increase in marine traffic in the port of Keelung. The increase has been evolutionary and, prior to this study, has lacked the benefit of supporting research necessary to ensure no loss in navigational efficiency. The study uses eclectic methodologies to: identify the nature of marine traffic at Keelung; assess the associated risks; and identify measures needed to reduce risk and increase navigational efficiency.

For contextual purposes the study reviews current marine traffic operations at Keelung against the background of geographical constraint and environmental conditions. Radar survey and extensive sampling of professional opinion indicate that existent traffic control measures are both inadequate and open to contravention. Casualty analysis further identifies areas of concern where navigation risk has been shown to exist. In particular the traffic separation scheme, introduced in 1990, has been found inadequate and lack of movement control reduces navigational efficiency.

Use of visual simulators, at Taiwan Ocean University and University of Plymouth, provided a unique opportunity to compare present marine traffic operations against a modified model. The modified model incorporated limited vessel traffic service functions and channel markers, neither of which exist at present in the live situation. Most significantly the experiment has enabled evaluation of the difference between Taiwanese and foreign ship masters when handling ships in the port approaches.

Analysis of ship's tracks, and subjects' perceptions, concludes that provision of channel markers and sequence control greatly simplifies the operation and reduces risk. The need to widen the traffic lanes by reducing the separation zone between inward and outward lanes is identified.

The study shows that navigational safety and efficiency at Keelung can be improved through the introduction of small changes to operation and working practices. The study provides the basis for a programme of continuing work necessary to maintain or further improve standards once the recommendations of the study have been implemented.

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LIST OF ABBREVIATIONS

ARPA	Automatic Radar Plotting Aids
COST-301	European Cooperation on Science and Technology
CNIS	Channel Navigation Information Service
COLREGS	Regulations for Preventing Collision at Sea
CPA	Closest Point of Approach
dwt	Dead Weight Tons
ETA	Estimated Time of Arrival
Ex-A	Exercise A in Simulation Experiment
Ex-B	Exercise B in Simulation Experiment
GATT	General Agreement on Tariffs and Trade
grt	Gross Tonnage
IMO	International Maritime Organization
K-W Test	Kruskal-Wallis Test
LPG	Liquid Petroleum Gas
M-W Test	Wicloxon-Mann-Whitney Test
m/sec	metres/second
NTOU	National Taiwan Ocean University
RPM	Revolution Per Minute
SPSS	Statistical Package for the Social Science
TCPA	Time of Closest Point of Approach
TEU	Twenty-foot Equivalent Unit
TSS	Traffic Separation Scheme
UP	University of Plymouth
VHF	Very High Frequency Telephone
VTS	Vessel Traffic Service

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Ports provide the interface between land transportation and sea trade, of great economic importance to many countries. Keelung is one of the principal ports of Taiwan, and provides important direct shipping services to the north Pacific coasts and to south east Asia. Following the rapid development of Taiwan's economy both local and export/import trading patterns, including the type of shipping and transport services, have a direct impact on the port[1]. During recent years, there has been considerable expansion in maritime trade. The number of ships calling at Keelung has increased significantly. The port authority has continuously improved cargo handling facilities, converting many small piers to container berths, to cope with the increased volume and changed nature of trade. The port now has to face the attendant problems of increased activity.

High traffic density in restricted navigational waters endangers navigational safety simply because the ship encounter rate increases[2]. Increased activity without a matching increase in port capacity inevitably leads to delays. Waiting ships occupying navigable water hamper other vessels' movements and increase accident risk. Concurrently the impact of meteorological conditions on traffic safety becomes more significant as increased congestion heightens the effects of poor visibility, strong wind and current[3].

The risk influences ship manoeuvring so as to reduce navigational efficiency. Navigating in a high risk area, ships may be delayed because navigators have to slow down ship speed and continuously take actions to avoid risk and prevent occurrence of accidents. Marine accidents which result in loss of life and property as well as environmental pollution can arouse public concern beyond the shipping community[4,5,6]. It is well understood that improved efficiency can decrease operation costs because ships can reduce transit time and accident damage, and make better use of the waterways in a port[7].

Safety is an inherent part of efficiency, and follows from it. A port has implicit obligations including the provision of a safe and efficient navigational environment. When a port authority is taking measures to provide a safer operation, improvement of efficiency must be simultaneously considered for most users in the area[8]. For a port, efficiency is necessary for survival in a competitive world. Reduced navigational risk can consequently bring greater profits to the port authority and ship owners.

In the absence of appropriate measures navigational risk at Keelung will also grow in hand with port development as the economy grows[9]. The nature of that increased risk, and whether appropriate measures can be identified and implemented, is a matter for investigation.

1.2 AIM OF THE STUDY

Reduction of risk and increase in navigational efficiency are proper objectives for any port authority. As a first step in achieving these objectives a study into the nature of the existing services and safety measures, and the identification of any shortcomings must be made. The study has to be wide enough to cover general factors as well as factors specific to the port under review. It needs to investigate and analyse activities and procedures that influence navigational safety and efficiency in marine operations in the port and its approaches. Against the background of increased activity at Keelung such a study for the port is now timely.

Keelung port authority established a traffic separation scheme in the port approaches in March 1990, with the aim of improving the flow of marine traffic. It is recognized that although separation schemes can produce substantial improvements in safety there is often a cost in lost time to pay[10]. No study has been conducted to assess the validity of the scheme at Keelung. A particular element of the navigational efficiency review conducted in the research will be directed at assessing the effectiveness of the traffic separation scheme, and whether the need for modification is indicated.

Finally there is a wide armoury of navigation aids, systems and techniques available in the promotion of navigational safety and efficiency. They are by no means universally applicable. The special characteristics of the situation existing at Keelung will be analysed with the aim of producing a best fit solution.

1.3 METHODOLOGY

1.3.1 Analysis of navigational safety

There have been a number of studies analysing navigational safety, some of which have been used to assess port efficiency[11,12]. A study of such work identifies salient factors and the nature of the costs resulting from marine casualties. The literature review also enables analytical comparison of the aids to port navigation available and used throughout the world.

1.3.2 Investigation of marine casualties in Keelung

Marine accidents may reflect navigational risk in the area. To assess the types and levels of risk, statistics have been obtained from the port authority, covering all accidents over the period 1987 to 1991. Particular attention has been paid to those accidents involving collision, grounding and contact. A detailed analysis has been made to determine the nature and frequency of those accidents in order to define the problem. Data has been collected relating to ship type, size, time of event, environmental conditions, etc., on statistical analysis and indication of relationships between the causes of accidents and ship characteristics and weather conditions. The damage costs resulting from accidents has been determined through direct approach to the owners of the vessels involved.

1.3.3 Assessment of professional opinions

An established method of obtaining data relating to navigational risk is by interviews with, and self-report questionnaires from, those active in the field of study. In order to obtain an initial supply of data with a more comprehensive understanding of the navigational problems at Keelung, it was decided to consult mariners serving on vessels frequenting the port. This eclectic approach widens the scope of the study and can provide a degree of compensation when statistical data is inadequate.

Commonly such surveys present interviewees with descriptions of situations involving navigational risk, and ask how they grade the attendant risk. Responses are subjective and individually can only give impressions, but collectively they indicate a level of navigational risk. In addition such a study can yield interesting qualitative data on individual attitudes to safety, and quantitative data on differences between different subject sets. Responses to questionnaires of this nature may be positively correlated[13]. Those who readily recognize risk equally recognize measures that increase or reduce such risk, while those who have difficulty identifying risk also have difficulty in identifying influencing factors.

1.3.4 Comparison with radar survey

Direct observation by radar of traffic flow provides positive information relating to the nature of traffic, and forms a further eclectic part of the study. Mariner behaviour is a vital input to many forms of marine traffic research. Radar observation gives sound indications of traffic patterns, areas of conflict, and as such adds to the overall understanding of the problem. In particular, observational surveys are free of the risk of bias that can exist in respondent centred data[14].

1.3.5 Simulation experiment

Simulation is a very powerful method for solving system problems because of its wide applicability and because it provides a laboratory to study systems without the costs of building or modifying the real systems[15]. When handling a simulator, mariners respond as they do in a real ship. It is possible to repeat sample situations to test several mariners in order to build up a statistically significant sample. Through simulation experiment by nautical simulator, the results of mariners' responses can offer a good source. Therefore, navigational risks under the particular situation can be emphasised, and then methods for improving safety and efficiency aiming to the risks can be found.

Comparisons of the existing situation in Keelung with a designed situation which is replaced some conditions related with the risks will provide the basis for determining the TSS and traffic control effectiveness. The existing traffic control measures can be simulated using the MRNS 9000 navigation simulator in the University of Plymouth and the shiphandling simulator in Taiwan Ocean University. Modifications to the traffic control measures can be evolved and again simulated. Subjects' perceptions and ship tracks from experiment are significantly useful data for analysis.

1.4 THE STRUCTURE OF THE THESIS

The thesis comprises eight chapters. Following this introductory chapter, Chapter two introduces the nature of marine traffic operations at Keelung, including physical characteristics such as geography and environment, and traffic statistics. It also considers the regulation and control of traffic at Keelung.

In Chapter three analysis is made of circumstances and effects of navigational casualties at the port during the five year period 1987-1991, while Chapter four provides an analysis of professional opinions regarding navigational risk at Keelung. The results of these analysis are compared with those from the radar survey.

Chapter five presents effectiveness of traffic separation scheme (TSS) and vessel traffic services (VTS). Through analysis of profession opinions, measures of improving navigational safety and efficiency are preliminarily found.

Taking the unique opportunity presented by availability of the simulators Chapter six introduces the criteria, indicated by the results of the previous chapters, for simulation experiment, and analyses ship tracks obtained from those experiments. The results are compared with those from Chapter seven, evidencing the effectiveness of floating aids and traffic control, and modifying the TSS. Chapter eight presents conclusions drawn from the earlier chapters, and details current studies.

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CHAPTER 2

MARINE TRAFFIC OPERATIONS IN KEELUNG

2.1 INTRODUCTION

Taiwan is an island, located 200 kilometres from Mainland China, between Japan and the Philippines (Figure 2-1). The area of the island is 35,961 square kilometres, about 66% of the land being covered by mountains. Owing to lack of natural resources, the development of the economy must be accomplished by means of international trade, involving import of materials and export of products. Based on the General Agreement on Tariffs and Trade (GATT) statistics, in 1991 Taiwan was ranked the 14th largest among trading nations of the world, with total exports taking 12th place and imports ranked 16th[1]. Textiles, machinery and electrical goods are among the chief exports, and marine transportation has become essential to economic growth over the past ten years. Recently, the Taiwanese government put forward major proposals for the future development of the Island, and the marine transportation role of Keelung port was highlighted.

2.2 GENERAL DESCRIPTION OF KEELUNG PORT

The Keelung port, on the northern end of the Island at Latitude 25°09'N, Longitude 121°45'E, faces northward to the East China Sea (Figure 2-2). The main channel between the breakwaters is about 250 metres wide. Inside the breakwaters lie the outer and inner harbours. The harbours have a total of 57 piers: 39 piers for merchant ships, 18 for customs and navy ships. Fishing vessels also berth at the eastern part of the harbour and use the main channel to enter or leave the port. There is a one-pier petroleum port, Sen-ao, four miles to the east (Figure 2-3).

The water area, outside the breakwaters, is bounded on the west and south by a curving coastline, and on the eastern side there is Keelung Island. The gap between Keelung Island and the western coast, called Yeh-liu Cape, is about five miles wide. Within this area and half a mile off the coast, the water depth is over 40 metres. The spit of gravel and rock, named An-tou-pao Shoal, extends one mile south-westward from Keelung Island with the water depth less than 10 metres. There are strong tidal currents on the shoal which should not be crossed by ships[2].

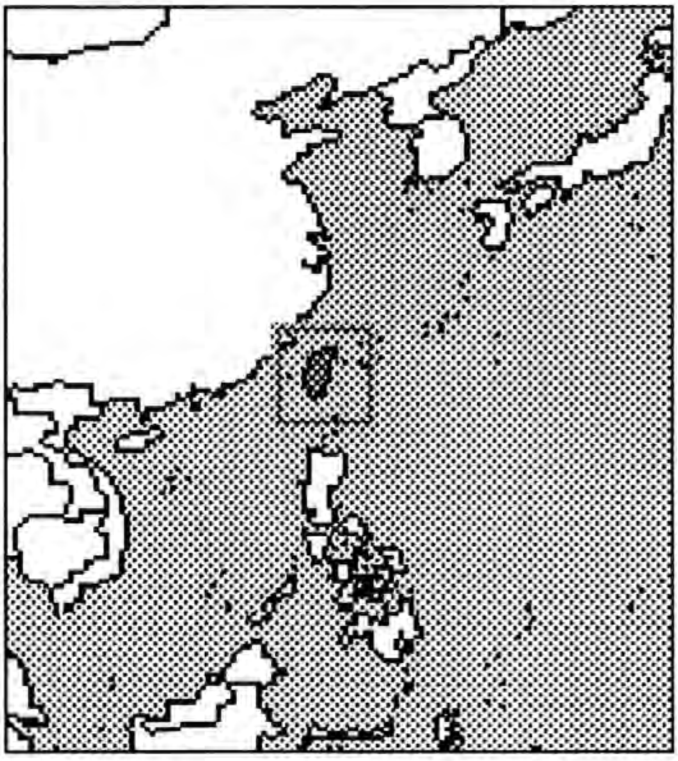

Figure 2-1 Location of Taiwan, ROC

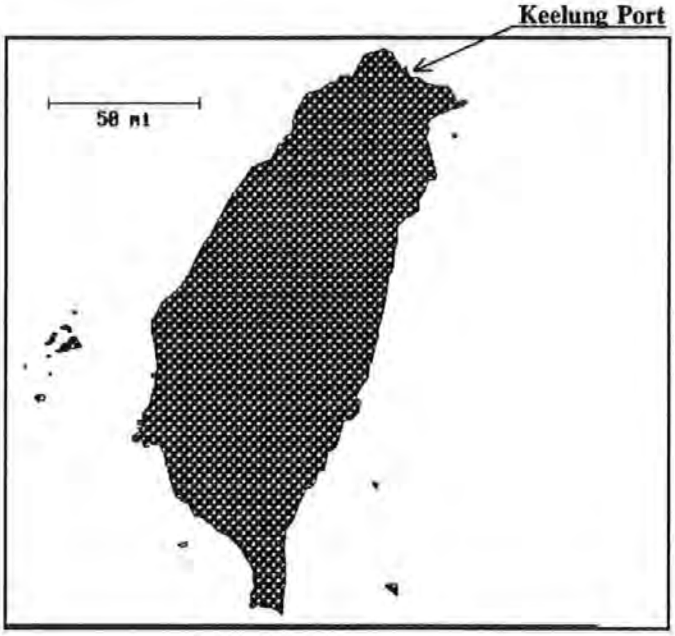

Figure 2-2 Taiwan map

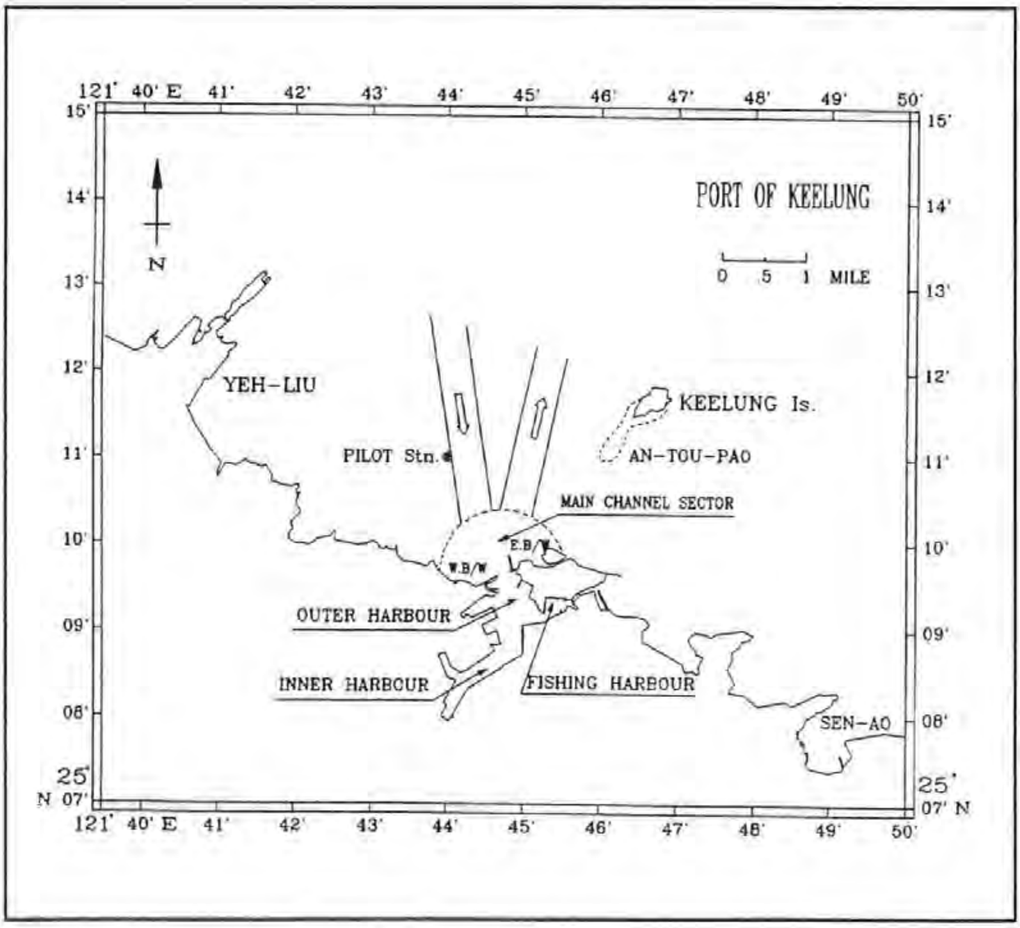

Figure 2-3 Keelung and approaches
Source: Author

2.2.1 Commercial activities

Keelung is one of two major commercial ports in Taiwan; the other being Kaohsiung. Keelung accounts for 29.2% of the total import and export cargoes of the Island[3]. In 1991 23,267 merchant vessels with 308 million gross tonnage (grt) visited Taiwan, and 7,514 vessels with 99 million grt called at Keelung, about 20.6 vessels per day (Table 2-1). During the past twenty years, not only has the size of vessels visiting Keelung tended to increase, but there has been a parallel shift towards containerization. The average grt of the ships in Keelung was 8,306 per ship in 1981, and 13,170 in 1991. From Table 2-2 and Table 2-3, it can be seen that the number of ships whose grt is over 40,000, increased significantly during the period under study, and the number of container ships increased from 1,915 in 1981, to 4,377 in 1991.

Table 2-1 Vessels visiting Keelung and all ports in Taiwan (1981-1991)

Year	Number			Gross Tonnage (1,000 GRT)		
	Keelung	All Ports	Ratio(%)	Keelung	All Ports	Ratio(%)
1981	5,622	15,747	35.7	46,698	131,311	35.6
1982	5,660	16,251	34.8	50,244	146,068	34.4
1983	5,919	17,131	34.6	54,212	163,786	33.1
1984	6,237	17,199	36.3	62,403	175,104	35.6
1985	6,184	17,195	36.0	64,798	186,285	34.8
1986	6,648	19,038	34.9	75,658	215,557	35.1
1987	6,977	20,119	34.7	87,099	242,569	35.9
1988	7,243	21,384	33.9	92,916	273,144	34.0
1989	7,572	21,957	34.5	96,367	284,429	33.9
1990	7,623	21,973	34.7	97,928	291,553	33.6
1991	7,514	23,267	32.3	98,959	308,029	32.1

Source : Monthly Statistics of Transportation, January 1992.
The Ministry of Communication, ROC.

Table 2-2 Category of vessel by gross tonnage in Keelung (1981-1991)

Year	Total	GRT Less Than 1,000	GRT 1,000 - 4,999	GRT 5,000 - 9,999	GRT 10,000-19,999	GRT 20,000-39,999	GRT More Than 40,000
1981	5,510	227	2,366	1,249	1,210	450	8
1982	5,660	288	2,282	1,166	1,398	521	5
1983	5,919	353	2,413	990	1,499	659	5
1984	6,237	460	2,425	861	1,562	900	29
1985	6,184	592	2,209	905	1,434	973	71
1986	6,648	555	2,187	970	1,692	1,130	114
1987	6,977	567	1,960	1,082	1,960	1,241	167
1988	7,243	480	1,990	1,277	2,017	1,189	290
1989	7,572	566	2,061	1,434	1,973	1,204	334
1990	7,623	584	1,988	1,507	1,975	1,207	362
1991	7,514	445	1,939	1,592	2,019	1,127	392
1991	100%	5.9%	25.8%	21.2%	26.9%	15.0%	5.2%
% change 1981-91	+36.4	+96.0	-18.1	+27.5	+66.9	+150.4	+4800

Source : Statistical Abstract 1991 (Keelung Harbour Bureau)

The number of container ships has doubled over the ten year period whilst the number of general cargo ships decreased and other ship types only slightly increased. The port authority, Keelung Harbour Bureau, converted many general cargo berths to container berths during the 1970's and 1980's. Currently, there are three container terminals comprising 13 berths. Ships up to 275 metres in length can be handled. Keelung was the seventh of the world's largest container ports in 1989[4]. In 1991 the number of containers handled in Keelung was two million 20-foot equivalent units (TEUs), about 13.9 million tons of cargoes accounting for 83.2% of the total cargoes handled in the port[5]. The Keelung Harbour Bureau has planned to convert another five piers to container berths in order to increase services for container ships.

Table 2-3 Category of vessel type in Keelung (1981-1991)

Year	No./grt.	Container	G. Cargo	Others	Total
1981	Number	1,915 (34.75%)	2,774 (50.34%)	821 (14.91%)	5,510 (100%)
	grt	19,906,009 (42.67%)	19,876,416 (42.61%)	6,864,200 (14.72%)	46,645,625 (100%)
1986	Number	3,471 (52.21%)	2,225 (33.47%)	952 (14.32%)	6,648 (100%)
	grt	55,189,785 (72.95%)	13,553,297 (17.91%)	6,914,606 (9.14%)	75,657,688 (100%)
1991	Number	4,377 (58.25%)	2,219 (29.53%)	918 (12.22%)	7,514 (100%)
	grt	72,827,643 (73.59%)	16,249,302 (16.42%)	9,882,330 (9.99%)	98,959,275 (100%)
% change 1981-1991	Number	+128.56%	-20.00%	+11.81%	+36.37%
	grt	+265.86%	-18.25%	+43.97%	+112.15%

Source : Statistical Abstract 1991 (Keelung Harbour Bureau)

Although the port authority has improved the wharf facilities, some shipping companies shifted their trade to Kaohsiung port instead of Keelung. On 1 January 1992 Maersk Line, the world's third largest container company, so moved its operation. At Kaohsiung Maersk now leases an exclusive berth, a facility not available to the company at Keelung[6].

Sen-ao port is an exclusive port for the China Petroleum Company. The berthing system is installed for the use of 36,000 dead weight (dwt) oil tankers or liquid petroleum gas (LPG) tankers with the length under 213 metres. In summer season, the draft for tanker entrance is limited to 11.8 metres and winter season to 10.8 metres. For the safe regulation of the port, the berthing operation should be in good weather with wind velocity less than 8 metres/sec (m/sec) and visibility not less than one mile[7]. The average number of tankers calling at Sen-ao Port is 74.8 per year during the period of 1987-1991 (Table 2-4). Some of them are used to anchoring at Keelung approaches.

Table 2-4 Distribution of calling ships in Sen-ao port (1987-1991)

Year	TYPE			GROSS TONNAGE				
	LPG	Product	Total	Under 10,000	10,000-19,999	20,000-39,999	Over 40,000	Total
1987	9	33	42	21	2	14	5	42
1988	18	50	68	20	-	37	11	68
1989	20	78	98	27	-	53	18	98
1990	17	65	82	4	11	67	-	82
1991	17	67	84	2	4	66	12	84
Total	81	293	374	74	17	237	46	374

Source: China Petroleum Company

2.2.2 Distribution of ship movement

According to the data (1987-1989) from the Keelung Harbour Bureau, 36.6% of vessels came from Japan and South Korea including through cargoes from North America, 31.6% from South-East Asian countries including the through cargoes from European countries, 29.6% from other ports in Taiwan where the major port was Kaohsiung, and 2.2% from the United States directly. From the traffic pattern of ships in 1991, shown in Figure 2-4, the arrivals were greatest in December, 5.8% higher than the mean, and least in March, 12.1% lower than that[8]. The traffic movements at Keelung during

January to March, accounted for about 23.2% of the annual total while that for July to September was 25.8%.

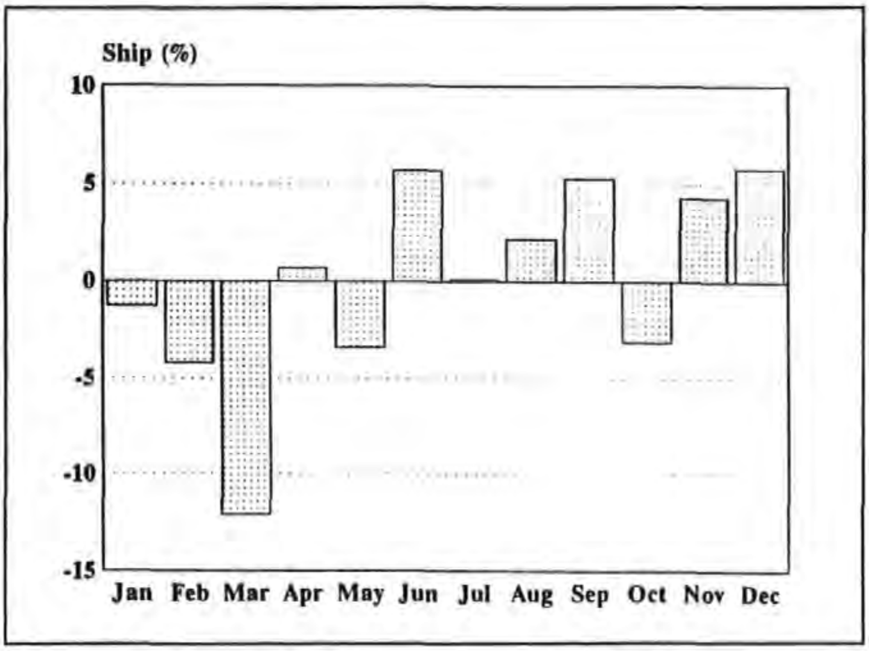

Figure 2-4 Monthly variation of calling ships from annual mean in Keelung in 1991

Source: Keelung Harbour Bureau Statistical Abstract 1991

The best and cheapest time to berth is early morning. Therefore, 56.3% of ships arrived in Keelung approaches in day-time, between 0600 and 1800 hours, and the peak time of ships arriving was between 0500 and 0800 hours during the five year period 1987-1991[9]. Some ships could not enter the port immediately and had to wait for a while due to pilot or berth unavailability. The proportion of ships entering the port in day-time was 83.5% and leaving ships was 60.5%. The peak time of entering appeared in the morning, especially between 0800 and 0900 hours, and that of departure between 0900 and 1000 hours (Figure 2-5, 2-6, 2-7).

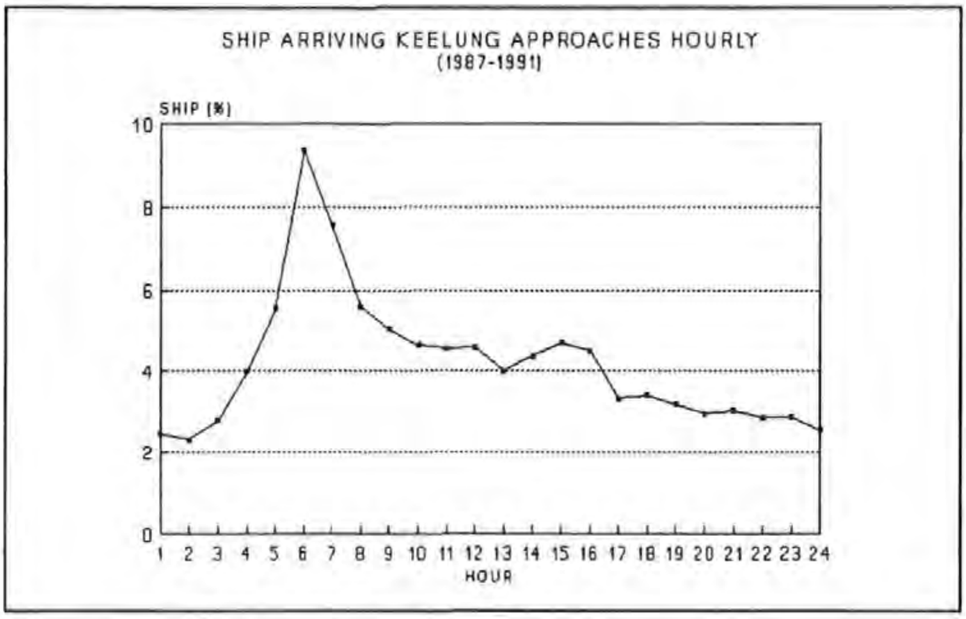

Figure 2-5 The hourly distribution of arriving ships in Keelung (1987-1991)

Source: China Port Consultant Institute, Taiwan

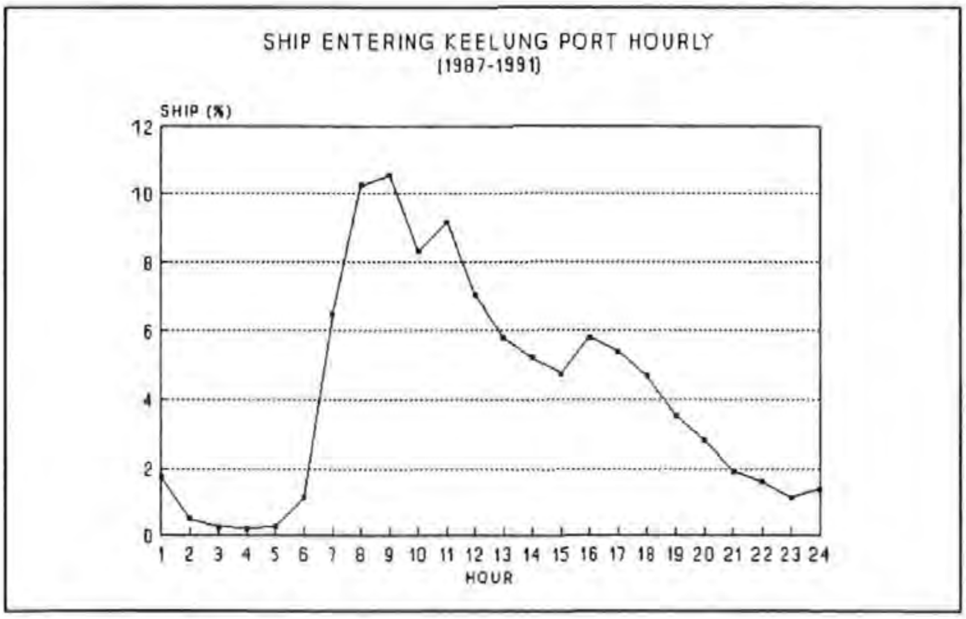

Figure 2-6 The hourly distribution of entering ships in Keelung (1987-1991)

Source: China Port Consultant Institute, Taiwan

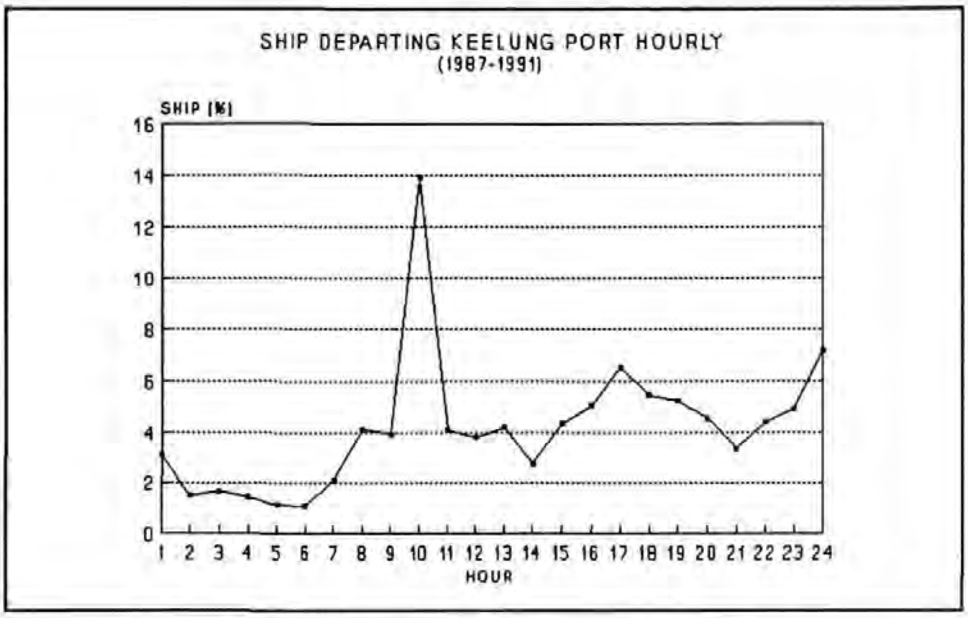

Figure 2-7 The hourly distribution of leaving ships in Keelung (1987-1991)

Source: China Port Consultant Institute, Taiwan

2.2.3 Climate and sea condition

1. Wind and sea

From September to May the prevailing wind direction is NE to NNE, whereas, from June to August they are SSW to S. In the winter season, the NE monsoon is an extremely strong wind, sometimes reaching a gale or force 9 on the Beaufort wind scale, the SW monsoon is not so strong, but occasionally the wind scale ranges from 7-8, or near gale to gale. The typhoon season is normally August and September for Keelung. From the weather reports, during the last five-year period 1987-1991, there were 5.4% of the total days with the maximum wind force over force 8, mostly from September to November, and 57.1% under force 5. The average wind force in winter is stronger than in summer[10] (Figure 2-8). The maximum speed has been recorded as high as 56.5 m/sec[11].

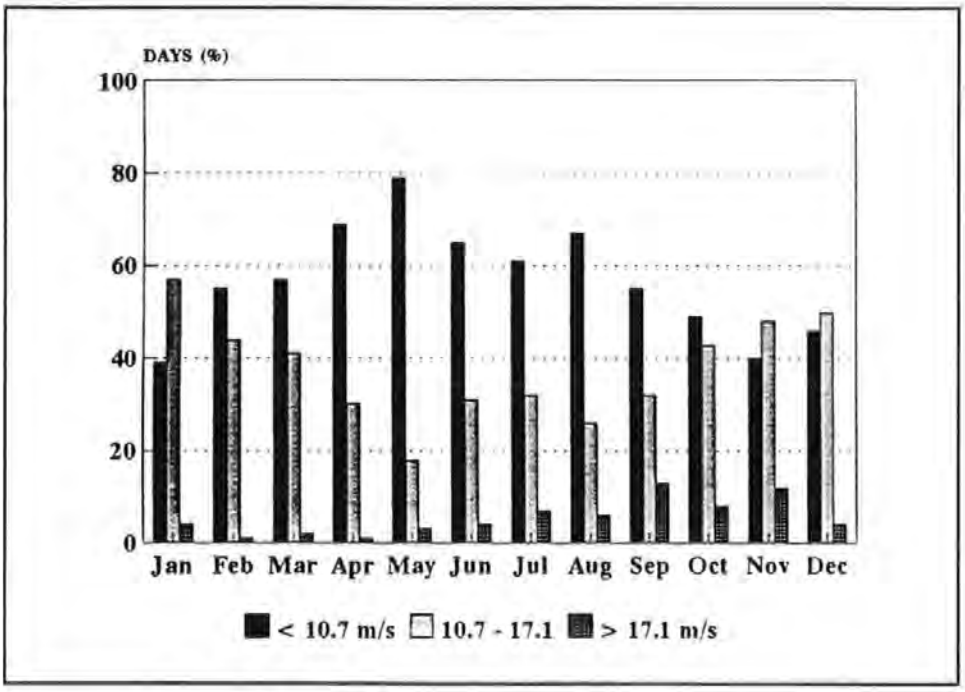

Figure 2-8 Distribution of maximum wind force in Keelung (1987-1991)

Source: Taiwan Central Weather Bureau

The harbour is sheltered by hills on the western, southern and eastern sides and by Keelung island on the north-east, but N winds create heavy seas in the harbour approaches[12]. During the NE monsoon period, there is frequently a rough sea with a NE direction. 4.4% of the total wave records annually have height greater than three metres.

2. Visibility

The winter season is also the rainy season from early October to the next early April each year. Because the port is surrounded by mountains, the vapour in the air tends to be more easily affected by the ocean current and frontal movement. Generally speaking, the rainfall in November, December and January is about two thirds of the annual rainfall. The foggy season is from February to April due to lower wind speed in spring and early summer season. However, because of air pollution, from the ever-increasing factory exhaust and traffic, poor visibility is an increasing occurrence[13]. Taiwan Central Weather Bureau's 1987-1991 records show, on 2% of all days visibility was less than two miles, and on 40.4% days between two and five miles[14]. The average visibility from January to April was worse than in other months (Figure 2-9).

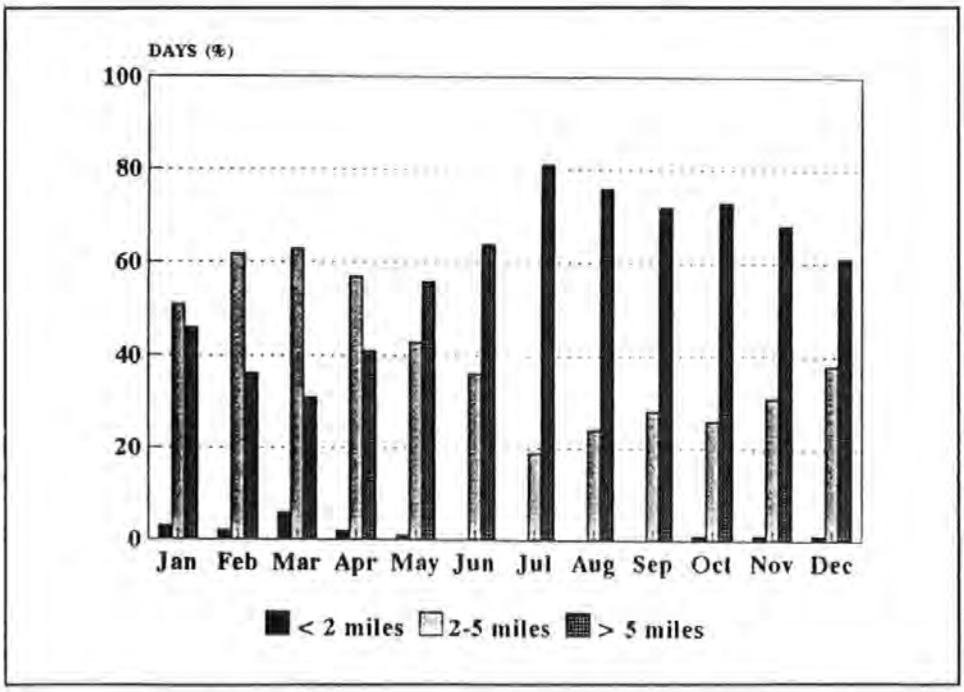

Figure 2-9 Distribution of visibility in Keelung (1987-1991)

Source: Taiwan Central Weather Bureau

3. Tide and tidal streams

The range of the tide varies from the maximum 1.9 metres to the minimum 0.0 metres. The tidal streams are negligible, and are less than one knot inside the breakwaters. As there is no large river in the harbour, the weather has no effect on the current, but in the monsoon season there are surges near the entrance.

Outside the harbour, the tidal current is the reversing current that flows alternately in approximately opposite directions with a six-hour period at each reversal of the current. The tidal streams two miles off the breakwaters have a maximum rate of three knots, with the W-going stream in flood tide and E-going stream in ebb tide. Just off the harbour entrance, the stream has a maximum rate of one to two knots. The direction of the streams almost perpendicular to the navigation fairway. A counter-current runs just outside the breakwater.

2.3 MARINE OPERATION IN KEELUNG PORT

2.3.1 Aids to navigation

1. Fixed aids to navigation

There are two conspicuous landmarks located at the outside of Keelung port: the Keelung Island and the Yeh-liu Cape; the former at the eastern side and the latter west. In good weather, when ships approach Keelung from 10 miles away, duty officers can easily find the above landmarks by visual observation or by radar. A light of 17 miles of luminal range is exhibited from a tower on the summit of Keelung Island, 182 metres in height. The Yeh-liu lighthouse is 92 metres high with a light of 14 mile range.

The Keelung lighthouse is another long distance visual aid located at the inside harbour near the west breakwater with a 16 mile light. In addition to the lighthouses, two columns with 6-mile luminal range light are built separately at each tip of two breakwaters to indicate the harbour entrance. Generally speaking, in clear weather navigators can easily fix positions visually no matter whether by day-time or night-time[15]. In poor visibility the position has to be fixed carefully with radar. There is no floating aid installed outside the harbour. In Taiwan, lighthouses and other fixed or floating aids to navigation are under the Customs' control.

2. Traffic Separation Scheme

Because of the strong requirement from ship owners and masters after some accidents outside the port, the port authority was forced to act. The rules on the use of the fairway under the traffic separation schemes in the approaches to the harbour were advised to navigators on 1st March 1990[16]. The fairway is in a sector-shaped separation that starts from 0.75 mile off the breakwater and extends outward for two miles (see Figure 2-3). The entrance lane leads 170 degree towards the entrance and the exit lane leads 012 degree from the entrance. The width of both navigation lanes is 700 metres. Vessels are prohibited from anchoring or lingering in this fairway.

From the outer harbour to the nearer edge of TSS is the main channel permitting the passage of one ship only at a time through the entrance channel. The outward bound ships have right of way over those entering. The main channel outside the breakwaters is also a sector-shaped.

2.3.2 Harbour control

1. Anchorage

In the outer harbour, a quarantine anchorage lies on the eastern side in the inner breakwater and clear of the main channel, in depths of about 7.3 metres to 13.1 metres. It is a small water area only allowing two or three ships to anchor, and usually congested. Anchorage is prohibited in the central and west part of the outer harbour.

No official anchorage is designated outside the harbour. The TSS rule by the port authority only prohibits vessels from anchoring in the fairway and the main channel, so except for those areas a master can anchor his ship anywhere he likes. Usually vessels anchor at the western side off the inbound traffic lane, north-west two miles off the breakwaters. This area is about four square miles, and the water depth is over 40 meters in the whole area.

It is recommended that the minimum length of mild steel cable to use, in metres, for the ship's anchoring may be taken as approximately 25 times the square root of the depth of water in metres[17]. Thus at least six shackles of cable are required for a ship anchoring in this area. In winter, the strong wind and tidal streams occasionally make the anchored ship drag the anchor, even breaking the anchor chain. So the Keelung Harbour Bureau gives notice to calling vessels that it is not advisable to anchor in this area during the NE monsoon season. Even in favourable weather, the anchored ship should always remain alert[18]. The China Master Association also suggests the ship anchoring should use six or seven shackles of cable, and are best advised to weigh anchor and drift at open sea if the wind is strong[19].

2. Pilotage

Pilotage is optional from the approaches up to the quarantine anchorage in the Outer Harbour, but is compulsory elsewhere in the harbour. Pilots are usually available for vessels arriving between 0700 and 2300 hours, but not outside those hours. Departure may be made at any time[20].

When the ship's master requires a pilot aboard his ship at the outer water of the port entrance, he may request his agent to apply to the Pilot Association[21]. Pilots board at the pilot station, Latitude 25°11'N, Longitude 121°44'E, a distance of 1.5 miles from the breakwaters, weather permitting. For safety to pass through the narrow entrance channel the agent usually requests the pilot to board from the pilot station. Sometimes, when a ship is approaching at night or in bad weather or other special circumstances, the pilot is unable to get out of the harbour. Under this situation, the master alternatively may proceed to the port entrance to pick up the pilot inside the breakwater at his own risk or stay outside the harbour to wait for the weather to improve.

When the ship is leaving, normally the pilot will leave the ship at the outer harbour main channel, about 0.7 miles to breakwaters, with the consent of the master. If the master requires pilotage extended to waters outside the harbour, he shall submit his request before the ship leaves. The pilot shall not refuse to render his service unless it is night-time or foul weather or other special circumstances.

Use of tugs is optional. Tug services work only inside the harbour in coordination with the pilot. Usually the tug attends the inbound ship or leaves the outbound ship at the outer harbour.

3. Port entry and exit

According to the rule of application procedures for ship's calling at Keelung, ships approaching the 10 miles water off the port shall call the Signal Station by VHF as early as possible to confirm the estimated time of arrival (ETA), and to provide a preferable pilot boarding time to avoid any mistakes. Permission to enter harbour must be obtained through the station. Ships waiting at the outside waters should maintain enough space for the ship's manoeuvring and the master must pay close attention to the safety of his own ship without the benefit of pilotage assistance. When more than one ship is requesting entry or departure simultaneously, priority will be determined by the station according to the situation. A warship has priority over other ships in using the entrance channel. Merchant vessels can be required to stop without prior notice. There is no information service to be provided for navigation assistance or advice from the station.

Upon arrival, with or without a pilot, the calling ship may anchor at the outer harbour anchorage for quarantine and other inspection formalities. After the completion of these formalities, the ship then can proceed to the assigned berth under the pilotage of a harbour pilot and berth with the assistance of linesmen and/or tug.

2.4 SUMMARY

Keelung port plays an important role in the Taiwanese economy. About one third of Taiwanese exports pass through this port. In Keelung some meteorological conditions are disadvantageous to navigation, such as the NE monsoon in winter, poor visibility in spring and the strong currents at the approaches. The port authority is faced with the requirement to ensure that the layout and operational strategies are adequate to cope with the increase of ship numbers and ship size in all likely operational conditions. Like other busy ports, the port authority has provided many aids to navigation, and established a TSS. To control ship movement, the compulsory pilotage in the harbour and VHF communication in reporting ship's ETA are regulated.

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CHAPTER 3

THE ANALYSIS OF MARINE TRAFFIC CASUALTIES

3.1 INTRODUCTION

During the past 20 years a number of serious casualties have occurred in the approaches to Keelung port. Although full details are difficult to obtain, the cases of the *Borag* and *Choong Yong* are exemplary.

On 5th February 1977, the Kuwait tanker, *Borag* (21,616 grt), anchored outside Keelung port to wait for a berth in Sen-ao port to discharge oil. On the 7th, just after weighing anchor and proceeding to Sen-ao, the ship grounded on the Hsinlai reef. The reef is located 2.2 miles north of the Keelung breakwater, and dredged to 18 metre depth in 1987. The result of the casualty incurred total loss of the ship and oil pollution that was estimated at US$60 million damage[1]. The cause of the accident was that the ship lacked proper charts to indicate the correct position of the reef. There was no pilot on board.

On 28th December 1984, the Korean general cargo ship, *Choong Yong* (12,477 grt), arrived at Keelung pilot station. While waiting for the pilot, the ship deviated from her position by strong wind and rough seas, and grounded[2]. The hull damage was US$6 million, and the cargo lost was US$8 million.

For the purpose of providing a substantial basis for ships' safety in the Keelung area, the first task must be to realize the risk by investigating ship casualties and interpreting casualty statistics. Each water area has its own navigation problems depending on the geography, weather, traffic situation, etc. Without a specific investigation into safety improvement, the actual causal factor is often unidentified. The proverb is "we learn by our mistakes". Past errors give clues to present safety. Once causes of accidents have been identified, action can be taken to prevent them happening again. Complete safety may be unattainable, but the level of safety can usually be increased.

3.2 METHODS

Before analysing navigational risk in the approaches to Keelung port, the first task was to build a data base and the second to identify factors related to the analysis. The central analysis is based on an investigation into the casualties occurring to seagoing trading ships. After the basic data were collected and augmented, the analysis was carried out by the SPSS/PC$^+$ computer software package, a statistical package for social sciences.

3.2.1 Scope of casualty data

Data on maritime casualties were required for giving an indication of existing levels of safety to assess the risk. Thus, the scope of casualty data in this research was defined by:

a. the area covered

b. a sufficient period of time being covered to make statistical techniques valid

c. casualties which actually occurred being included.

3.2.1.1 Scope of area

The sea area of Keelung port includes inside and outside the harbour. Inbound ships passing the breakwaters and entering the harbour, should reduce speed to less than five knots in compliance with the port regulation[3], and tugs may have been waiting for the ship to assist in its manoeuvring. Generally speaking, the situation inside the harbour for ship handling is safe, especially under pilot control. The northern water areas of Keelung Island and Yeh-liu Cape are open sea, and from the record of the Keelung Harbour Bureau appear to have a very low probability of marine accidents. Therefore the area of this study is from the main channel between the breakwaters extending five miles seaward to Latitude 25°15'N. It is bounded to the east by Keelung Island and the west by Yeh-liu Cape and the shoreline. This water area encompassing 25 square miles is referred to as the Keelung approaches.

3.2.1.2 Scope of period

Vessel casualties are relatively rare events[4]. The Keelung approaches cover a small area. The short term accident history contains too few accidents to obtain a reliable indication of future events. To obtain enough area-specific casualties for analysis, many years of data are required. Yet, over a long period, many factors that can affect the occurrence of casualties change. Especially, the TSS that was established in 1990, has changed the route patterns in the given area. Conversely long term records are considered unsatisfactory, since they do not represent the instantaneous reality. Therefore this chapter will present and analyse information relating to the number of vessel movements for the time period 1987 to 1991 inclusive to give the indication of the number of ships involved in casualties within the defined area.

3.2.1.3 Scope of casualty categories

The Casualty Returns published by Lloyd's Register of Shipping divides marine accidents into nine primary groupings[5]. There were other different explanations to define the marine accidents in some papers[6,7]. Generally, maritime casualties can be divided into two distinct groups according to their primary causes: traffic accidents and technical accidents. Collisions, groundings, and contacts are traffic accidents; founderings, explosions and fires, floodings are technical accidents. Tuovinen commented[8]:

> "The remedies against traffic accidents can be found in the development of the traffic situations and environment but the technical accidents call for technical developments of the ships."

This study is concentrated on the marine traffic operation in Keelung port. It is however possible to analyse the accidents relating to factors including human errors and adverse environment. Thus here the casualties covered are categorised by three major divisions:

a. Collision includes ships, underway under their own power, colliding with another vessel, whether underway, moored or anchored.

b. Grounding includes ships that had gone onto or gone against a shoal or an underwater reef, or run aground in the shore zone, where the shore area was visible above the sea surface.

c. Contact includes ships colliding with all objects other than other vessels or the bottom, e.g. hitting breakwaters.

3.2.2 Investigation of casualty data

It is an essential contribution to encompass all casualties from the trifling up to the most serious, as often major disasters have followed trivial events. Accidents occurring within harbours, rivers, canals or inland waters almost invariably involve special circumstances or local factors[9]. Nevertheless, the Marine Research Institute of Netherlands pointed out that it was very difficult to obtain sufficient data concerning the causes of accidents, the environmental conditions and the damage sustained[10], especially of those accidents which involved foreign vessels.

In the Keelung Harbour Bureau accident reports and protests including fishing boat accidents are not differentiated. There are many reports and protests without full information. The basic features of the accident reports in Keelung were the ship name and date of accident. Thus, the part-completed accident data base needed to be augmented by adding more data from the standard references. In circumstances where data on certain aspects were not found, entries were classified as, "not determined".

3.2.3 Definition of casualty data

1. Ship type and size

In the records three-quarters of the required data concerning ship's type and tonnage was available. The remainder was obtained from the Lloyd's Register of Shipping. In this study the ship type was categorised into container ship, general cargo ship, bulk carrier and tanker according to the Keelung Harbour Bureau's statistics. The general cargo ship includes all dry cargo ships, except container ships. There are various measures to describe the size of a ship. Gross tonnage is the most commonly used measure, not only for data on traffic statistics but also in most IMO conventions[11]. For the availability of the analysis ship size was divided into three groups:

a. Small size includes the ships with grt under 5,000.

b. Medium size includes the ships with grt between 5,000 and 20,000.

c. Large size includes the ships with grt more than 20,000.

2. Wind

Wind is an important factor in relation to navigational risk and its effect on local traffic patterns. The wind speed at which the navigation of a vessel is significantly affected clearly depends upon the size, shape and speed of the vessel. This implies that a range of different wind forces exists. In COST 301, a project carried out by European Cooperation on Science and Technology, two levels of wind force were adopted: wind up to 33 knots (Beaufort Force 7), and wind over 33 knots (Beaufort Force 8 and above). It was thought that when the wind was stronger than force 7, it might have a significant effect on the navigation of the average ship[12]. To emphasise wind effect, three levels of wind force were adopted in this study:

a. Wind up to 22 knots (10.7 metres/second)

b. Wind between 22 and 33 knots (10.7 and 17.1 metres/second)

c. Wind over 33 knots (17.1 metres/second).

3. Visibility

Reduced visibility is still a risk factor for ship traffic. When vessels arrive at the Keelung approaches, about five nautical miles off the breakwaters, the need for navigators to appreciate the traffic movement situation in whole area, encompassing the pilot station and entrance, is essential. Navigators obtaining timely information by sight can take better action to avoid risk than getting it from other navigational equipment. Therefore, the levels of visibility in this study of the casualties have been classified into three categories:

a. Clear weather, with a visibility greater than five miles

b. Restricted visibility, with a visibility range between two miles and five miles.

c. Poor visibility, with a visibility range less than two nautical miles.

4. Tidal current

It is believed that currents have an important effect on groundings and contacts, but little effect on collision accidents[13]. Unfortunately, most of the accident reports in Keelung lack current information. That information available appeared very poor in comparison with what was needed to arrive at sufficient conclusions.

3.3 STATISTICS OF CASUALTY DATA

The results of investigation obtained from the Keelung Harbour Bureau on traffic accidents in the defined boundaries of the Keelung approaches are summarized in Table 3-1. The accidents in which the vessel was a merchant ship of over 100 grt were considered. Among collision accidents a ship colliding with another at anchor was counted as two ships involved in one case, and a collision involving a merchant ship and a fishing vessel was considered as a case with one ship. It contains 29 collision cases, four grounding cases and six contact cases, and there were 61 merchant ships involved in the accidents. Compared with the total of 36,929 incoming ships, which called at Keelung during the five years from 1987 to 1991, the accident probability was 1.65 per 1,000 ships. The figures of the rate of ships involved showed variations from year to year. There was no significant difference to explain the tendency of accidents that occurred. The location of all above casualties are plotted in Figure 3-1.

Table 3-1 The number of casualties and ships (1987-1991)

	1987	1988	1989	1990	1991	Total
Collision	7 (12)	5 (9)	6 (12)	5 (8)	6 (10)	29 (51)
Grounding	2 (2)	1 (1)	0 (0)	1 (1)	0 (0)	4 (4)
Contact	1 (1)	1 (1)	0 (0)	1 (1)	3 (3)	6 (6)
Total	10(15)	7 (11)	6 (12)	7 (10)	9 (13)	39 (61)
Incoming Ships	6,977	7,243	7,572	7,623	7,514	36,929
Ratio	0.215%	0.152%	0.158%	0.131%	0.173%	0.165%

Remark: 1. Number of cases (Number of ships involved in the cases)
2. Ratio = Number of ships / Incoming ships.

Source: Author

According to Taiwan's regulations[14], any vessel, regardless of register, involved in an accident within the jurisdiction waters of the harbour must submit a report or a protest to the port authority for endorsement. Unfortunately collisions occurring in port areas usually result in only minor damage and are therefore less likely to be reported[15]. Sometimes the ship might submit the report at the next port because the office of the Bureau was closed during the period of vessel calling. Therefore the actual casualties could be higher than the figures given.

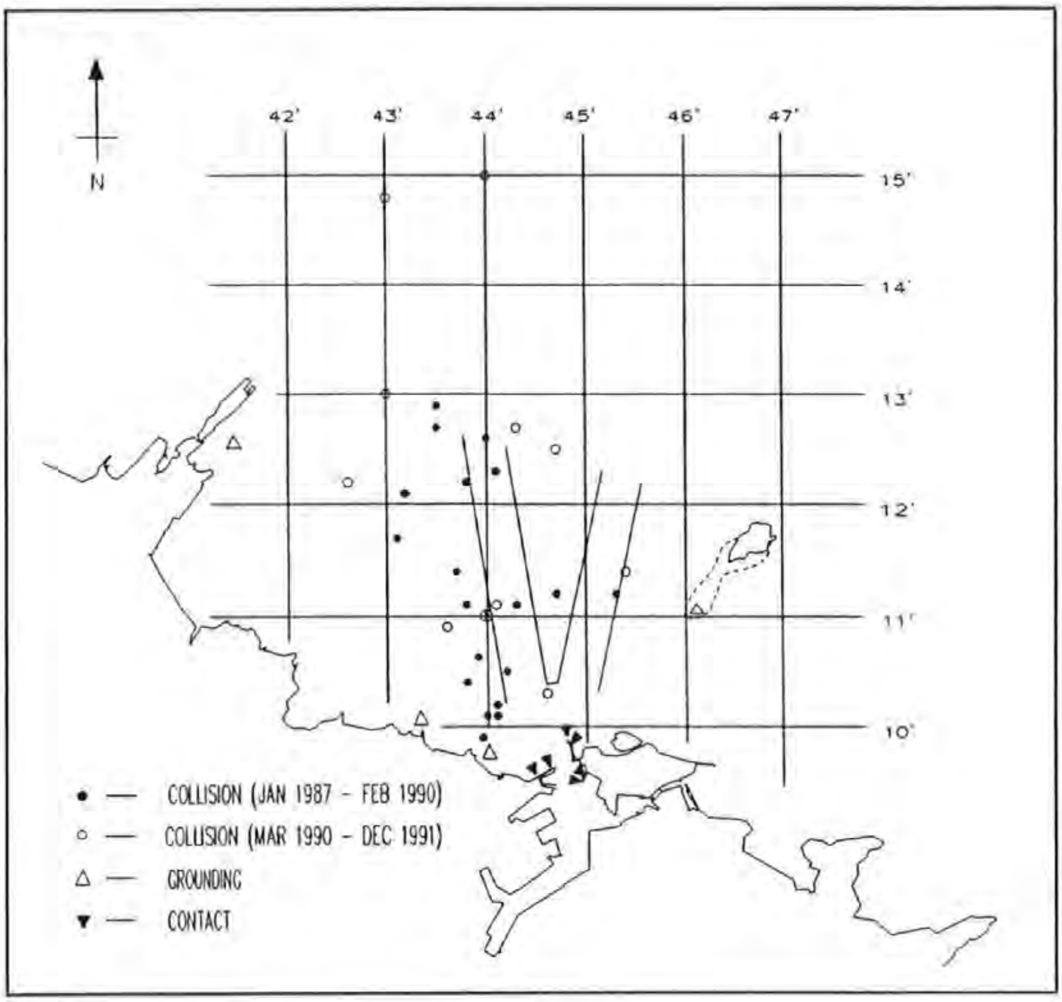


Figure 3-1 Casualty positions in the approaches to Keelung Port (1987-1991)
Source: Author

3.3.1 Effect of ship type and size

To categorise by type 61 ships involved in the accidents, it was found that 34 container ships accounted for 55.7% of all accidents (Table 3-2). Due to efforts of the port authority to establish new container piers and renew the facilities of container operation, container ships have been increasingly attracted to call at Keelung. During the five years of 1987-1991, 55.6% of visiting ships in Keelung were container ships. The ratio was equivalent to the proportion of container ships involved in accidents. The more container ships visited, the more accidents occurred with those. The general cargo ship and the bulk carrier were other types also significant in the accident records. General cargo ships comprised 35.6% of total traffic, but were involved in only 19.7% of the accidents. By comparison, bulk carriers experienced an accident rate three times higher than their share of the traffic.

Table 3-2 Accidents categorised by ship types (1987-1991)

Ship Type	Collision	Grounding	Contact	Total	1987-1991
Container	28 (54.9%)	0	6 (100%)	34 (55.7%)	20,544 (55.6%)
General Cargo	10 (17.6%)	2 (50.0%)	0	12 (19.7%)	13,162 (35.6%)
Bulk Carrier	10 (19.6%)	1 (25.0%)	0	11 (18.0%)	1,871 (5.1%)
Tanker	3 (5.9%)	1 (25.0%)	0	4 (6.6%)	1,352 (3.7%)
Total	51 (83.6%)	4 (6.6%)	6 (9.8%)	61 (100.0%)	36,929 (100.0%)

Source: Author

Table 3-3 shows the relationship between ship size and accident rates. The large ship appears significantly more prone to accidents than other groups. The previous chapter has shown the number of large container ships, bulk carriers and tankers calling Keelung has increased significantly. That large ships have a higher accident risk has provided a warning to the port authority of the need to improve navigational efficiency.

3.3.2 Casualty affected by circumstance

In order to assess the influence of environmental conditions on the number of casualties, it is necessary to relate these casualty parameters to the prevailing light condition, wind and visibility. Table 3-4, 3-5, 3-6 and 3-7 display the accident distribution under each environmental condition.

Table 3-3 Accidents categorised by ship gross tonnage (1987-1991)

Ship Size	Collision	Grounding	Contact	Total	1987-1991
Small ship	8 (16.0%)	1 (25.0%)	0	9 (15.0%)	12,580 (34.1%)
Medium ship	25 (50.0%)	2 (50.0%)	2 (33.4%)	29 (48.3%)	16,836 (45.6%)
Large ship	17 (34.0%)	1 (25.0%)	4 (66.6%)	22 (36.6%)	7,513 (20.3%)
Total	50 (83.3%)	4 (6.7%)	6 (10.0%)	60 (100%)	36,929 (100%)

Remark: One ship gross tonnage is non-determined.

Source: Author

Table 3-4 Accidents by time of day in Keelung (1987-1991)

Time	Collision	Grounding	Contact	Total
Day-time	11 (45.8%)	2 (50.0%)	6 (100%)	19 (55.9%)
Night-time	13 (54.2%)	2 (50.0%)	0	15 (44.1%)
Total	24 (70.6%)	4 (11.8%)	6 (17.6%)	34 (100%)

Remark: five cases are non-determined.

Source: Author

Table 3-5 Accidents by wind direction (1987-1991)

Wind Direction	Collision	Grounding	Contact	Total
North	6 (20.7%)	3 (75.0%)	2 (33.3%)	11 (28.2%)
North-East	12 (41.4%)	1 (25.0%)	3 (50.0%)	16 (41.0%)
East	6 (20.7%)	0	1 (16.7%)	7 (17.9%)
South-East	2 (6.9%)	0	0	2 (5.1%)
South	3 (10.3%)	0	0	3 (7.7%)
Total	29 (74.3%)	4 (10.3%)	6 (15.4%)	39 (100%)

Table 3-6 Accident by wind force (1987-1991)

Wind Force	Collision	Grounding	Contact	Total
< 10.7 m/sec	14 (48.3%)	0	5 (83.3%)	19 (48.7%)
10.7-17.1 m/sec	13 (44.8%)	2 (50.0%)	1 (16.7%)	16 (41.0%)
> 17.1 m/sec	2 (6.9%)	2 (50.0%)	0	4 (10.3%)
Total	29 (74.3%)	4 (10.3%)	6 (15.4%)	39 (100%)

Table 3-7 Accident by visibility (1987-1991)

Visibility	Collision	Grounding	Contact	Total
< 2 miles	3 (10.3%)	0	1 (16.7%)	4 (10.3%)
2 - 5 miles	11 (37.9%)	4 (100.0%)	3 (50.0%)	18 (46.2%)
> 5 miles	15 (51.7%)	0	2 (33.3%)	17 (43.6%)
Total	29 (74.3%)	4 (10.3%)	6 (15.4%)	39 (100%)

Source: Author

3.3.3 Damage cost

Casualties causing damage involve the ship owners in increased costs. From the Lloyd's Registration, 42 shipping companies, managing the 55 ships involved in the accidents at during the period, were found. Damage forms were mailed to those companies seeking damage information. Only 16 companies replied to the letter. Among them, 11 companies provided 19 ships' damage data. The few returned damage records and the diverse types of losses make the analysis of damage costs complex. To resolve the problem, this study divided the ship repair costs by US dollars into three groups for accident damage: less than $10,000, $10,000-$100,000, more than $100,000.

Table 3-8 indicates the repair costs that were derived from the response forms. The average cost in collision accidents was $203,600 including one bulk carrier which sunk with total loss. The costs by grounding or contact accidents were much higher than the collision accidents. One large tanker sustained $2,700,000 damage to the hull following grounding. Average repair cost of three contact ships was $1,110,000. When approaching a port, the ship speed has to be reduced from sea speed to manoeuvre speed. So the casualty damage in collision should be lighter than those occurring at sea. An examination of the Canadian Coast Guard's Casualty investigation showed that the damage casualties in the harbour were less serious on the average of all casualties; the repair costs were 48% of overall average[16].

The repair will take the ship out of service for several days, even several weeks with serious damage. From the response forms of shipping companies, there were four ships granted permission from survey to delay the repair until the annual refit, five ships delayed the service for repairs and one ship became a total lost. Excluding the total loss, the repair period of three collision ships was under one week with $7,900 for the average of loss of use, one aground ship for four months and one contact ship for six weeks. From the response letters, the hire rate of a 30,000 grt container ship was $24,000 per day, and a 10,000 grt container ship was $10,000 in 1990.

Table 3-8 Repair costs to the accident ships (1987-1991)

Cost	Collision	Grounding	Contact	Total
Less than $10,000	6	0	0	6
$10,000-$100,000	5	0	0	5
More than $100,000	4	1	3	8
Total	15	1	3	19

Source: Author

Among the accidents, there was one grounding case causing human death. Two people died during the rescue operation for the aground ship. Fortunately only one grounding accident caused slight oil spill in all cases which was cleaned up quickly. Regarding the effect to traffic movement, no report in the Keelung Harbour Bureau mentioned the fairway being blocked through ship accident.

3.4 ANALYSIS OF CASUALTIES

3.4.1 Collision accidents

Almost three-quarters of all accidents in the study period were collisions. Most collision cases were at the centre of the approaches within a 3-mile range near the entrance, the area of the greatest traffic density in Keelung port. Theoretically, the probability of collision increases with the traffic density. Captain Cockcroft pointed out[17]:

> "For traffic proceeding in random direction on a plane surface the frequency of collisions, if no avoiding action is taken, is approximately proportional to the square of the traffic density and directly proportional to the size and speed of the craft."

Before the TSS was established in 1990, the inbound and outbound ships encountered each other in the middle of the Keelung approaches, and most of the collisions occurred in the central section of the approaches. Since 1990, the ship encounters shifted to the outside area of the TSS. It was still found that collisions could not be avoided after the TSS was established during 1990-1991, and the number of cases was almost average in this two year period. Among the collision accidents, one collision case involving an inbound ship and an outbound ship occurred in the main channel sector, and two cases in traffic lanes involving a ship at anchor after the TSS was established. The accident colliding with an anchored vessel tends to be of high ratio. There were 17 cases (58.6%) involving a ship at anchor. Fishing vessels' obstacles caused some collisions. There were another eight cases (27.6%) involving a fishing vessel.

From the distribution of collision by ship type and size (Figure 3-2), 25 container ships (92.6%) and all 10 bulk carriers involved were medium and large size; all 10 general cargo ships were small and medium size.

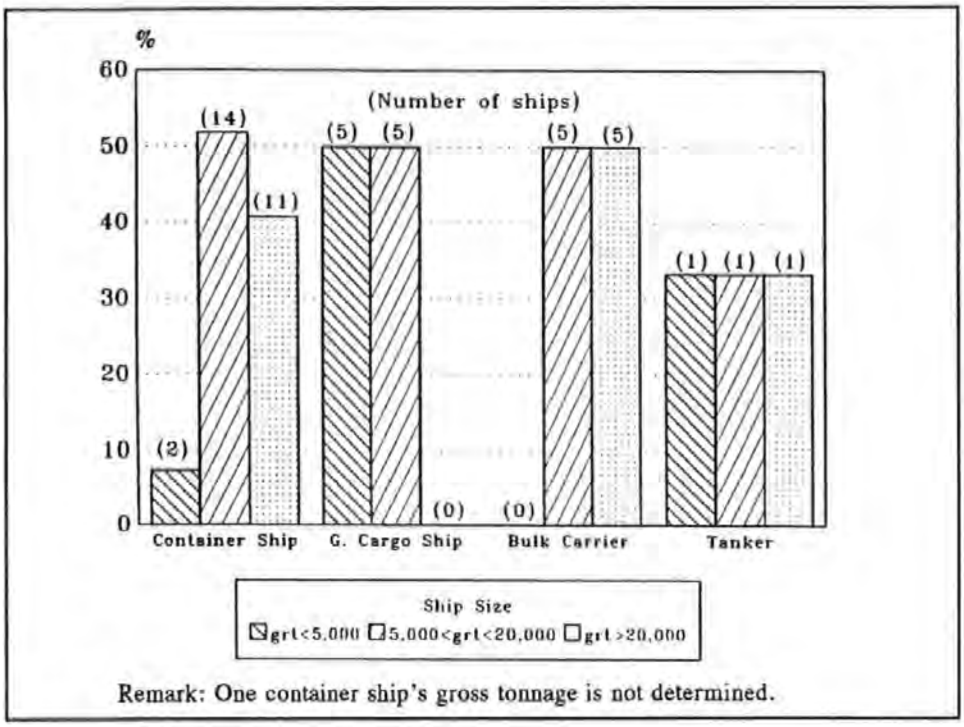


Figure 3-2 Ship type and size in collision accidents (1987-1991)
Source: Author

The daily distribution of the collision accidents at night-time was little more than at day-time. If traffic pattern was considered, there was 41.6% of traffic moving in the night-time[18]. Hence the distribution of collision accidents, 54.2%, seems a high ratio. 82.8% of collisions were under the N, NE and E winds. There was no significant finding relating wind force to collision. While during the five year period under review visibility less than two miles occurred on just 2% of days, 10% of collisions were during poor visibility.

From analysis of type and size of 51 ships involved in collisions, three in two cases happening under strong wind involved one medium general cargo ship, one large container ship and one bulk carrier; five in three cases happening under poor visibility involved three medium ships and two large ships (Figure 3-3, 3-4, 3-5, 3-6).

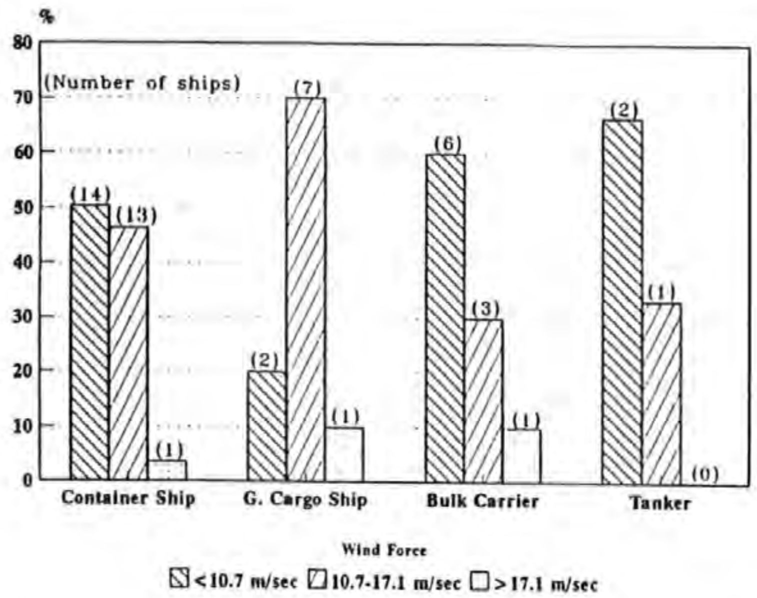
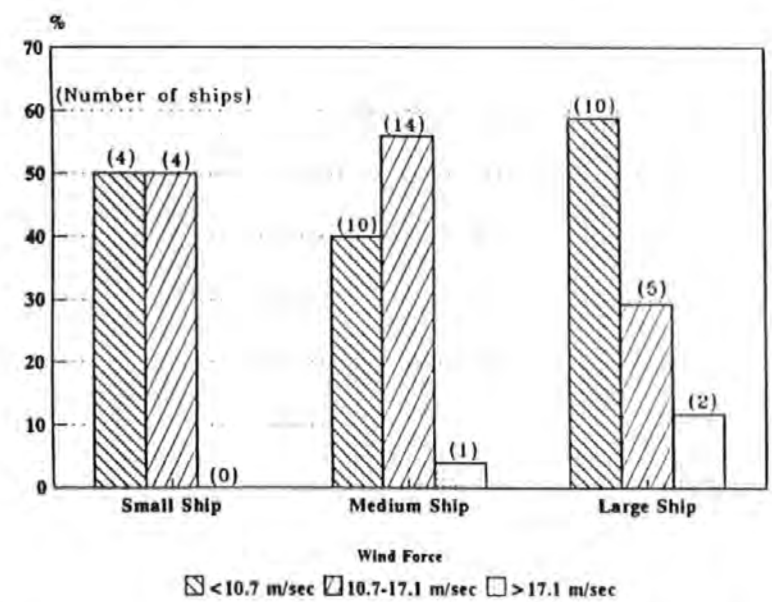


Figure 3-3 Distribution of ship type with wind force in collision accidents (1987-1991)

Source: Author



Remark: One container ship's gross tonnage is not determined.

Figure 3-4 Distribution of ship size with wind force in collision accidents (1987-1991)

Source: Author

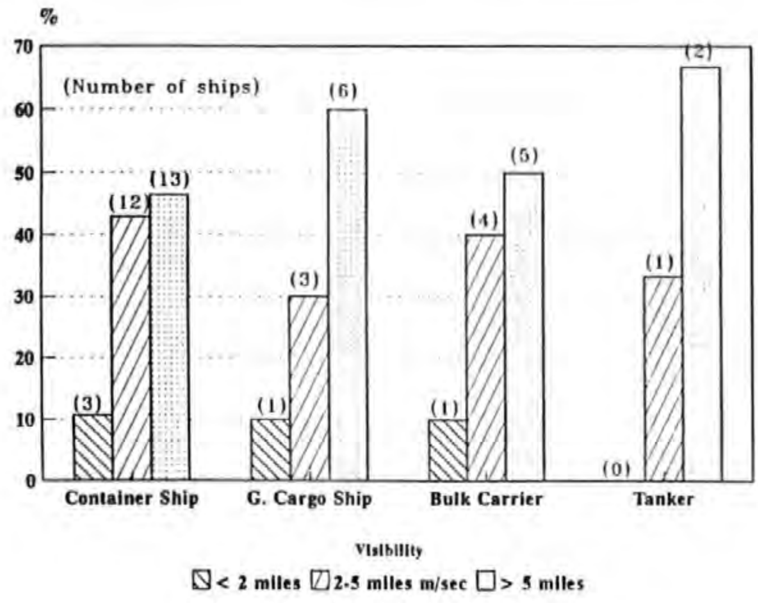
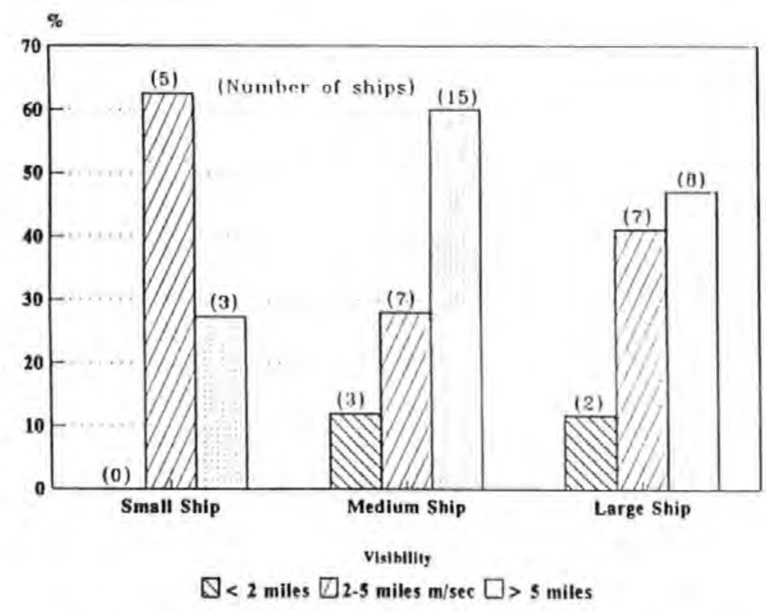


Figure 3-5 Distribution of ship type with visibility in collision accidents (1987-1991)

Source: Author



Remark: One container ship's gross tonnage is not determined.

Figure 3-6 Distribution of ship size with visibility in collision accidents (1987-1991)

Source: Author

3.4.2 Grounding accidents

During the study period the groundings had shown a considerable decrease. One grounding at the An-tou-pao shoal in five metres of water depth was remarkable. No container ship was involved in grounding. But all groundings occurred with the wind force over force 5 from N and NE, one of those by force 6 and the others over force 7. Strong wind has a significant effect on grounding rate. Two ships ran aground due to dragging the anchor under strong NE monsoon. Visibility did not influence the groundings.

3.4.3 Contact accidents

The sharp increase of contact accidents in 1991 might highlight the risk. The most obvious feature of the contacts is all of them involved container ships striking the breakwaters, two medium ships and four large ships. That all contacts happened to inbound ships in the day-time may be related to Keelung pilots mostly working inbound ships in the day-time. Wind was not significant to influence the contacts. Besides on contact with wind force 7, the other five contact accidents were under force 5. One accident occurred in poor visibility. Unfortunately no current information was provided for these accidents. A simulation test for ship's manoeuvring in Keelung port carried out by the Taiwan Ocean University commented as follows[19]:

> "A 25,000 grt container ship with full cargoes could safely pass the breakwaters by its ability under the good ship handling with current under 1.0 knots and wind under 25 knots. The navigational risk to strike the breakwaters will increases following the increase of current and wind force, especially with current over 2.5 knots and wind force over 30 knots."

3.5 CONCLUSIONS

Owing to the accident reports kept by the Keelung Harbour Bureau lacking uniformity there has been a significant lack of detailed information, however, from the available data, the following results of accident analysis can still give indications (Table 3-9):

a. Collisions constituted 74.4% of all accidents, and 58.6% of the collisions involved a ship at anchor, 27.6% involved a fishing boat.

b. Large and medium ships were involved in most collision and contact accidents, especially container ships and bulk carriers.

c. The component contributing to the collisions was poor visibility.

d. The component contributing to the groundings was the ship dragging under the strong NE winds.

e. The component contributing to the contacts was possibly the strong current.

f. Groundings and contacts caused the cost relating to ship repairs to be high.

Table 3-9 Factors relating to traffic accidents

Factors	Collision	Grounding	Contact
Container ship	X		X
Large ship	X		X
Night-time	X		
Poor visibility	X		
Strong wind		X	
Strong current			X
High damage costs		X	X

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CHAPTER 4

THE ANALYSIS OF NAVIGATIONAL RISKS

4.1 INTRODUCTION

Casualty analysis can identify factors relating to navigational risk, but there may be inconsistencies between different sources. The casualty data base for this study was relatively small and incomplete, and may not sufficiently cover some elements. In order to obtain a more comprehensive understanding of problems, within the area concerned, it was decided to complement the study by means of a questionnaire eliciting mariners' opinions. The investigation of mariner opinion is a participant observation, which is usually considered the basic method of qualitative research[1]. Learning from the experience of mariners is probably one of the most effective ways of preventing accidents. They are in a position to judge what happens to endanger navigation, and what information is valuable for safe passage planning and decision making on board. After all, the purpose of establishing any safety system is for assistance to mariners. In order to assessing the effectiveness of TSS, the results of the questionnaire will be compared with an analysis of radar observation survey.

4.2 QUESTIONNAIRE SURVEY

The construction of the questionnaire used in this research, shown in Appendix A, is in three parts :

A. Basic information of the respondents

- Function of respondent and type of vessel
- Recent experience calling at Keelung Port

B. Factors of navigation risk

- Risk factors at the outside area, the TSS area and the anchorage respectively
- Overall risk by area, season and light

C. Risk deduction

- Methods of improving marine safety
- Modification to the existing TSS

Every part provided the respondent with an opportunity to write a further interpretation for the answers given and to offer their suggestions. This chapter only concentrates on the part B, navigation risk. Regarding risk deduction, it will discuss in the next chapter.

4.2.1 Pilot study

Initially this research was evaluated by a field test. The results of the pretest were used to refine the questionnaire and locate potential problems in interpretation or analysis of the results. The pre-test of the research was carried out by five masters, two pilots and three maritime instructors in person. Their comments were embodied in the revised questionnaire.

4.2.2 Participants of the survey

Keelung is an international commercial port. The experience and technique of navigators on merchant ships are the most valuable sources in this study for assessment of the present risk. Although the approaches to the outer harbour are a non-compulsory pilot area, most ships request pilotage assistance due to the narrow entrance and to adverse weather. The pilot is primarily occupied with the safe and efficient navigation of the individual ship. Thus, pilots' opinions give other important information, and the pilot often provides specific information on their aspects of interest.

After the TSS was established in 1990, the traffic pattern was changed in the defined area. Masters of merchant ships that called at Keelung before 1990 provide their opinions to compare with the present situation data to assess the effectiveness of the TSS.

The survey commenced in April 1992. All questionnaires were anonymous and self-addressed envelopes were attached. Merchant ships calling at Keelung Port were given a copy of the questionnaire at random by Keelung pilots. Initially 200 questionnaire forms were used. In addition, questionnaires were sent to all 24 Keelung pilots. 40 forms were sent to masters ashore, chosen at random by the China Master Association.

4.2.3 Results of the survey

4.2.3.1 Distribution of sample groups

Of these 264 questionnaire, 161 were duly completed and returned before 31 August 1992, a response rate of 61.0%. There were 122 questionnaire samples collected from navigators who recently called at Keelung port with fulltime shipboard experience. The perception of the respondents can effectively explain the requirement of navigational safety for merchant ships within the defined area. The sea experience of the 122 samples ranged from one to 36 years. It would be impossible in the context of the present study to analyse a group mixing all navigators without considering the aspect of experience. Experienced mariners are less likely to pass dangerously close and hence less likely to spend unnecessary time increasing their miss distance, if already at safe distance. Thus, these respondent navigator were broken down into two occupational groups: a senior group comprising 67 navigators with more than 10 years experience, and a junior group of 55 navigators with 10 years experience or less (Table 4-1). The average of fulltime shipboard experience of the former group was 16.8 years, and the latter was 7.1 years.

Table 4-1 Distribution of questionnaire survey

Sample name of survey	Number of survey	Number of return	Rate of return	Group name of analysis	Number of analysis	Rate in total
Merchant ship	200	122	61.0%	Senior	67	41.6%
				Junior	55	34.2%
Pilot	24	10	41.7%	Pilot	10	6.2%
Former master	40	29	72.5%	Ex-master	29	18.0%
Total	264	161	61.0%		161	100.0%

Source: Author

The pilot was considered to be an occupational group. There were 24 pilots working in Keelung Port for service, but only 10 questionnaire samples were collected; the response rate was 41.7%. The pilot is in control of all the tasks with his experience based on local knowledge when working on board. In Taiwan, a pilot must have experience of at least three years working as master on merchant ship with gross tonnage more than 3,000. The average marine experience of the pilot group was 20.9 years. Another 29 masters, with a response rate of 72.5%, who visited Keelung Port by ship before 1990 meaning they had no experience of navigating in the TSS, was attributed to another occupational group, the ex-master group.

4.2.3.2 Distribution of ship's type and gross tonnage

The responses in the navigator groups of senior and junior navigators are affected by ship type and size. Naturally, it is important that the distribution of the returned questionnaire according to vessel type and size is in reasonable agreement with the traffic composition. The distribution of the 122 navigators were divided into four ship type groups including container, general cargo, bulk and tanker group, and three ship size groups including small, medium and large size groups. The definition of ship size coincides with that for the analysis of accidents in para 3.2.3. Compared with the distribution of ships calling at Keelung, the small ship proportion seemed low. Most general cargo ships were medium-sized, and all tankers were large-sized, shown in Table 4-2.

Table 4-2 The type and size of merchant ships in respondents

TYPE (Count / Row Percent / Column Percent)	less than 5,000	5,000 - 19,999	more than 20,000	Row Total
Container ship	5 5.0 62.5	36 36.0 83.7	59 59.0 83.1	100 82.0
G. cargo ship	1 14.3 12.5	6 85.7 14.0		7 5.7
Bulk carrier	2 20.0 25.0	1 10.0 2.3	7 70.0 9.9	10 8.2
Tanker			5 100.0 7.1	5 4.1
Column Total	8 6.6	43 35.2	71 58.2	122 100.0

Source: Author

4.2.4 Methods of statistics

Navigational safety is affected by many factors. By applying probability concepts, the analysis of data in samples can make a conclusion or inference about an entire population. From mariners' responses this study seeks to analyse the most dangerous factors influencing ships moving in the Keelung approaches by statistical methods, and in the meanwhile to find significant differences between the populations, if existent.

The state of a null hypothesis in this survey was that H_0: the populations of all groups are identical on the response of the variables in the questionnaire; the alternative hypothesis was that H_1: some of the groups tend to choose greater or lower scores than other groups. The significance level was established at 5% in two tail test. The non-parametric test was chosen to analyse the data in this survey because the sample size of the pilot group and ship type groups were small, and no evidence could prove the samples had come from normal distribution population. In some situations non-parametric tests are probably more powerful than the parametric tests, especially if the sample size is small[2]. The power of any test increases as the sample size increases. So a less powerful test could also be used with a larger sample size. There were two non-parametric test methods using for the null hypotheses test in this part, Wilcoxon-Mann-Whitney test and Kruskal-Wallis test. Analysis of response data was carried out by computer with the SPSS/PC$^+$ software package. The commands and procedures of the SPSS/PC$^+$ programme used in this research are shown in Appendix B.

4.2.4.1 Wilcoxon-Mann-Whitney test

The Wilcoxon-Mann-Whitney test, also known as the M-W test, is used to test whether two independent samples have been drawn from the same population. This is one of the most powerful of the non-parametric tests. The test requires only that the observations be a random sample and that values can be ordered. In the computation of the M-W test, all data of both samples are combined into ascending order and replaced by ranks from the smallest to the largest. The statistic for testing the hypothesis that the two distributions are equal is the sum of the ranks for each sample. If the populations have the same distribution, their sample distributions of ranks should be similar. If the average rank for one of the groups is very small (or very large), then there is reason to suspect that the two samples were not drawn from the same population[3].

For the M-W test in this survey, the responses in occupation groups were composed to six pairs, named senior/junior, senior/pilot, senior/ex-master, junior/pilot, junior/ex-master and pilot/ex-master respectively. Meanwhile, the responses of navigators were also composed to pairs depending on ship type and ship size. In ship type category, there were six pairs, named container/general-cargo, container/bulk, container/tanker, general-cargo/bulk, general-cargo/tanker and bulk/tanker; in ship size category, there were three pairs, named small/medium, small/large and medium/large. The M-W test was used to comparing the distribution of two groups in each pair.

4.2.4.2 Kruskal-Wallis test

The Kruskal-Wallis one-way analysis of variance (K-W test) by ranks is an extremely useful test for deciding whether three and more independent samples are from different populations. It is the direct extension of the M-W test, and in applying the K-W test, the data are also combined and replaced by ranks. The K-W test assesses the differences among the average ranks to determine whether these samples were drawn from the same population.

In this survey, every question was first tested by the K-W comparing the responses of four occupation groups, and also comparing those of four ship type groups and three ship size groups. If the result of probability was smaller than 5%, the null hypothesis had to be rejected, and significant difference was existing within the populations. Then the three (or four) groups had to be separated by two group as a pair and be tested by the M-W test to find which couples had significant difference between the groups. The responses were tested by the K-W test first, because the M-W test would make too many pairs and some would appear to be significant even when all population were equal. Multiple comparison tests could protect against calling too many differences significant[4].

4.3 ANALYSIS OF MARINER OPINIONS

In the questionnaire, part B investigated the risk perception. Question B1 asked respondents to what extent marine accident risks would be increased by certain risk factors, and question B2 asked respondents the risk associated with each geographical area, season and light condition.

4.3.1 Overall risk by area

In this survey the Keelung approaches were divided into three zones: outside the TSS, within the TSS and near the breakwaters, and within the outside anchorage, because traffic patterns and the navigational circumstance that mariners face differed within these zones after TSS was established. Theoretically, approaching or leaving the TSS a ship would encounter other crossing ships near the entrance. For an example, a inbound ship coming from Japan must cross course lines of ships bound for south-east Asia from Keelung. Within the TSS, movement follow directions of traffic lanes and the encounter in which ships meet each other in overtaking or being overtaken is simplified. At anchorages, the encounter is probably between a ship underway and a ship at anchor.

From the arithmetical means of response scores, all occupation groups significantly considered the area within the TSS and near the breakwaters to be the most dangerous area, and the figures were quite higher than other areas (Appendix C-1). They marked the risk was over moderate risk to that question. Most senior navigators (58.5%) and junior navigator (66.6%) judged that the risk was high or very high (Appendix D-2). Through the K-W test to examine the difference between the groups, no significance was found in this area (Table 4-3). That meant the responses from mariners of the four groups were identical. When the results were analysed with the ship type and size groups, the small ship group was with lower risk than the medium and large groups significantly, but no significant difference in ship type was identified through the statistical tests (Table 4-4). Thus most navigators working on larger ships, regardless of ship type, had the tendency to declare a higher risk in this area.

Table 4-3 The significance level by K-W test for overall risk

ITEM	Occupation group	Ship type group	Ship size group
B2. PERCEPTION ON OVERALL RISK			
Outside area of Traffic Separation Scheme	**0.0072**	0.6248	0.1012
Within area of TSS and near the breakwater	0.0886	0.0519	**0.0245**
Within area of anchorage	0.1216	0.1182	0.1969
January to March	0.3778	0.0802	**0.0048**
April to June	0.0706	0.4515	**0.0115**
July to September	**0.0016**	0.3436	0.2841
October to December	0.1209	0.3028	0.0763
During day-time	**0.0405**	0.7540	**0.0319**
During night-time	**0.0183**	**0.0071**	**0.0123**

Source: Author

Table 4-4 The significance level by M-W test for overall risk

Occupation group	S / J	S / P	S / M	J / P	J / M	P / M
Outside area of the TSS	0.7516	**0.0031**	0.8160	**0.0002**	0.9850	**0.0033**
July to September	**0.0434**	**0.0053**	0.8585	**0.0002**	0.1001	**0.0157**
Day-time	0.0585	0.1305	0.7188	**0.0151**	0.0607	0.2211
Night-time	0.3774	**0.0136**	0.3713	**0.0030**	0.1002	**0.0421**
Ship type group	**C / G**	**C / B**	**C / T**	**G / B**	**G / T**	**B / T**
Night-time	**0.0031**	0.3133	0.0729	**0.0504**	0.6479	0.3234
Ship size group	**S / M**	**S / L**	**M / L**			
Within area of the TSS	**0.0331**	**0.0091**	0.2914			
January to March	**0.0342**	**0.0037**	0.0577			
April to June	**0.0383**	**0.0059**	0.1236			
Day-time	**0.0448**	**0.0073**	0.4480			
Night-time	0.2033	**0.0115**	**0.0334**			

Group symbol: Occupation S- Senior J- Junior P- Pilot M- Ex-master
Ship type C- Container G- General cargo B- Bulk T- Tanker
Ship size S- Small M- Medium L- Large

Source: Author

4.3.2 Overall risk by season

All occupation groups indicated that the overall risk during the winter and spring months, from October to March, was higher than the summer and autumn months, from April to September (Appendix C-1). The same result was also reflected on the ship type and ship size groups. The distribution revealed that about 70% of respondents in navigator groups considered high risk or very high risk during spring and winter. In both of the two seasons, 60% of pilots commented on high risk (Appendix D-4, D-7).

Through K-W test to compare the mean rank of occupation groups in each season, no significant difference was found in spring and winter months. With the same tests to ship type and ship size groups, no significant difference was found within ship type groups, but significant differences within ship size groups was found in spring. The responses of the large ship group indicated higher risk than those of the small ship. Consequently, no matter the ship type, most users considered navigation in the Keelung approaches had high risk during spring and winter than in summer and autumn.

4.3.3 Overall risk by time of day

The means of responses by all groups revealed navigation with much higher risk during night-time (Appendix C-1). Significant difference within the occupation groups was found at night-time. Pilot's scores for night-time, although 90% with moderate and high risk, were lower than other groups' scores. From the navigator groups, there were significant differences found in ship type and size categories. For night-time risk, respondents from container ships indicated higher risk than those from general cargo ships. Similarly, respondents from small ships selected lower risk than those from large ships. Through M-W test, pilots seemed to have more confidence to manoeuvre ships in night-time. General cargo group and small ship group had significant differences from other groups in each category with lower risk.

4.3.4 Factors of risk

When investigating the dangerous factors to navigational risk, it found nearly all occupation groups ranked poor visibility, fishing vessel congestion, strong wind and strong current as the four most dangerous factors to ships navigating in Keelung approaches (Appendix C-2, C-3, C-4). The mean scores of these four factors were higher than other four factors.

Within the area of TSS and near the breakwaters, these four dangerous factors were consistently weighted similarly by each occupation group, although the mean scores in pilot group were higher than those in other groups. This indicated the factors often increase risk, especially poor visibility and strong wind. When comparing navigator responses with ship type and size, the four factors mentioned above still kept the most dangerous place with different sequence. Significant difference within occupation groups was found in factor of strong wind by K-W test for this area (Table 4-5). Then through M-W test to compare each pair, pilots had a higher risk perception on strong wind than senior navigators (Table 4-6). Through the tests, navigators on container ships had higher risk perception than those on tankers for the factor fishing vessel's congestion. No significant difference was found in ship size groups.

Table 4-5 The significance level by K-W test for area of TSS

ITEM	Occupation group	Ship type group	Ship size group
B1. PERCEPTION ON RISK FACTORS			
2. Within area of the Traffic Separation Scheme and near the breakwater			
High density of traffic	0.4623	**0.0067**	0.8700
Fishing vessels in shipping lanes	0.8627	**0.0169**	0.5549
Strong currents	0.6017	0.2030	0.9106
Poor visibility (fog, rain)	0.1044	0.2247	0.8834
Strong wind	**0.0332**	0.3665	0.7322
Shallow water	0.0603	0.1789	0.9443
Natural underwater hazard	0.1029	0.1890	0.7969

Table 4-6 The significance level by M-W test for area of TSS

Occupation group	S / J	S / P	S / M	J / P	J / M	P / M
Strong wind	0.0897	**0.0070**	0.3158	0.0566	0.7382	0.0530
Ship type group	**C / G**	**C / B**	**C / T**	**G / B**	**G / T**	**B / T**
High density of traffic	**0.0266**	0.2202	**0.0082**	0.3246	0.4811	0.1232
Fishing vessels in area	0.0790	0.1651	**0.0127**	0.6361	0.2350	0.1072

Group symbol: S- Senior J- Junior P- Pilot M- Ex-master
C- Container G- General cargo B- Bulk T- Tanker

Source: Author

There were interpretations from the questionnaire of personal perceptions regarding risk factors in Keelung approaches as follows:

a. The signal station often advised two or three ships to meet at the pilot station at the same time for pilot boarding without giving any entering sequence.

b. Under strong wind and seas, the ship had to enter the port under the master's handling to pick up the pilot, when the pilot boat could not overcome the seas.

c. The long waiting times for the pilot increased risk.

d. Many ships contravened the regulations preventing collision, and anchored within the traffic lanes.

e. Fishing vessels in the vicinity of shipping routes were a great danger to navigators, especially during poor visibility.

f. Navy ships having the priority to enter caused all merchant vessels immediately had to stop moving to wait for permission again, without any regard to danger.

g. Communications between ship and shore were defective.

h. There was no official anchorage designed for merchant ships.

4.4 ANALYSIS OF RADAR OBSERVATION

The investigation of traffic flow in the vicinity of Keelung was carried out, with a mobile radar from 6th to 9th of March 1992, by the Marine Transportation Department of Taiwan Ocean University acting in collaborating with this study. The author joined this investigation and obtained raw data for analysis.

During the continuous period of 96 hours, there were 78 inbound ships arriving at Keelung comprising 38 ships entering the harbour directly, and 40 ships stopping to anchor. There were another 22 ships, which included some of the 40 anchoring ships mentioned, entering the harbour from the anchorage. Sixty-nine outbound ships were identified. Among the outbound tracks, only one was stopped outside the breakwater (Appendix E). Because the ship tracks were transferred from data which only included ship's bearing and distance from the observation point written down by hand, some data was incomplete and has been deleted. The ship numbers observed is, therefore, less than the average number of calling ships mentioned in para 3.2.2.

4.4.1 Traffic flow

To analyse the traffic flow, a base line is established. The line crosses both the start point of the inbound lane and the end point of the outbound lane from the northern end of Yeh-liu Cape to Keelung Island, where it is 4.2 miles wide. The northern water of the base line was divided two 90-degree section, named NW, and NE respectively. From the radar observation, the proportion of the inbound ships and outbound ships passing through the NW section was 64.1% and 60.3% respectively; through the NE section was 35.9% and 39.7% (Figure 4-1). The distribution of traffic flow from radar observation was very close with that from governmental statistic data[5].

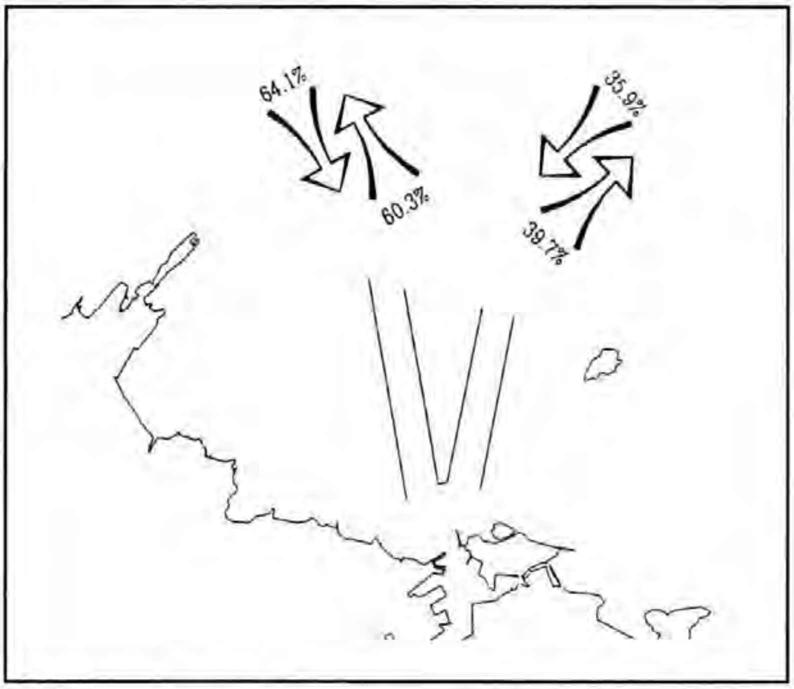

Figure 4-1 Distribution of ship directions
Source: Author

To evaluate the efficiency of the TSS, the base line is divided into 10 sections, section 5 encompassed the inbound lane and section 8 encompassed the outbound lane. Among the inbound ships, except the ships directly entering the harbour, 35 anchoring ships and three ships from anchorage passed the base line (Figure 4-2).

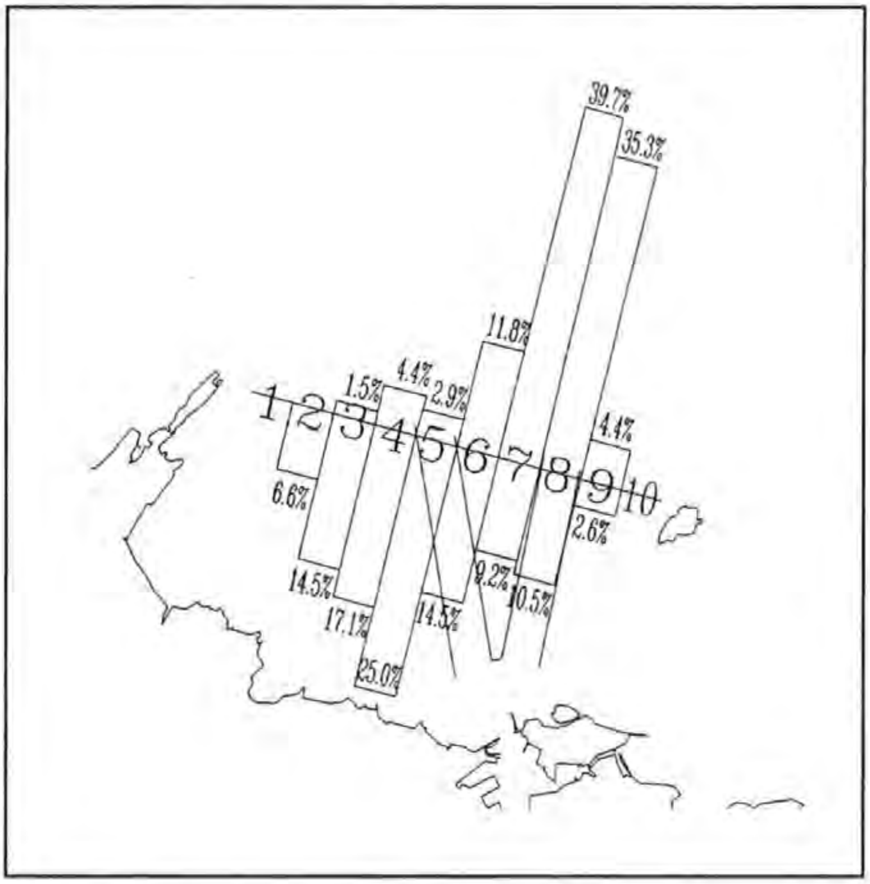

Figure 4-2 Distribution of ships passing the base line
Source: Author

There were 13.1% of inbound ships passing the line within section 8 and 9, and 8.8% of outbound ships passed within section 3, 4 and 5 (Table 4-7). That means those ships crossed the opposite traffic lane. All of them travelled from the NE sector or toward the NW sector. Another 23.7% of inbound ships and 51.5% of outbound ships passed the line within section 6 and 7 which is between both lanes. Those ships might encounter each other within the area between two lanes in a head-on meeting. It is also found that ships drifted at the pilot station hindering other ships' movement. Among the 38 ships directly entering there were six ships that drifted to wait for the pilot more than 30 minutes. One of them arrived at the pilot station then turned outward passing the base line and entering again.

Table 4-7 Distribution of ships crossing base line

SECTION	1	2	3	4	5	6	7	8	9	10	Total
Directly entering ships											
Number	0	0	2	4	11	10	5	5	1	0	38
Per cent			5.3	10.5	28.9	26.3	13.2	13.2	2.6		100
Anchored ships											
Number	0	5	7	9	8	1	1	3	1	0	35
Per cent		14.3	20.0	25.7	22.9	2.9	2.9	8.5	2.9		100
Entering from anchorage											
Number	0	0	2	0	0	1	0	0	0	0	3
Per cent			66.7			33.3					100
TOTAL OF INBOUND SHIPS											
Number	0	5	11	13	19	12	6	8	2	0	76
Per cent		6.6	14.5	17.1	25.0	15.8	7.9	10.5	2.6		100
TOTAL OF OUTBOUND SHIPS											
Number	0	0	1	3	2	8	27	24	3	0	68
Per cent			1.5	4.4	2.9	11.8	39.7	35.3	4.4		100

Source: Author

The ship speed analysed while ships were passing the base line is shown on Table 4-8. It is found that the outbound ships have higher speed than the inbound ships. Among the inbound ships, the speed of the ships entering directly is higher than that of the ships to anchor. The anchoring ship has to stop the movement after passing the base line, but the ship directly entering keeps a slow speed to pick up the pilot and then increases speed to pass the breakwaters.

4.4.2 Location of ship anchoring

The figure 4-3 shows the location of 40 ships at anchor. Most of ships anchored at the west area of the TSS, four ships within the inbound traffic lane, and some ships near the boundary of the lane. For avoiding risk of dragging to ground, they kept more than one mile off shore for safe distance.

Table 4-8 Ship speed crossing the base line

	Directly entering ships	Anchored ships	Entering from anchorage	Total inbound ships	Total outbound ships
Number	38	35	3	76	68
Means	9.32	7.88	5.81	8.51	11.21
St dev.	3.12	3.08	1.37	3.16	2.93

Source: Author

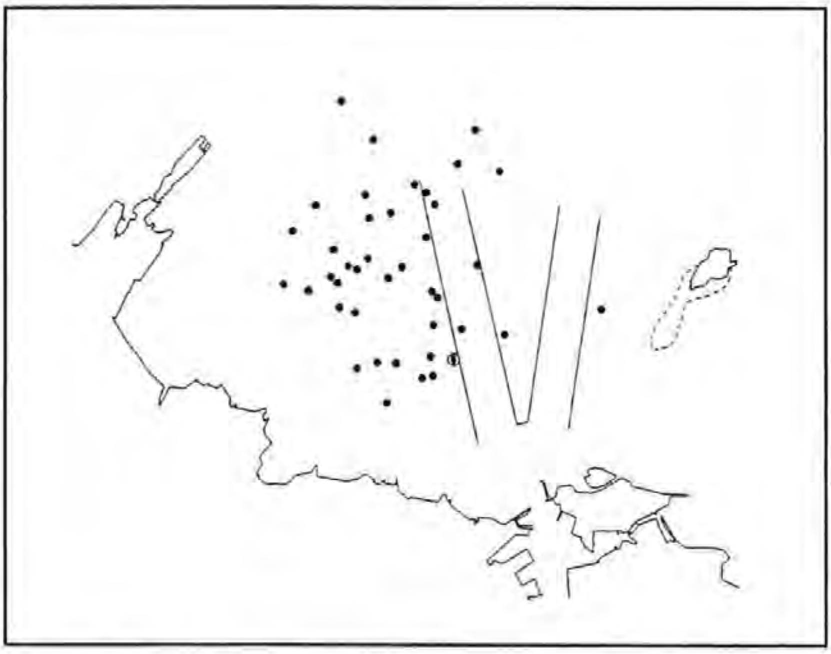

Figure 4-3 Locations of ships dropping anchor
Source: Author

4.5 FACTORS OF NAVIGATIONAL RISK

From the analysis of marine casualties, mariner opinions and radar observation, navigational risks in Keelung approaches emerged. Generally speaking, those risks could be attributed to three factors: geographical factor, human factor and environmental factor.

4.5.1 Geographical factor

The accident records in Keelung revealed many collision cases involving anchoring ships and fishing vessels. Keelung approaches, about five miles in width, is used by merchant ships and fishing vessels. The navigable water in this area is constrained. When designating a fairway for ships moving, a port authority also needs to consider providing sea room for ships anchoring in safety. The water depth in Keelung approaches is over 40 metres in the outside anchorage, and deeper at northern area of the approaches. Except this area, there is no safe area in the vicinity of the port for anchorage. Therefore, without alternative, the TSS is designated at the east side of the approaches, and the width of traffic lanes is constrained. The west side is left for anchorage, although there is not an official anchorage and not very suitable for anchoring under adverse weather.

In the recent years, following the increase in the number and size of merchant ships calling at Keelung, higher traffic density causes the movement of several ships simultaneously in the narrow channel, increasing collision risk. Meanwhile there has been an increase in the number of anchoring ships due to port facilities not being sufficient for all arriving ships to berth directly. From radar observation, the number of anchoring ships was often about ten in that small anchorage. The presence of ships anchoring reduces the traditional margins of safety on turning areas, and increases the potential for accident.

4.5.2 Human factor

4.5.2.1 Violation of TSS regulations

The area within the TSS and near breakwaters was consistently recognized as the most dangerous water at Keelung for navigation by all users in the questionnaire. There was no difference between the navigator and ex-master groups, and the mean score of the former was even higher than that of the latter. That indicated the risk in that area has not effectively improved since the TSS established. The purpose of establishing TSS is to simplify the patterns of traffic flow and then decrease the risk of the potential encounter leading to collision[6]. But contravention of the Regulations for Prevention Collision at Sea (COLREGS) in Keelung: such as ships anchoring in the lanes causing collisions, fishing vessels congesting in the lanes to obstruct ship's movement, ships moving in the opposite lane, causes ships moving in the lanes still having to cope with encounters.

Det Norske Veritas reports human navigation errors composed the largest percentage of causal factors in accidents involving Norwegian registered vessels during 1970-1978[7]. The most frequent error, with a 23.4% incidence rate, was violation of COLREGS. Other researches also found violation in TSS influenced navigational safety[8,9]. These studies indicated the violation threatened the safety of ships complying with the TSS regulation, and increased accident risk. Collision risk in Keelung has grown because of higher traffic density. The increasing encounter probability in traffic lanes causes dangerous situations. Radar observation revealed the contravention ships become a serious risk factor to navigation. The chief pilot in Keelung pointed out in the questionnaire:

> "The TSS has been established for two years, but many masters contravene the regulations for TSS, and the fishermen still work by the same means without any knowledge about the regulations. If they cannot be managed, the TSS functions will be reduced, and the accident cannot be prevented."

4.5.2.2 Port operation defection

From radar observation some ships linger in the traffic lanes for more than half an hour. That is prohibited by the TSS regulation of Keelung port. There are two reasons for such lingering: one is waiting for pilots, the other is waiting permission from the signal station to enter the port. Without an explicit time for pilot boarding, or due to a navy ship having priority, the inbound ship probably faces drifting in the restricted area. When inbound ships converge simultaneously at the pilot station collision risk increases. One collision case in 1987, causing great damage, involved two ships waiting for pilots.

Another factor is optional pilotage permitting inbound ships to pass through the main channel without a pilot. Most masters are not familiar with the port and local environmental conditions. They may not recognize the potential risk in Keelung. For ships entering the port, the manoeuvring in the narrow channel between breakwaters is very dangerous without pilots. The risk of contact with the breakwaters threatens all calling ships. In 1991 one large container ship colliding with the inner breakwater was under master's handling.

4.5.3 Environmental factors

Ships in transit in the coastal area are exposed to the variable effects of tidal current, reduced visibility, wind and sea states. These factors cause serious navigational risk. According to the users' view in questionnaire, poor visibility, strong wind and strong current are the major risk factors to navigation in the approaches.

4.5.3.1 Restricted visibility

An investigation into navigational safety near the Taiwanese coast in 1989 found poor visibility was the major risk factor[10]. The concern about the risk by poor visibility is related to the higher risk perception in spring, the foggy and rainy season in Keelung. Collisions occurred consequently due to the encounter of two or more ships which were clearly unable to take effective action in the time available. Within the confined sea room, it would be difficult for the ship to take proper and effective action to avoid collision timely under restricted visibility. An analysis of marine accidents in London and Mersey ports (1968-1970) indicated risk of incident was between four and ten times higher in fog[11]. Restricted visibility was reportedly a factor some 35% of sea collisions world-wide. Cockcroft commented that the risk of collision is greater for encounters between vessels proceeding in opposite directions in poor visibility[12]. Therefore the ship of violating TSS regulation in Keelung will increase collision risk during poor visibility. That is confirmed in the collision records in Keelung.

The respondents of questionnaire also agreed a higher risk at night when human judgement is affected by darkness. At night identifying other ship movements by sight is more difficult than by day. According to Cockcroft's study collisions by night are twice as frequent as those by day. Pilots have gained their expertise with experience and local knowledge in navigating the vessel through the area so that their comments on risk at night were lower than navigators.

4.5.3.2 Strong wind and current

In winter the strong NE monsoon wind in Keelung increase the risk to ship grounding due to wind direction toward shore. It was found in grounding records that the probability of grounding was higher under strong wind. Radar observation revealed anchoring ships kept one mile distance from the shore to reduce the risk from wind effect. That decreases the availability of the small anchorage and increases ship density leading to collision risk. Cross currents in the approaches may also cause the ship to drift off the course line.

The influence of wind and current on manoeuvring is a recognized accident causal factor. Large vessels, especially container ships when in light condition are less manoeuvrable in strong winds and currents[13]. A vessel which is stopped will tend to lie with the wind approximately abeam, but may drift as much as 60 degrees off the downwind direction[14]. Movement of unassisted vessels is generally controlled by the action of propellers and rudders. The higher the speed, the more rudder effect produced. Allowing for the influence of wind and current at low ship speeds is often difficult. Through analysis of the questionnaire, it was found that navigators on large container ships and bulk carriers had higher risk perception to strong wind. Pilots also recognized that strong wind within the TSS increases risk. The result could be related with the pilot's work environment. When an inbound ship moves in the vicinity of the pilot station, the speed has been changed to manoeuvring speed and reduced to under five knots for pilot boarding in comply with the port regulation. Manoeuvring the ship at low speed in restricted channels tends to be more affected by wind and current. This risk will increase when more large container ships call at Keelung.

4.6 CONCLUSIONS

From the responses and comments in questionnaire, mariners pointed out their perceptions regarding risk in Keelung. The most dangerous area in the approaches is within TSS and near the breakwaters. During spring and winter, and at night, all mariner had higher risk perception. The most important factors to affect navigational safety were poor visibility, strong winds and currents, and fishing vessels congesting. From radar observation, many ships navigated in the opposite traffic lane, and anchored in the lanes. Combining these results with accident records, the factors increase navigation risks are: higher traffic density being constrained by narrow navigable water, ships violating TSS regulations, ships drifting near pilot station and main channel, poor visibility in spring, strong NE monsoon in winter, and strong cross current.

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CHAPTER 5

METHODS OF RISK REDUCTION

5.1 INTRODUCTION

From the preceding chapters, factors of risks to navigation at Keelung approaches are identified Keelung port authority should recognize that their efforts to improve safety run short of mariner requirements. The trend of the shipping market shows growth in large container vessel services. If the risks at Keelung are not reduced, the possibility of marine accident may increase as large container ships are at high risk. The port authority holds the key to finding a solution to the problem, and needs to improve on port operation. This study is concerned not only with identifying existent navigational risks, but also means of reducing the risks. Measures for improving safety adopted elsewhere in the world, and mariner opinions, are good references for this study.

5.2 LITERATURE REVIEW

Historically, the responsibility for navigational safety has largely rested with ship owners. Over the past twenty years accidental spillage of oil, due to marine traffic accidents, has often caused great damage incurring social costs. Increasingly the burden of responsibility has shifted towards coastal states and port authorities to establish effective systems, aimed at producing acceptable levels of vessel safety and incident prevention within their areas. In addition to visual and electronic navigational aids, traffic separation schemes (TSS) and vessel traffic services (VTS) have been established throughout the world to assist safe navigation.

5.2.1 Effectiveness of TSS

High traffic density demands an organised system of routeing. TSS is the most useful routeing system. In addition to providing a one way traffic route for ships and removing head-on encounter, TSS also separate traffic flow from dangerous water in areas of convergence. For accurate position fixing within a scheme, there should be adequate marking by buoys. The statistics for collisions and groundings show a gradual decrease after establishment of a TSS, and there has been a considerable decrease of meeting collisions in the separation areas. The decrease can be attributed to the effects of TSS[1,2].

But the effectiveness of TSS can be reduced by 'rogue' vessels that fail to comply with the scheme. Where traffic separation is not in force, the number of meeting situations may be expected to be of the order of three times the number of overtaking situations. It has long been appreciated that narrow angle encounters between ships on opposite or nearly opposite courses present the greatest collision risk. Therefore, radar surveillance systems have been introduced to monitor traffic and improved the traffic discipline. Emden stated[3]:

> "A Traffic Separation Scheme, without surveillance and without a coordinating information service, was inadequate for the dense and complex maritime traffic problems."

5.2.2 Effectiveness of VTS

In harbour approaches a vessel may experience high traffic density within close proximity to shallow water and other obstructions. Improved information decreases risk. Passive aids, such as visual aids and TSS, provide only one part of the information needed by the navigator, and do not provide mariners with full knowledge of the ever-changing interactions between vessels[4]. When passive aids cannot effectively reduce navigational risk, assistance given from the shore providing interactive dynamic information is of greater benefit to the navigator. VTS is such an interactive navigational aid.

The functions of a modern VTS are: (a) surveillance; (b) radio communications; (c) identification (d) information; (e) monitoring; and (f) obtaining general information such as the position of navigation marks. It often includes some means of area surveillance, a traffic separation scheme, perhaps a vessel movement reporting scheme, a traffic centre, and, of necessity, some method of enforcement that can increase a specific level of safety and traffic efficiency. Hence, TSS and visual aids to navigation may be elements of, but do not constitute, VTS. The addition of radar surveillance provides a means to monitor compliance with and effectiveness of any traffic scheme. The shore-based radar system can identify the ships and survey the traffic situation to give a useful tactical warning about ships apparently contravening the separation scheme, about the progress of hampered shipping, about concentration of shipping and about other transient hazards.

Since the shore control centre has VHF and shore based radar, even in the most restricted modes of operation, these can be used for obtaining estimates of the future movements of vessels. Further, the accurate position of a ship can be sufficiently determined so that advice can be given to the ship from the shore in an emergency. The Marine Research Institute of Netherlands concluded that in areas with a busy and complicated traffic pattern, intensive offshore activities involving noxious or dangerous cargoes, navigational difficulties, and environmental sensitivity, the implementation of a VTS should be seriously considered[5].

Figures regarding the effect of the Channel Navigation Information Service (CNIS), one kind of VTS at the Dover Strait, showed that since the implementation of this service, the number of rogues contravening the TSS in the Dover Strait had decreased from approximately 40 per day in 1972 to approximately 6 per day in 1982[6]. Captain Cockcroft analyzed the collisions in the Dover Strait during the period 1957-1981[7]:

> "The incidence of collisions between vessels proceeding in opposite directions has been reduced to approximately 10% of the incidence before TSS was introduced in this area; There have been no collisions between vessels proceeding in opposite directions within the traffic lanes since 1972 when the CNIS into operation."

The proven value of VTS in increasing safety factor in sensitive areas was identified by two research projects: Canadian Vessel Traffic Services and European Co-operation on Science and Technology (COST-301), assessing the effectiveness of existing VTS systems in Canada and Europe respectively[8]. The Canadian Coast Guard undertook their project from 1977 to 1984. The success of VTS in reducing marine risk was shown to be widespread. For complex traffic situations in confined waters, the VTS effectiveness by bridge-to-shore broadcasting system with restriction regulation in reducing accidents was 35%. The system was more effective with radar surveillance and automated analysis. The maximum effectiveness for the most sophisticated VTS system when considering collisions, rammings and groundings was assumed to be 70%. The VTS effectiveness percentages determined are shown in Table 5-1.

Table 5-1 VTS effectiveness percentages

VTS System	Water Attributes			
	Open Waters		Confined Waters	
	Simple Traffic Patterns	Complex Traffic Patterns	Simple Traffic Patterns	Complex Traffic Patterns
Bridge-to-Bridge	12	10	15	10
with TSS/MRR	35	25	20	15
Ship-to-Shore	35	20	40	30
with TSS/MRR	40	30	45	35
Ship-to-Shore plus basic Radar Surveillance	45	50	45	50
with TSS/MRR	55	55	55	65
Ship-to-shore plus basic Radar Surveillance plus Automated Analysis	55	65	50	55
with TSS/MRR	65	70	60	70

Remark: TSS (Traffic Separation Schemes) are not viable in confined waters.
MRR (Movement Restriction Regulation) is assumed to have a significant effect in confined water areas only.
Source: Vessel Traffic Services (Canadian Coast Guard)

COST-301 was undertaken by the Council of the European Communities co-operating during the four-year period, 1983-1986, in an effort to reduce collisions and groundings in European waters[9]. From the experimental results, the summary of VTS effects on collision and stranding avoidance is as follows:

a. With VTS, ship-ship communications increased dramatically, particularly when other ships had been identified by name.

b. A VTS was considered helpful in clarifying the intentions of other ships and in reducing ship-ship collision risks.

c. Identification of ships was an important factor. Not only did it improve the speed and effectiveness of communications but it also assisted in enforcement of rules.

d. A VTS may be able to provide advance warning of local hazards, and perhaps advise the navigator of the ship on a course of action to follow.

e. For those ships with cross-current, the effect of VTS was significantly to reduce cross-track deviation from the centre-line.

f. For ships in poor visibility, VTS had the effect of reducing cross-track error.

g. The levels of effectiveness were derived and given in Table 5-2.

Table 5-2 VTS effectiveness on reduction of casualties

VTS Level	% Reduction in Casualties	
	Collisions	Strandings
VTS with VHF communications	30	0
VTS with VHF communication and a single radar installation with automatic processing	40	40
VTS with VHF communications and five radar stations with automatic processing	40	40

Source: COST 301 Final Report

5.3 MARINER OPINIONS FOR RISK REDUCTION

In the questionnaire mentioned in Chapter 4, the part C investigated what extent certain measures would improve marine safety at Keelung port. Meanwhile, the suitability of the TSS is evaluated from the responses.

5.3.1 Methods contributing to safety improvement

In question C1, eight options offering improved safety, aimed directly at the risk factors, were indicated in the questionnaire as follows:

a. Institution of speed limits in traffic lanes

b. Improved provision of weather information

c. Improved control over fishermen in traffic lanes

d. Improved control of ship sequence at pilot station

e. Stricter enforcement of ship safety regulations

f. Upgraded fixed and floating aids

g. Upgraded shore based electronic navigational aids

h. Provision of Vessel Traffic Services.

According to the mean responses of navigators, any of these options could reduce risks and achieve safety improvement. Among the options, they emphasised the safety improvement by control of ship sequence at the pilot station, provision of vessel traffic services, improvement by control over fishermen in traffic lanes, and enforcement of ship safety regulations would be significant. Although individual rankings varied nearly all respondents placed these four options at the top of their choice of methods. Provision of VTS was received with particular approval by the junior group. Beyond the above four options, upgraded visual and electronic navigational aids were identified as second priorities (Appendix C-5).

Pilots gave first priority to the same options, but provision of VTS received only moderate approval with a large standard deviation, revealing inconsistency between the pilot opinions. The remaining four options were rated relatively lowly, although the ex-master group showed more interest in improved navigational aids than other groups.

The K-W test was applied to each of the options between the occupation groups. No significant difference was found in the four priority options, the M-W test indicating all mariners were in the same distribution. Some significant differences were found in the other options, because pilots marked lower scores. By both tests to ship type and size groups, only the method of sequence control at pilot station was identified as having special significance to the container group, who showed greater desire than others to improve safety by this method (Table 5-3, 5-4). Additional to the above methods, there was a strong demand to equip certain buoys with racons to mark the TSS.

Table 5-3 The significant level by K-W test on improving safety

ITEM	Occupation group	Ship type group	Ship size group
C1. OPTIONS FOR RISK REDUCTION			
Institution of speed limits in traffic lanes	**0.0010**	0.4822	0.8013
Improved provision of weather information	**0.0030**	0.4819	0.3687
Improved control over fishermen in traffic lanes	0.4608	0.2358	0.2706
Improved control of ship sequence at pilot station	0.0503	**0.0220**	0.9332
Stricter enforcement of ship safety regulations	0.4222	0.6230	0.4950
Upgraded fixed and floating aids	**0.0004**	0.5752	0.9704
Upgraded shore based electronic navigational aids	**0.0025**	0.5819	0.8581
Provision of Vessel Traffic Services	0.1131	0.4026	0.1981

Source: Author

Table 5-4 The significant level by M-W test on improving safety

Occupation group	S / J	S / P	S / M	J / P	J / M	P / M
Speed limits in traffic lanes	0.4060	**0.0003**	0.4195	**0.0001**	0.8643	**0.0009**
Provision of weather information	0.4346	**0.0019**	0.4901	**0.0002**	0.9406	**0.0005**
Upgrade visual navigational aids	0.2533	**0.0016**	0.1195	**0.0001**	0.4393	**0.0001**
Upgrade shore based electronic aids	0.2565	**0.0155**	**0.0250**	**0.0026**	0.1521	**0.0005**
Ship type group	C / G	C / B	C / T	G / B	G / T	B / T
Ship sequence at pilot station	**0.0471**	0.5362	**0.0124**	0.2439	0.5526	0.0632

Group symbol: S- Senior J- Junior P- Pilot M- Ex-master
C- Container G- General cargo B- Bulk T- Tanker

Source: Author

5.3.2 Modification to TSS

In Question C2, navigators and pilots, who were using the TSS, were asked to express their views on how the TSS should be modified. Addressing the length, width, location of pilot station and direction, navigators agreed a need to modify the location of pilot station, but were satisfied regarding the other three items. Pilots were satisfied with the existing TSS configuration (Appendix C-6). Through K-W test on the responses of these three groups, significant differences were found from responses to pilot station location (Table 5-5). Most pilots' scores were lower than navigators' scores, especially in the junior group. More than 50% of respondents in the junior groups sought to modify the location. No significant differences were found from ship type groups and ship size groups on modification of the location of pilot station (Table 5-6). But significant differences were found from ship type groups. The general cargo group had a greater desire to modify the length of traffic lanes, and the container ships had a greater desire to modify the width of traffic lanes.

Table 5-5 The significance level by K-W test on modification to TSS

ITEM	Occupation group	Ship type group	Ship size group
C2. MODIFICATION TO TRAFFIC SEPARATION SCHEME			
Length of traffic lanes	0.1702	**0.0157**	0.2802
Width of traffic lanes	0.2653	**0.0346**	0.2872
Location of pilot station	**0.0041**	0.2072	0.2632
Direction of traffic lanes	0.2173	0.0584	0.0511

Table 5-6 The significance level by M-W test on modification to TSS

Occupation group	S / J	S / P	J / P			
Location of pilot station	0.0781	**0.0333**	**0.0007**			
Ship type group	C / G	C / B	C / T	G / B	G / T	B / T
Length of traffic lanes	**0.0024**	0.9657	0.1814	**0.0194**	0.4386	0.3078
Width of traffic lanes	0.1236	0.3305	**0.0094**	0.5104	0.1550	0.1865

Group symbol: S- Senior J- Junior P- Pilot M- Ex-master
C- Container G- General cargo B- Bulk T- Tanker

Source: Author

5.4 SOLUTIONS FOR RISK REDUCTION

The above options considered by mariners are directly related to the risks in Keelung mentioned in para 4.5. The four priority options identified relate to control of ships complying with TSS regulations. Visual navigational aids would further reduce human errors and environmental effects. Shifting pilot station to a more suitable location would improve available sea room for ships.

5.4.1 Establishment of VTS

Human error, including ships contravening TSS regulations and drifting simultaneously at the pilot station, is the most serious problem in Keelung. No system or aid to navigation that can prevent human error. But safety can be enhanced by suitable traffic control within the lanes, and the possibility of mistake or confusion can also be reduced. An efficient VTS would provide such control. The key factors of an efficient VTS, now existing in many major water areas in the world, must by definition be communication and surveillance. In Keelung, the communication in reporting ship's ETA to the signal station exists, but so far radar surveillance is not provided.

In addition to the installation of shore-based radar, the association of communication and surveillance to identify ship movements also needs to be made at Keelung. Traffic regulation cannot be achieved solely by prescribing different lanes for traffic proceeding in the opposite directions, but also requires identification. With ship's identity and position, contravention can be identified and stopped, and the problem of fishing vessels working in the lanes to obstruct ship movement can be reduced. Due to development of computer techniques, processors can precisely monitor and identify ship's movement, once the ship's position is reported.

Simultaneously, traffic control in Keelung could include ship's sequence in the lanes. Collision is always related to the probability of ships encounter. Restricted by the navigable channel, a number of potential encounters become actual encounters leading to collisions. The actual encounter by overtaking situation in TSS is increased[10]. The overtaking situation within Keelung TSS must become an actual encounter, because a ship cannot maintain a safe distance to the overtaken ship within the narrow traffic lane, 700 metres (0.38 miles), except by moving outside the lane with risk of colliding with opposite or anchored ships. It is necessary to prohibit overtaking in the lanes. The best method is to control ships in sequence maintaining a safe distance. With control, the risk of two ships congesting at pilot station could be reduced. Determination of safe distances, and safe waiting areas, can be made by experiment.

With the assistance of VTS, human errors may be detected and timely remedial action taken[11]. According to the definition of the Canadian Coast Guard report, Keelung approaches is a confined water with simple traffic patterns. If VTS with shore-based radar plus automatic processing were established, and TSS regulations enforced effectively, the opportunity for undetected failure to comply with regulations could be minimised, and navigational risk could be reduced by 60%.

5.4.2 Installation of visual aids

In Keelung approaches, there is an apparent lack of aids to navigation in the existing traffic operation. To install buoys marking the entrance and exit of the TSS would assist navigation accuracy in the lanes, especially under poor visibility, and make the scheme more effective. Contravention of TSS regulations may be either deliberate or accidental[12]. Although both would be remedied by radar surveillance, the chance of accidental contravention could be prevented by provision of buoys.

The nature of harbour approach navigation differs from that in open seas, and is characterised by the necessity for an immediate reaction to avoid dangers. There is little time for navigators to fix position when having to cope with other urgent events, such as pilot communication and collision avoidance. When the demands of navigation and collision avoidance are in conflict, other techniques are required to ensure safe navigation. The use of the buoys to identify traffic lanes is one such technique. A U.S. Coast Guard project indicated that turn point buoys significantly improved the accuracy of cross track position when ships turned into a straight channel[13].

Estimation of ship's position using traffic buoys can be accurate and reliable, and reduce navigational errors that occur when estimating position from landmarks, under conditions of strong wind or cross current. Danger can be immediately determined, and a safe passage follows with complete confidence[14], as evidenced by COST-301.

Another buoy installed at An-tou-pao shoal, as a cardinal buoy placed between the danger and the outbound traffic lane, could warn ships of the risk of grounding. The shoal is 0.7 miles off the outbound traffic lane, and the maximum E-going stream in ebb tide is 5.5 knots in the vicinity. Adverse weather affecting navigational safety can not be prevented, but its influence can be reduced by improved navigation aids[15].

5.4.3. Modification of pilot station

A great number of respondents in the questionnaire indicated that the pilot station at Keelung was too near the breakwaters, giving insufficient sea room for a ship to drift safely in bad weather with wind and current towards shore. Before designating an optimal position for the pilot station, the required sea room and the configuration of the TSS should be considered.

Assuming that the central line of the traffic lane is the track intended by navigators, ship position can rarely be maintained on the course line due to wind and current. To avoid the ship deviating across the lane boundary, toward dangerous areas, adjustments keeping the ship in the centre line have to be executed. Nevertheless, the compensatory actions are seldom perfect and require continuous adjustment. Therefore ship positions oscillate and the actual path seldom coincides with the central line. At the Keelung pilot station, the track of a ship moving with low speed has greater deviations than that with high speed under cross current. Therefore the traffic lane near the pilot station has to be wide enough to cater for oscillation in ship's track under local environmental conditions. Whether the inbound traffic lane is wide enough, or the pilot station needs to shift, can be evaluated through experiment.

5.4.4 Compulsory pilotage

Compulsory pilotage is commonplace around the world, but Keelung is one of a minority of ports providing optional pilotage. Shiphandling is constrained not only by the ship's inherent manoeuvring performance but also by the skill and experience of operators. Pilot experience can make up for a master's lack, reducing risk. As a matter of fact, the pilot enhances not only the safe conduct of the vessel he is piloting, but also the safety and protection of other vessels navigating or moored in the area. In the public interest and in the interests of port authority and port users, Keelung port should make pilotage compulsory for certain ships entering and leaving the port.

5.5 SUMMARY

Through mariner opinions on the improvement of safety at the Keelung approaches, the need to establish a VTS with shore-based radar as surveillance to control the traffic flow within TSS, and the sequence of entrance at the pilot station is identified as an urgent requirement by mariners. Buoys should also be established to delineate the TSS. Compulsory pilotage for entering and leaving the port must be taken into account for navigation safety. Although respondents' experience give validity to their opinions, these methods and navigational efficiency from them should be further investigated through experiment. Simultaneously, location of pilot station and safe distance between ships in the lanes should also be evaluated.

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CHAPTER 6

SIMULATION EXPERIMENTS

6.1 INTRODUCTION

The experiments were designed to assess the existing traffic operation, and test the use of visual aids and some VTS functions in reducing accidents, in Keelung approaches under chosen conditions. The purposes of the experiments were:

1. to establish the extent to which provision of additional visual aids may help improve lane discipline;
2. to investigate whether the configuration of traffic lanes provides enough sea room to maintain a safe distance from other ships during adverse weather;
3. to establish the potential of movement information and sequence control as means of reducing close quarter situations near the pilot station;
4. to evaluate the role of pilotage and to observe on the pilot station location.

6.2 SIMULATOR FOR EXPERIMENTS

Simulation is a powerful analysis tool for studying system dynamics and solving system problems where it would be impossible or impractical to study the real situation. Simulation involves some kind of model or simplified representation. Payne defined[1]:

> "Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies for the operation of the system."

A model can be developed to represent an object, system, or concept. As such it can substitute in whole or part for a real situation[2]. Experimentation using models can eliminate many of variables that create difficulty in obtaining good match under real conditions. A marine simulator is a compound of models representing the systems and environment. Simulation provides advantages over other techniques in areas of cost, safety and repeatability. Experimentation using simulated traffic flow gives the ability to examine navigational problems. University of Plymouth and Taiwan Ocean University provided a unique opportunity for simulation experiment in support of this study.

6.2.1 Experiments by ship simulator

Maritime industries have generally accepted that the efficiency of training and research by means of simulators is superior to all other known methods. With a simulator, dangerous situations can be generated in order to observe the mariner's response, and if a collision results there is no damage to the ship or risk to life and oil pollution. To achieve the purpose of training or research, different situations, operational scenarios, fault or emergency conditions, and encounter situations can be repeated many times in order to build up a statistically significant sample of responses. The validity of simulator in research has been confirmed by the results of Curtis and Barratt's study[3]:

> "The results (of their validation investigation) gave no reason to doubt the validity of radar simulator data; mariners at sea can be expected to respond in the same way as the subjects in the tests (on the simulator)."

With a real-time simulator the ship manoeuvring simulations can be simulated under real-time condition in a real-looking environment. In order to give navigators an actual feeling of attendance on board, a ship simulator will[4]:

1. display the view from the bridge
2. model realistically the dynamic behaviour of the ship
3. provide a simulated radar and instrumentation package.

In recent years, a ship simulator has comprised five sections (Figure 6-1), namely: bridge section, visual display section, computer section, control and monitoring section, and recording section[5]. The simulator uses computer-generated imagery to provide a visual scene consisting of own ship's bow, land, other ships, and simple presentations of aids for day and lights for night. The manoeuvring behaviour of the own ship is accurately and reliably governed by a fairly complex computer mathematical model so that the ship's manoeuvring characteristic is correct giving users a real ship feeling. The ship models combine sophisticated hydronamics with the capability for a variety of environmental effects, such as tidal stream and wind effects. Varying conditions of visibility may also be simulated.

6.2.2 Simulator in the University of Plymouth

In the University of Plymouth, the marine radar and navigation simulator Racal MRNS 9000, called the UP simulator in this study, is manufactured by Racal Simulation Limited. The UP simulator is fitted with full radar facilities comprising radar and separate ARPA, and a wide range of navigational equipment[6]. Helm and engine telegraph controls are used for manual input of heading and speed changes. The operator can directly control over the speed and the heading of the ship. The design of this real time simulator is based on a night-time presentation. The visual scene covers 135 degrees horizontal.

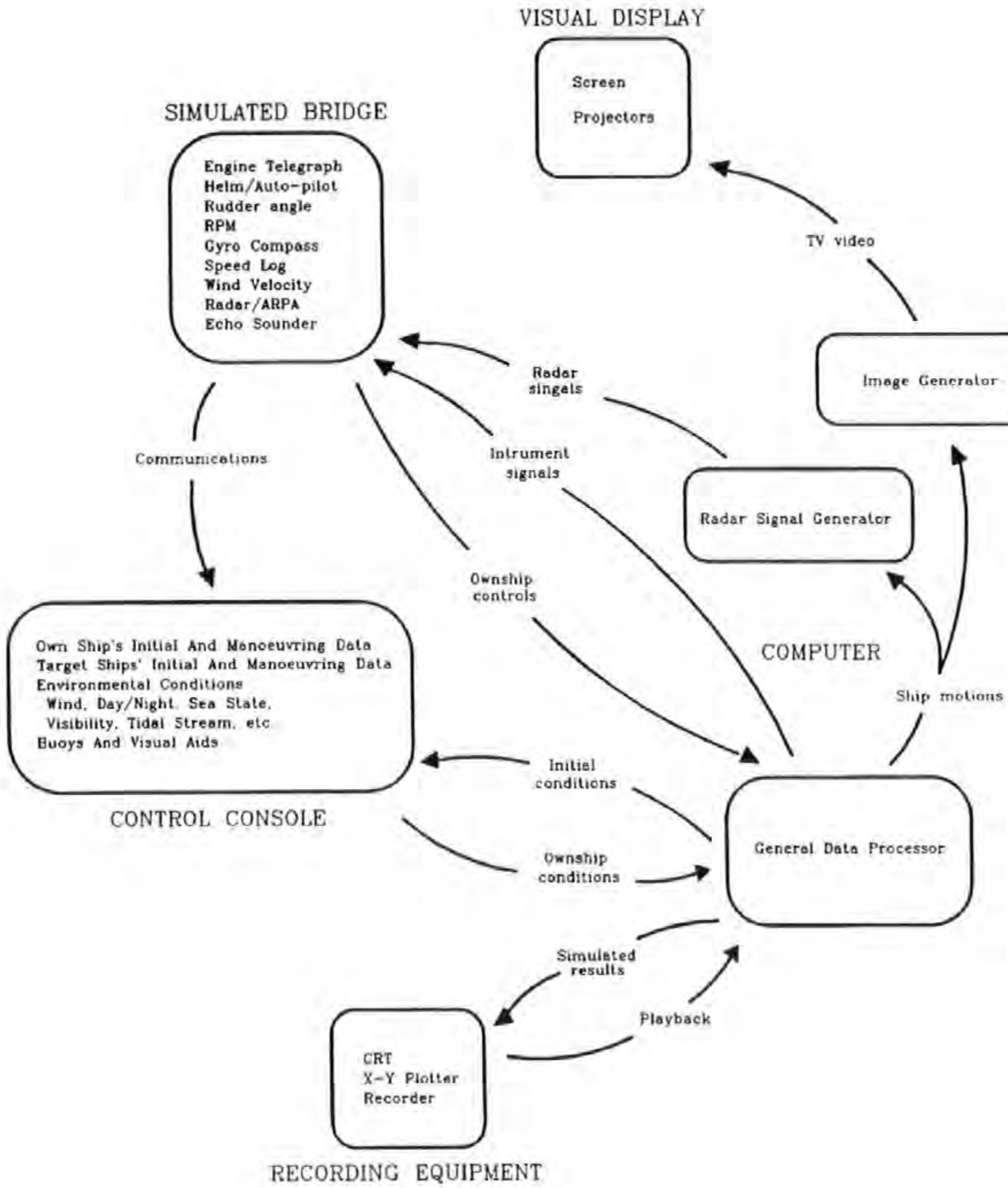

Figure 6-1 Schematic of a ship simulator
Source: Author

6.2.3 Simulator in Taiwan Ocean University

The majority of the experiments in this study were run on a ship handling simulator at Taiwan Ocean University, called the NTOU simulator. The NTOU simulator was manufactured by Krupp Atlas Elektronik GMBH in 1985. This simulator, also a real time simulator, has a full-size bridge compartment which is mounted on a motion base to simulate ships' sea state motion providing a high level of realism to the operators undergoing the exercise[7]. A six-section screen is fixed around the bridge compartment, providing a visual scene with 135-degree horizontal field of view and the capability for a very complex visual scene. The significant difference between the UP and NTOU simulators is the kind of visual display. The visual system of the NTOU simulator generates a coloured picture of the environment with appropriate display of day-time scenes and night-time scenes by six projectors.

6.3 DESCRIPTIONS OF EXPERIMENTS

Generally, the first stage of an assessment with an experiment is necessary to test the model which represents the existing real system. The second stage is to change the model to represent the proposed real system. The purpose of the experiments then is to measure the effect of this on the response and compare the difference between the two models[8].

6.3.1 Criteria of scenario design

In this study there were two simulation experiments comprising an inbound experiment and an outbound experiment. Each subject for either experiment should operate two exercises, named Ex-A and Ex-B in this study. In Ex-A the scenario of traffic operation system was simulated to be the nearest approach possible to that currently existing at Keelung. In Ex-B buoys and ship control with different environmental conditions were added. Difficulty in bringing together voluntary bridge teams, including a master, mate and a quarter master, for the experiment led to each exercise being conducted solely by a master.

The data base of Keelung harbour has been built in the NTOU simulator. The coast line on both visual screen and radar display presents a true situation. There is no data base of Keelung harbour built in the UP simulator, and it is impossible to built the data base due to problems of obtaining the data source. Instead the data base of Cromarty Firth in Scotland was partially rebuilt and set up in the UP simulator to model Keelung approaches. A chart (Figure 6-2) encompassing this area was redrawn, and TSS as in Keelung approaches was added to the chart for the experiments using the UP simulator. The current indications were also converted onto this chart.

The own ship used in the UP simulator for this study was a large container ship, the ship type with higher risk in Keelung, with displacement 50,100 tonnes. Unfortunately, without the same ship model in the NTOU simulator, the biggest container ship model with displacement 32,000 tons (32,514 tonnes) was used (Table 6-1). The details of two ship models are shown at Appendix-F. The experiment results by the different ship models required comparison.

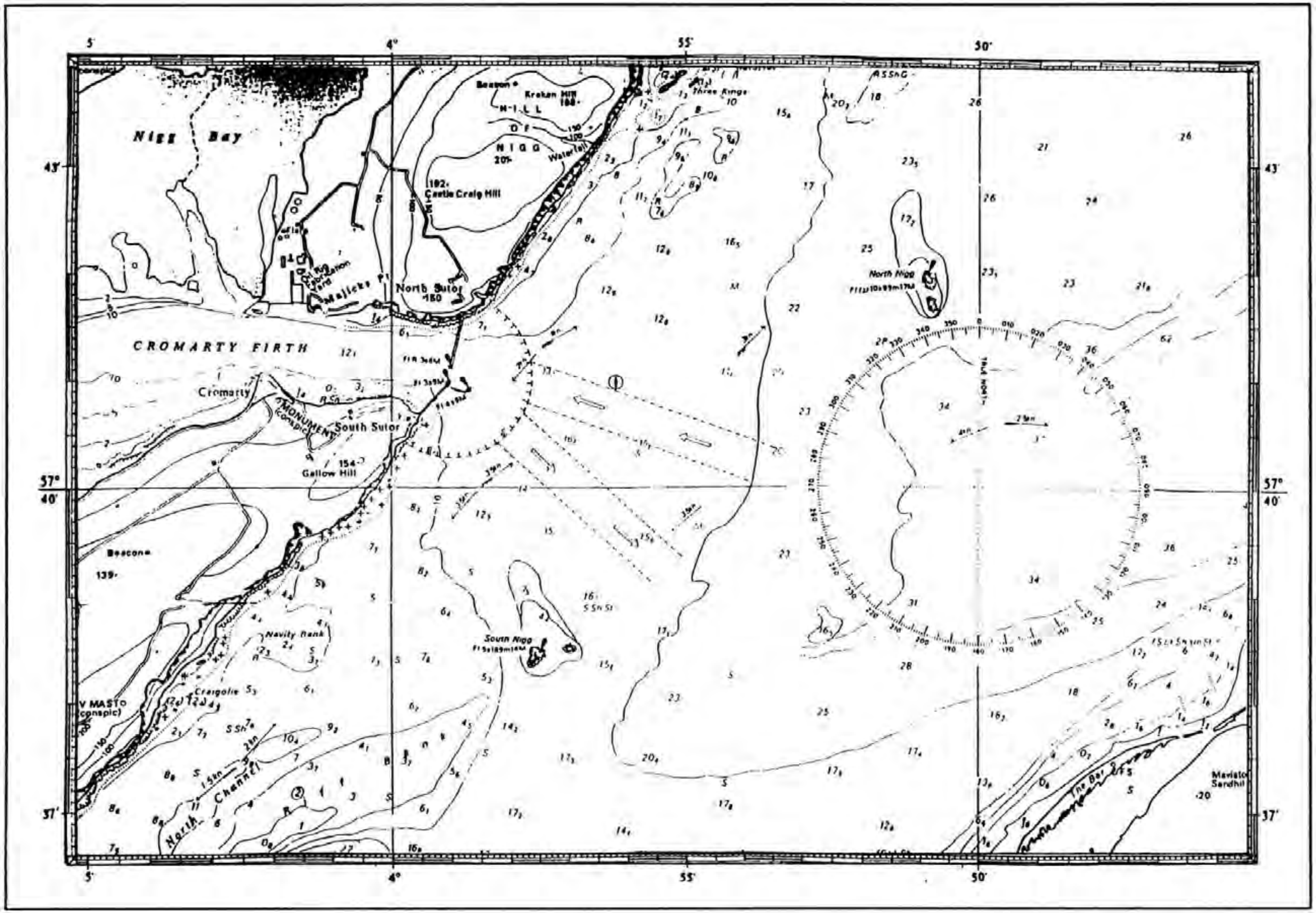

Figure 6-2 The chart for UP simulator experiments Source: Author

Table 6-1 Own Ship Particulars

Item	NTOU simulator	UP simulator
Type	Container	Container
Length (LBP)	202.4 metres	212 metres
Beam	32.2 metres	-
Draft	8.2 m /8.4 m	12.2 m /12.2 m
Displacement	32,000 tons	50,100 tonnes
Maximum speed	24.4 knots	23 knots
Maximum RPM	125	120

Source: Simulator MRNS-9000 Operator's Manual, and Simulator SFS/NTC System Description.

6.3.1.1 Ship routes in experiments

The study was concentrated on the TSS and adjacent waters to examine ship manoeuvre and usage of sea room. The own ship in the inbound experiment started from the centre of the NE sector and ended in the vicinity of the pilot station. The ship in the outbound experiment started from the outer harbour, and went away through the centre of the NW sector. From radar observation, most ships contravening TSS regulations took these routes. As soon as each experiment started, the subject was free to choose his course and speed (Figure 6-3, 6-4).

Collision is the major type of accident occurring in the Keelung approaches. One type of potential encounter in these experiments involved two threat ships, the own ship and another target ship. The participant might take avoiding action by altering own ship's course and/or speed. The target ship in each experiments was a container ship. The initial scenarios for the validation study were programmed so that the initial speed and locations would be as similar as possible to those experienced in the live situation.

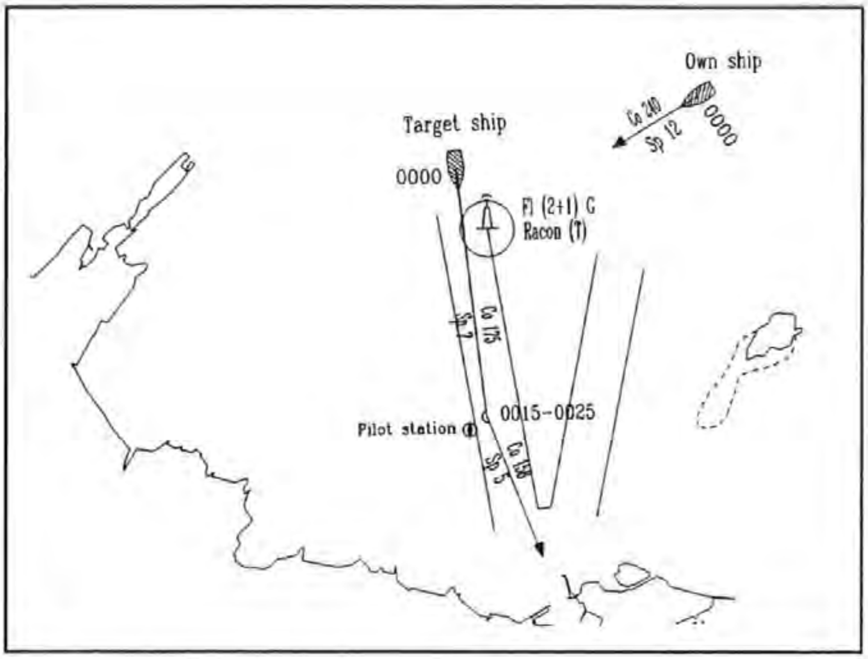

Figure 6-3 Scenario of inbound experiment
Source: Author

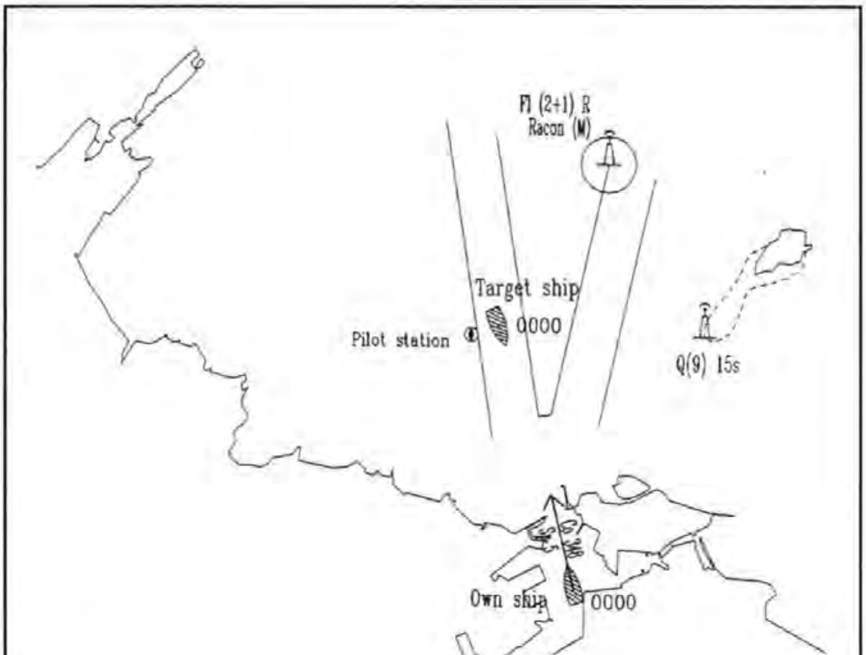

Figure 6-4 Scenario of outbound experiment
Source : Author

1. Inbound experiment

The own ship started from Lat 25°13.5'N Long 121°46.1'E, two miles to the NE of the entrance of inbound traffic lane, with 240°(T) initial course and 12-knot initial speed. When the ship arrived at the pilot station, ship speed should reduce to under five knots ready for picking up the pilot. Total running distance was about four miles. The target ship, two miles ahead of the own ship, entered the traffic lane with seven knots speed. The own ship was a give-way ship, and the target ship was a privilege ship. When the target ship arrived the pilot station, she would stop engines for ten minutes to pick up the pilot, and then move toward the harbour.

2. Outbound experiment

The own ship started from the outer harbour at usual the pilot disembarkation zone, 0.7 miles inside breakwaters, with 5-knot initial speed and 348°(T) initial course. The ship passed through the main channel without pilot assistance. The destination was at three miles NW off the exit of outbound traffic lane, but the exercise ended when the ship left the traffic lane without further danger. Total running distance by the ship was also about four miles. The target ship, an inbound ship stopping at the pilot station, was ready to enter the harbour, after own ship had clear the main channel.

6.3.1.2 Environmental conditions

In this study, Ex-A and Ex-B were given different environmental conditions for comparison of weather effects. The wind and visibility in Ex-A were in normal condition, NE wind direction with force 10.7 m/sec and good visibility. In Ex-B a bad weather conditions were designed with NE and 17.1 m/sec wind, and 2-mile visibility. The wind and visibility design depended on consistency with casualty data. Experiments carried out by the UP simulator were in night-time scenario, and by the NTOU simulator were either day-time or night-time conditions.

Both exercises kept the same tidal stream conditions: SE with 2.5-knot stream at the adjacent water of the entrance and exit of traffic lanes, SE with 1-knot stream near the pilot station, no tidal stream in the harbour. This stream design is often a normal condition of ebb tide in Keelung approaches[9]. The difference between the exercises on current was that no current information was provided to subjects in Ex-A, and information was provided in Ex-B.

6.3.1.3 Aids to Navigation

In Ex-A navigational aids were kept as at present. Two kinds of aids were additionally arranged in Ex-B. First, an entrance buoy was positioned at the start point of the east boundary of the inbound traffic lane for the inbound experiment; An exit buoy was positioned at the end point of the western boundary of the outbound traffic lane, and another buoy at the end of An-tou-pao shoal for the outbound experiment. All buoys were fixed with lights, illustrated in Figure 6-3, 6-4. To enhance the buoys echoes on radar screen, a racon was mounted on each traffic buoy.

Secondly, traffic information and control of movement sequence was provided. Before the beginning of the exercise, the movement of target ship including course, speed turning point and her actions was notified to subjects. Meanwhile, the own ship in the inbound experiment was advised to keep a safe distance from the target ship, which was to be first to pick up the pilot.

6.3.2 Data collected from experiments

Two sorts of data were collected from the experiments: one relating to subjects' intentions, the other to results of their actions. Regarding the former a form of questionnaire was used. The latter was extracted from ship tracks. Before a mariner handles a ship to arrive at a defined point or a particular situation, he has to judge what heading or speed is best. Sometimes the result of his actions is quite different from his intention because external influences are too complicated to predict. By analysing mariners' intentions in the experiments, their concepts and perceptions to safety can be judged. Comparing their intentions with the results, the external effects can be assessed.

6.3.2.1 Subject perception

Expressions in quantitative terms of marine traffic situations have been used by researchers to analyse navigational risk[10]. The questionnaire is one method by which human perception can be quantified. Any change of the existing situation should consider navigators' perceptions. Subjects completed the questionnaire after the experiment. By comparing response to Ex-A with Ex-B, findings specific to improvement of safety at Keelung approaches were deduced. The elements of the questionnaire, shown in Appendix G and Appendix H, were:

1. participant's personal background;
2. assessment of the effectiveness of the designed buoys on identification of the traffic lanes;
3. analysis of wind effect and current effect to ship manoeuvring;
4. analysis of collision risk by the designed potential encounter;
5. assessment of the effectiveness of sequence control at pilot station in the inbound experiment; assessment of the effectiveness of the designed buoy at An-tou-pao shoal for reduction of grounding risk in the outbound experiment;
6. analysis of contact risk at breakwaters.

6.3.2.2 Data from simulator

During experiments own ship data, including heading, rudder angle and speed, were recorded at one minute intervals from the UP simulator's monitor, and at half minute intervals from the NTOU simulator. Additionally, an X-Y plot track record was maintained. The raw data of ship track, the computer-recorded position of the ship centre, were primary data for this research. The tracks were converted into X, Y coordinates and the following details computed:

1. CPA, TCPA and relative bearing to the target ship;
2. distance to a defined point when passing a defined base line.

6.3.3 Statistical methods for analysis

No two mariners are identical, and as a consequence each has his own preferred course of action in any particular situation[11]. The navigation of a ship is an intensely personal affair with every mariner having his concept of safety. The performance of one subject generates a single result in the experiment. Repeating runs by different subjects of simple procedure were treated as independent sample values[12]. The results of the experiments by questionnaire and ship track were divided into three groups depending on scenario time and experiment location: day-time in NTOU, night-time in NTOU, and night-time in UP. To analyse the difference between any two independent groups the M-W test was used. The null hypothesis was that between the populations of two groups there was the same concept and action to navigation safety in the experiment. The comparison of two groups in NTOU was to examine the effect of light on a mariner's ship handling. The comparison of two groups in the night-time scenario was to examine the influence of environment factors on different size of container ships, and the difference of ship handling between subjects.

In this simulation experiment, every subject needed to operate an Ex-A exercise first, and then an Ex-B exercise for each experiment. Two groups of experimental data from the two exercises could not be treated as independent samples, because these were produced by the same person under their personal performance standards. When analysing the difference between results, the samples had to test as matched-pairs, the existing situation and the defined situation.

The standard non-parametric technique for analysing data from two matched-pair samples is to apply the Wilcoxon matched-pairs signed-ranks test, called the Wilcoxon test in this study. In this study the null hypothesis assumed the average rank differences in the population is zero. Based on the sampling distribution, the observed significance level could be calculated. If the observed significance level was smaller than 5%, the hypothesis was rejected.

6.3.4 Application of simulation experiments

As the programme was developing, pre-experiments were conducted by three masters to test the validity of the models using the UP simulator. The visual perception and ship manoeuvring were acceptable. The programme was modified on their advice. After it was completed, the simulation experiments were conducted in Taiwan Ocean University and the University of Plymouth respectively. The experiment had to be performed by a master, because he has responsibility on the bridge to select a safe course and make proper safety decisions when the ship is navigating in port approaches. 27 experiments in Taiwan were carried out by Taiwanese, including four Keelung pilots, five navigation lecturers, and 18 ship masters who were recommended by shipping companies. All of them need master certificates, with experience calling at Keelung port. In Plymouth experiments were carried out by seven mariners including three British, one Korean and three from Hong Kong. Except one lecturer with pilotage experience, subjects were students with master certificate. There were eight subjects, four in Taiwan and four in Plymouth, with sea experience less than 10 years.

When the experiments in Taiwan were divided by light, there were 17 in day-time performance (Run 1 to 17) and 10 in night-time performance (Run 18 to 27). The seven experiments in Plymouth were night-time experiments (Run 28 to 34). Most subjects were lacking in simulator experience. They had the benefit of an introduction on simulator handling before conducting the experiment. However, through this preparation and their many years experience afloat, they experienced no difficulty in manoeuvring the simulator instead of a real ship.

Essential data provided to the participant in Ex-A were a chart with pilot station and TSS designated, own ship's initial position and speed, wind force and speed, and visibility. The participant had to detect target ship's movement and current information by himself. As in the existing circumstance in Keelung, advice was given indicated the pilot was going to board when the ship arrived. In Ex-B every subject was not only informed above data, but also provided actual current, target ship's movement and the advice that clearly indicated the own ship was the second ship after the target ship to pick up pilot and a safe distance from the target ship must be kept. During exercise run, each subject remained alone on the bridge without external contact.

6.4 RESULTS OF SIMULATION EXPERIMENTS

As soon as the own ship was moving, ship position data were recorded and drawn on the simulator X-Y plotter. These have been reproduced by using AutoCAD. The separate tracks of each subject with ship positions, at one minute interval for Run 1 to Run 27 and two minute interval after the first minute for Run 27 to Run 34, are shown in Appendix-I and J. Total 34 ship tracks in each exercise and each experiment are shown in Figure 6-5, 6-6, 6-7 and 6-8.

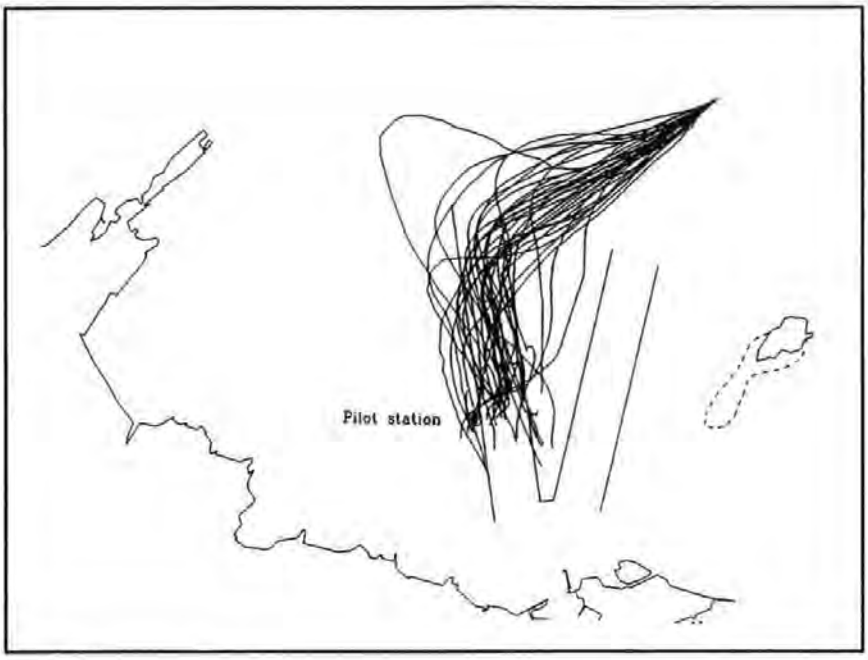

Figure 6-5 All inbound ship tracks in Ex-A
Source: Author

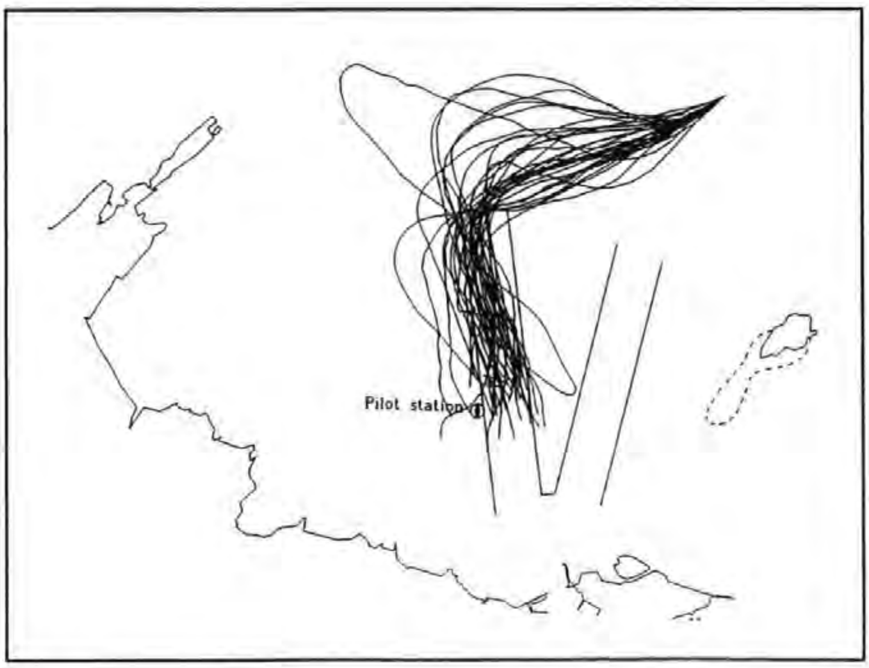

Figure 6-6 All inbound ship tracks in Ex-B
Source: Author

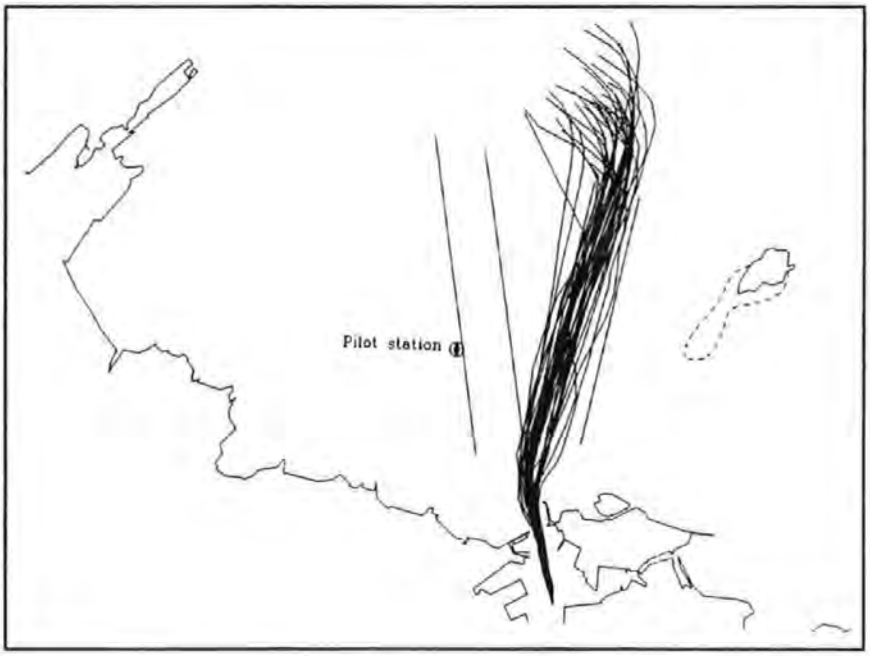

Figure 6-7 All outbound ship tracks in Ex-A
Source: Author

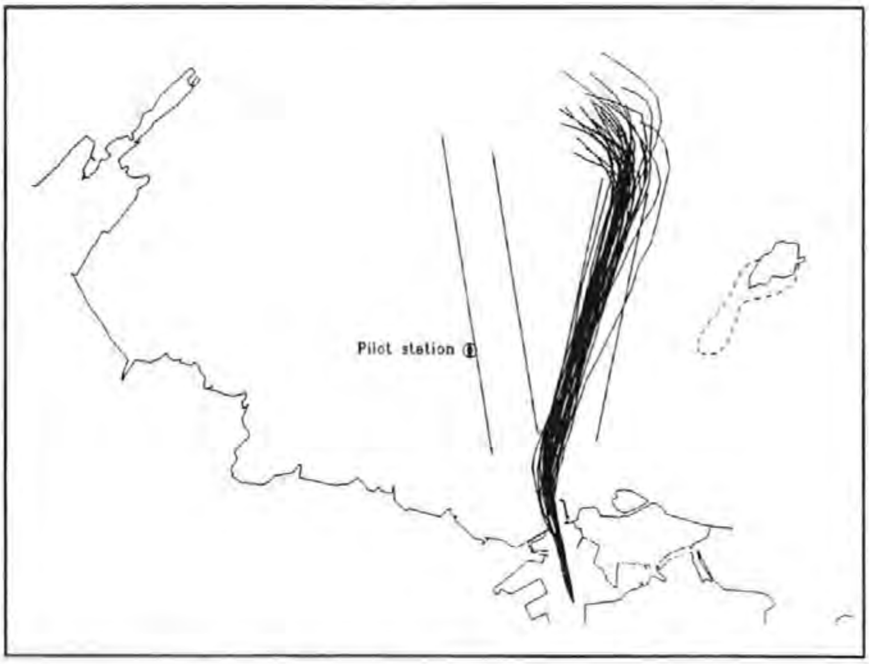

Figure 6-8 All outbound ship tracks in Ex-B
Source: Author

For the purpose of analysis, the sea room used by inbound ships was divided into two parts, outside area and lane area. In the outside area, a base line was constructed, connected from the start point of the own ship to the east boundary of the inbound lane. 20 data lines perpendicular to the base line were spaced 0.1 mile (185 metres) apart across the traffic flow. The first data line was near the ship start point, and the 20th data line was passed the lane start point. In the lane area various data lines, perpendicular to the centre line with 0.1 mile interval space to each line, were constructed in the inbound traffic lane. The first data line also crossed the point designating the entrance buoy, and the 15th line was near the pilot station (Figure 6-9).

The sea room used by outbound ships was also divided into two sections, main channel area and lane area. In the outbound traffic lane, there were 21 data lines constructed, as in the inbound lane, to defined sea room. The first data line started from the beginning of the lane, and the 21st line crossed the end of west boundary designating the exit buoy (Figure 6-10).

In order to obtain further details, the tracks needed to be quantified. Measuring the ship's cross track position at specified lines could analyse the traffic distribution[13]. Therefore, a linear interpolation of the track position at each data line, and the distance between the position and the base line were calculated by computer using Turbo Basic language (Appendix-K). The mean and standard deviation of the 34 track distances passing each data line in each exercise are shown in Appendix-L.

6.4.1 Inbound ship tracks

The graphical tracks provide a general impression regarding subjects' actions. The distribution of tracks in Ex-B which is obviously influenced by the positioned buoy and by sequence control is different from that in Ex-A.

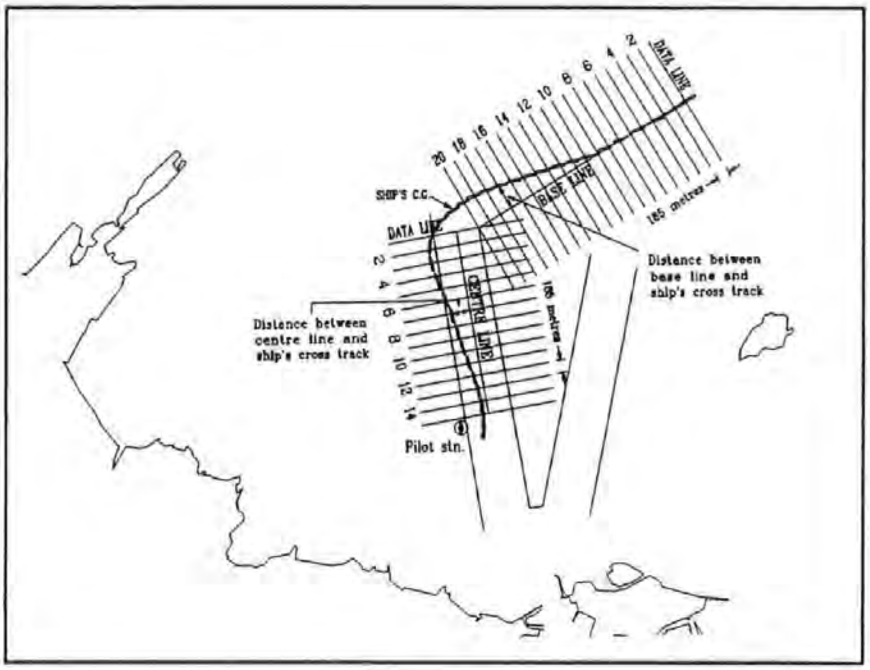

Figure 6-9 Data line for analysis of inbound ship tracks

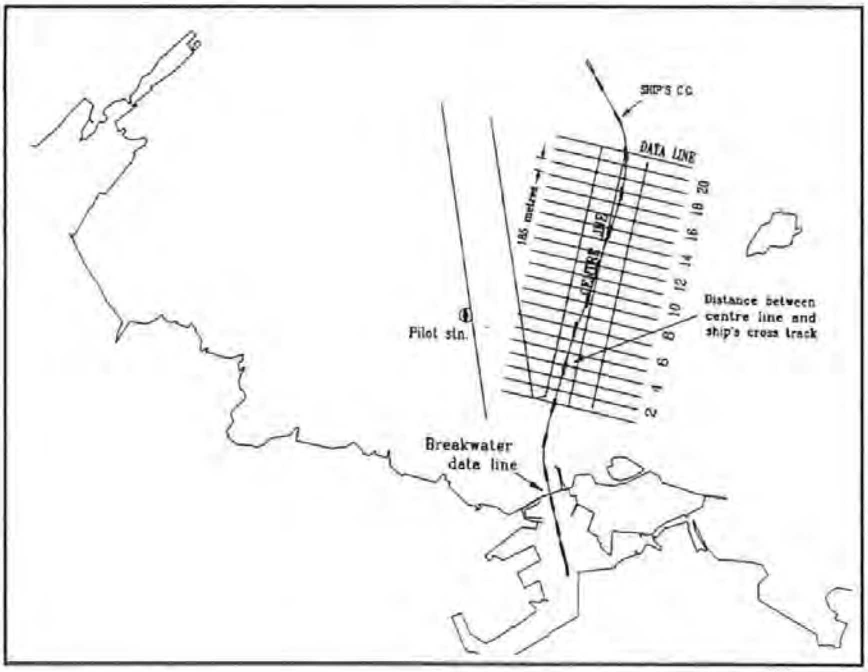

Figure 6-10 Data line for analysis of outbound ship tracks

6.4.1.1 Inbound traffic at outside area

The ship tracks in the outside area indicate how subjects took action to join the inbound lane and to avoid the defined encounter situation. The right side of the base line is open sea. While a track position was on the left of the base line, the ship might cross the separation zone. The track distribution in Ex-A was wide spread. After the exercise started, most ships kept position on the left side of the base line. When ships crossed the 20th data line, 23 track positions, 67.6% of total tracks, were on the left side. Those then crossed the east boundary of the inbound lane to arrive at the pilot station, except one ship which ended in the separation zone. When all data lines were sub-divided into gates of 200 metres so as to clearly indicate the distribution, the scatter of track number in each gate is shown in Figure 6-11. The mean distance crossing data lines was on the left side from start, shown in Figure 6-12, and generally further from the base line. Eventually, the mean distance was 216.8 metres to the left of the base line.

Although the traffic flow in Ex-B also had a wide distribution, it was spread to the right side. All tracks crossed the right side of the 20th data line, except one ship; the proportion of tracks to the left dropped to 2.9%. In Ex-B the mean distances on the beginning were close to that of Ex-A, but from the 4th data line the Ex-B curve started to diverge towards the right. At the 20th data line, the mean distance was 554.2 metres to the right of the base line. The greatest distance was 1,815 metres in Run 30. The scatter of ship tracks is showed in Figure 6-13. It was simple to find significant differences on the distance of each track between two exercises through the Wilcoxon test. From the first data line to the 20th data line, except the third and 4th where the two curves of mean distance met together, the observed significance level between two exercises were less than 0.05, reaching the significant difference (Appendix M-1).

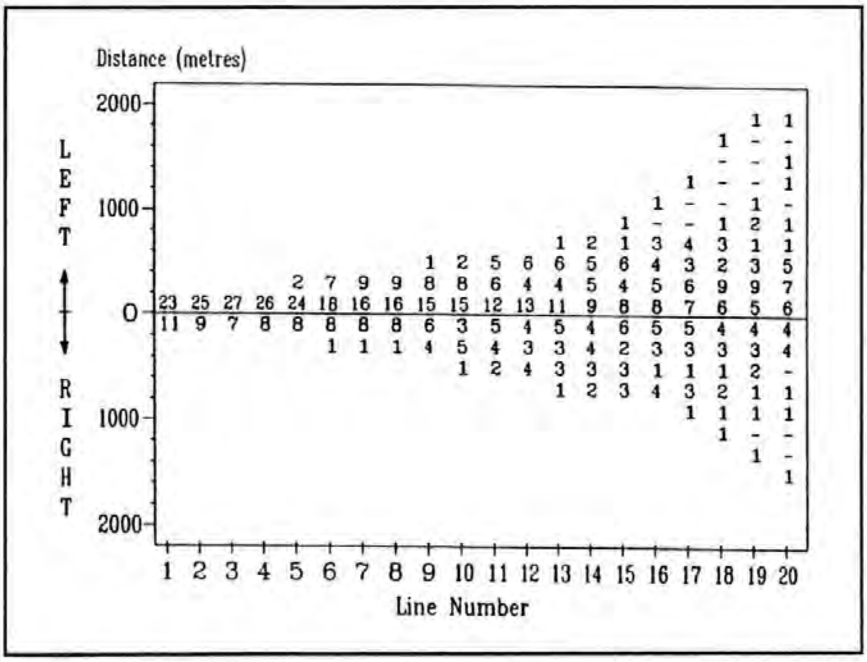

Figure 6-11 Scatter plot of track number of inbound ships in outside area in Ex-A

Source: Author

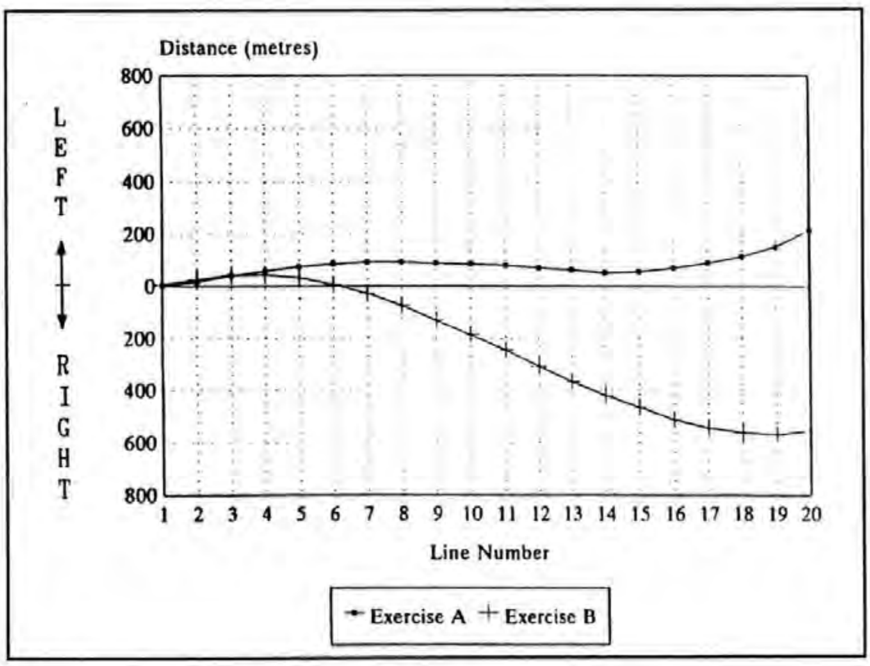

Figure 6-12 Mean distance of Ex-A and Ex-B in outside area of inbound experiment

Source: Author

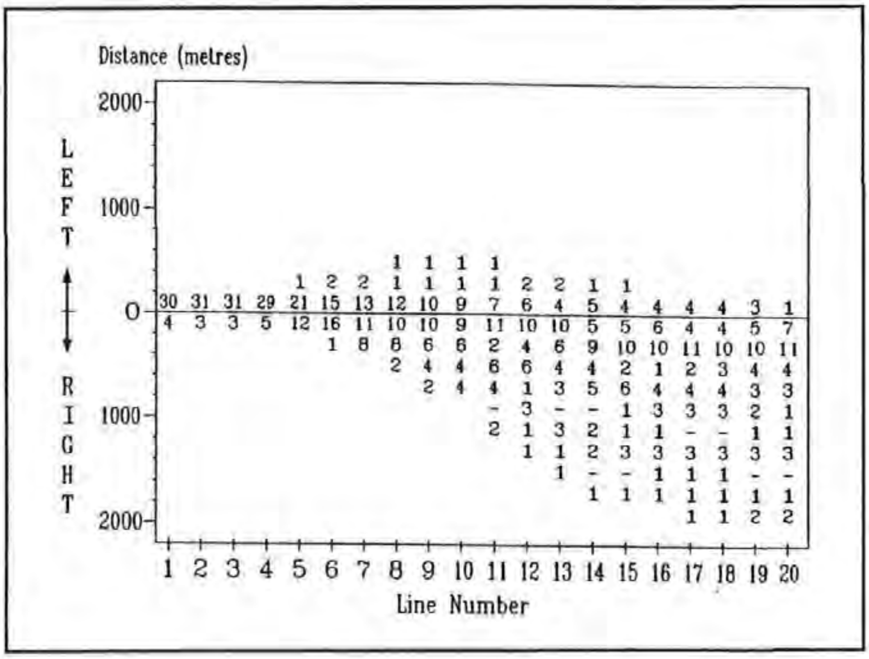

Figure 6-13 Scatter plot of track number of inbound ships in outside area in Ex-B
Source: Author

Through the M-W test to check the cross tracks divided into three groups: day-time in NTOU, night-time in NTOU and night-time in UP, no significance was found between the two groups in NTOU, neither in Ex-A nor in Ex-B. When compared with two night-time groups in both exercises, the tracks between the groups had significant difference at the front data lines where the UP tracks had the trend to lay on the NTOU tracks' left. Because the large ship on the UP simulator was more influenced by current effect before the masters were ready to take actions for the exercises.

6.4.1.2 Inbound traffic in lane area

On leaving the outside area ship tracks enter the adjacent area of the inbound lane, and show how ships used the sea room in the lane to approach pilot station. In Ex-A, ships continued with their tracks spreading very wide. At the first data line of lane area, 29 tracks were on the left side of the centre line of the inbound traffic lane (Figure 6-14). When calculating the distance between ship position and the centre line, 23 tracks were outside the east boundary, three tracks outside the west boundary, the remaining 23.5% of total tracks within the lane. The mean distance was 718.2 metres on left side of the centre line (Figure 6-15). The range of greatest distance on both side covering usage of sea room was some 3,000 metres.

Then, while ships approached the pilot station, the tracks gradually concentrated on the centre line. The distance of tracks to the left of the centre line apparently decreased, and the right tracks moved to centre slowly. At the 15th data line, which was close to the pilot station, the number of ship tracks reduced to 24, because there were 10 tracks which ended their exercises in the vicinity of pilot station but ahead of the station. The mean distance was 65.1 metres to the right of the centre line, 66.7% of tracks in the lane. The range of sea room covering reduced to 1,411 metres. There were one track outside the east boundary and seven tracks outside the west boundary.

In Ex-B, tracks were more concentrated than those in Ex-A at the beginning. When ships passing the first data line, 23 tracks (67.6%) entered the lane within both boundaries, one track outside the east boundary and 10 outside the west boundary. The mean distance from the centre line was 204.5 metres to the right. The standard deviation was less than half of that in Ex-A. The farthest distance was 986 metres to the right, and 652 metres to the left, covering 1,638 metres (Figure 6-16). The next farthest track, on the left, was only 120 metres. That revealed no ship moved near the buoy within 230 metres at this data line.

After the first data line, the change of spread was not apparent, but the distribution moved toward the left in parallel. The smallest range covered was 1406.4 metres at the third data line. There were also 24 tracks crossed the 15th data line, including 18 tracks (75.0%) within the lane and three tracks outside either boundary of the lane. The mean distance to the centre line was 20.9 metres on the line left, covering 1,905 metres. The average range covering at total 15 data lines was 1590.9 metres.

Through the M-W test, no significant difference regarding distance at each data line was found between groups, neither in Ex-A nor in Ex-B, except at the 14th between the two night-time groups in Ex-A. Compared all cross tracks in Ex-A with Ex-B through the Wilcoxon test, the differences from the first to the 8th data line were significant, and the remains were not (Appendix M-2).

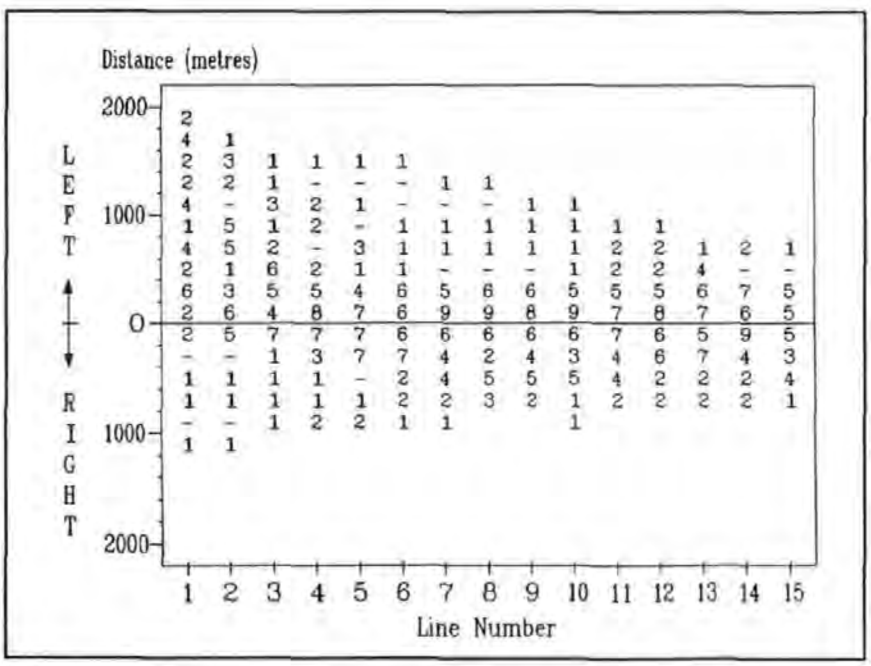

Figure 6-14 Scatter plot of track number of inbound ships in lane area in Ex-A

Source: Author

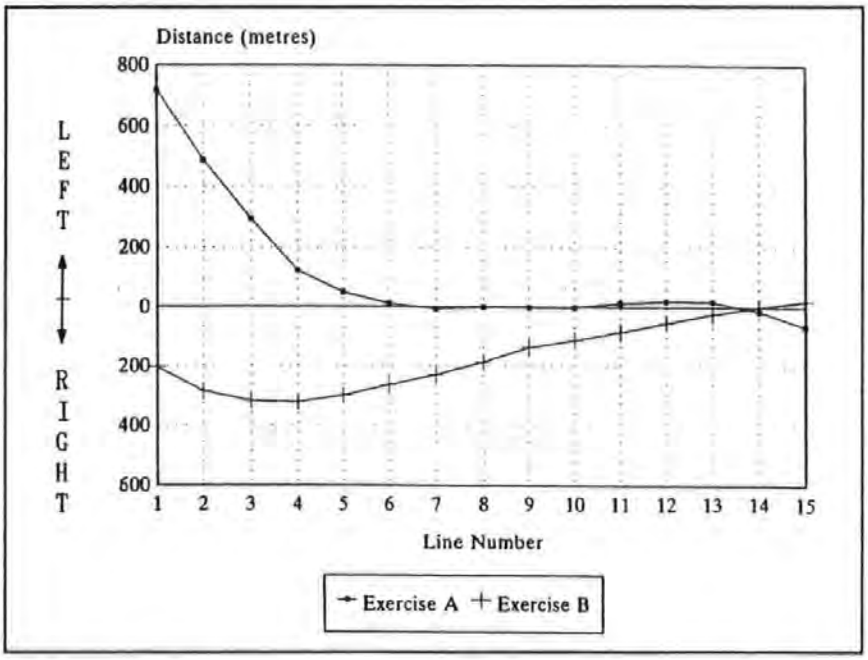

Figure 6-15 Mean distance of Ex-A and Ex-B in lane area in inbound experiment

Source : Author

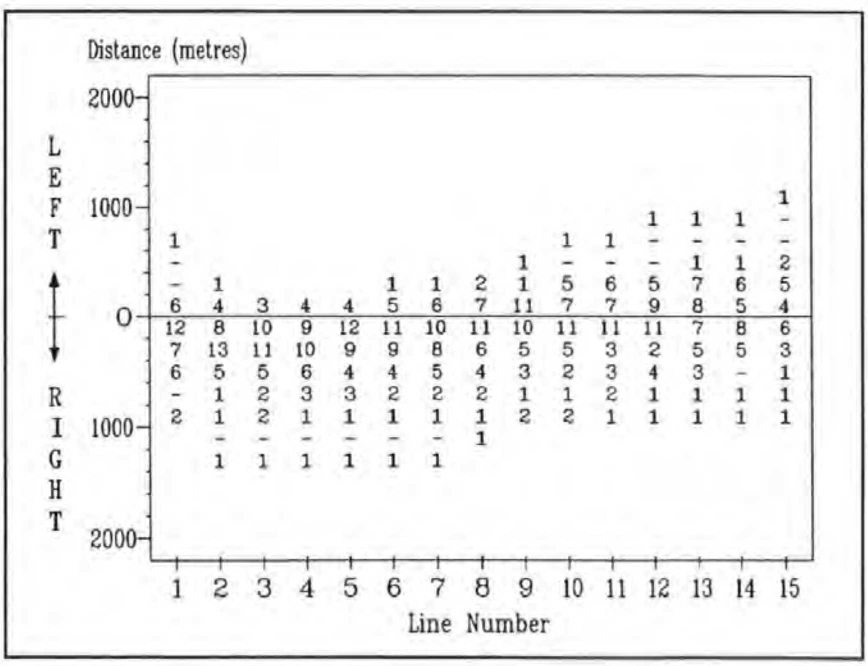

Figure 6-16 Scatter plot of track number of inbound ships in lane area in Ex-B

Source: Author

6.4.2 Outbound ship tracks

6.4.2.1 Outbound traffic in main channel

The width of main channel between breakwaters is about 250 metres. With a line connecting the breakwaters as a datum line, cross track distance from ship's centre to the centre point of the datum line could be measured. In Ex-A, the mean distances was 11.7 metres left to the centre point, range from 71 metres left to 51 metres right (Table 6-2). Through the M-W test, the difference between two groups in the NTOU simulator was not significant, but that between two night-time groups was significant, $P = 0.0006$. All tracks performed in the UP simulator were close to the west breakwater. Among the tracks the closest distance to the breakwater was 54 metres.

Table 6-2 Distance of tracks to the central point of main channel

Subjects	No. of tracks	Ex-A		Ex-B	
		Mean	St. dev.	Mean	St. dev.
Day-time in NTOU	17	-3.0	26.1	9.6	17.7
Night-time in NTOU	10	7.0	20.6	15.2	17.1
Night-time in UP	7	-59.6	7.5	-70.9	21.6
Total	34	11.7	33.0	-5.3	38.4
Remark: Positive values of mean are on the right side of the centre point. Negative values are on the left side.					

In Ex-B, the mean distance to the centre point was 5.3 metres to left, range from 98 metres left to 41 metres right. Compared with Ex-A by the Wilcoxon test, the tracks passing the breakwaters were not different between two exercises. The comparison of groups by the M-W test, the results were the same as Ex-A, significant difference between two night-time groups. The nearest distance to the west breakwater was only 27 metres, on the UP simulator. When examining the difference between the tracks at UP in both exercises, no significant difference was found.

6.4.2.2 Outbound traffic in lane area

After passing the breakwaters, the outbound ship had to turn right immediately to avoid entering the inbound traffic lane. In this experiment, there was another inbound ship drifting at pilot station. In Ex-A, 12 tracks (35.3%) were on the outside of the west boundary at the first data line. The mean distance to the centre line was 291.1 metres on the left. The farthest distance on the centre line left was 527 metres, and on the line right was 106 metres, the range being 633 metres. Then the tracks generally joined the lane, but there were still three tracks on the outside at the 21st data line. No track was outside the east boundary (Figure 6-17, 6-18). The mean distance of the cross track positions at the 21st data line was 97.3 metres to the left of the centre line. The range between the farthest tracks on either side was 1,263 metres. The mean range of total 21 data lines was 835.0 metres.

In Ex-B, nine tracks were outside the west boundary at the first data line. The mean distance of all tracks to the centre line was 276.7 metres to left. The farthest distance on the left was 457 metres to the centre line. The extreme right track was also on the centre line left with 73 metres (Figure 6-19). The range was 384 metres. At the 21st data line, no track was outside the west boundary, but 2 tracks outside the east boundary, where the mean distance was 42.4 metres to the centre line right. The farthest distances to that line were 224 metres on the left and 579 metres on the right, with a range of 803 metres. The mean range at all 21 data lines was 593.3 metres. The Wilcoxon test revealed the significant differences between Ex-A and Ex-B were from the ninth to the 21st data line. When the tracks were divided into groups, no difference between groups reached the significant level (Appendix M-3).

6.4.2.3 Closest distance to An-tou-pao shoal

Before outbound ships leave the traffic lane, there is a grounding risk at An-tou-pao shoal. The mean closest distance of ship tracks to the shoal was 1,738.9 metres in Ex-A, and the nearest track was 1,282 metres. The mean closest distance in Ex-B was 1,654.4 metres (Table 6-3), and the nearest track was 1,257 metres. When testing the difference between two exercises through the Wilcoxon test, it was significant with $P = 0.0133$. Most of tracks in Ex-B had smaller distance than those in Ex-A. When testing the difference between two groups in each exercise, no significance was found.

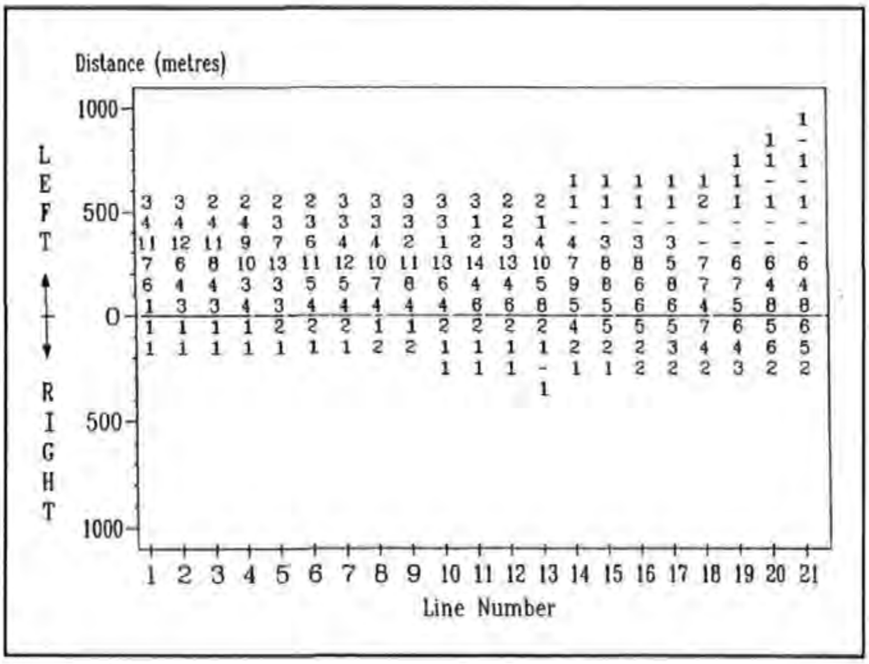

Figure 6-17 Scatter plot of track number of outbound ships in lane area in Ex-A

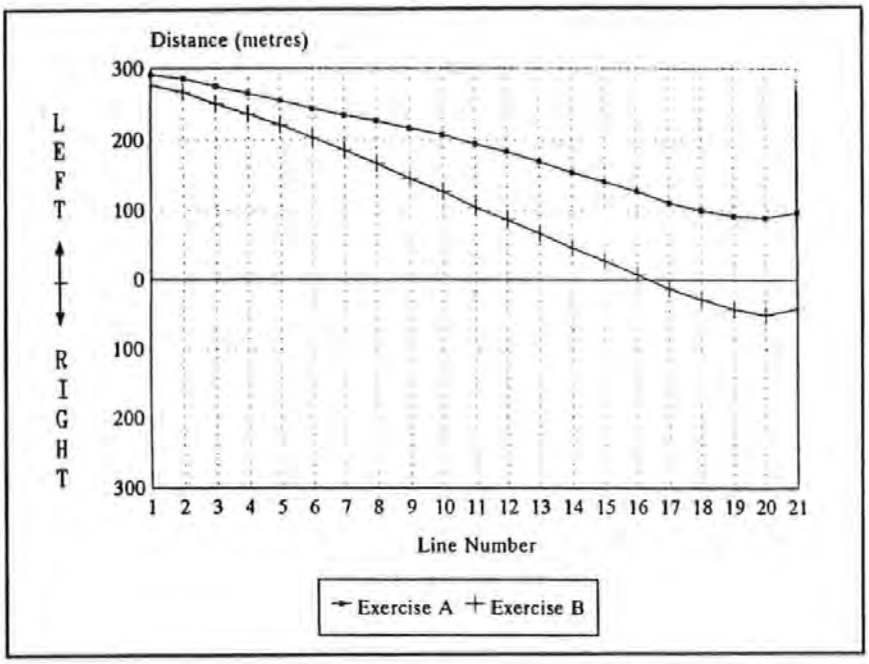

Figure 6-18 Mean distance of Ex-A and Ex-B in outbound experiment in lane area

Source : Author

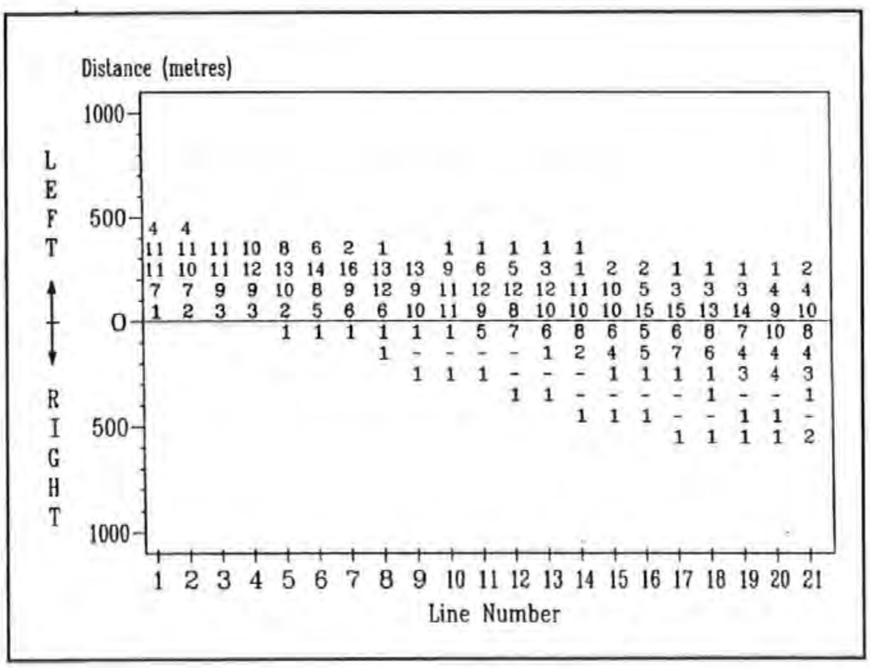

Figure 6-19 Scatter plot of track number of outbound ships in lane area in Ex-B

Source: Author

Table 6-3 The closest distance of tracks to An-tou-pao shoal

Subjects	No. of tracks	Ex-A		Ex-B	
		Mean	St. dev.	Mean	St. dev.
Day-time in NTOU	17	1,735.5	189.4	1,673.5	78.1
Night-time in NTOU	10	1,746.8	129.5	1,673.2	97.9
Night-time in UP	7	1,736.0	241.7	1,581.3	192.5
Total	34	1,738.9	180.6	1,654.4	117.2

6.5 FINDINGS FROM SHIP TRACKS

The above results from ship tracks indicate some points. The first is that the violation in use of the TSS in Keelung could be prevented from traffic control and installation of traffic lane buoys. Comparing ship tracks in both exercises in the inbound experiment, the situation of crossing the separation zone was significantly improved in Ex-B. Statistical tests, evidenced quite different performances between exercises, except when approaching within 0.6 miles of the pilot station. In Ex-A , masters tended to used the sea room on left side of the base line, the opposite resulted in Ex-B. One reason was the sequence control at the pilot station caused the own ship to delay her time at the station when there was another ship waiting. The action to defer ETA was either by reducing ship speed early and/or detouring ship route. From Figure 6-6, the distribution of ship tracks obviously shifted to north of the lane in Ex-B. Many ships run a great turn before entering the lane. Another reason impinging on traffic flow was the buoy positioned at the inbound traffic lane. Ships took the buoy as a reference point keeping a short distance to turn into the lane. In the experiment, the initial course had an angle of 65 degrees to the direction of the inbound lane. Over half of the tracks in Ex-B passed north of the buoy within 400 metres. That was confirmed in Ex-B of the outbound experiment that no tracks were on the left of the exit buoy.

Ship tracks also evidenced that the violation in use of the TSS is serious in the existing situation. In Emden's study, some ship masters deliberately contravened COLREGS for taking a short-cut if no radar surveillance[14]. According to the Rule 10(e) of COLREGS, the separation zone is only used by crossing vessel or in cases of emergency. But the destination of the own ship in the experiment was the pilot station, so that she should use the lane and wait for the pilot. The ship had to join the lane at the termination. In Ex-A, 23 inbound ships crossed the separation zone towards the pilot station. This supports the findings in Chapter 4 that occasionally inbound ships from the NE sector will take a risky operation to save time, regardless of the hazard to their own and other ships.

The second is that the span of sea room used, especially near the pilot station, was much wider than the traffic lane. In Ex-B of the inbound experiment, 67.6% of ships joined the lane at the entrance, and at most 82.4% of ships were within the lane. But at the pilot station the proportion decreased to 75%. That trend of using sea room was consistent with the range covered by tracks. It was slightly decreased to 1,406 metres at first, but eventually increased to 1,905 metres, near three times of the width of the lane. Even in Ex-A with moderate wind force, the range was still 1,411 metres. That indicated ships, even with higher speed, joining the lane had difficultly maintaining positions in the lane. When arriving at the station, the manoeuvring became more difficult under strong wind.

Third, ships had more risk of contact the west breakwater without pilot assistance. In both exercises of the outbound experiment, the tracks on the UP simulator had significant difference from those on the NTOU. It was apparent in the experiment that larger container ships drifted to lee side, even under moderate wind force. The nearest track was 27 metres from ship to the breakwater; when half width was deducted, the distance of ship side to breakwater was only 12 metres. Examining the speed at the time of passing the breakwaters, those ship speeds were lower than others in NTOU. In order to disembark the pilot, ship speed has to be reduced to under five knots. After that, it has to be increased for sufficient steerageway for pass the breakwater. The distance allowance for that is 0.7 miles. Under strong wind, before the rudder effect is available, the ship has drifted away from the centre line. Most Taiwanese masters increased ship speed as soon as the exercises started. Masters serving on large container ships without experience calling at Keelung might delay the time increasing speed. That resulted higher risk to contact the breakwater.

Fourth, the edge of the inbound lane is too close to the breakwaters. Although the track distribution in the outbound experiment was more narrow than the inbound track distribution, most tracks were concentrated on the left side of the lane at the beginning. All tracks in Ex-B turned to the right immediately, when the subjects considered the breakwaters had been passed clearly, but there were still 26.4% of tracks which did not join the lane at the first data line. The usage of sea room at the main channel sector seemed not enough for ships turning into the outbound lane. A few ship tracks were very close to the inbound lane when they were turning the right. The track distribution in Ex-B had no difference from Ex-A at the first eight data lines. It indicated the manoeuvring was difficult for some masters to properly turn into the lane, even with a traffic buoy.

There are other findings, such that light is not an influencing factor; the outbound lane provides sufficient sea room for ships keeping from An-tou-pao shoal. All findings from ship tracks are compared with subjects' intentions in the questionnaire in the next chapter, to conclude some optimal methods for safety improvement in Keelung.

6.6 SUMMARY

Simulation provided an efficient method to assess the navigational risks and the measures for safety improvement found from the previous chapters. Ship tracks resulted from the simulation experiments indicate range of performance. The risk of the violation of crossing the separation zone could be minimised by traffic control through shore based-radar surveillance and installation of traffic buoys. The width of the inbound traffic lane is insufficient for ships manoeuvring under strong wind, especially at the pilot station. Outbound ships handling by masters with little local knowledge have higher risk to contact the west breakwater without pilot's assistance. Before turning into the outbound lane, some ships have risk of colliding with an inbound ship waiting for entering.

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CHAPTER 7

IMPROVEMENT OF NAVIGATION EFFICIENCY IN KEELUNG

7.1 INTRODUCTION

Navigator intention is related to experience and knowledge. Through analysis of subjects' intentions, methods reducing navigational risk evidenced from ship tracks can be emphasised. The questionnaire designed to accompany the experiments addressed comparison of the defined condition with the existing situation, and focused on the risk. That was different from the questionnaire used in the earlier chapters. Additionally, after assessing the available sea room used by ships, the TSS can be effectively modified. This is the first assessment of the benefit of the scheme, since it was established in 1990. With risk reduction, navigation efficiency may increase.

7.2 EFFECTIVENESS OF FLOATING BUOYS

7.2.1 Effectiveness of traffic lane buoys

Part B of the questionnaire sought to find the effectiveness of the lane buoys. From Table 7-1, it is apparent to reveal that in Ex-B the identification of traffic lanes by the buoys became easier in both inbound and outbound experiments. Using the Wilcoxon test to compare the difference between two exercises, it reached significance level in both experiments, $P = 0.0003, 0.0005$ respectively.

In question B3 and B4, if an entrance buoy were located on the traffic lane, 70.6% of mariners would use it to check the location of the lane by vision in clear visibility; 64.7% used it by radar under poor visibility. The proportion using the exit buoy was higher in clear visibility and lower in poor visibility than that in the inbound experiment (Table 7-2). Some mariners interpreted the best method was to identify by vision with buoy, and then by radar for double check, if visibility was available. In question B5, that the effectiveness of the buoys would be increased significantly when fitted with a racon was agreed by 94% of responses in the inbound experiment and 82.4% in the outbound experiment. No significant difference was found in group comparisons in these three questions. That indicated all mariners had the same distribution, regardless of time and ship size.

These results confirmed the efficiency of the lane buoys. There were conspicuous landmarks for position fixing by radar or by vision during the experiment, especially Keelung island only one mile from the outbound lane. Question B1 evidenced the identification of the traffic lanes was not very difficult, and was easier for outbound ships than inbound ships. But mariners were still favoured installation of the buoys, to provide more significant information, such as a safe area, ship position and location of traffic lanes, than the landmarks. Cotter interpreted in his study that the establishment of fairway lights instead of a 'danger light' would help to minimise groundings and collisions[1]. After TSS was established, the navigation problem of position fixing seems to be replaced by the problem of how to find traffic lane. It was believed that many ships could not properly turn into the lane due to inaccurate estimation of position. From ship track analysis, the buoy influenced the performance of traffic flow on making tracks near by it to turn into the lane. By using the buoys, the inaccurate estimation incurring contravention of TSS regulations may be minimised[2], and the traffic flow pattern may be narrowed near the termination of the TSS[3]. Therefore, the benefit from the buoy is not only reducing risk but also increasing efficiency in transit.

Table 7-1 The mean responses for identification of traffic lanes

	Day (NTOU)	Night (NTOU)	Night (UP)	Total
Question B1: To identify the entrance of the inbound traffic lane in Ex-A.				
Inbound	2.6471	3.3000	2.7143	2.8529
Outbound	2.1765	2.6000	2.8571	2.4412
Question B2: To identify the entrance of the inbound traffic lane in Ex-B.				
Inbound	1.8824	2.0000	1.1429	1.7647
Outbound	1.5294	1.6000	1.5714	1.5588

Score: 1 - very easy, 2 - easy, 3 - average, 4 - difficult, 5 - very difficult.

Significance level	Day/Night (NTOU)		Night (NTOU)/(UP)	
	Inbound	Outbound	Inbound	Outbound
Question B1	0.1022	0.2201	0.2747	0.5333
Question B2	0.8444	0.8216	0.0275	0.9563

Table 7-2 The best methods for identification of the traffic lanes

Methods	Inbound ships		Outbound ships	
	Clear Visibility	Poor Visibility	Clear Visibility	Poor Visibility
1. by vision with landmarks	11.8%	-	11.8%	5.9%
2. by vision with the lane buoy	70.6%	11.8%	82.3%	11.8%
3. by radar with landmarks	5.9%	23.5%	2.9%	26.5%
4. by radar with the lane buoy	11.8%	64.7%	2.9%	55.9%

7.2.2 The buoy on An-tou-pao shoal

Answers to El and E2 in the outbound experiment revealed mariners did not consider An-tou-pao shoal constituted a serious risk (table 7-3). No significant difference was found between the two questions, $P = 0.1166$. When testing the difference between groups, the subjects in UP had a moderate risk perception, relatively higher than those in NTOU. Although the shoal was little dangerous, the strong wind and poor visibility made subjects consider a larger distance from it (Table 7-4). 38.3% of subjects thought the safe distance should be greater than one mile in Ex-A condition, but 61.8% in Ex-B had the same view.

Table 7-3 The mean responses of risk to An-tou-pao shoal

	Day (NTOU)	Night (NTOU)	Night (UP)	Total
Question E1: The shallow water to the outbound ship in Ex-A.				
	2.3529	1.9000	3.0000	2.3529
Question E2: The shallow water to the outbound ship in Ex-B.				
	2.0000	1.8000	2.5714	2.0588

Score: 1 - very little dangerous, 2 - little dangerous, 3 - moderate dangerous, 4 - dangerous, 5 - very dangerous.

Significance level	Day/Night (NTOU)	Night (NTOU)/(UP)
Question E1	0.3796	**0.0081**
Question E2	0.9543	**0.0080**

The buoy established at An-tou-pao shoal gave a characteristic which indicated that it placed between the danger and the traffic lane. But the tracks in Ex-B concentrating on the west side of the lane were more influenced by the lane buoy than the shoal buoy.

When moving in the lane, most subjects increased ship speed so as to produce better turning effect and maintain straight tracks[4]. They did not take action to avoid the shoal. The average distance of tracks to the shoal was about 0.9 miles, similar to their concepts. Mariners could keep a safe distance from the shoal without a location buoy. It is therefore not suggested here that a buoy be provided.

Table 7-4 The safe distance to An-tou-pao shoal

Safe distance (mile)	Wind 10.7 m/s Clear visibility		Wind 17.1 m/s Poor visibility	
	number	percent	number	percent
1. 0.3 - 0.5	1	2.9%	-	-
2. 0.5 - 0.7	6	17.6%	5	14.7%
3. 0.7 - 1.0	14	41.2%	8	23.5%
4. 1.0 - 1.5	11	32.4%	16	47.1%
5. more than 1.5	2	5.9%	5	14.7%

7.3 REDISTRIBUTION OF USAGE OF SEA ROOM

7.3.1 Environmental factors to traffic

Through part C of the questionnaire, effects of wind and current on ship manoeuvring in traffic lanes were analysed. Table 7-5 indicates the influence of wind and current had similar weights in the experiments. Affected by the defined wind and current, ship position might deviate from the intended course line. In Ex-B with strong wind and current information provided, subjects needed to set a large leeway to maintain the ship on the course line (Table 7-6).

Table 7-5 The mean responses of wind and current effects

	Day (NTOU)	Night (NTOU)	Night (UP)	Total
C1: Wind effect has more influence than current to ship's manoeuvring in Ex-A.				
Inbound	2.2941	2.6000	3.4286	2.6176
Outbound	2.7059	2.7000	3.4286	2.8529
C2: Wind effect has more influence than current to ship's manoeuvring in Ex-B.				
Inbound	3.0588	3.0000	2.7143	2.9706
Outbound	3.0588	3.0000	3.4286	3.1176

Score: 1 - disagree strongly, 2 - disagree, 3 - uncertain, 4 - agree, 5 - agree strongly.

Significance level	Day/Night (NTOU)		Night (NTOU)/(UP)	
	Inbound	Outbound	Inbound	Outbound
Question C1	0.1988	0.8713	0.1098	0.0615
Question C2	0.7515	0.9370	0.4743	0.3840

Table 7-6 Leeway set in experiments

Leeway	Inbound ships		Outbound ships	
	Wind 10.7 m/s no current data	Wind 17.1 m/s current data provided	Wind 10.7 m/s no current data	wind 17.1 m/s current data provided
1. < 3 degrees	14.7%	2.9%	29.4%	5.9%
2. 3-5 degrees	38.2%	2.9%	50.0%	44.1%
3. 5-10 degrees	32.4%	44.1%	17.6%	44.1%
4. 10-15 degrees	11.8%	26.5%	-	2.9%
5. > 15 degrees	2.9%	23.5%	2.9%	2.9%

When wind force was 17.1 m/s, 94.1% of inbound traffic and 49.9% of outbound traffic set leeway more than five degrees; half of subjects in inbound experiment needed to allow for leeway of more than ten degrees. With the significant difference, wind effect with 17.1 m/s speed would cause difficulty of ship manoeuvring. Generally, leeway is continuously estimated, tested, and adjusted by a navigator until he obtains a reasonable heading overcoming wind and current effects to keep ship position on the desire route.

When the leeway is large, the navigator has to take long time to fix position and assess the problem. During the process, ship position will probably deviate far from the route. If the ten-degree leeway, under the define situation in the experiment, was ignored, a ship would drift about 480 metres off the course line when arriving at the pilot station. Therefore, a large sea room has to be provided for ship manoeuvring when local environmental effects are strong.

7.3.2 Assessment of lane width

The subjects indicated that the manoeuvre to keep the ship within the inbound lane would be easier after current information was provided. Because the difference between questions C3 and C4 was significant, $P = 0.0054$ (Table 7-7). Due to rudder effect, the problem of current effect within the outbound lane was lessened. There was a similar question E1 asked the situation of waiting for pilot at station with slow speed. 50% of subjects considered the manoeuvre was difficult. The mean score was even higher than that in C3 and C4. That confirmed the most difficult area of ship manoeuvring in the approaches is near pilot station.

Determination of current effect is not certain by ship-borne facilities, and the velocity of current is also subject to change[5]. The navigator may estimate it from deviation of ship position caused by many external factors. Sometimes before he detects the existing current the ship will have drifted well off course. Underestimating local current could take the ship towards danger. Therefore, according to subject responses, Keelung port should provide this information. Providing current information can remind navigators to take early compensation action and can reduce the number of manoeuvres needed to maintain position. Following the action, track deviation and oscillation could decrease. Consequently, efficiency in the use of the sea room and the transit time could increase.

Table 7-7 The mean responses of ship manoeuvring in inbound lane

	Day (NTOU)	Night (NTOU)	Night (UP)	Total
C3: To keep ship position within the lane without current information in Ex-A				
Inbound	3.0000	3.6000	3.2857	3.2353
Outbound	2.5294	3.0000	3.0000	2.7647
C4: To keep ship position within the lane with current information provided in Ex-B				
Inbound	2.6471	2.2000	2.7143	2.5294
Outbound	1.7647	2.1000	2.5714	2.0294
E1: To keep ship position in the lane at pilot station to wait for pilot				
Inbound	3.5882	3.6000	3.5714	3.5882
Score: 1 - very easy, 2 - easy, 3 - average, 4 - difficult 5 - very difficult				
C7: Widening the inbound traffic lane to provide large sea room for ship manoeuvring				
Inbound	3.0588	3.7000	3.4286	3.3235
Outbound	2.5294	3.6000	3.4286	3.0294
Score: 1- very unimportant, 2- unimportant, 3- average, 4- important, 5- very important.				

Significance level	Day/Night (NTOU)		Night (NTOU)/(UP)	
	Inbound	Outbound	Inbound	Outbound
Question C3	0.0734	0.0840	0.3780	1.0000
Question C4	0.2680	0.0837	0.1039	0.0517
Question E1	0.9576		0.9166	
Question C7	0.1676	**0.0037**	0.6465	0.7947

Through the above questions in this part, the subjects were eventually asked whether the width of the lane was adequate for ship manoeuvring against the defined wind and current condition. Although the average response, *3.3235*, revealed that widening the inbound traffic lane to provide large sea room was slightly important, 55.9% of subjects marked "important". No significant difference was found between groups. That meant more than half of mariners agreed the need to increase the lane width.

However, most of mariners responded that the width of the inbound lane cannot provide sufficient sea room, when taking account of the probable deviations by the wind and current effects. Ship tracks have revealed that the average range of covering sea room was 1590.9 metres. It is apparent that the present inbound traffic lane is insufficient. Many concepts now being taken to improve safety of navigation in the world are based essentially on traffic separation. To achieve the aim of separating opposing traffic, the lane width should be adequate to allow safe navigation[6]. Although the TSS in Keelung is constrained by the area, it must provide safe passage for transit.

7.3.3 Modification of TSS

When revision of lane width is undertaken, other risks have to be addressed. One risk is the An-tou-pao shoal to outbound ships, another is to ships anchoring at the west side of the inbound lane. According to the majority of subject perceptions, the least distance of outbound ships to the shoal should be 0.7 miles under clear visibility and 1.0 miles under poor visibility. The TSS is not only for the reduction of collisions but is also concerned with the reduction of strandings. The east boundary of the present outbound lane is about 0.7 miles to the shoal, and the west boundary is about 1.05 miles. The tracks also indicated that outbound ships had no alternative but to use the left side of the lane, when entering. Therefore, not only has the east boundary already been the margin for safety from the shoal, but also the west boundary should shift to the left. Regarding the anchoring ships, the water area between the inbound lane and Yeh-liu coast is the favourite anchorage for small and medium ships. Due to the deep water surrounding Keelung approaches, only this area is suitable for anchoring. To consider segregating anchoring ships by the TSS, it is impossible to widen the inbound lane to the left.

As sea room is limited it will be necessary to use some of the separation zone for widening lanes. The zone is 1,600 metres wide at the northern edge and 200 metres at the southern edge at present. It is recommended that the zone is reduced to a "straight-line" width of 200 metres allowing a 1,400 metres least width for both lanes. 200 metres is an appropriate buffer under the circumstances assuming emergent actions are taken. A separation line to separate traffic flow has been used in some ports in the world, such as Lamma channel in Hong Kong, when water area of port approaches is confined[7].

After the separation zone is replaced by the proposed separation line, the buffer region is decreased. On the other hand, the probability of head-on encounter increases, if there is no other aids to assist navigators to detect ship's deviation. Therefore, the role of radar surveillance and traffic lane buoy, mentioned in 7.2 para, becomes more important. A buoy fitted with highly visible light and racon would positioned at the north point of the separation providing a good mark for ships to identify the location of lanes, and keeping to the designated traffic lanes. It is fair to assume that the great majority of merchant ships rely on the radar when in poor visibility or high density traffic. With experience in the use of radar it becomes apparent that navigators would benefit from the improved detection and identification of the buoys with racon[8]. The water depth at that point is about 70 metres. According to information from a marine engineering company advising for this study, there is no technical problem mooring a buoy in deep water[9].

Additional to reducing navigation risk, a significant increase of efficiency is in the use of the sea room, after the TSS is modified. Ships coming from the NE section or leaving to the NW section will save the time of passage unnecessary to detour a great turn into or out the lane. When all inbound tracks in Ex-A were analysed with the datum line used in para 4.4, 44.2% of tracks passed through section 6. Those ships would have become in legal transit, if the separation zone were minimised. Meanwhile, ships joining the lane from the west boundary encountering anchored ships may be expected to decrease. Obviously the widened lanes can make smooth ship movement.

7.3.4 Location of pilot station

Regarding the pilot station in question E5, 44.1% of subjects were satisfied that the location was appropriate, while 14.7% were uncertain. The remaining 14 subjects (41.2%) thought the location was inappropriate, and suggested various position for the pilot station depending on their experience; four subjects considered two miles off breakwaters; two subjects thought open sea outside TSS; eight subjects preferred the entrance of the inbound lane to be pilot station. No significant difference was found in this questions between groups by the M-W test.

In para 6.5.1, the mean distance of 24 inbound tracks near the station in Ex-B was 20.9 metres on the left of the centre line with 371 metres the standard deviation. Through the Kolmogorov-Smirnov test, specifically designed for analysing the goodness-of-fit situation[10], the distribution of track distances was a normal distribution, $P = 0.961$. After the separation zone is minimised, the lane width at the 15th data line will be about 920 metres, still only covering 78.3% of tracks. For increasing the possibility of ships navigating within the lane, the station should shift to a wider area.

When replacing the station, a potential encounter has to be considered. Some outbound tracks in the experiment turned the left as soon as passing the lane buoy and then crossing the northern area outside the inbound lane. Inbound ships drifting at the this area will increase collision risk. For providing a safe area to the subsequent coming ship not only keeping a safe CPA from the ship waiting at the pilot station but also from those NW bound leaving ships, the new station should keep one mile from the entrance. The area in the entrance with 1,400 metre width can provide sufficient sea room, for the subsequent ship waiting, without collision risk. Therefore, the optimal choice from subjects' suggestions for the station is 1.9 miles off the breakwaters, about 0.4 miles north from the present station. The lane width there is 1,058 metres, covering tracks increasing to 84.5%. In the investigation of marine opinions, pilots did not agree to modify the station. But for reduction of risk, this shift should be approved by them. Meanwhile, they have more time for judgement and to gain sufficient steerageway before entering.

7.4 ESTABLISHMENT OF TRAFFIC CONTROL

7.4.1 Inbound ship's encounter

In the existing situation, no information about ship movements is provided to arriving ships at Keelung. In D1 with Ex-A condition, subjects identified a high collision risk, when potential encounters happened in the experiment. After information was provided, in D2, mean score steeply descended to *1.6176* (Table 7-8). Obviously the difference between the two questions was significant, $P = 0.0000$. The navigators in each group had the same perception. That indicated the information was positively effective in reducing the collision risk, even in poor visibility.

Following the target ship, the own ship entered the traffic lane. Under clear visibility in question D3, 85.3% of subjects thought the safe distance to the privileged ship could be between 0.3 and 1.0 mile, and most of them took the choice of from 0.5 to 1.0 mile. Under restricted visibility in D4, the risk perception to subjects increased. 97.1% agreed the distance should be more than 0.5 miles. Over half of subjects considered the distance should be more than 1.0 mile (Table 7-9).

Table 7-8 The mean responses of collision risk in inbound experiment

	Day (NTOU)	Night (NTOU)	Night (UP)	Total
D1: Collision risk under two-ship encounter without information of ship movement				
Inbound	4.0000	4.4000	3.7143	4.0588
D2: Collision risk under two-ship encounter with information of ship movement				
Inbound	1.5882	1.8000	1.4286	1.6176

Score: 1 - very low, 2 - low, 3 - moderate, 4 - high, 5 - very high.

Significance level	Day/Night (NTOU)	Night (NTOU)/(UP)
Question D1	0.4682	0.0960
Question D2	0.2687	0.1260

Table 7-9 The safe distance to the privileged ship

Safe distance (mile)	Wind 10.7 m/s Clear visibility		Wind 17.1 m/s Poor visibility	
	number	percent	number	percent
1. less than 0.1 mile	-	-	-	-
2. 0.1 - 0.3	2	5.9%	-	-
3. 0.3 - 0.5	12	35.3%	1	2.9%
4. 0.5 - 1.0	17	50.0%	14	41.2%
5. more than 1.0	3	8.8%	19	55.9%

7.4.2 Sequence at pilot station

From part F of the questionnaire, 30 subjects had called on Keelung when they worked on ships. Apart from two, all had met other ships at the pilot station at the same time waiting for the pilot. 16 subjects had that experience frequently.

When there were two ships near the pilot station simultaneously, the perceived collision risk was high. In question E3, subjects agreed the risk could be reduced by control of ship sequence. Consequently, the difference between those two questions was significant, $P = 0.0000$. The mean scores were respectively higher than D1 and D2. The inference through the M-W test was navigators had same perception to collision risk at pilot station (Table 7-10).

Table 7-10 The mean responses of collision risk at pilot station

	Day (NTOU)	Night (NTOU)	Night (UP)	Total
E2: Collision risk when two ships waiting for pilots near pilot station				
Inbound	4.2941	4.4000	4.0000	4.2647
E3: Collision risk when two ships with same ETA to pilot station by sequence control				
Inbound	2.1176	1.9000	1.8571	2.0000

Score: 1 - very low, 2 - low, 3 - moderate, 4 - high, 5 - very high.

Significance level	Day/Night (NTOU)	Night (NTOU)/(UP)
Question E2	0.9084	0.2779
Question E3	0.8627	0.7934

In question E4, when the sequence of pilot boarding and the movement information were provided, 20.6% of subjects considered the best location for a privileged ship awaiting pilot was near pilot station. 32.4% considered the place was at the entrance of traffic lane, and 47.1% of subjects would drift the ship outside the TSS.

7.4.3 Outbound ship's encounter

Outbound ships also have a risk of potential encounter due to inbound ships waiting to enter. An outbound ship has priority on leaving the main channel. But before turning into the outbound lane, she may be close to any ship waiting near the pilot station. Based on past experience of those who had visited Keelung, in question F7, another ship drifting near pilot station during their leavings was a normal situation.

Subjects thought, in question D1, that the inbound ship drifting near the pilot station was a moderate collision risk to the outbound ship. After the information of another ship's movements was provided in D2, even under restricted visibility, the collision risk became very low (Table 7-11). A significant difference between the two questions, $P = 0.0000$.

Table 7-11 The mean responses of collision risk to outbound ships

	Day (NTOU)	Night (NTOU)	Night (UP)	Total
D1: Collision risk when inbound ships drifting near pilot station without information				
Outbound	3.1176	3.1000	2.8571	3.0588
D2: Collision risk when inbound ships drifting near pilot station with information				
Outbound	1.4118	1.3000	1.5714	1.4118

Score: 1 - very low, 2 - low, 3 - moderate, 4 - high, 5 - very high.

Significance level	Day/Night (NTOU)	Night (NTOU)/(UP)
Question D1	0.9794	0.6112
Question D2	0.5688	0.2776

How far from the breakwaters should the inbound ship have to remain to avoid obstructing the movement of the outbound shipping? 41.2% of subjects thought the safe distance could be less than one and half miles under clear visibility, and another 41.2% agreed from one and half miles to two miles. Under restricted visibility, the proportion of responses to the former distance dropped to 14.7%, and the same proportion on the later. But the remaining 44.1% thought the distance should be at least two miles (Table 7-12).

Table 7-12 The safe distance to the leaving ship

Safe distance (mile)	Wind 10.7 m/s Clear visibility		Wind 17.1 m/s Poor visibility	
	number	percent	number	percent
1. 1.0 - 1.5	14	41.2%	5	14.7%
2. 1.5 - 2.0	14	41.2%	14	41.2%
3. 2.0 - 2.5	5	14.7%	6	17.6%
4. 2.5 - 3.0	-	-	6	17.6%
5. more than 3.0	1	2.9%	3	8.8%

7.4.4 The closest distance in ship tracks

In addition to the distance from the base line, tracks also provided the distance to the target ship for potential encounter. The distance between both ships was measured at one minute intervals from ship tracks. The output data included time, heading of the own ship and relative bearing between both ships. Through the data, the closest distance of approach was found, and own ship's heading and relative bearing at that time. Lewison represented that collision was always related with the probability of potential encounter and actual encounter[11]. He defined that the situation where two ships would pass within half a mile of each other in the absence of avoiding action was potential encounter; the situation where two ships eventually passed within the given distance was actual encounter. The actual encounter may give rise to a collision. However, if one ship takes avoiding action to pass another ship with larger distance than half a mile, no actual encounter will arose. Therefore, the probability of actual encounter directly relates to the number of collisions.

7.4.4.1 CPA in inbound tracks

In the inbound experiment, the target ship would stop steer for 10 minutes from the 15th to 25th minute after the start of exercise play. In Ex-A, the average of CPAs to the target ship was 681.9 metres (0.37 miles); In Ex-B, that was 1258.9 metres (0.68 miles), shown in Table 7-13. There were eight tracks in Ex-A incorporating actions by alteration of course or/and speed to keep CPA greater half a mile. The encounter of the remaining 26 tracks became the actual encounter, CPAs less than half a mile. Among those tracks, the smallest CPA was in Run 17 in which two ships collided, when the TCPA was at the 23rd minute. The next smallest CPA was only 14 metres in Run 3 at the 19th minute. Both of exercises were carried out with the NTOU simulator in day time.

In Ex-B, 20 tracks kept a safe CPA to the target ship. In the remaining 14 tracks the CPAs were less than half a mile. The smallest CPA, 109 metres, was occurred in Run 24. Some ships drifted in the northern area, one mile off the lane entrance, to wait for traffic to clear. From simulator records, the maximum heading reached 302 degrees. Through statistical tests, the CPA in Ex-B was significantly larger than that in Ex-A. Furthermore, the CPA performed by the UP subjects was larger than that by the NTOU subjects, and the former had very small standard deviation indicating consistency among the subjects.

With sequence control navigators' actions in avoiding collision risk are influenced. Without traffic control some masters do not consider carefully the risk of encounter with other ships. When collision risk is eventually detected, they take emergency action by reversing propulsion to stop the ship, even going astern. It is possible to observe subject behaviour on entering an actual encounter situation. The experimental programme designed that at the 25th minute the target ship completed pilot boarding and moved into the harbour from the station. If the TCPA was between the 15th and 25th minute, the period of the target ship being stopped, that indicated the own ship was stopping or moving astern at that time to avoid collision by urgent reduction of speed. On the contrary, when the TCPA was at or after the 25th minute, the own ship was moving forward slowly at the time because the subject had taken early avoiding action. In Ex-A, there were 13 tracks for either situation. In Ex-B, there were only four tracks before and ten tracks after the 25th minute. Under traffic control, navigators would take an early and safe actions of collision avoidance.

Table 7-13 CPA to the target ship in inbound experiment

Subjects	No. of tracks	Ex-A		Ex-B	
		Mean	St. dev.	Mean	St. dev.
Day-time in NTOU	17	676.9	520.8	988.9	628.6
Night-time in NTOU	10	670.5	345.8	1076.2	561.4
Night-time in UP	7	710.6	739.2	2175.8	339.5
Total	34	681.9	513.5	1258.9	724.2

7.4.4.2 CPA in outbound tracks

In Ex-A, the average closest distance between the outbound ship and the target ship waiting at the pilot station, was 1060.2 metres (Table 7-14), five tracks came into encounter with CPAs less than half a mile. The smallest CPA was 789.8 metres in Run 33. In Ex-B, the mean CPA was 1187.9 metres with no track resulting in encounter within half a mile. Through statistical tests, no difference between either exercises or groups was significant.

Table 7-14 CPA to the target ship in outbound experiment

Subjects	No. of tracks	Ex-A		Ex-B	
		Mean	St. dev.	Mean	St. dev.
Day-time in NTOU	17	1186.1	167.0	1209.8	82.1
Night-time in NTOU	10	1149.4	106.4	1186.0	91.0
Night-time in UP	7	1112.6	216.9	1137.6	256.2
Total	34	1160.2	161.3	1187.9	135.1

7.4.5 Provision of traffic control

On account of the dangerous situation in Keelung approaches, in addition to installation of shore-based radar to monitor the movement of vessels in the TSS and detect infringement of the one-way lanes, the traffic control should include:

1. organisation of inbound ships to pilot station;
2. providing information of ship movement to relevant ships;
3. suggestion of safe distance to other ships in the lanes;
4. arranging accurate pilot boarding time.

Subject perceptions indicated the information of ship movement and sequence control were effective in reducing collision risk. The inbound tracks confirmed the CPA could be increased by those methods when visibility is restricted. Due to ship congestion in the port approaches, potential encounter is unavoidable. In such confined waters, the ships path cannot be fixed as in the open sea. Masters have to alter course and speed frequently to maintain a safe distance from other vessels. Theoretically, the relative distance to the target ship when taking action to resume the passage is affected by the range of first detection[12]. With earlier and more accurate detection navigators can take safer action. Accordingly, knowledge of other ship movements is necessary. When work pressure is high, knowledge of an appropriate quality cannot always be obtained from shipboard observation. Assistance from the shore is widely acceptable, and when such information about ship movements is provided, the master can consider carefully before judgements.

Due to the consideration of risk on overtaking, the number of ships using the lanes has to be controlled. In Curtis' study[13], there were a significant number of mariners who passed dangerously close, when they were overtaking other ships in fog. In the experiment, it was also found that 76.5% of own ships were close to the target ship within 0.5 mile under clear visibility, and 41.2% under poor visibility, when there was no radar monitoring and control. After the lane is widened, sea room is still insufficient for two ships congesting near the pilot station. According to subjects, half agreed to 0.5 miles as a safe CPA in the inbound lane. Nevertheless, the unpredictable situation causing risk made the final CPA, 0.37 miles as the average of tracks, shorter than their intentions. After the sequence control was performed in Ex-B, those actions of collision avoidance mentioned above decreased the probability of actual encounter and increased

CPA to the ship picking up pilot. The average CPA of tracks, 0.68 mile distance, was still less than the reasonable CPA from subjects' concepts. The result revealed traffic control of safe distance between ships must make allowance for ship manoeuvring in emergency. Under a complicated situation, navigators cannot always handle ships as they would wish.

Therefore, the shore station has to control the distance between ships in lanes to one mile to give sufficient reserve for emergencies. To prevent possible saturation, traffic should be restricted in numbers of ships waiting at the pilot station. If there is a ship waiting, the subsequence ship has to slow down near the entrance in the lane where sufficient sea room exist for manoeuvring. Mariners would be informed of precedence in picking up the pilot and would prefer to be called forward by shore control, so as to maintain one mile separation between inbound vessels at all times.

Meanwhile, traffic control should include accurate pilot boarding time. The subjects considered it was difficult to keep ship position within the lane whilst waiting for pilots. After the TSS is modified, the lane's width at the pilot station is still narrower than the covering range of ship tracks. Therefore, the shore station has to coordinate ship's ETA with the pilot to avoid drifting while waiting for the pilot.

In addition to control of the closest distance between inbound ships the situation of an inbound ship, waiting for clearance, threatening leaving ships in the main channel also needs to be considered. In the experiment, 35.3% of tracks could not join the lane from the first data line under the existing situation, and 26.5% were out of the lane under the defined situation. Some of them almost invaded the inbound lane. There was no significant difference between tracks in Ex-A and Ex-B, when ships turned into the lane. Therefore, the average CPA in both exercises were about 0.63 miles. That revealed the sea room of the main channel sector was too small. The present main channel sector in Keelung extends for 0.75 miles from the breakwaters. Accordingly, many inbound ships waiting for entrance tend to stay at the edge of the sector, rather than at pilot station, to save time on entering. It is impossible for outbound ships to keep a safe distance from those ships. In order to protect outbound ships from being threatened by inbound ships waiting to enter, the main channel sector needs to be extended to one mile in accordance with subjects perceptions, and the shore station should control entry of those ships staying near the pilot station to ensure enough sea room for outbound ships.

Strict regulation of traffic movements within TSS has to be complete in a super port[14]. To enforce strict control can ensure smooth and safe flow. Under control, there may be inconvenience to some ships following shore station advice to maintain position within a lane or area, but safer navigation will reduce time used in avoiding risk. Provision of information on traffic movement enable masters to take early and efficient collision avoidance action.

7.5 IMPROVEMENT OF PILOT SERVICES

A serious accident contacting the breakwater might cause blockage of the main channel. Maintaining a clear port entrance is a basic requirement on navigational efficiency[15]. Among the 30 subjects who had called at Keelung, 46.7% had experience entering the port through breakwaters without pilot's assistance. In question F5, 19 subjects recognized that action was very dangerous under bad weather, and 9 subjects agreed that was dangerous. The accident of an inbound ship contacting the breakwaters occasionally happens.

When outbound ships passed the breakwaters the pilot had very often disembarked. 19 of the 30 subjects stated that to be standard practice under any weather condition, although the pilot assistance could be requested. After the outbound experiment. In F1, 14 subjects thought that action was dangerous, and another 14 thought it safe, while six were uncertain. Through the Wilcoxon test, significant difference, $P = 0.0000$, was found between the questions, F5 in the inbound experiment and F1 in the outbound experiment. That revealed the action of ship master handling ship to enter the port was more dangerous than when leaving. Although no simulation experiment of inbound ship entering the main channel was undertaken in this study, from analysis of ship tracks and accident records it could be concluded that the risk to the inbound ship under master's handling on entering port is high, and compulsory pilotage for ships passing the main channel must be introduced. When pilots are unable to operate and the service is suspended due to adverse weather, ship masters should not be allowed to substitute. The port should be temporarily closed under such extreme condition.

7.6 SUMMARY

The nature of navigation in the approaches to Keelung, the identification of risk and means of addressing that risk have been identified through simulation and questionnaire. It has been shown that:

1. While identification of traffic lanes is not a major problem provision of racon fitted the buoy at the outer ends of the separation line would prove advantageous.

2. Under strong wind and current condition, maintaining position within the inbound lane is not easy. The problem is complicated when vessels have to progress at slow speed or are delayed in the vicinity of the pilot station while awaiting the pilot. Under normal conditions, minimising the separation zone to enlarge the sea room of both lanes can provide adequate separation between ships.
3. While collision risk, such as contravention of TSS regulation and congestion in traffic lanes, is a major problem, shore-based radar monitoring, sequence control to pilot station, advice of a safe distance between ships and providing information of current and traffic movements are available methods for reducing the risk.
4. For vessels to pass between the breakwaters with the benefit of pilotage advice improves safety.

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CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 NAVIGATIONAL RISKS IN KEELUNG

In recent years, increased ship size and traffic density have heightened navigational risk in Keelung. Risk reduces navigational efficiency and serious accidents have occurred. The probability of traffic accidents including collisions, groundings and contacts, was 1.65 per 1,000 ships during the five years from 1987 to 1991. Among the accidents some three quarters were collisions. Incidence of collision has not significantly decreased since the TSS was established in 1990. With regard to Keelung port, mariners observed that the water areas within the TSS and near the breakwaters were the most dangerous. Through analysis of investigations in this study, factors incurring navigational risk in the approaches have been identified (Table 8-1).

A major cause of navigational risk is violation of the regulations. According to the COLREGS and Keelung TSS regulation, "ships shall proceed in the appropriate traffic lane in the general direction of traffic flow for that lane." Through radar survey, a few ships proceed in the opposite lane regardless of the establishment of TSS. A number of ships do not cross the lanes at right angles, and many ships anchor in the TSS or near its terminations. Fishing vessels work in traffic lanes and obstruct ship movement. Among the collision accidents in the approaches, 28% of the collisions involved fishing vessels.

Table 8-1 Factors of navigational risk found from investigations

Factors	Casualty Records	Mariner Opinions	Radar Survey	Simulation Experiment
Navigable water insufficient	X		X	X
Violation of TSS regulations	X	X	X	X
Fishing vessel congestion		X		
Port operation defection		X	X	X
Poor visibility	X	X		X
Strong wind	X	X		X
Strong current	X	X		X

Inadequacy of traffic management also constitutes a risk. Ships congesting near the pilot station and the main channel sector caused a high risk of collision. Regulation gives the priority to outbound ships, but the signal station cannot effectively communicate this to inbound ships. As the west part of the approaches provides anchorage for ships, the area designated to the fairway is very narrow, only 700 metres width for each traffic lane. It is difficult for ships manoeuvring to avoid collision risk, or to wait for the pilot in the lane. The accident records revealed many collision cased involving ships in the anchorage.

Another identified risk factor relates to the ship handling techniques applying to large vessels. Container ships and bulk carriers formed a higher proportion than other type ships in collisions. Navigators on large container ships, especially without experience calling at Keelung, have a higher than average risk perception.

Restricted visibility is the major environmental factor in navigational risk. Users expressed concern when transiting at night and in spring, the rainy and foggy season. Strong winds have a significant effect on grounding. The NE monsoon often causes ships to drag anchor in the outside anchorage. Strong current is a potential factor in contacts. In the simulation experiment most subjects agreed that the strong current was the main environmental factor in the cases of inbound ships colliding with breakwaters. The strong current also was similarly considered to be a major concern when anchoring.

8.2 NAVIGATION EFFICIENCY AFFECTED BY RISKS

Navigation efficiency is reduced by accidents and by traffic congestion in the approaches. Depending on traffic flow, efficiency was considered in terms of costs and time. Costs resulting from accidents were determined from information providing from shipping companies, although information was only obtained relating to 31.1% of the vessels involved. During 1987-1991, the average cost of hull damage caused by collision accidents was US$203,600 including one bulk carrier which sank as a total loss. The repair costs attributable to grounding or contact were much higher than those of collisions. In addition to hull repair cost, a ship owner may increase operational cost due to charter other ships to continue the service. Fortunately, during the five years there was only one grounding accident causing oil spillage, and that was cleaned up quickly. Two people died in rescue operations following a further grounding. The Keelung Harbour Bureau confirmed no accident blocked the fairway.

From the radar survey, it was found that 16.8% of inbound ships were delayed more than 30 minutes while waiting at the pilot station. The drifting denies other ships the use of sea room. Due to the navigable water being constrained, any action drifting in the lanes or violating the TSS regulations may cause subsequent ships to increase passage time in collision avoidance by altering courses and/or speed. The simulation experiment revealed some ships took a great turn at the northern part of the approaches. That may endanger other users, such as ships bound for the NW section. Strong wind and current cause ships need to take a great leeway to maintain position, especially large container ships. It can be inferred that some ships take time in adjusting ship position.

8.3 IMPROVEMENT OF NAVIGATIONAL SAFETY AND EFFICIENCY

The majority of accidents occurring in Keelung approaches result in additional costs to ship owner, port authority and public. In order to decrease these costs, reducing navigational risk is a principal object to Keelung port authority in competition with other ports. It is apparent that efficient traffic flow will automatically result from the safe navigation environment so produced.

According to mariners' opinions, the navigational risk in Keelung approaches could be reduced by sequence control at the pilot station, traffic control in traffic lanes, and enforcement of safety regulations. They also support TSS functions to strictly separate the opposing traffic flow, particularly in cases of poor visibility. Due to violation of regulations by merchant ships and fishing boats, the safety improvement by the TSS is not significant. It was supposed that there were some reasons for these violations, including lack of sufficient sea room, lack of identification mark and lack of surveillance. Through the simulation experiment, these suppositions were confirmed.

In the experiment, the width of lanes were found insufficient to cover the observed range of ship tracks. Taking account of limitation of navigable water area, the only way to increase the lane area is to change the relatively large separation zone to a narrow separation line, using this sea area for wider traffic lanes. Then, establishment of a fairway buoy provides an accurate identification of lanes (Figure 8-1, 8-2). Radar surveillance is necessary to monitor ship movement and warn against violation. The effectiveness of these methods for changing traffic flow into a safer system has been evidenced and supported by the experiment.

The restriction of traffic flow is concerned not only with proper ship movement but also with safe distance between ships in the lanes. Control of ship sequence at the pilot station is another measure for improving safety. After the separation line recommendation is adopted, the inbound lane near the pilot station is wider but the manoeuvring room is still insufficient for two ships to pass safely during a strong wind. From subjects' opinions, a one mile CPA to a ship boarding pilot is necessary for safety. Therefore, the signal station in Keelung must establish a sequence control so that following ships can reduce speed early and choose a safe area for drifting. Provision of weather and ship movement information may enable relevant ships to take early and proper action.

Meanwhile, the experiment pointed out that vessels without pilots were more at risk of striking the breakwaters, especially in adverse weather. Compulsory pilotage is commonplace in the majority of ports throughout the world. Any accident in Keelung could damage not only the ship but also port facilities, and a serious accident could block the channel. So as to maximise profit it is recommended that Keelung should become a compulsory pilotage area for some ships transiting the main channel.

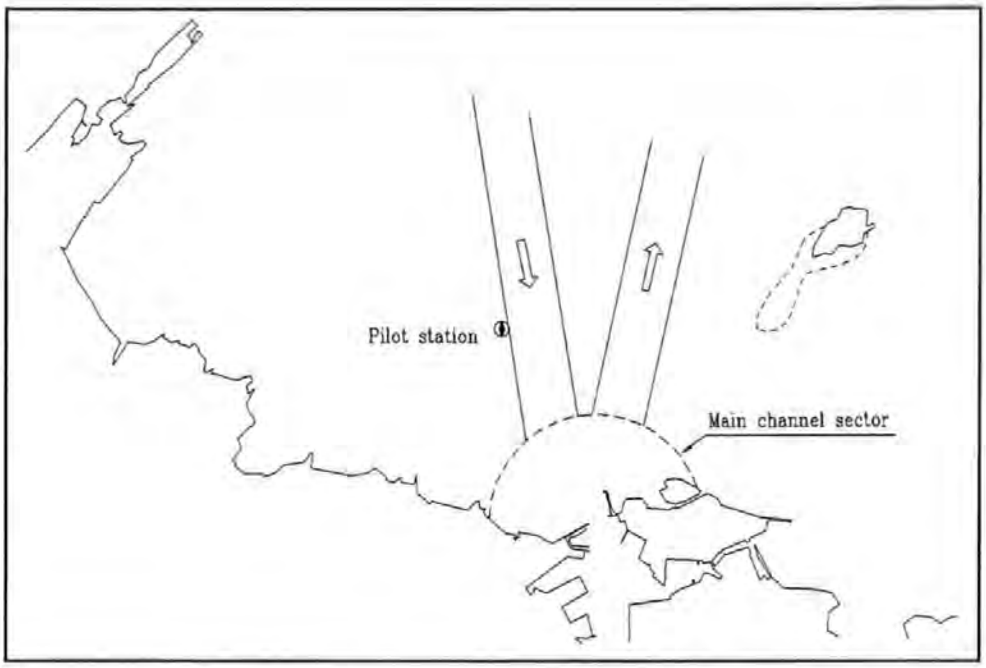


Figure 8-1 The existing Keelung TSS

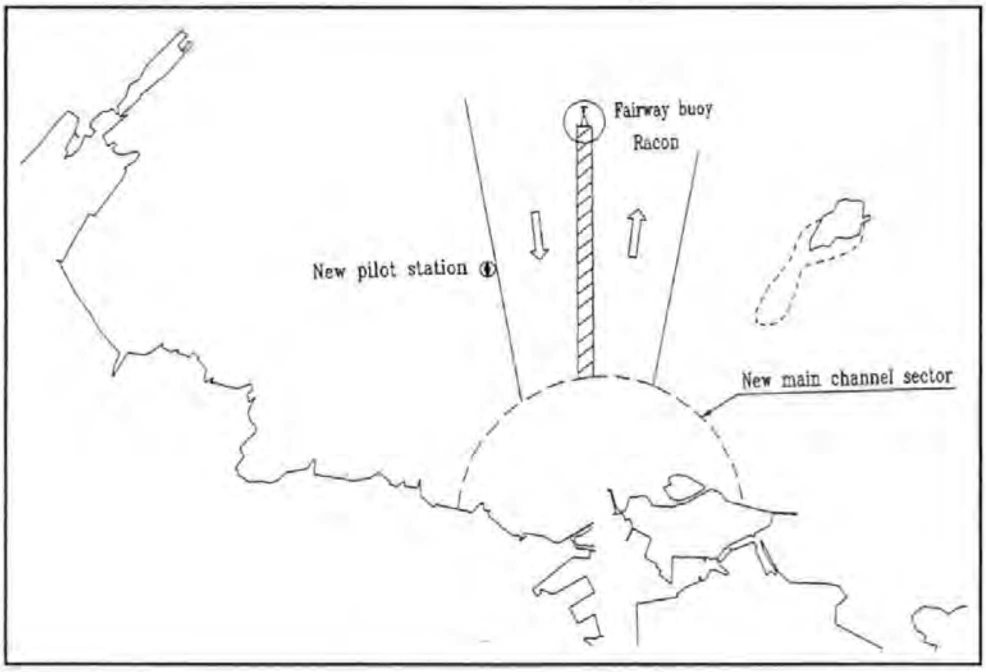


Figure 8-2 The recommended Keelung TSS

Improvement of navigational efficiency may be expected to follow these measures (Table 8-2), especially for large container ships and foreign flag ships whose masters are not familiar with the port conditions. Traffic control and compulsory pilotage may inconvenience a few ships, but this would be a marginal cost when compared with the overall economic gains in safety and efficiency. Once the traffic lanes are widened and the fairway buoy installed, ships could easily locate the lane entrance or exit, and make a better approach and departure route. Position fixing would be simplified allowing greater alteration to other tasks. The lane width would be adequate for ships waiting at the pilot station, and under positive shore control delays at the pilot station should be minimised or removed.

Table 8-2 Navigational efficiency from measures improving safety

Methods	Reducing deviation	Reducing position error	Decreasing collision risk	Smoothing traffic flow	Shortening ship route
Widening lane width			X	X	X
Positioning fairway buoy	X	X			X
Radar surveillance	X	X	X	X	
Sequence control			X	X	X
Distance control			X		
Compulsory pilotage	X	X	X	X	
Providing current information	X				X
Providing ship movement information			X	X	

The measures, including: shore-based radar surveillance; sequence control and CPA advice; provision of current and ship movement information; compulsory pilotage; and particularly modification of the TSS and installation of a fairway buoy, are recommendations to Keelung port authority for improvement of navigational safety and efficiency. It is thought that this study may contribute to Keelung port development.

8.4 FUTURE RESEARCH

The recommendations made in para 8.3 are set against the existing situation at Keelung. It is recognized that many of the problems that need to be overcome, in this study, stemmed from the lack of an adequate information data base. As improvement of navigational safety and efficiency is a continuing objective, it is necessary to build up an archive giving an accurate record of marine accidents, from which to evaluate continuing risk. Following complete or partial implementation of the recommendations stemming from this study, further observations and analysis are required. The future investigations include the speed profile of ships entering and leaving Keelung harbour and ship encounter rate in the area north of the separation scheme. The traffic control in the traffic lanes may associate with speed limit. The encounter is related to the collision risks near the suggested fairway buoy. From such analysis the effectiveness of the measures and any need to fine tune could be determined.

APPENDIX - A

Questionnaire's form of mariner opinions

QUESTIONNAIRE ON MARINE SAFETY IN KEELUNG PORT WATER

A. BASIC INFORMATION

A1. FULLTIME SHIPBOARD EXPERIENCE

Please indicate your number of years of fulltime shipboard experience.

______ year(s)

A2. MOST RECENT YEAR OF FULLTIME SHIPBOARD EXPERIENCE

Please indicate your most recent year of fulltime shipboard experience calling Keelung port. 19______

Please indicate your occupation during your most recent year of fulltime shipboard experience calling Keelung port. Circle the appropriate number.

1. Master/Mate of a merchant vessel.
2. Master/Mate of a fishing vessel.
3. Master/Mate of a government vessel.
4. Pilot.
5. Other, please specify ________________________

If your answer is "1", please indicate the type and gross tonnage of the vessel by circling the appropriate number.

Type:

1. Container ship.
2. General cargo ship.
3. Bulk carrier.
4. Tanker.
5. Passenger ship.
6. Other, please specify ________________________

Gross tonnage:

1. Less than 500 grt.
2. 500 - 999 grt.
3. 1,000 - 4,999 grt.
4. 5,000 - 9,999 grt.
5. 10,000 - 19,999 grt.
6. 20,000 - 39,999 grt.
7. More than 40,000 grt.

B. RISK PERCEPTION

B1. RISK FACTORS

Various factors contribute to accidents or to situations where the chance of an accident increase. Based on your total experience, please indicate how often, in your opinion, the factors below would increase marine risk in Keelung port. Circle the appropriate number on each row.

1. Outside area of the Traffic Separation Scheme:

	Undecided/ no opinion/ don't know	Very seldom increases risk	Seldom increases risk	Sometimes increases risk	Often increases risk	Very often increases risk
High density of traffic	0	1	2	3	4	5
Fishing vessels in shipping lanes	0	1	2	3	4	5
Strong currents	0	1	2	3	4	5
Poor visibility (fog, rain)	0	1	2	3	4	5
Strong wind	0	1	2	3	4	5
Shallow water	0	1	2	3	4	5
Natural underwater hazard	0	1	2	3	4	5

Other, please specify ______________________________

2. Within area of the Traffic Separation Scheme and near the breakwater:

	Undecided/ no opinion/ don't know	Very seldom increases risk	Seldom increases risk	Sometimes increases risk	Often increases risk	Very often increases risk
High density of traffic	0	1	2	3	4	5
Fishing vessels in shipping lanes	0	1	2	3	4	5
Strong currents	0	1	2	3	4	5
Poor visibility (fog, rain)	0	1	2	3	4	5
Strong wind	0	1	2	3	4	5
Shallow water	0	1	2	3	4	5
Natural underwater hazard	0	1	2	3	4	5

Other, please specify ______________________________

3. Within area of anchorage:

	Undecided/ no opinion/ don't know	Very seldom increases risk	Seldom increases risk	Sometimes increases risk	Often increases risk	Very often increases risk
High density of traffic	0	1	2	3	4	5
Fishing vessels in shipping lanes	0	1	2	3	4	5
Strong currents	0	1	2	3	4	5
Poor visibility (fog, rain)	0	1	2	3	4	5
Strong wind	0	1	2	3	4	5
Shallow water	0	1	2	3	4	5
Natural underwater hazard	0	1	2	3	4	5

Other, please specify ______________________________

B2. OVERALL RISK

For each area, season, daytime and nighttime in Keelung port, and for the generally prevailing conditions, please indicate its overall risk as you see it. Circle the appropriate number.

	Undecided/ no opinion/ don't know	Very low risk	Low risk	moderate risk	Hgh risk	Very high risk
By area:						
Outside area of Traffic Separation Scheme	0	1	2	3	4	5
Within area of Traffic Separation Scheme and near the breakwater	0	1	2	3	4	5
Within area of anchorage	0	1	2	3	4	5
By season:						
Jan.- Mar.	0	1	2	3	4	5
Apr.- Jun.	0	1	2	3	4	5
Jul. - Sep.	0	1	2	3	4	5
Oct.- Dec.	0	1	2	3	4	5
By light:						
Day-time	0	1	2	3	4	5
Night-time	0	1	2	3	4	5

Other, please specify ______________________________

C. OPTIONS FOR RISK REDUCTION

C1. OPTIONS

There are different ways of improving marine safety. Please indicate the contribution of the following methods in improving marine safety in Keelung port. Circle the appropriate number on each row.

	Undecided/ no opinion/ don't know	Very little	Little	Moderate	Significant	Very significant
Institution of speed limits in traffic lanes	0	1	2	3	4	5
Improved provision of weather information	0	1	2	3	4	5
Improved control over fishermen in traffic lanes	0	1	2	3	4	5
Improved control of ship sequence at pilot station	0	1	2	3	4	5
Stricter enforcement of ship safety regulations	0	1	2	3	4	5
Upgraded fixed and floating aids	0	1	2	3	4	5
Upgraded shore based electronic navigational aids	0	1	2	3	4	5
Provision of Vessel Traffic Services	0	1	2	3	4	5

Other, please specify ______________________________

C2. MODIFICATION TO TRAFFIC SEPARATION SCHEME

Please indicate how, in your opinion, the design of Traffic Separation Scheme in Keelung port should be modified by circling the appropriate number.

	Undecided/ no opinion/ don't know	Disagrees	Slightly disagree	Slightly agree	Agree
Length of traffic lanes	0	1	2	3	4
Width of traffic lanes	0	1	2	3	4
Location of Pilot station	0	1	2	3	4
Direction of traffic lanes	0	1	2	3	4

Other, please specify ______________________________

APPENDIX - B

Commands of the SPSS/PC+

```
TITLE 'NAVIGATIONAL RISK SURVEY'.

SET DISK = ON.
SET LISTING 'QUESTION.LIS'.
DATA LIST FILE = 'QUESTION.DAT'
    / No 1-3 Ex 4-5 Yr 6-7 Occ 8 Rank 9 Type 10 Ton 11
      B11 TO B18 13-20
      B21 TO B28 21-28
      B31 TO B38 29-36
      B41 TO B50 38-47
      C11 TO C19 48-56
      C21 TO C25 57-61.

VARIABLE LABELS
      Ex   'the number of years of experience'
    / Yr   'the recent year calling Keelung port'
    / Occ  'occupation'
    / Rank 'the rank on the merchant vessel'
    / Type 'the type of the merchant vessel'
    / Ton  'the gross tonnage of the merchant vessel'
    / B11  'high density of traffic at outside area'
    / B12  'fishing vessel at outside area'
    / B13  'strong current at outside area'
    / B14  'poor visibility at outside area'
    / B15  'strong wind at outside area'
    / B16  'shallow water at outside area'
    / B17  'natural underwater hazard at outside area'
    / B18  'the other factors at outside area'
    / B21  'high density of traffic within TSS area'
    / B22  'fishing vessel within TSS area'
    / B23  'strong current within TSS area'
    / B24  'poor visibility within TSS area'
    / B25  'strong wind within TSS area'
    / B26  'shallow water within TSS area'
    / B27  'natural underwater hazard within TSS'
    / B28  'the other factors within TSS area'
    / B31  'high density of traffic in anchorage'
    / B32  'fishing vessel in anchorage'
    / B33  'strong current in anchorage'
    / B34  'poor visibility in anchorage'
    / B35  'strong wind in anchorage'
    / B36  'shallow water in anchorage'
    / B37  'natural underwater hazard in anchorage'
    / B38  'the other factors at outside area'
    / B41  'overall risk at outside area'
    / B42  'overall risk within TSS area'
    / B43  'overall risk at anchorage area'
    / B44  'overall risk from January to March'
    / B45  'overall risk from April to June'
```

```
    / B46  'overall risk from July to September'
    / B47  'overall risk from October to December'
    / B48  'overall risk at day-time'
    / B49  'overall risk at night-time'
    / C11  'speed limitation'
    / C12  'provision of weather information'
    / C13  'controlling fishermen'
    / C14  'sequence at pilot station'
    / C15  'stricter regulations'
    / C16  'visual navigational aids'
    / C17  'electronic navigational aids'
    / C18  'the reduction of risk by VTS'
    / C19  'the reduction of risk by other options'
    / C21  'length of traffic lanes'
    / C22  'width of traffic lanes'
    / C23  'location of pilot station'
    / C24  'direction of traffic lanes'
    / C25  'modification to TSS in other options'.

MISSING VALUE
      Ex (99)/ Yr (99)/ Occ (9)/ Rank (9)/ Type (9)/ Ton (9)/ B11 to C25 (9).

VALUE LABELS
      Type     1 'Container Ship'
               2 'General Cargo Ship'
               3 'Bulk Carrier'
               4 'Tanker'
    / Ton      1 'Small ship'
               2 'Medium ship'
               3 'Large ship'.

RECODE
      Ton (lo thru 3 = 1) (4 thru 5 = 2) (6 thru 7 = 3).

MEAN Ex by Occ.

CROSSTABULATION Type BY Ton
     /OPTIONS = 3,4.

MEANS B11 to B18 by Occ.

CROSSTABULATION Occ by B11 to B18
     /OPTIONS = 3.

NPAR TESTS K-W = B11 to B18 by Occ(1,4).

NPAR TESTS K-W = B11 to B18 by Type(1,4).
```

```
NPAR TESTS K-W = B11 to B18 by Ton(1,3).

NPAR TESTS M-W = B11 to B18 by Occ(1,2).

NPAR TESTS M-W = B11 to B18 by Occ(1,3).

NPAR TESTS M-W = B11 to B18 by Occ(1,4).

NPAR TESTS M-W = B11 to B18 by Occ(2,3).

NPAR TESTS M-W = B11 to B18 by Occ(2,4).

NPAR TESTS M-W = B11 to B18 by Occ(3,4).

NPAR TESTS M-W = B11 to B18 by Type(1,2).

NPAR TESTS M-W = B11 to B18 by Type(1,3).

NPAR TESTS M-W = B11 to B18 by Type(1,4).

NPAR TESTS M-W = B11 to B18 by Type(2,3).

NPAR TESTS M-W = B11 to B18 by Type(2,4).

NPAR TESTS M-W = B11 to B18 by Type(3,4).

NPAR TESTS M-W = B11 to B18 by Ton(1,2).

NPAR TESTS M-W = B11 to B18 by Ton(1,3).

NPAR TESTS M-W = B11 to B18 by Ton(2,3).
```

APPENDIX - C

Means and standard deviation of mariner opinions

C-1 Overall risk

	Senior	Junior	Pilot	E/master	Total
Outside area of TSS					
No.	65	54	10	24	153
Per cent	42.5%	35.3%	6.5%	15.7%	100.0%
Mean	2.9846	3.0000	2.2000	3.0417	2.9477
Std Dev	0.8384	0.7004	0.4216	0.8065	0.7846
Within area of TSS and near B/W					
No.	65	54	10	26	155
Per cent	41.9	34.8%	6.5%	16.8%	100.0%
Mean	3.6308	3.7407	3.2000	3.3462	3.5935
Std Dev	0.7618	0.9150	0.6325	1.0175	0.8556
Outside anchorage					
No.	64	54	10	23	151
Per cent	42.4%	35.8%	6.6%	15.2%	100.0%
Mean	3.1250	3.1481	2.6000	2.8261	3.0530
Std Dev	0.9172	0.7869	0.6992	0.7777	0.8469
January - March					
No.	66	54	10	26	156
Per cent	42.3%	34.6%	6.4%	16.7%	100.0%
Mean	3.9242	4.0000	3.8000	3.7308	3.9103
Std Dev	0.7905	0.9316	0.6325	0.8274	0.8376
April - June					
No.	62	53	10	26	151
Per cent	41.1%	35.1%	6.6%	17.2%	100.0%
Mean	2.7419	2.8491	2.4000	2.3846	2.6954
Std Dev	0.7668	0.8412	0.8433	0.8038	0.8164
July - September					
No.	62	53	10	25	150
Per cent	41.3%	35.3%	6.7%	16.7%	100.0%
Mean	2.5645	2.8491	1.9000	2.5600	2.6200
Std Dev	0.7601	0.7441	0.3162	0.8206	0.7743
October- December					
No.	65	54	10	26	155
Per cent	41.9%	34.8%	6.5%	16.8%	100.0%
Mean	3.8154	4.0370	3.4000	3.7308	3.8516
Std Dev	0.7684	0.8459	0.8433	0.8744	0.8280
Day-time					
No.	63	53	9	28	153
Per cent	41.2%	34.6%	5.9%	18.3%	100.0%
Mean	2.5397	2.7547	2.1111	2.5000	2.5817
Std Dev	0.6905	0.6476	0.7817	0.6939	0.6941
Night-time					
No.	66	53	10	28	157
Per cent	42.0%	33.8%	6.4%	17.8%	100.0%
Mean	3.6970	3.8491	3.1000	3.5714	3.6879
Std Dev	0.8222	0.7178	0.5676	0.6341	0.7583

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

C-2 Risk factors at outside area of the TSS

	Senior	Junior	Pilot	E/master	Total
High density of traffic					
No.	64	54	10	27	155
Per cent	41.3%	34.8%	6.5%	17.4%	100.0%
Mean	3.1875	3.2222	2.5000	2.7778	3.0839
Std Dev	1.0820	0.9648	0.8498	0.8916	1.0126
Fishing vessel in area					
No.	66	54	10	25	155
Per cent	42.6%	34.8%	6.5%	16.1%	100.0%
Mean	3.5303	3.6296	3.0000	3.3200	3.4968
Std Dev	0.9643	0.9961	0.9428	0.9000	0.9695
Stronger currents					
No.	64	55	10	28	157
Per cent	40.8%	35.0%	6.4%	17.8%	100.0%
Mean	3.4375	3.4000	3.2000	3.2143	3.3694
Std Dev	0.9900	0.9926	0.9189	0.8325	0.9560
Poor visibility					
No.	63	54	10	25	152
Per cent	41.4%	35.5%	6.6%	16.4%	100.0%
Mean	3.6825	3.7593	4.0000	3.3600	3.6776
Std Dev	0.9972	0.9098	1.0541	1.1136	0.9940
Strong wind					
No.	65	54	10	28	157
Per cent	41.4%	34.4%	6.4%	17.8%	100.0%
Mean	3.4154	3.6496	3.5000	3.7143	3.5478
Std Dev	0.9167	0.9770	1.1785	0.8545	0.9436
Shallow water					
No.	59	52	10	27	148
Per cent	39.9%	35.1%	6.8%	18.2%	100.0%
Mean	2.4407	2.8269	1.9000	2.8519	2.6149
Std Dev	0.9874	1.1669	1.1005	1.0635	1.0975
Natural underwater hazard					
No.	58	49	10	26	143
Per cent	40.6%	34.3%	7.0%	18.2%	100.0%
Mean	2.3966	2.7347	2.1000	2.8462	2.5734
Std Dev	1.0077	1.1863	0.9944	1.1556	1.1101

1 - very seldom increase risk
2 - seldom increases risk
3 - sometimes increases risk
4 - often increases risk
5 - very often increases risk

C-3 Risk factors within area of the TSS and near the breakwater

	Senior	Junior	Pilot	E/master	Total
High density of traffic					
No.	64	55	10	26	155
Per cent	41.3%	35.5%	6.5%	16.8%	100.0%
Mean	3.4688	3.6727	3.5000	3.2692	3.5097
Std Dev	1.1543	1.0725	0.9718	1.2508	1.1303
Fishing vessel in area					
No.	65	54	10	24	153
Per cent	42.5%	35.3%	6.5%	15.7%	100.0%
Mean	3.7077	3.8333	4.0000	3.7083	3.7712
Std Dev	1.0266	0.9857	0.8165	1.1221	1.0098
Stronger currents					
No.	65	55	10	27	157
Per	41.4%	35.0%	6.4%	17.2%	100.0%
Mean	3.6923	3.8182	4.0000	3.5185	3.7261
Std Dev	0.9507	1.0017	0.8165	1.1887	1.0039
Poor visibility					
No.	64	55	10	25	154
Per cent	41.6%	35.7%	6.5%	16.2%	100.0%
Mean	3.7188	3.8545	4.4000	3.4000	3.7597
Std Dev	1.0461	1.0787	0.5164	1.2910	1.0910
Strong wind					
No.	65	55	10	28	158
Per cent	41.2%	34.8%	6.3%	17.7%	100.0%
Mean	3.5538	3.8545	4.4000	3.7500	3.7468
Std Dev	0.9525	0.9313	0.9661	1.0408	0.9770
Shallow water					
No.	59	54	10	28	151
Per cent	39.1%	35.8%	6.6%	18.5%	100.0%
Mean	2.8814	3.3148	2.3000	2.9643	3.0132
Std Dev	1.2047	1.1627	1.3375	1.2905	1.2328
Natural underwater hazard					
No.	55	51	10	26	142
Per cent	38.7%	35.9%	7.0%	18.3%	100.0%
Mean	2.5636	2.9608	2.1000	2.8846	2.7324
Std Dev	1.1982	1.2643	1.1972	1.4513	1.2823

1 - very seldom increase risk
2 - seldom increases risk
3 - sometimes increases risk
4 - often increases risk
5 - very often increases risk

C-4 Risk factors at outside anchorage

	Senior	Junior	Pilot	E/master	Total
High density of traffic					
No.	65	52	9	26	152
Per cent	42.8%	34.2%	5.9%	17.1%	100.0%
Mean	3.2923	3.4615	3.3333	3.1538	3.3289
Std Dev	0.9957	0.9385	0.7071	1.1556	0.9885
Fishing vessel in area					
No.	66	53	9	26	154
Per cent	42.9%	34.4%	5.8%	16.9%	100.0%
Mean	3.2576	3.4717	3.1111	3.0385	3.2857
Std Dev	1.0570	1.0489	0.6009	1.0385	1.0335
Stronger currents					
No.	66	52	9	26	153
Per cent	43.1%	34.0%	5.9%	17.0%	100.0%
Mean	3.3030	3.5962	3.5556	3.3462	3.4248
Std Dev	0.9441	0.9754	0.5270	0.8458	0.9226
Poor visibility					
No.	65	53	9	26	153
Per cent	42.5%	34.6%	5.9%	17.0%	100.0%
Mean	3.4769	3.6792	3.7778	3.5385	3.5752
Std Dev	1.0474	1.0701	1.2019	0.9479	1.0431
Strong wind					
No.	64	53	9	26	152
Per cent	42.1%	34.9%	5.9%	17.1%	100.0%
Mean	3.7500	3.5556	3.5556	3.6923	3.6776
Std Dev	0.8729	1.0065	0.5270	0.9282	0.9106
Shallow water					
No.	60	53	9	26	148
Per cent	40.5%	35.8%	6.1%	17.6%	100.0%
Mean	2.8833	3.2264	2.2222	3.1538	3.0135
Std Dev	1.1802	1.1708	0.9718	1.0842	1.1663
Natural underwater hazard					
No.	59	50	9	26	144
Per cent	41.0%	34.7%	6.3%	18.1%	100.0%
Mean	2.8136	3.1200	1.8889	2.9615	2.8889
Std Dev	1.1814	1.1718	0.7817	1.2159	1.1892

1 - very seldom increase risk
2 - seldom increases risk
3 - sometimes increases risk
4 - often increases risk
5 - very often increases risk

C-5 Risk deduction in improving marine safety

	Senior	Junior	Pilot	E/master	Total
Speed limits in traffic lanes					
No.	63	55	10	27	155
Per cent	40.6%	35.5%	6.5%	17.4%	100.0%
Mean	2.9048	3.0727	1.6000	3.0370	2.9032
Std Dev	0.9790	0.9973	0.6992	1.0913	1.0431
Provision of weather information					
No.	65	55	10	26	156
Per cent	41.7%	35.3%	6.4%	16.7%	100.0%
Mean	3.3231	3.4909	2.2000	3.5000	3.3397
Std Dev	1.0913	0.9403	0.6325	0.9055	1.0255
Control over fishermen in traffic lanes					
No.	65	55	10	27	157
Per cent	41.4%	35.0%	6.4%	17.2%	100.0%
Mean	4.2000	4.2727	3.9000	4.2222	4.2102
Std Dev	0.7746	0.7807	0.5676	0.7511	0.7598
Control of ship sequence at pilot station					
No.	64	55	10	26	155
Per cent	41.3%	35.5%	6.5%	16.8%	100.0%
Mean	4.4219	4.4364	3.9000	4.1538	4.3484
Std Dev	0.8127	0.6314	0.5676	1.0077	0.7862
Enforcement of ship safety regulation					
No.	66	55	10	27	158
Per cent	41.8%	34.8%	6.3%	17.1%	100.0%
Mean	4.0909	4.3455	4.2000	4.1111	4.1899
Std Dev	0.8544	0.7257	1.0328	0.9740	0.8458
Upgraded visual navigational aids					
No.	63	55	10	26	154
Per cent	40.9%	35.7%	6.5%	16.9%	100.0%
Mean	3.7460	4.0364	2.4000	4.1923	3.8377
Std Dev	1.1635	0.8812	0.9661	0.8494	1.0815
Upgraded shore based electronic navigational aids					
No.	61	55	8	25	149
Per cent	40.9%	36.9%	5.4%	16.8%	100.0%
Mean	3.6393	3.9091	2.5000	4.2800	3.7852
Std Dev	1.2115	1.0690	1.0690	0.8426	1.1482
Provision of Vessel Traffic Services					
No.	64	55	8	25	152
Per cent	42.1%	36.2%	5.3%	16.4%	100.0%
Mean	4.2500	4.4727	3.3750	4.4400	4.3158
Std Dev	0.8729	0.6900	1.5059	0.5831	0.8412

1 - very little improvement
2 - little improvement
3 - moderate improvement
4 - significant improvement
5 - very significant improvement

C-6 Modification to TSS

	Senior	Junior	Pilot	E/master	Total
Length of traffic lanes					
No.	59	52	10	20	141
Per cent	41.8%	36.9%	7.1%	14.2%	100.0%
Mean	2.1356	2.2115	1.9000	2.3000	2.1702
Std Dev	0.6005	0.4985	0.3162	0.8013	0.5850
Width of traffic lanes					
No.	58	51	10	20	139
Per cent	41.7%	36.7%	7.2%	14.4%	100.0%
Mean	2.1034	2.2157	2.0000	2.4500	2.1871
Std Dev	0.6124	0.4610	0.4714	0.8256	0.5967
Location of pilot station					
No.	64	53	10	21	148
Per cent	43.2%	35.8%	6.8%	14.2%	100.0%
Mean	2.4219	2.6226	1.9000	2.6667	2.4932
Std Dev	0.7929	0.6272	0.3162	0.8563	0.7423
Direction of traffic lanes					
No.	60	52	10	21	143
Per cent	42.0%	36.4%	7.0%	14.7%	100.0%
Mean	2.1000	2.2308	2.0000	2.6190	2.2168
Std Dev	0.7059	0.5465	0.4714	0.9207	0.6934

1 - disagree to modify
2 - slightly disagree to modify
3 - slightly agree to modify
4 - agree to modify

APPENDIX - D

Distribution of responses on risk

D-1 Overall risk at outside area

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior	1 1.5	18 27.7	29 44.6	15 23.1	2 3.1	65 42.5
Junior	2 3.7	6 11.1	37 68.5	8 14.8	1 1.9	54 35.3
Pilot		8 80.0	2 20.0			10 6.5
Ex-master		6 25.0	12 50.0	5 20.8	1 4.2	24 15.7
Column Total	3 2.0	38 24.8	80 52.3	28 18.3	4 2.6	153 100.0

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

D-2 Overall risk within TSS area

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior		4 6.2	23 35.4	31 47.7	7 10.8	65 41.9
Junior	1 1.9	4 7.4	13 24.1	26 48.1	10 18.5	54 34.8
Pilot		1 10.0	6 60.0	3 30.0		10 6.5
Ex-master	1 3.8	4 15.4	9 34.6	9 34.6	3 11.5	26 16.8
Column Total	2 1.3	13 8.4	51 32.9	69 44.5	20 12.9	155 100.0

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

D-3 Overall risk at anchorage area

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior	1 1.6	15 23.4	28 43.8	15 23.4	5 7.8	64 42.4
Junior	1 1.9	7 13.0	32 59.3	11 20.4	3 5.6	54 35.8
Pilot		5 50.0	4 40.0	1 10.0		10 6.6
Ex-master	1 4.3	6 26.1	12 52.2	4 17.4		23 15.2
Column Total	3 2.0	33 21.9	76 50.3	31 20.5	8 5.3	151 100.0

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

D-4 Overall risk from January to March

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior		3 4.5	14 21.2	34 51.5	15 22.7	66 42.3
Junior	1 1.9	3 5.6	8 14.8	25 46.3	17 31.5	54 34.6
Pilot			3 30.0	6 60.0	1 10.0	10 6.4
Ex-master		2 7.7	7 26.9	13 50.0	4 15.4	26 16.7
Column Total	1 0.6	8 5.1	32 20.5	78 50.0	37 23.7	156 100.0

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

D-5 Overall risk from April to June

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior	2 3.2	21 33.9	31 50.0	7 11.3	1 1.6	62 41.1
Junior	2 3.8	15 28.3	27 50.9	7 13.2	2 3.8	53 35.1
pilot	1 10.0	5 50.0	3 30.0	1 10.0		10 6.6
Ex-master	3 11.5	12 46.2	9 34.6	2 7.7		26 17.2
Column Total	8 5.3	53 35.1	70 46.4	17 11.3	3 2.0	151 100.0

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

D-6 Overall risk from July to September

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior	3 4.8	28 45.2	24 38.7	7 11.3		62 41.3
Junior	1 1.9	16 30.2	26 49.1	10 18.9		53 35.3
Pilot	1 10.0	9 90.0				10 6.7
Ex-master	1 4.0	12 52.0	7 28.0	4 16.0		25 16.7
Column Total	6 4.0	66 44.0	57 38.0	21 14.0		150 100.0

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

D-7 Overall risk from October to December

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior		3 4.6	17 26.2	34 52.3	11 16.9	65 41.9
Junior		2 3.7	12 22.2	22 40.7	18 33.3	54 34.8
Pilot		2 20.0	2 20.0	6 60.0		10 6.5
Ex-master		2 7.7	8 30.8	11 42.3	5 19.2	26 16.8
Column Total		9 5.8	39 25.2	73 47.1	34 21.9	155 100.0

1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

D-8 Overall risk at day-time

Count / Row Percent / Group	1	2	3	4	Row Total
Senior	3 4.8	27 42.9	29 46.0	4 6.3	63 41.2
Junior	2 3.8	13 24.5	34 64.2	4 7.5	53 34.6
Pilot	2 22.2	4 44.4	3 33.3		9 6.0
Ex-master	1 3.6	14 50.0	11 39.3	2 7.1	28 18.3
Column Total	8 5.2	53 37.9	77 50.3	10 6.5	153 100.0

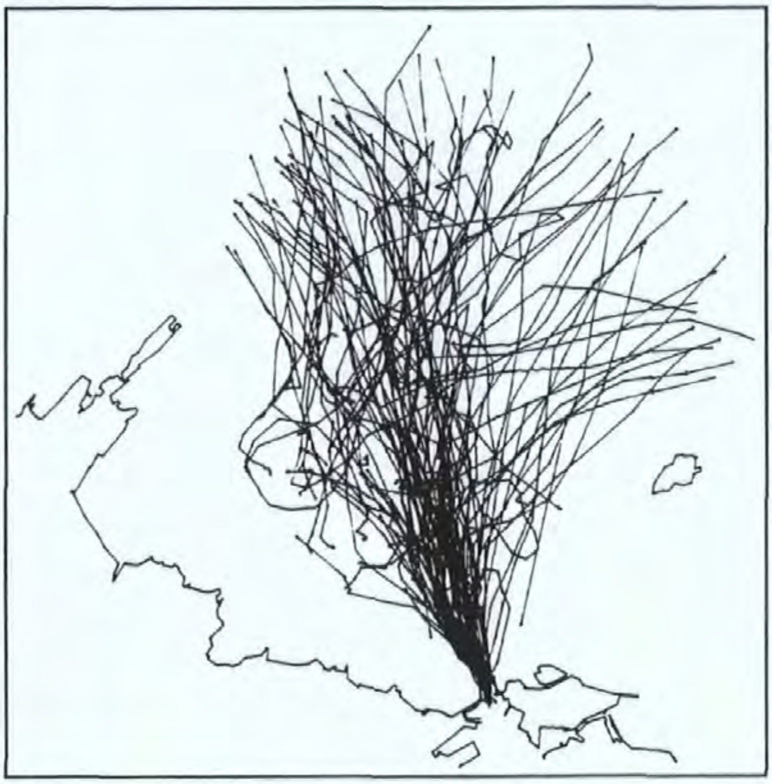
D-9 Overall risk at night-time

Count / Row Percent / Group	1	2	3	4	5	Row Total
Senior	1 1.5	3 4.5	20 30.3	33 50.0	9 14.3	66 42.0
Junior		1 1.9	15 28.3	28 52.8	9 17.0	53 33.8
Pilot		1 10.0	7 70.0	2 20.0		10 6.4
Ex-master		1 3.6	11 39.3	15 53.6	1 3.6	28 17.8
Column Total	1 0.6	6 3.8	53 33.8	78 49.7	19 12.1	157 100.0

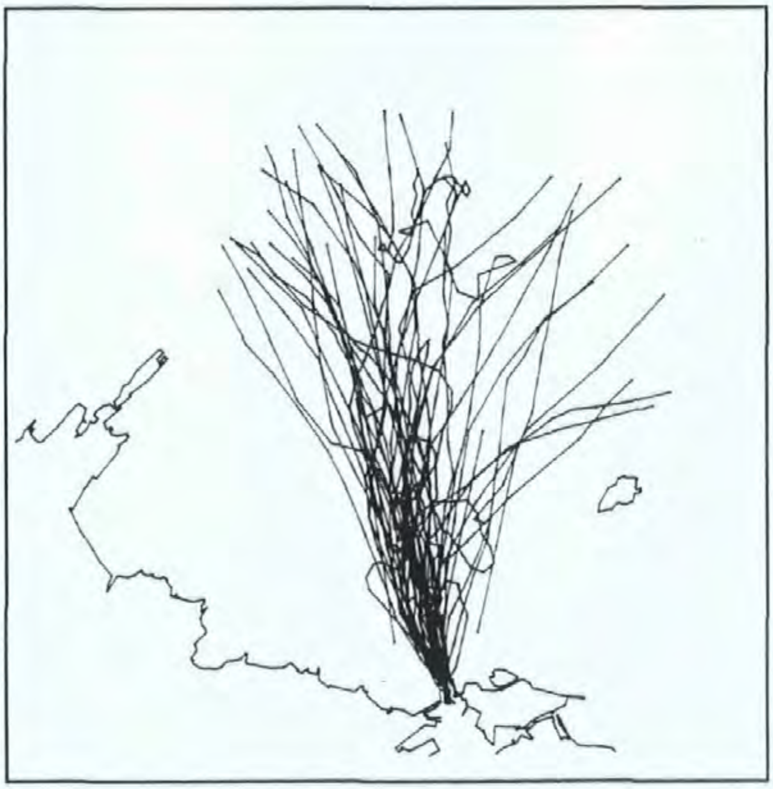
1 - very low risk
2 - low risk
3 - moderate risk
4 - high risk
5 - very high risk

APPENDIX - E

Tracks of ship movement from radar observation

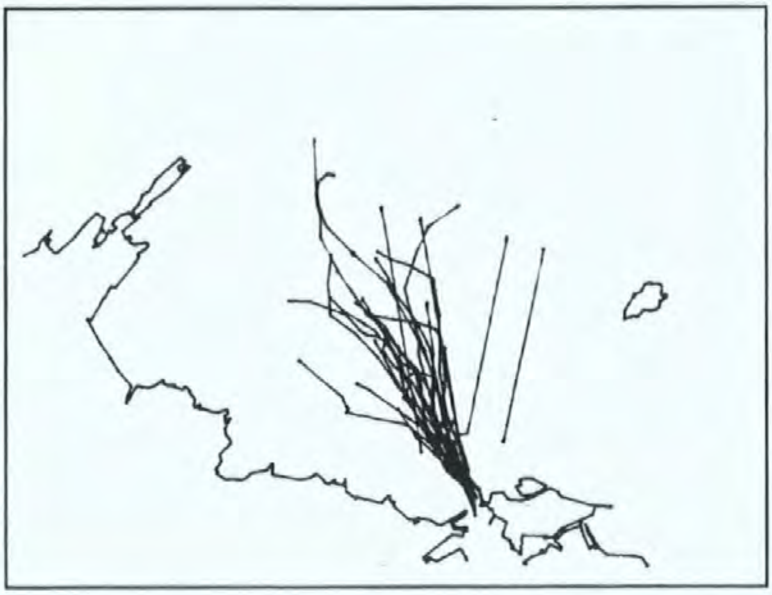


E-1 All inbound ship tracks (6-9 March 1992)

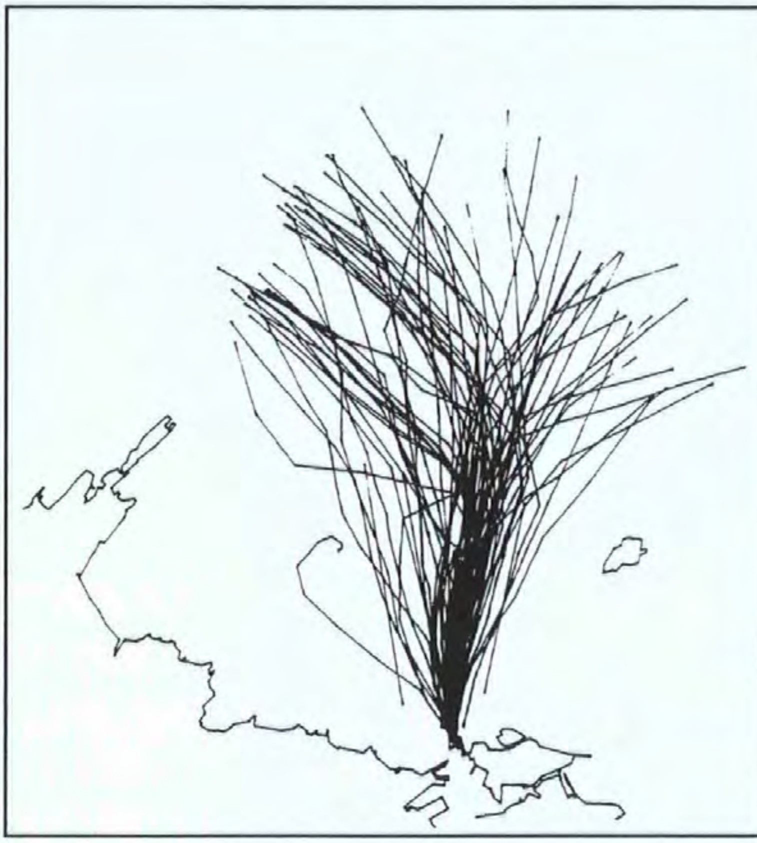


E-2 Tracks of inbound ships entering directly (6-9 March 1992)

E-3 Tracks of inbound ships anchoring first (6-9 March 1992)



E-4 Tracks of entering ships from anchorage (6-9 March 1992)



E-5 All outbound ship tracks (6-9 March 1992)

APPENDIX - F

Details of ship models for simulation

Container ship in University of Plymouth

Specification

Displacement:	50100	Tonnes
Length B P:	212	
Block Coefficient:	0.6	
Type of Engines:	ssd	
Number of Shafts:	1	
Shaft Separation:	-	M
Direction of Rotation:	Clockwise	
Maximum Shaft Speed:	120	RPM
Type of Propellers:	1 Fixed	
Propellers Depth:	11	M
Area of Each Rudder:	44	Sq M
Maximum Rudder Angle:	35	Deg
Rudder Time Mid/Max:	13	S
Maximum Speed Full Away:	23	Kts
Maximum Speed Full Ahead:	17.2	Kts
Half Ahead to Full Ahead Time:	860	S
Draught Forward:	12.2	M
Draught Aft:	12.2	M
Moulded Depth:	26	M
Bridge Height From Deck:	20	M
Bridge Distance From COG:	-71	M
Antenna Height From Sea:	37	M
Antenna Offset From COG:	-71	M
Radar Blind Arc:	178-183	DEG REL

Characteristics (35 Deg Port Rudder)

Time to Steady State		
Speed and Rate of Turn:	631	S
Maximum Rate of Turn:	60.6	DEG/MIN
Percentage Loss of Speed:	50.9	
Steady State Speed:	8.4	Kts
Steady State Rate of Turn:	40.3	DEG/MIN
Steady State Drift Angle:	23.4	Deg
Time to Turn 360 Degrees:	491	S

Telegraph Settings

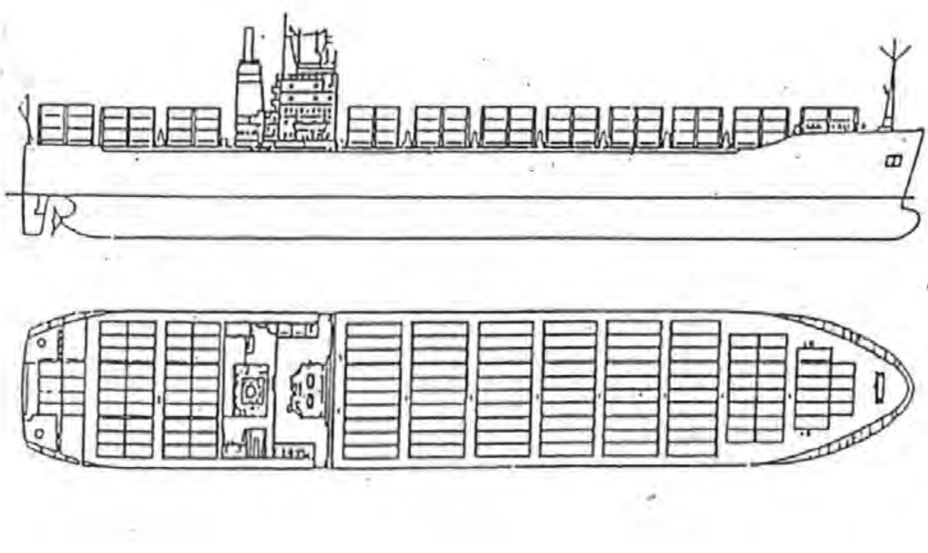
Ahead:	*RPM*	*Speed*	*Pitch-%*
Full	90	17.2 Kts	100
Half	70	13.4 Kts	100
Slow	50	9.6 Kts	100
Dead Slow	35	6.7 Kts	100
Stop	0	0 Kts	100
Astern:			
Dead Slow	35	5.4 Kts	100
Slow	45	6.9 Kts	100
Half	60	9.2 Kts	100
Full	80	12.2 Kts	100

Container ship in Taiwan Ocean University

NAME: KEELUNG EXPRESS

OWN SHIP PARTICULARS

Type of ship: CONTAINER SHIP WITH DECK LOADED
Length: LOA 209.92 M. / LBP 202.40 M.
Beam: 32.20 METERS
Draft, full load: 8.40 M. / DEPTH 12.33 M.
Displacement, full load: 32,000 TONS
half load;28,600 TONS
ballast ;23,000 TONS
Rudder arrangement: SINGLE RUDDER
RUDDER TURNING SPEED: (MINIMUN) 1.2 °/SEC.
DISTANCE BOW TO BRIDGE: 137.4 M.
Propeller arrangement: SINGLE SCREW
Type of propeller: FIXED PITCH PROPELLER
Power plant type: DIESEL ENGINE
Total power: 24,500 KW / 33,000 PSE
Maximum RPM: 125 RPM / 24.4 KNOTS
CRITICAL RPM : 90 RPM
Thrusters: BOW THRUSTER
DRAFT IN DEFFERENT LOADING CONDITION:
BALLAST: FORE 5.2 M. /AFT 7.5 M.
HALF LOAD: " 7.5 M. / " 7.7 M.
FULL LOAD: " 8.2 M. / " 8.4 M.



NAME: KEELUNG EXPRESS (CONTAINER SHIP

RPM – SPEED – TABLE

ORDER	RPM	PITCH	SPEED KNOTS
10 (SEA SPEED)	125	100 %	24.4 (24.1)
8 (FULL AHEAD)	100	100 %	19.5 (20.0)
6 (HALF AHEAD)	75	100 %	14.6 (15.4)
4 (SLOW AHEAD)	50	100 %	9.8 (10.5)
2 (D/S AHEAD)	30	100 %	5.9 (6.4)
0 (STOP)	0	100 %	0
– 2 (D/S ASTERN)	-24	100 %	(-5.1)
– 4 (SLOW ASTERN)	-40	100 %	(-8.5)
– 6 (HALF ASTERN)	-60	100 %	(-12.5)
– 8	-80	100 %	(-16.3)
– 10 (FULL ASTERN)	-100	100 %	(-19.9)

( ) SPEED FIGURES OF TEST OUT

Loading condition: BALLAST Wind: 0
CURRENT: 0
Water depth: 100 M. Seastate: CALM

NAME: KEELUNG EXPRESS (CONTAINER SHIP)

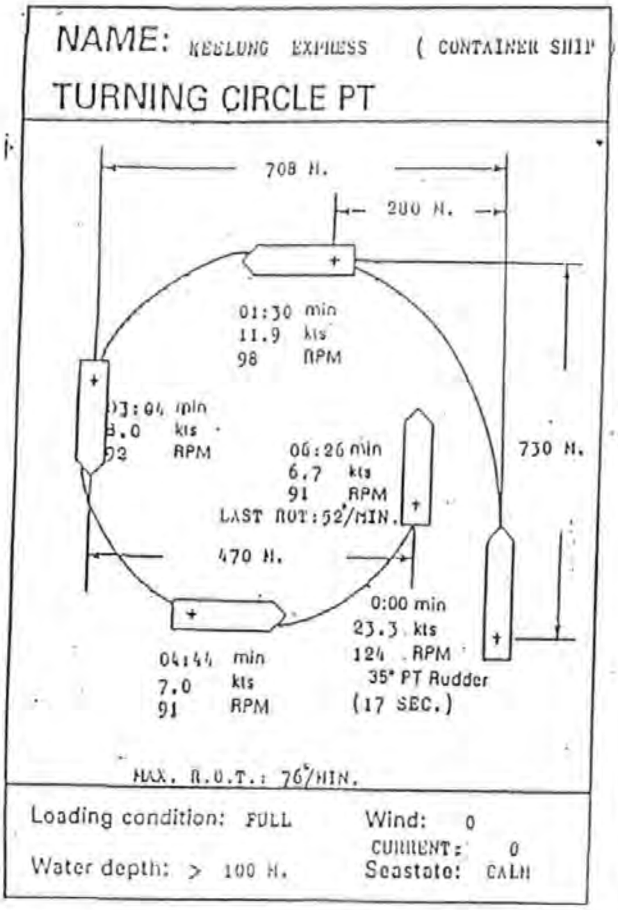
STOPPING TEST WITH REVERSE ENGINE

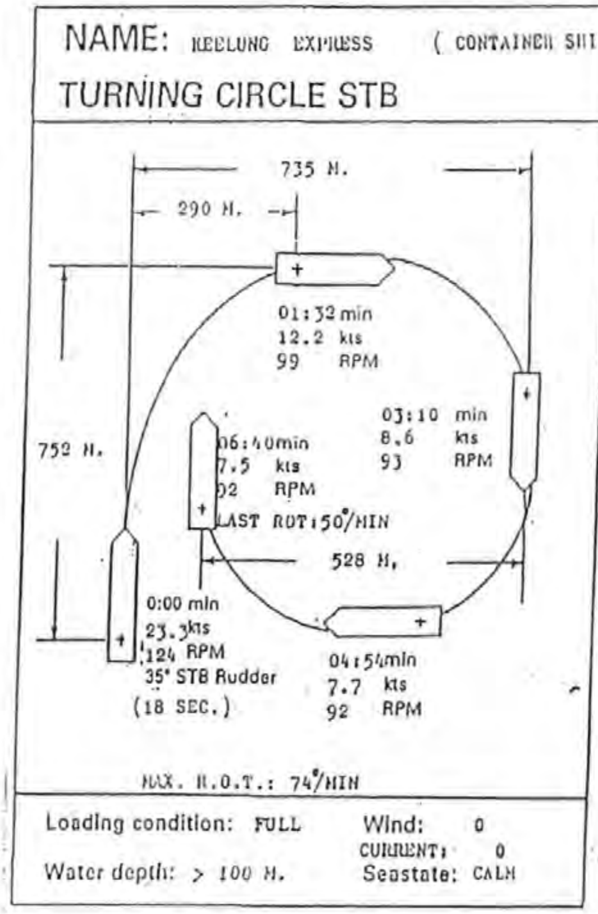
Initial speed: 24.1 KNOTS
Initial RPM: 124 RPM
Initial heading: 000 DEGREE.

Engine order: FULL ASTERN
Time to reverse engine: 5 MIN. 23 SEC.
NORMAL REVERSE RPM: 34 RPM

Stopping distance: 1.5 N.MILES
Stopping time: 7 MIN. 34 SEC.
Final heading: 022 DEGREES
Final RPM: -69 RPM
TRANSFER DISTANCE: 100 M.

Loading condition: BALLAST Wind: 0
CURRENT: 0
Water depth: 100 M. Seastate: CALM


NAME: KEELUNG EXPRESS (CONTAINER SHIP)
TURNING CIRCLE PT
708 M.
200 M.
01:30 min
11.9 kts
98 RPM
03:04 min
8.0 kts
92 RPM
06:26 min
6.7 kts
91 RPM
LAST ROT:52°/MIN.
730 M.
470 M.
0:00 min
23.3 kts
124 RPM
35° PT Rudder
(17 SEC.)
04:44 min
7.0 kts
91 RPM
MAX. R.O.T.: 76°/MIN.
Loading condition: FULL
Wind: 0
CURRENT: 0
Water depth: > 100 M.
Seastate: CALM


NAME: KEELUNG EXPRESS (CONTAINER SHIP
TURNING CIRCLE STB
735 M.
290 M.
01:32 min
12.2 kts
99 RPM
03:10 min
8.6 kts
93 RPM
752 M.
06:40min
7.5 kts
92 RPM
LAST ROT:50°/MIN
528 M.
0:00 min
23.3kts
124 RPM
35° STB Rudder
(18 SEC.)
04:54min
7.7 kts
92 RPM
MAX. R.O.T.: 74°/MIN
Loading condition: FULL
Wind: 0
CURRENT: 0
Water depth: > 100 M.
Seastate: CALM

APPENDIX - G

Questionnaire for inbound experiment

A. Background of the navigator

1. Rank on the merchant ship:
   ☐Pilot ☐Master ☐Chief Mate ☐Second Mate ☐Third Mate
   ☐others________________________.
2. Experience of sea service:
   ☐less than 5 years ☐5-9 years ☐10-14 years ☐15-19 years
   ☐more than 20 years.

B. Identification of the entrance of the inbound traffic lane

1. In Ex1A, to identify the entrance of the inbound traffic lane is:
   ☐very easy ☐easy ☐average ☐difficult ☐very difficult.
2. In Ex1B, to identify the entrance of the inbound traffic lane is:
   ☐very easy ☐easy ☐average ☐difficult ☐very difficult.
3. If a buoy were established at the termination of the inbound lane in Ex1A, when the visibility is clear, the best method for identification of the entrance of the lane should be:
   ☐by vision with landmarks ☐by vision with entrance buoy ☐by radar with landmarks ☐by radar with entrance buoy ☐by others________________.
4. When the visibility is poor, as Ex1B, the best method for identification of the entrance of the inbound traffic lane is:
   ☐by vision with landmarks ☐by vision with entrance buoy ☐by radar with landmarks ☐by radar with entrance buoy ☐by others________________.
5. In Ex1B, the effectiveness of the racon on the entrance buoy is:
   ☐very little ☐little ☐moderate ☐significant ☐very significant.

C. Wind effect and current effect

1. In Ex1A, wind effect is the more important factor to influence ship's manoeuvring than current effect.
   ☐disagree strongly ☐disagree ☐uncertain ☐agree ☐agree strongly.
2. In Ex1B, wind effect is the more important factor to influence ship's manoeuvring than current effect.
   ☐disagree strongly ☐disagree ☐uncertain ☐agree ☐agree strongly.
3. In Ex1A, when ship is moving in the traffic lane, to keep ship position within the lane without current information is:
   ☐very easy ☐easy ☐average ☐difficult ☐very difficult.

4. In Ex1B, after current information is provided, to keep ship position within traffic lane with the information is:
   □very easy □easy □average □difficult □very difficult.
5. How many degrees did you set as leeway in Ex1A?
   □less than three degrees □3-5 degrees □5-10 degrees □11-15 degrees □more than 15 degrees.
6. How many degrees did you set as leeway in Ex1B?
   □less than three degrees □3-5 degrees □5-10 degrees □11-15 degrees □more than 15 degrees.
7. Widening the inbound traffic lane to provide large sea room for ship manoeuvring against wind and current effects in the exercises is:
   □very unimportant □unimportant □average □important □very important.

D. Ship's encounter

1. In Ex1A, when two ships encountered at the restricted water area without information about ship movements provided, the collision risk is:
   □very low □low □moderate □high □very high.
2. In Ex1B, after the information of other ship movements was provided, the collision risk to the own ship is:
   □very low □low □moderate □high □very high.
3. Within the port approaches, the safe distance to keep from other ships under clear visibility, as Ex1A, is:
   □less than 0.1 miles □0.1-0.3 miles □0.3-0.5 miles □0.5-1.0 miles □more than 1.0 miles.
4. Within the port approaches, the safe distance to keep from other ships under restricted visibility, as Ex1B, is:
   □less than 0.1 miles □0.1-0.3 miles □0.3-0.5 miles □0.5-1.0 miles □more than 1.0 miles.

E. Ship's manoeuvre near the pilot station

1. In the exercises, when ship is waiting for the pilot with slow speed at the pilot station, to keep ship position in traffic lane is:
   □very easy □easy □average □difficult □very difficult.
2. When two ships waiting for pilots near the pilot station at the same time without control of ship sequence, as Ex1A, the collision risk is:
   □very low □low □moderate □high □very high.

3. When two ships have the same ETA to pilot station under sequence control, as Ex1B, the collision risk is:
   □very low □low □moderate □high □very high.
4. In Ex1B, where is the best place for the own ship waiting for the pilot under poor visibility?
   □near pilot station □at the entrance of traffic lane □outside of TSS.
5. The position of the pilot station in this port is appropriate.
   □disagree strongly □disagree □uncertain □agree □agree strongly.
6. In Q6, if your answer is 'disagree strongly' or 'disagree', where is the best position as pilot station in this port approaches?

   ____

   ____

F. Ship handling in entrance channel between breakwaters

1. Have you ever been Keelung when working on ship?
   □Yes □No.

If your answer to Q1 is 'Yes', please answer the following questions:

2. How many times have you been Keelung?
   □once □twice □3-5 times □6-10 times □more than 10 times.
3. Do you have the experience that two or more ships were waiting for the pilot at Keelung pilot station at the same time?
   □never □seldom □sometimes □often □all times.
4. Do you have the experience that your ship entered Keelung port through breakwaters by ship master control without pilots?
   □never □once □twice □three times □more than three times.
5. Occasionally an entering ship has to pass through breakwaters by master's ability without pilot's assistance due to bad weather. The action is:
   □very safe □safe □moderate □dangerous □very dangerous.
6. Occasionally an inbound ship strikes the breakwater. The main environmental factor involved in those accidents to affect ship's handling is strong current.
   □disagree strongly □disagree □uncertain □agree □agree strongly.
7. In Q6, if your answer is 'disagree strongly' or 'disagree', which environmental factor is the main reason for the accident?

   ____

   ____

APPENDIX - H

Questionnaire for outbound experiment

A. Background of the navigator

1. Rank on the merchant ship:
   ☐Pilot ☐Master ☐Chief Mate ☐Second Mate ☐Third Mate
   ☐others________________________.
2. Experience of sea service:
   ☐less than 5 years ☐5-9 years ☐10-14 years ☐15-19 years
   ☐more than 20 years.

B. Identification of the exit of the outbound traffic lane

1. In Ex2A, to identify the exit of the outbound traffic lane is:
   ☐very easy ☐easy ☐average ☐difficult ☐very difficult.
2. In Ex2B, to identify the exit of the outbound traffic lane is:
   ☐very easy ☐easy ☐average ☐difficult ☐very difficult.
3. If a buoy were established at the termination of the outbound lane in Ex2A, when the visibility is clear, the best method for identification of the exit of the lane should be:
   ☐by vision with landmarks ☐by vision with exit buoy ☐by radar with landmarks ☐by radar with exit buoy ☐by others________________.
4. When the visibility is poor, as Ex2B, the best method for identification of the exit of the outbound traffic lane is:
   ☐by vision with landmarks ☐by vision with exit buoy ☐by radar with landmarks ☐by radar with exit buoy ☐by others________________.
5. In Ex2B, the effectiveness of the racon on the exit buoy is:
   ☐very little ☐little ☐moderate ☐significant ☐very significant.

C. Wind effect and current effect

1. In Ex2A, wind effect is the more important factor to influence ship's manoeuvring than current effect.
   ☐disagree strongly ☐disagree ☐uncertain ☐agree ☐agree strongly.
2. In Ex2B, wind effect is the more important factor to influence ship's manoeuvring than current effect.
   ☐disagree strongly ☐disagree ☐uncertain ☐agree ☐agree strongly.
3. In Ex2A, when ship is moving in the traffic lane, to keep ship position within the lane without current information is:
   ☐very easy ☐easy ☐average ☐difficult ☐very difficult.

4. In Ex2B, after current information is provided, to keep ship position within traffic lane with the information is:
   □very easy □easy □average □difficult □very difficult.
5. How many degrees did you set as leeway in Ex2A?
   □less than three degrees □3-5 degrees □5-10 degrees □11-15 degrees □more than 15 degrees.
6. How many degrees did you set as leeway in Ex2B?
   □less than three degrees □3-5 degrees □5-10 degrees □11-15 degrees □more than 15 degrees.
7. Widening the outbound traffic lane to provide large sea room for ship manoeuvring against wind and current effects in the exercises is:
   □very unimportant □unimportant □average □important □very important.

D. Ship's encounter

1. In Ex2A, when another inbound ship drifting at pilot station without information about her movements provided, the collision risk to the own ship is:
   □very low □low □moderate □high □very high.
2. In Ex2B, after the information of another ship's movements is provided, the collision risk to the own ship is:
   □very low □low □moderate □high □very high.
3. When an outbound ship is passing the breakwaters under clear visibility, as Ex2A, other inbound ships shall keep a safe distance from breakwaters at least:
   □1 mile □1.5 miles □2 miles □2.5 miles □3 miles.
4. When an outbound ship is passing the breakwaters under restricted visibility, as Ex2B, other inbound ships shall keep a safe distance from breakwaters at least:
   □1 mile □1.5 miles □2 miles □2.5 miles □3 miles.

E. Shallow water near An-tou-pao shoal

1. In Ex2A, the shallow water to the outbound ship is:
   □very little dangerous □little dangerous □moderate dangerous □dangerous □very dangerous.
2. In Ex2B, the shallow water identified by a buoy to the outbound ship is:
   □very little dangerous □little dangerous □moderate dangerous □dangerous □very dangerous.
3. In Ex2A, the safe distance to an outbound ship keeping from the shallow water and Keelung Island shall be at least:
   □0.3 mile □0.5 miles □0.7 miles □1 miles □1.5 miles.

4. In Ex2B, the safe distance to an outbound ship keeping from the shallow water and Keelung Island under strong wind shall be at least:
   ☐0.3 mile ☐0.5 miles ☐0.7 miles ☐1 miles ☐1.5 miles.

F. Ship handling in main channel between breakwaters

1. Usually a leaving ship has to pass through breakwaters by master's ability without pilot's assistance. The action is:
   ☐very safe ☐safe ☐moderate ☐dangerous ☐very dangerous.
2. Occasionally an outbound ship strikes the breakwater. The environmental factor to affect ship's handling is strong current.
   ☐disagree strongly ☐disagree ☐uncertain ☐agree ☐agree strongly.
3. In Q2, if your answer is 'disagree strongly' or 'disagree', which environmental factor is the main reason for the accident?

   ____

   ____

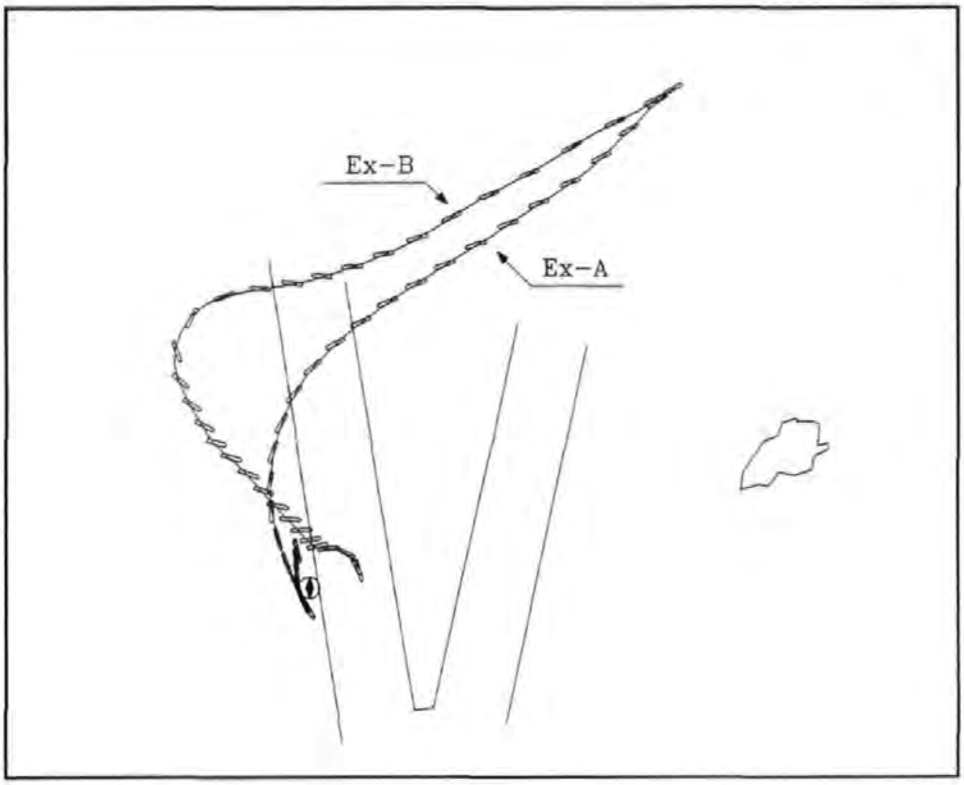
4. Have you ever been Keelung when working on ship?
   ☐Yes ☐No.

If your answer to Q4 is 'Yes', please answer the following questions:

5. How many times have you been Keelung?
   ☐once ☐twice ☐3-5 times ☐6-10 times ☐more than 10 times.
6. Do you have the experience that your ship left Keelung port through breakwaters by ship master control without pilots?
   ☐never ☐seldom ☐sometimes ☐often ☐all times.
7. Do you have the experience that another ship drifting near pilot station when your ship was leaving Keelung port?
   ☐never ☐seldom ☐sometimes ☐often ☐all times.

APPENDIX - I

Ship tracks of inbound experiment



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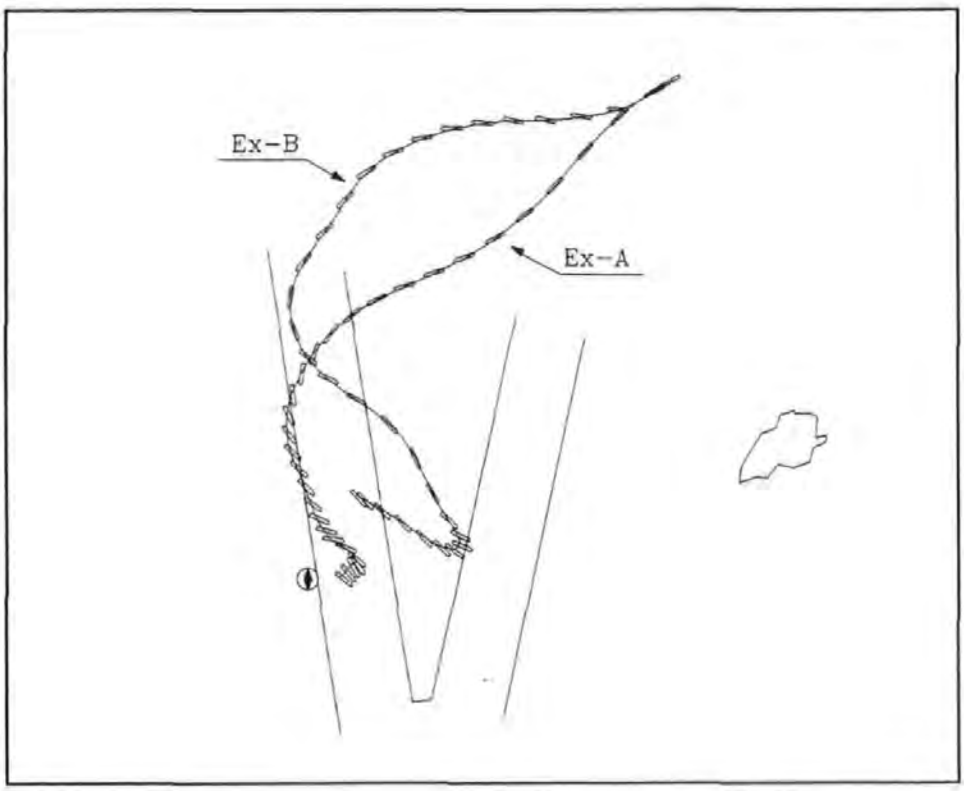

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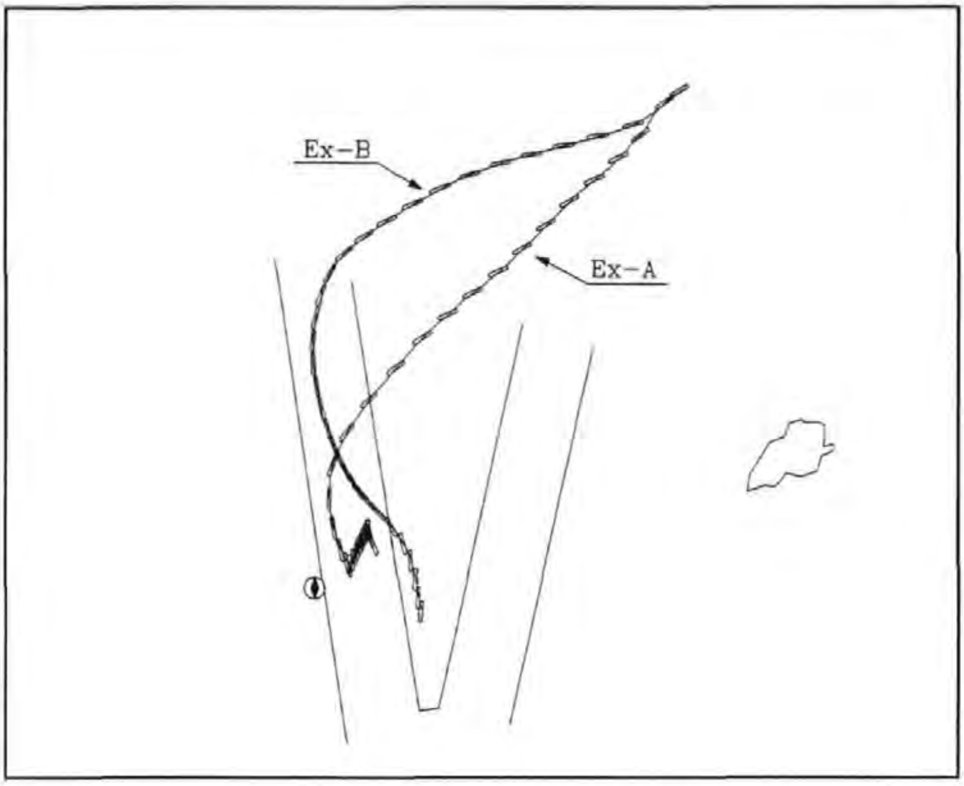

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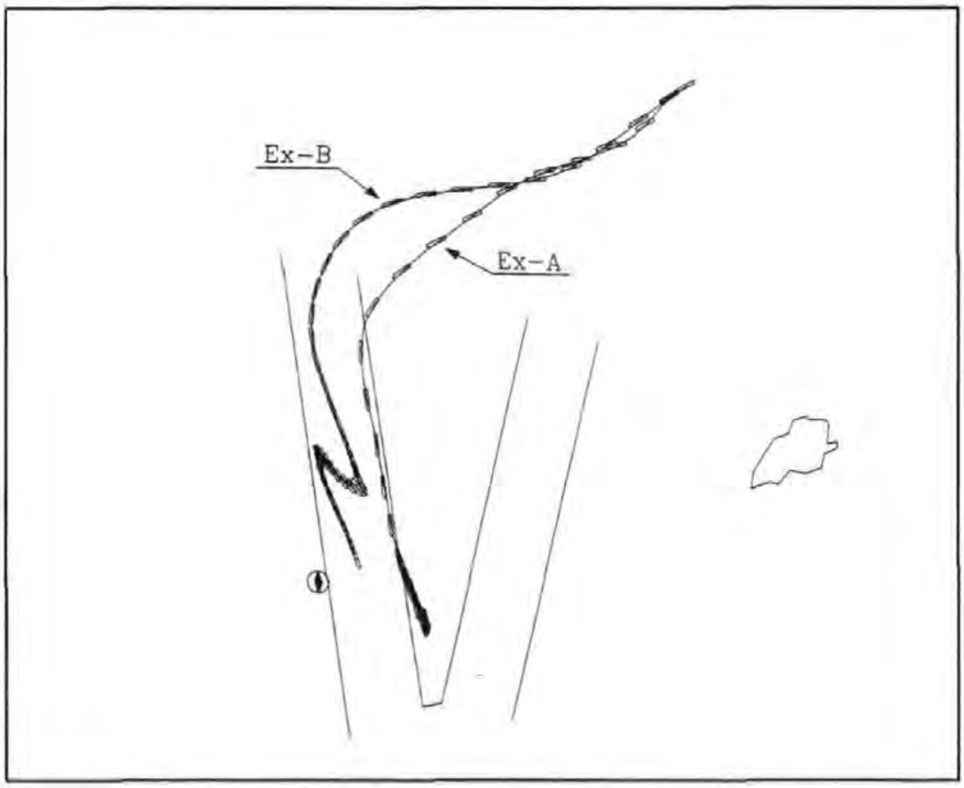

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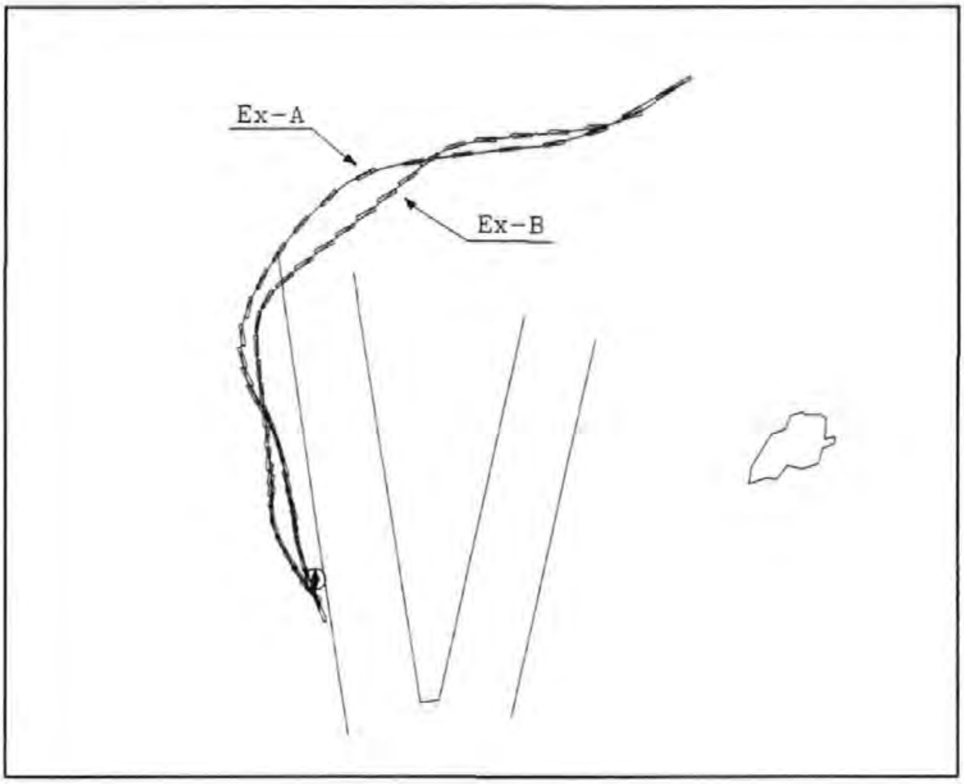

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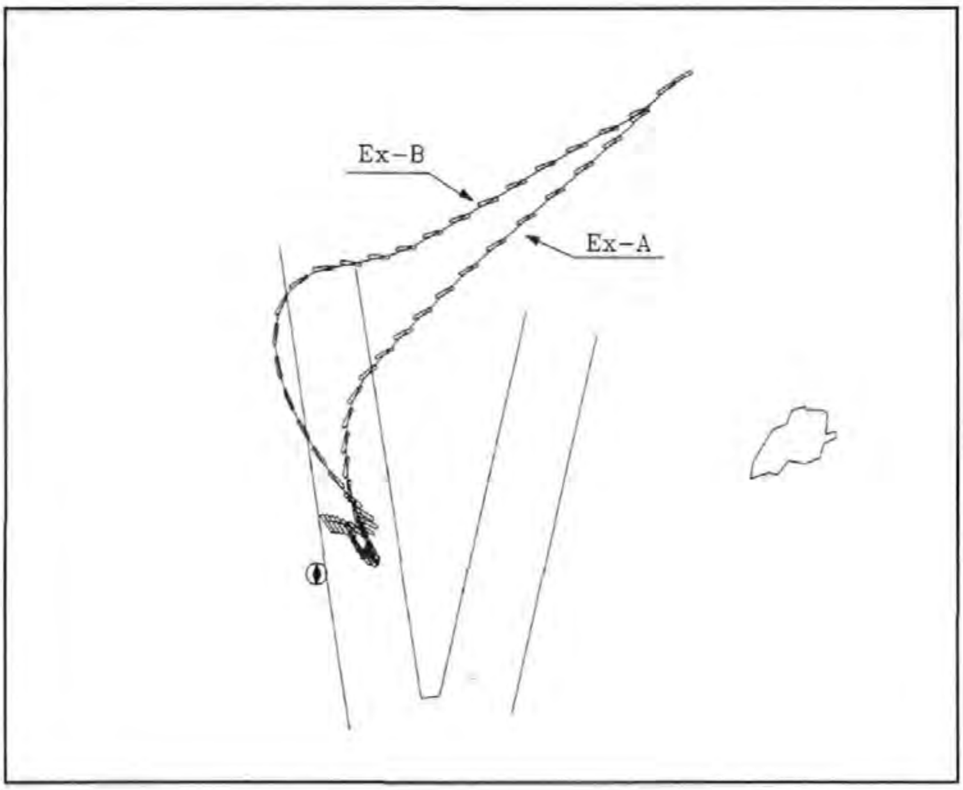

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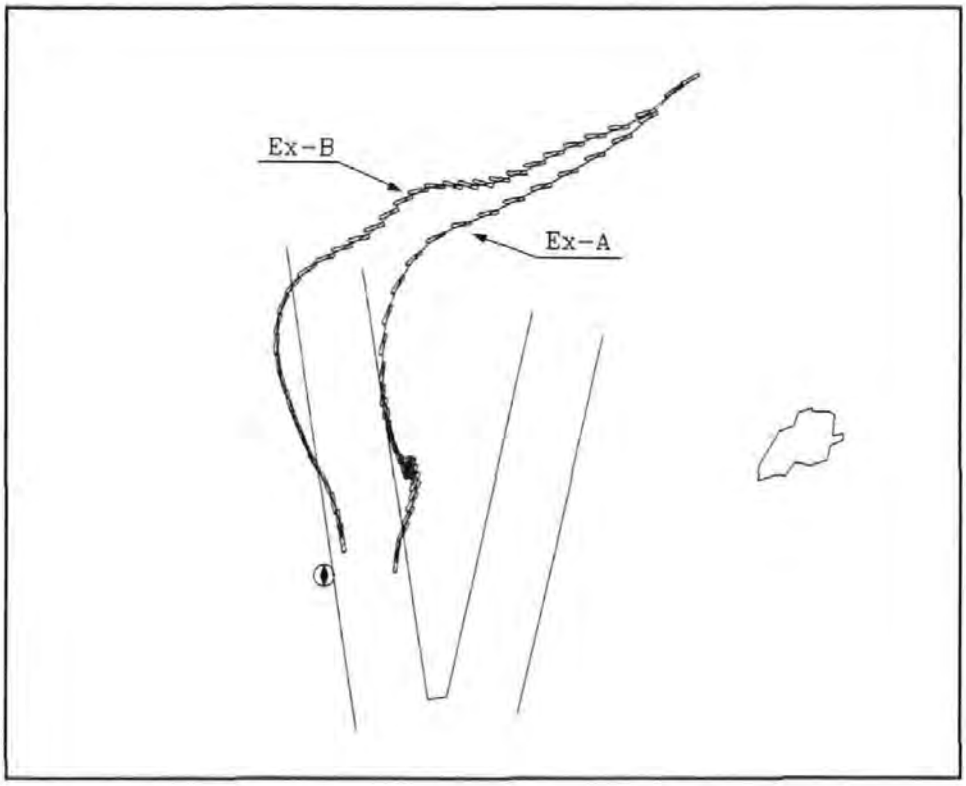

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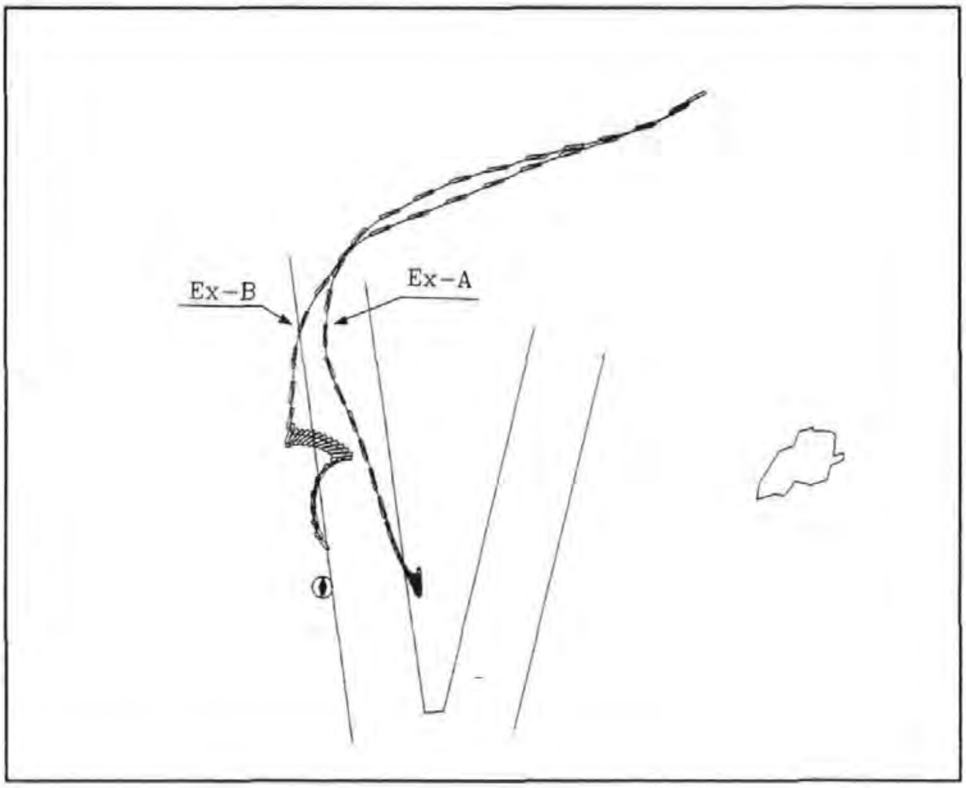

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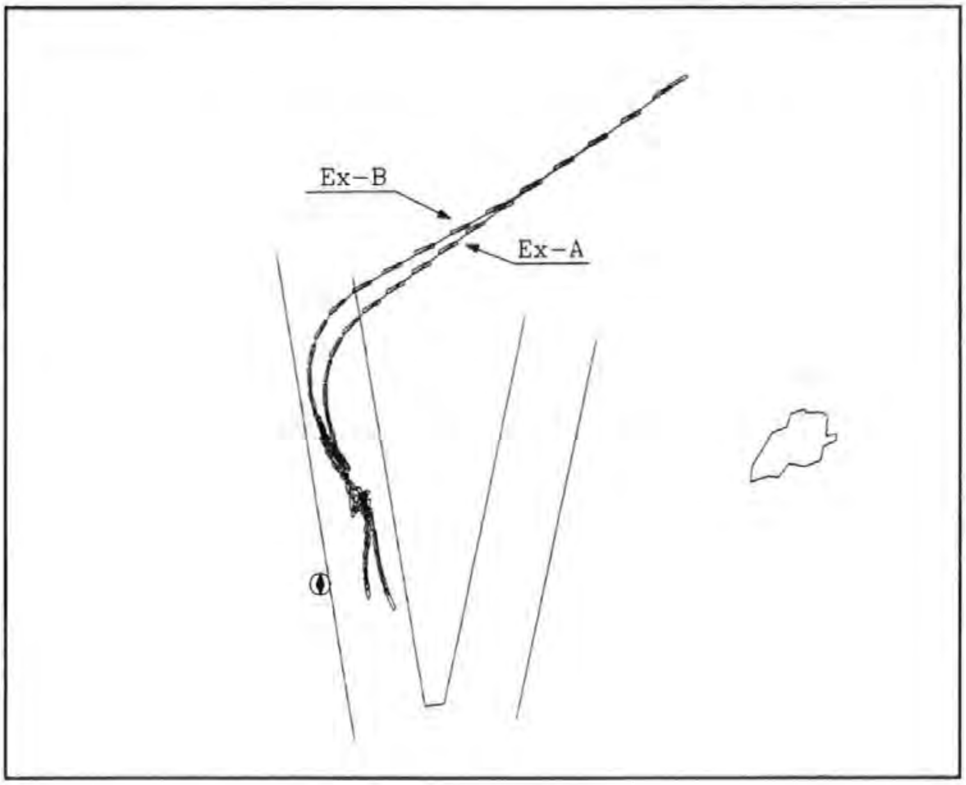

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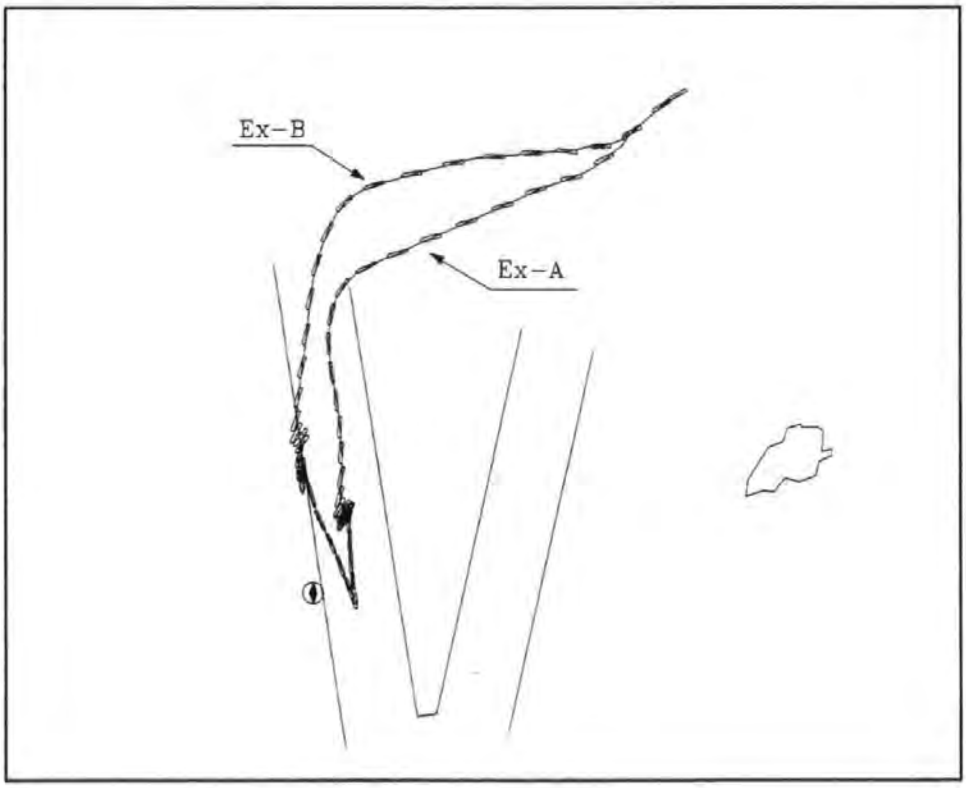

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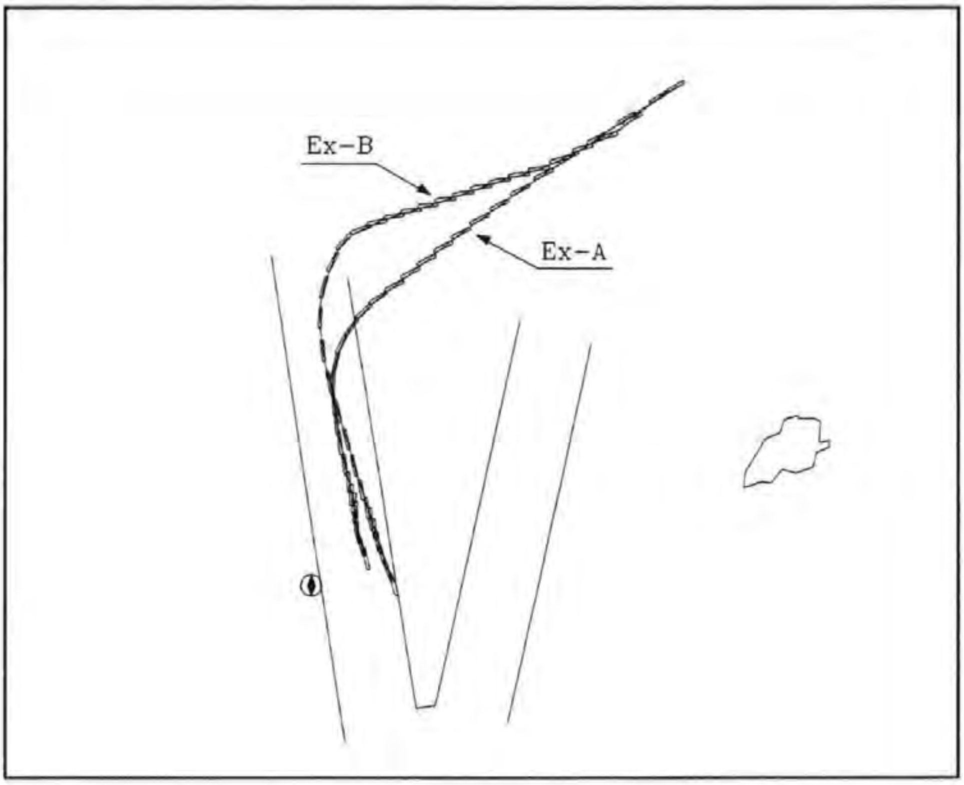

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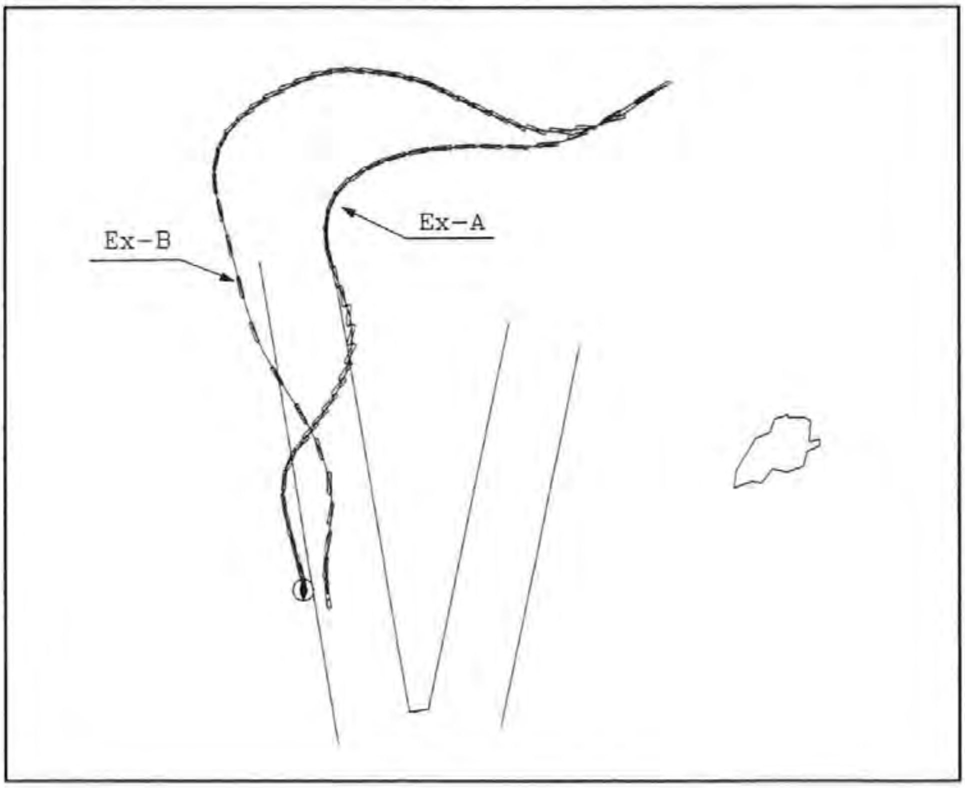

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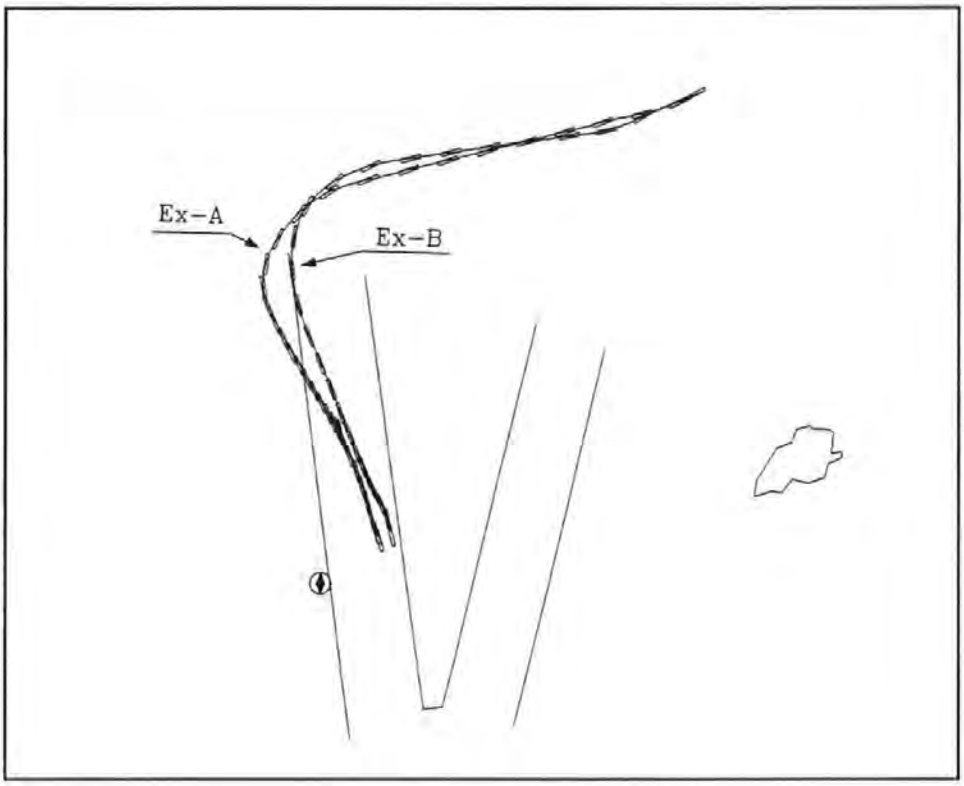

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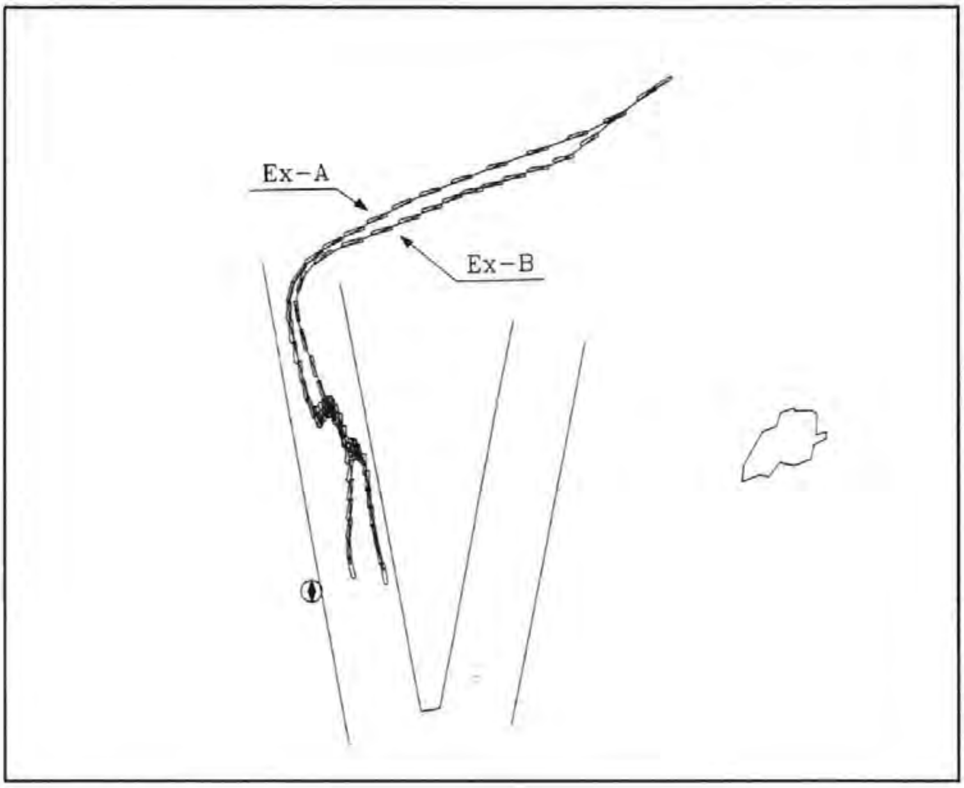

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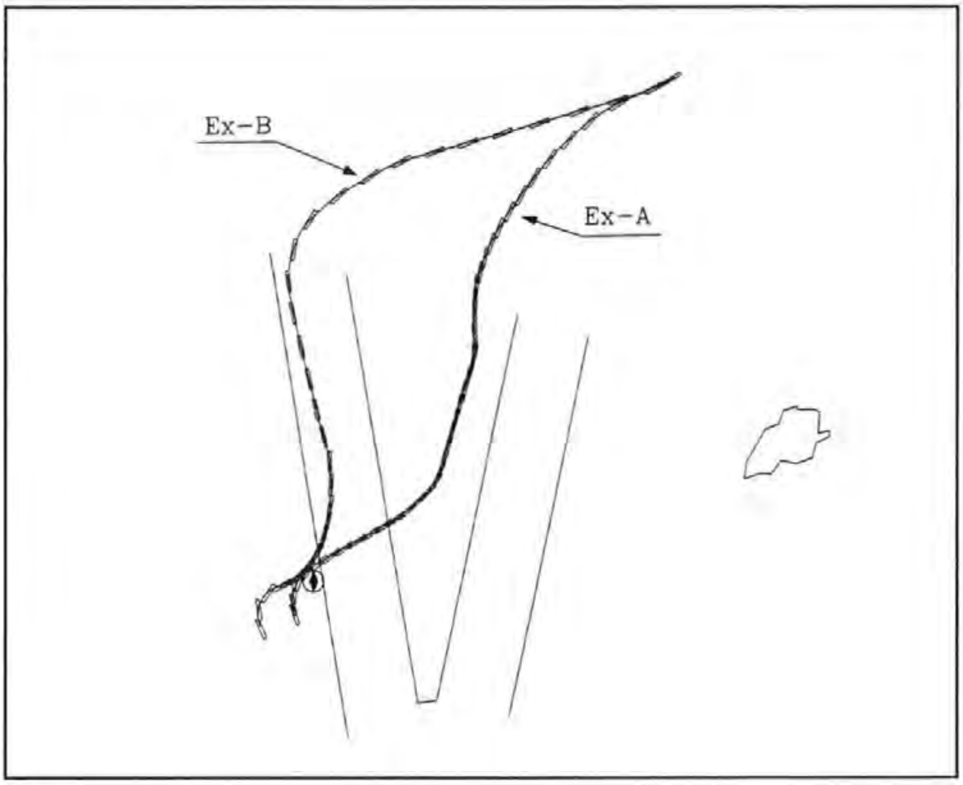

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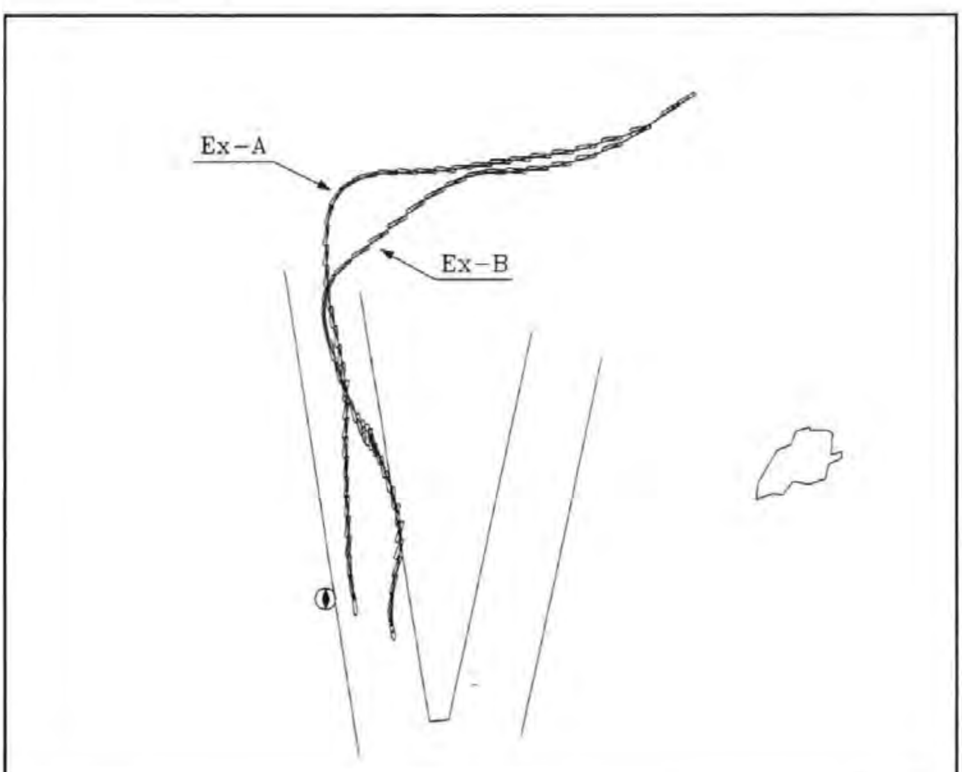

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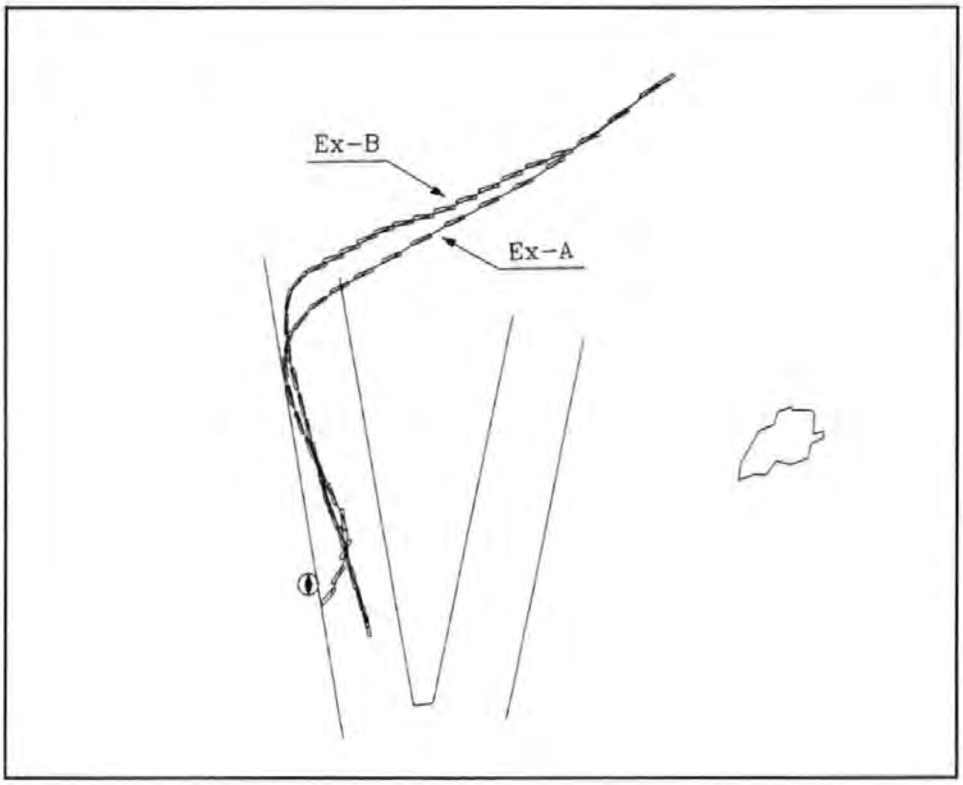

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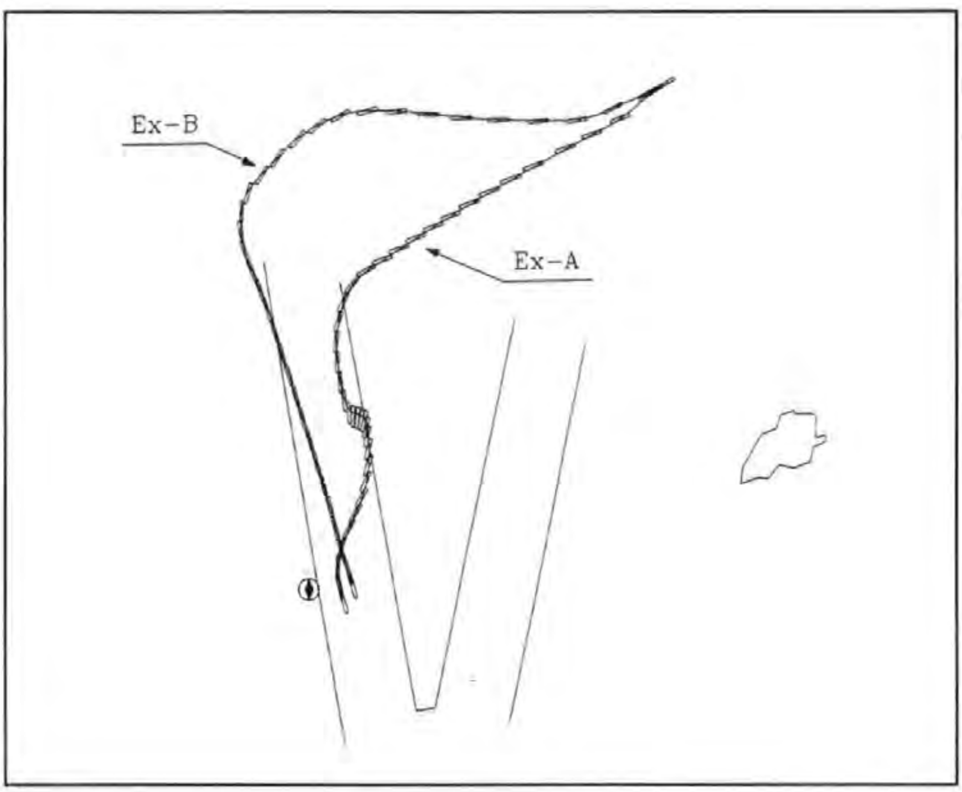

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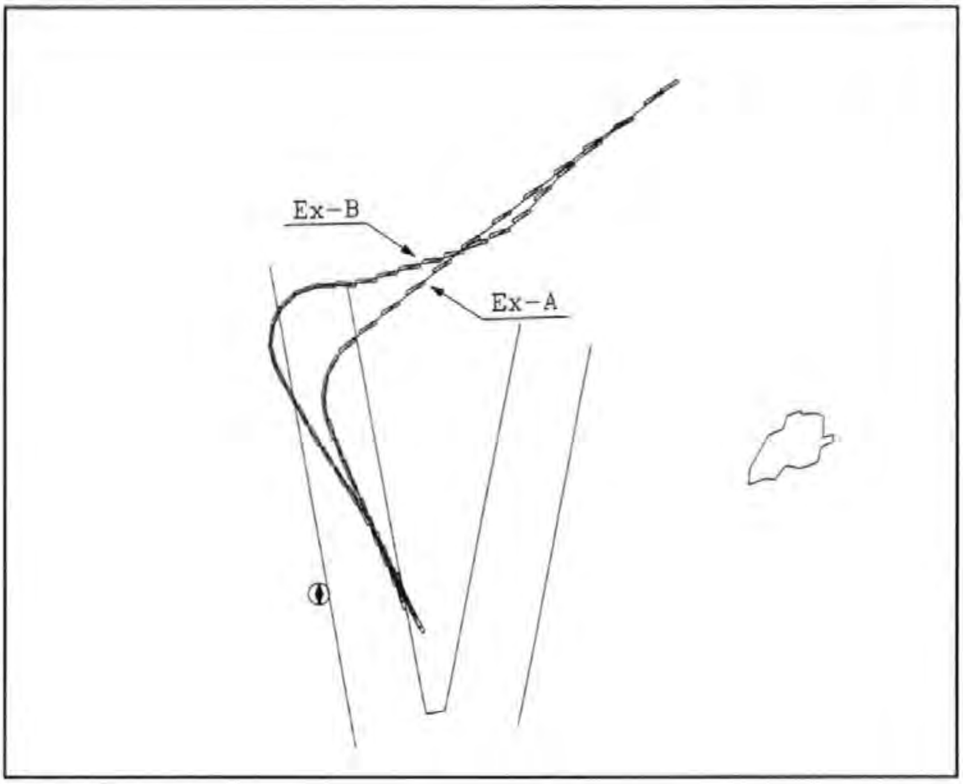

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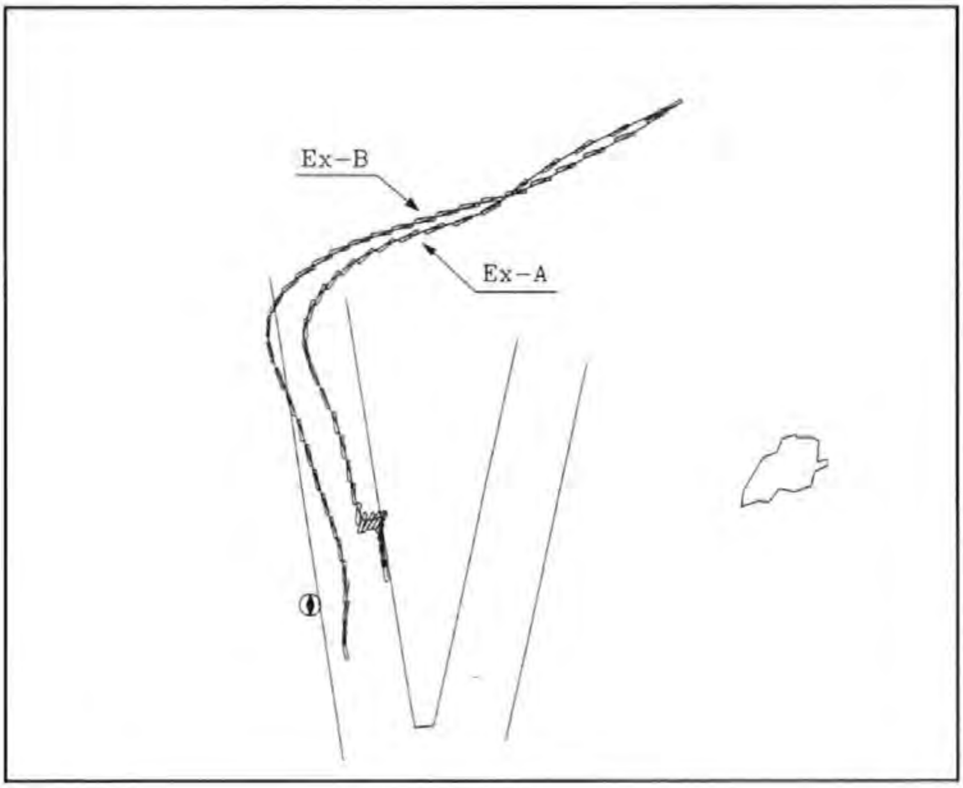

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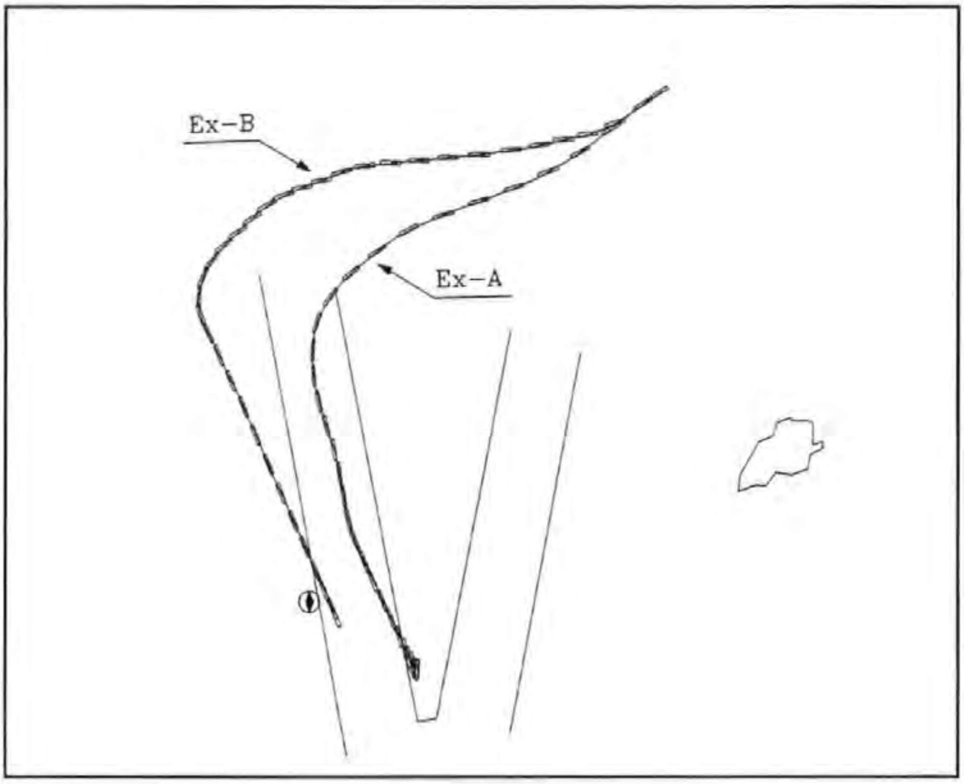

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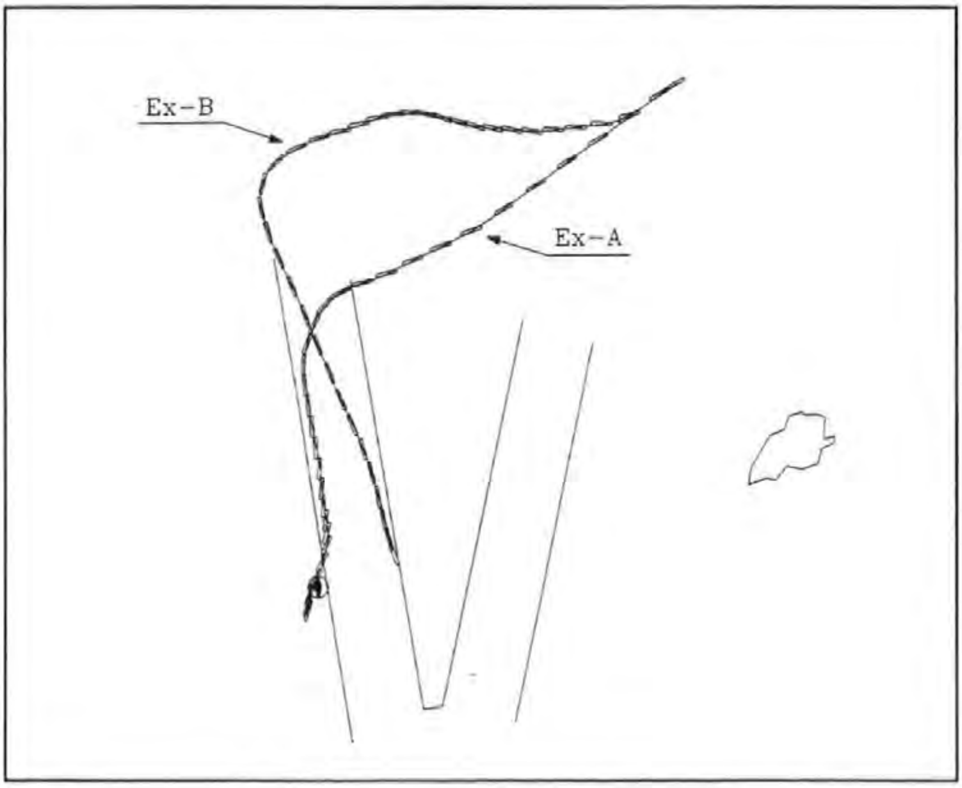

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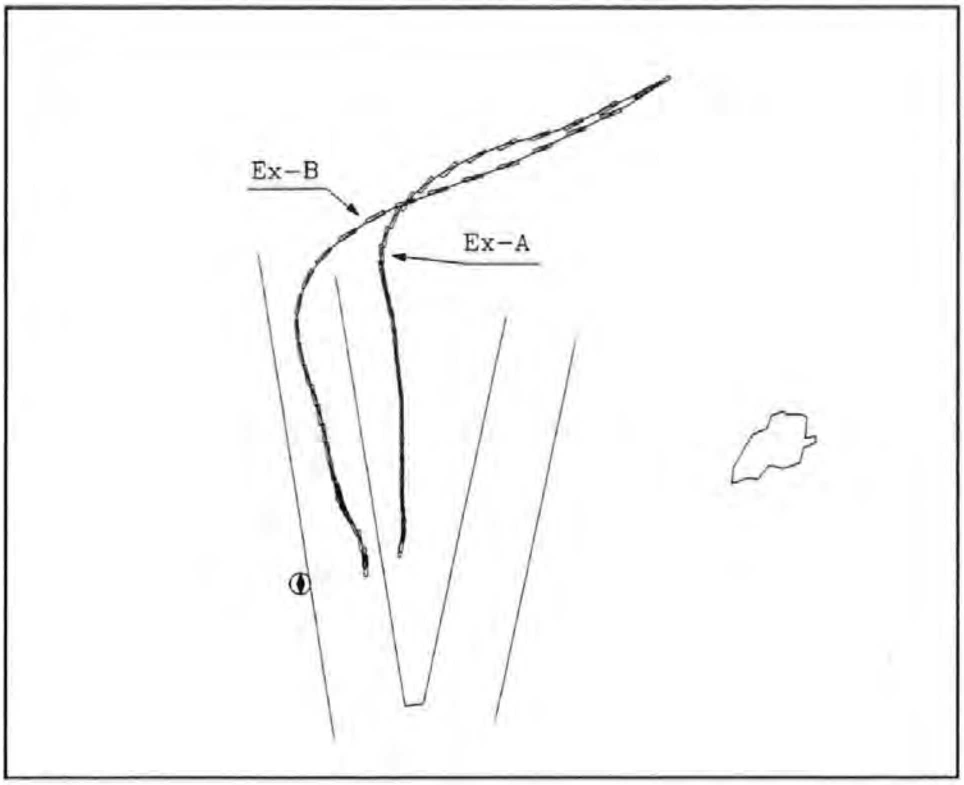

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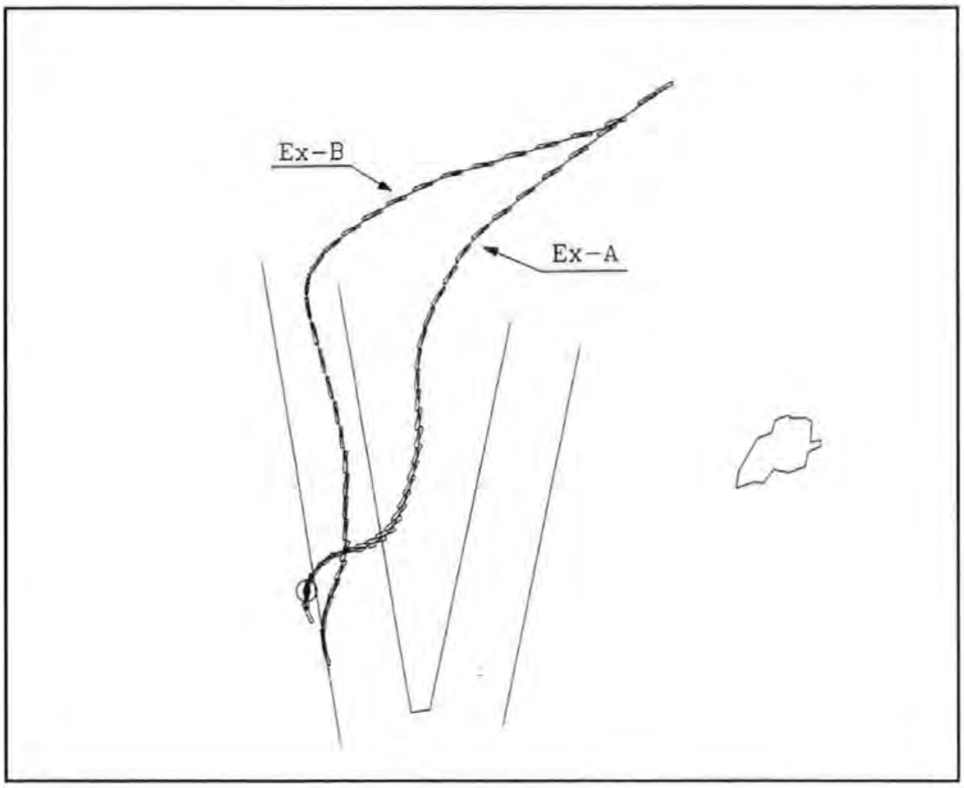

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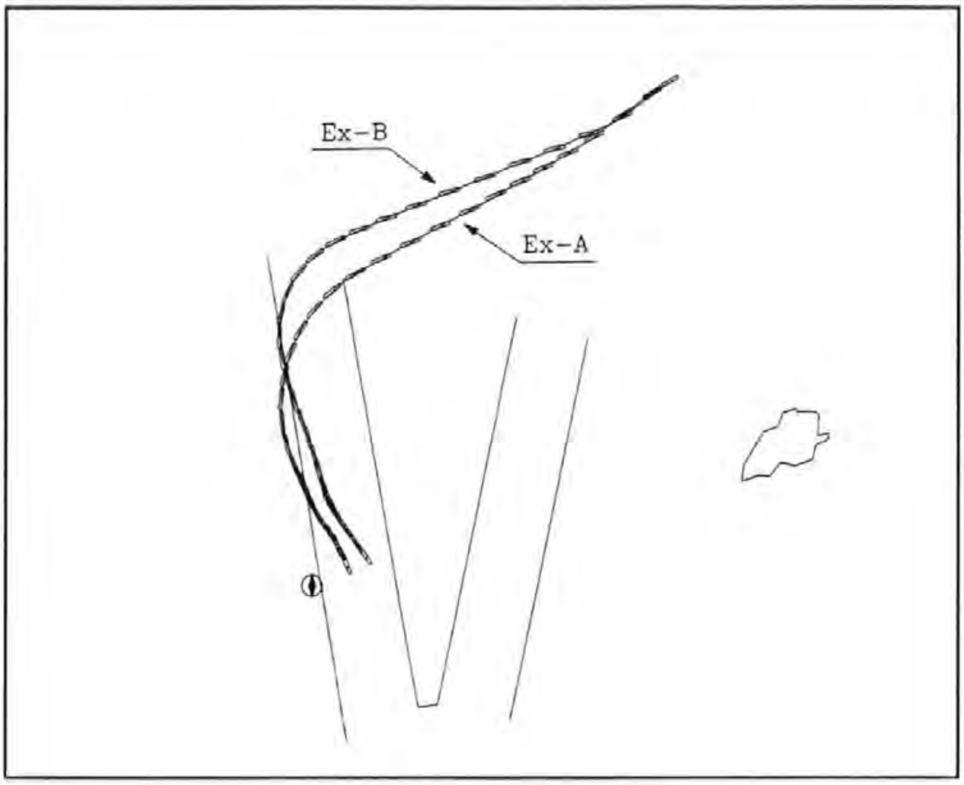

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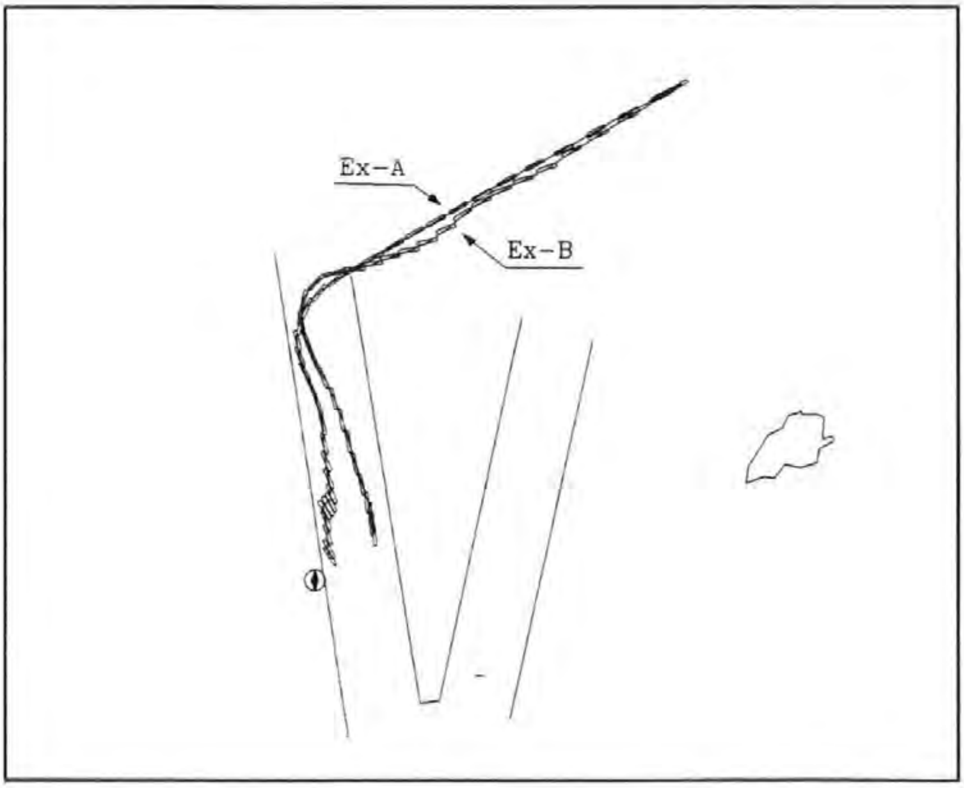

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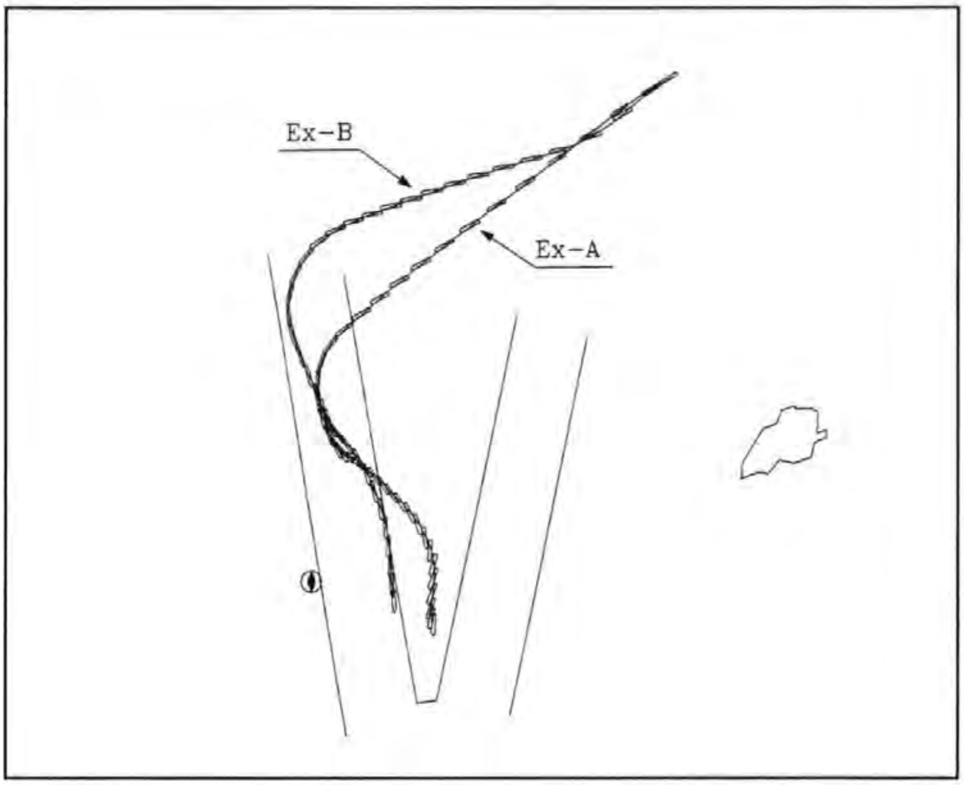

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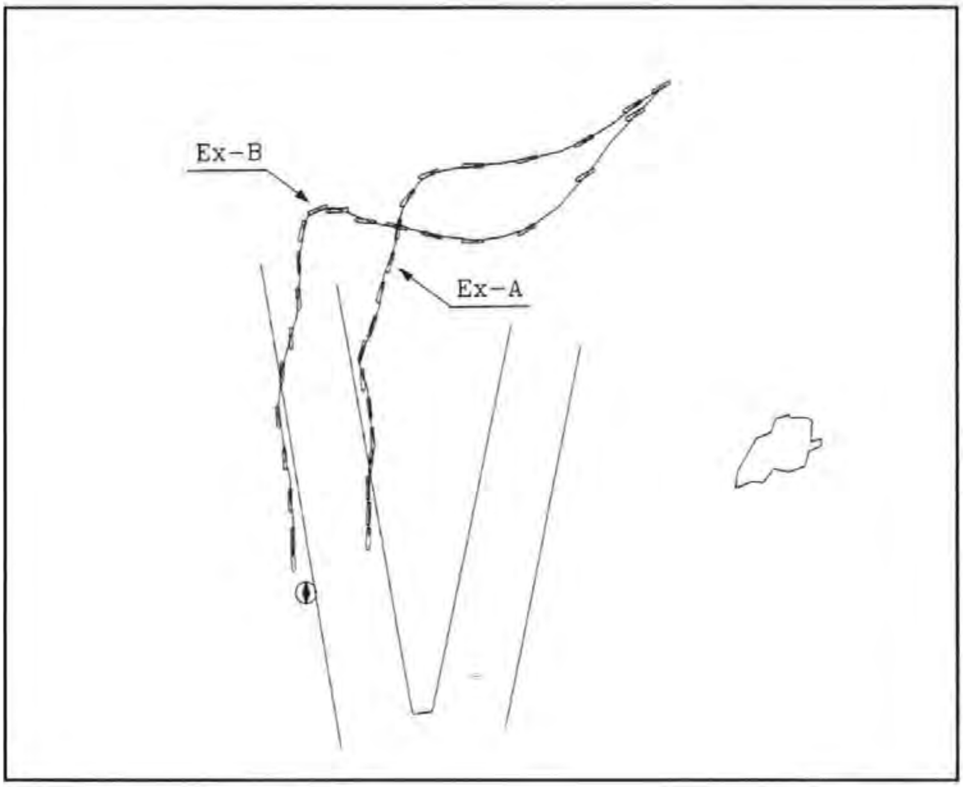

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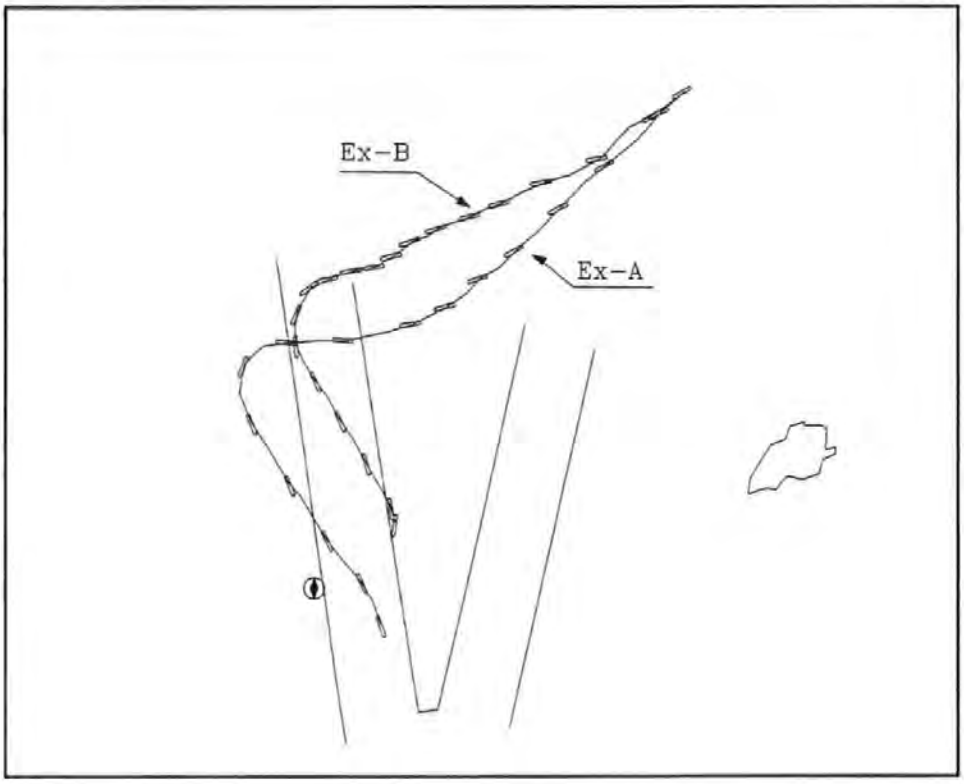

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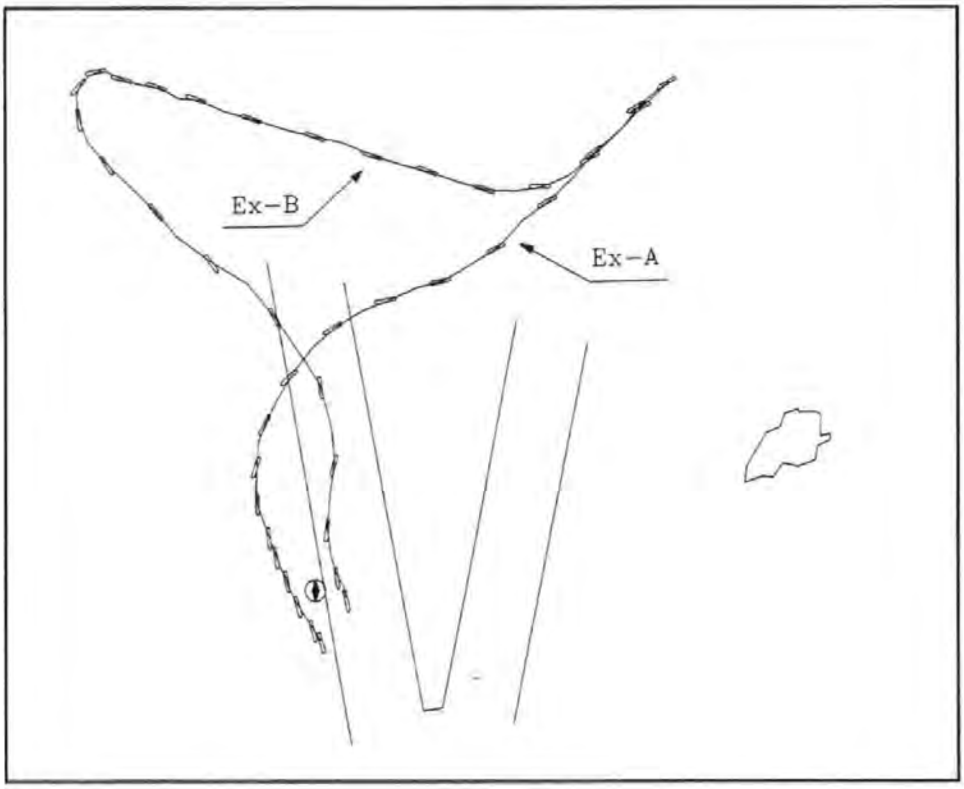

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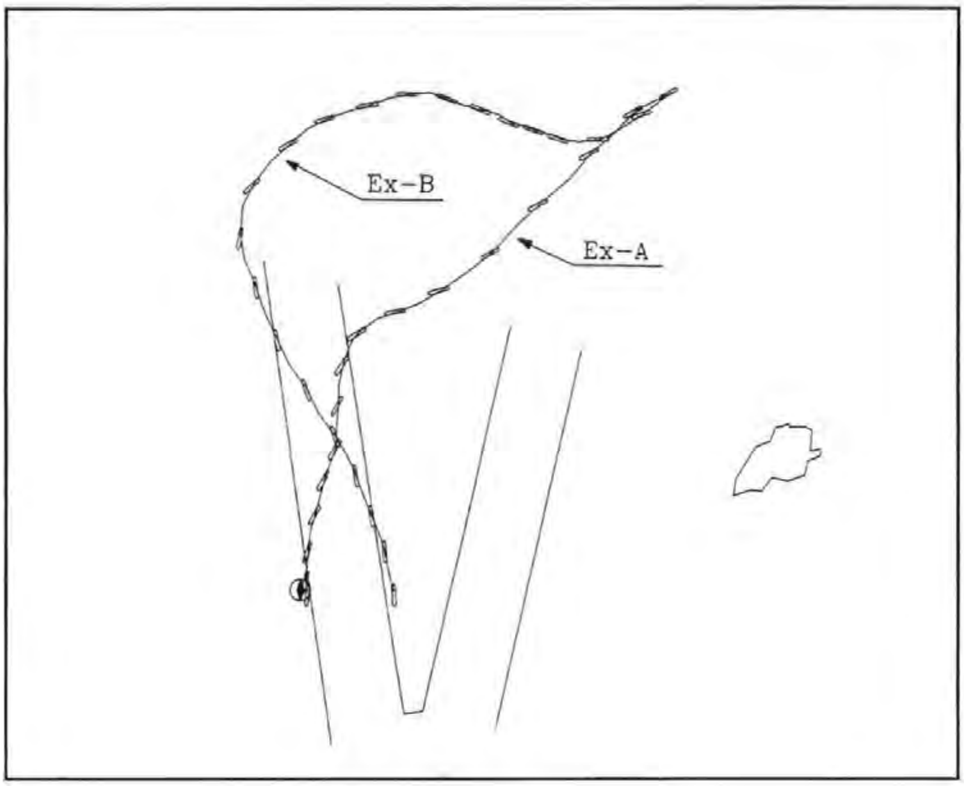

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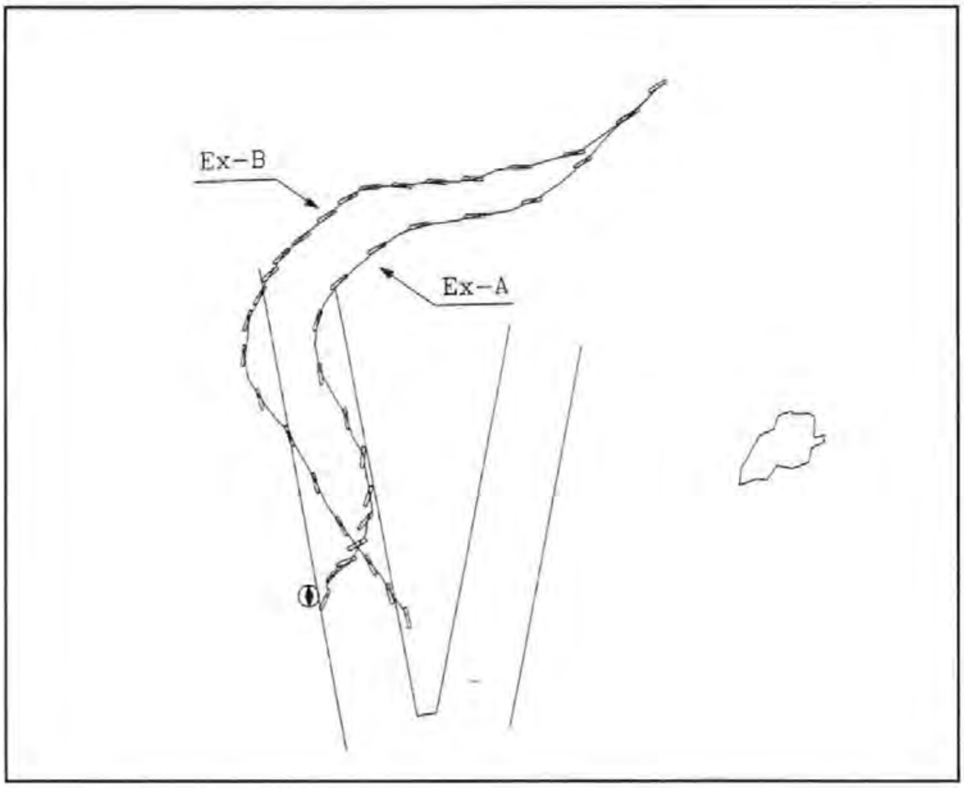

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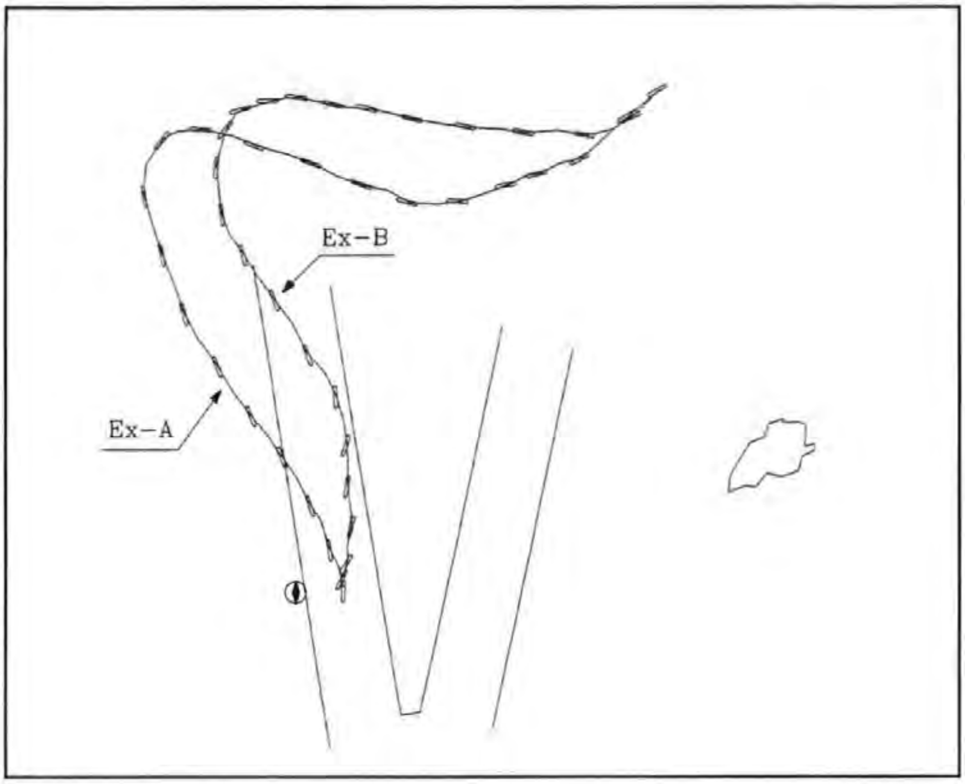

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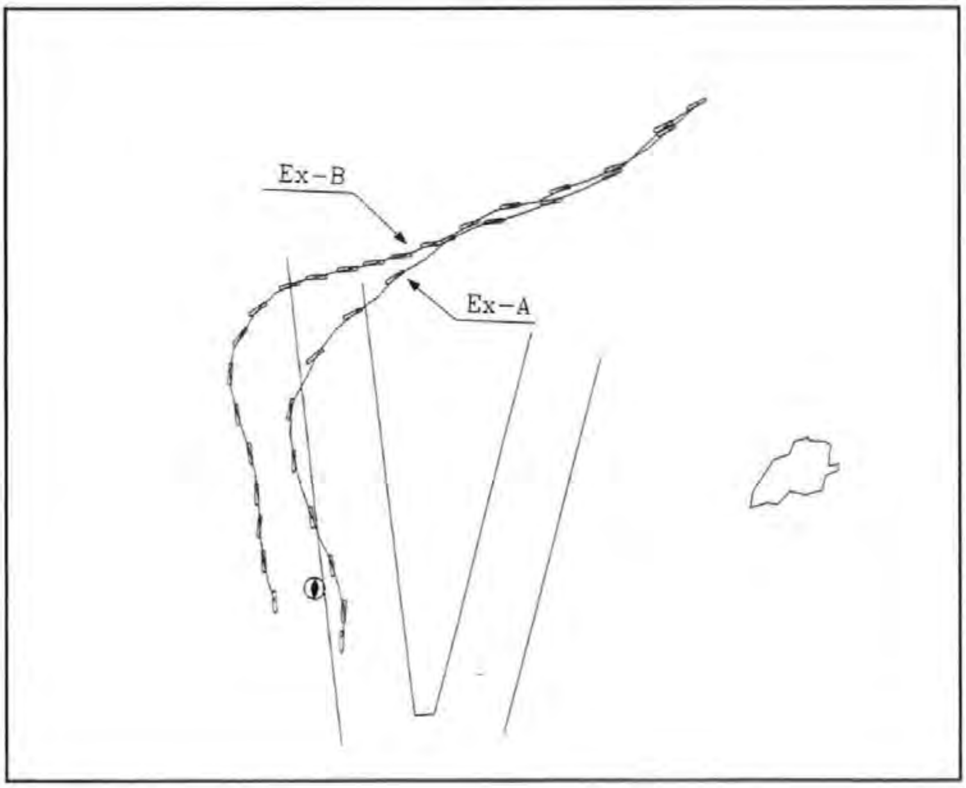

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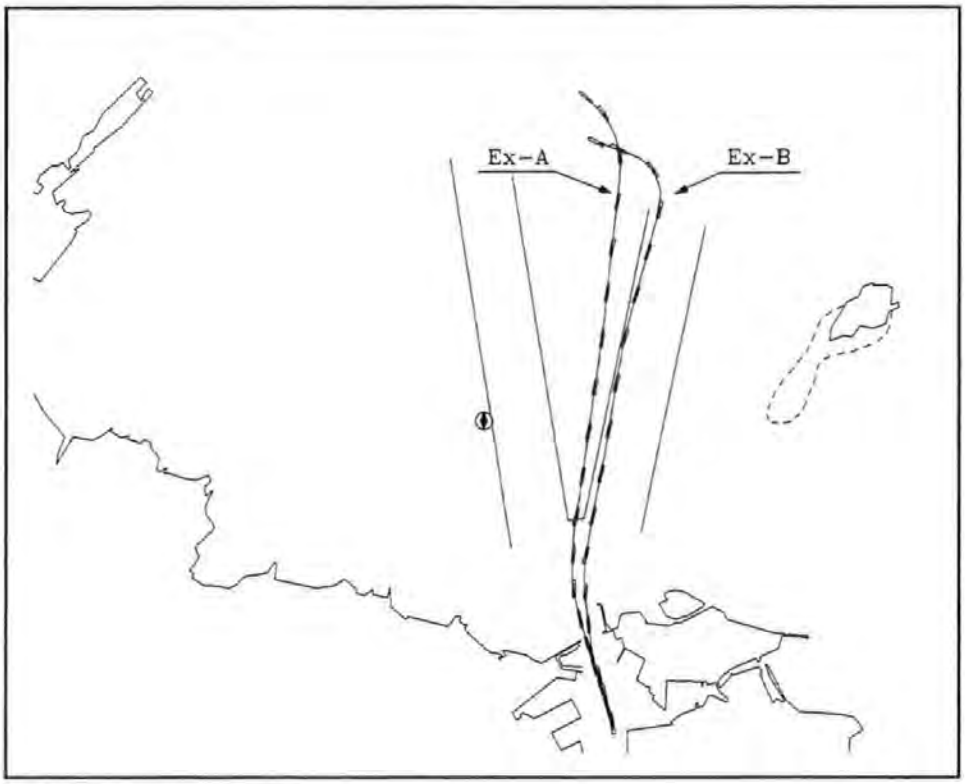
APPENDIX - J

Ship tracks of outbound experiment



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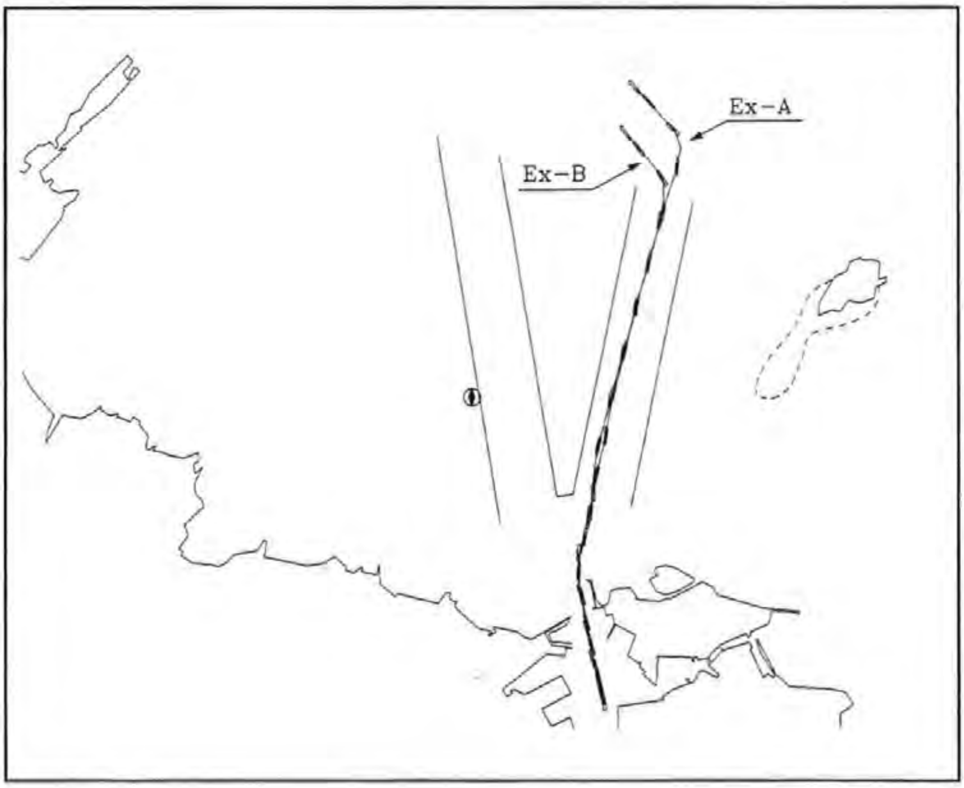

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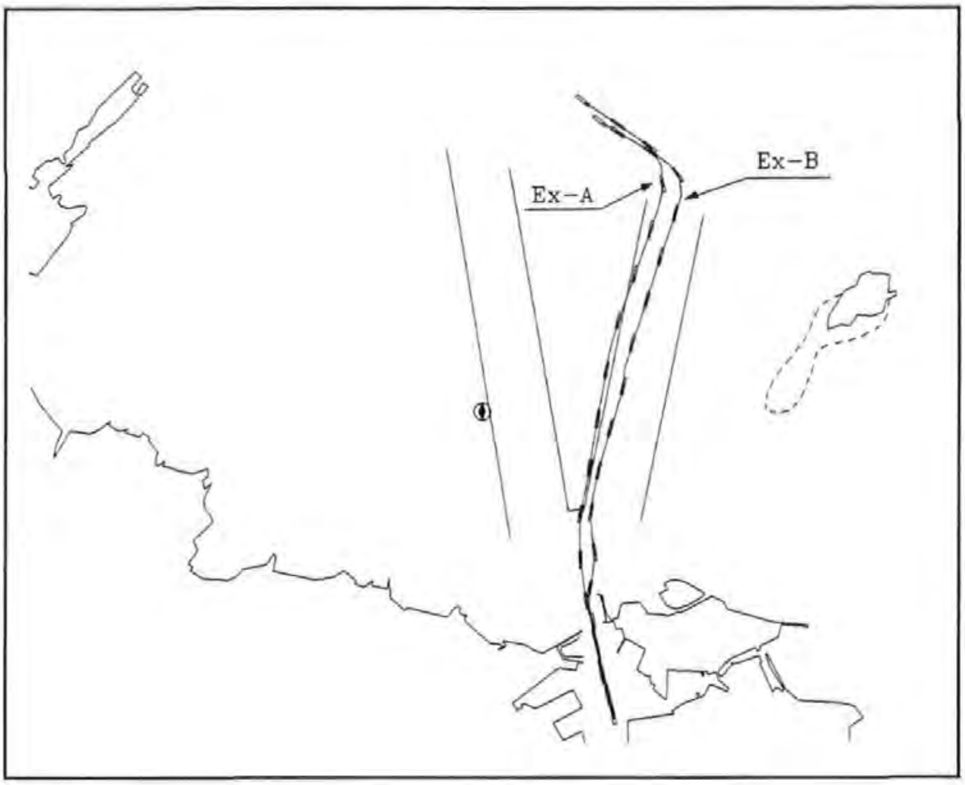

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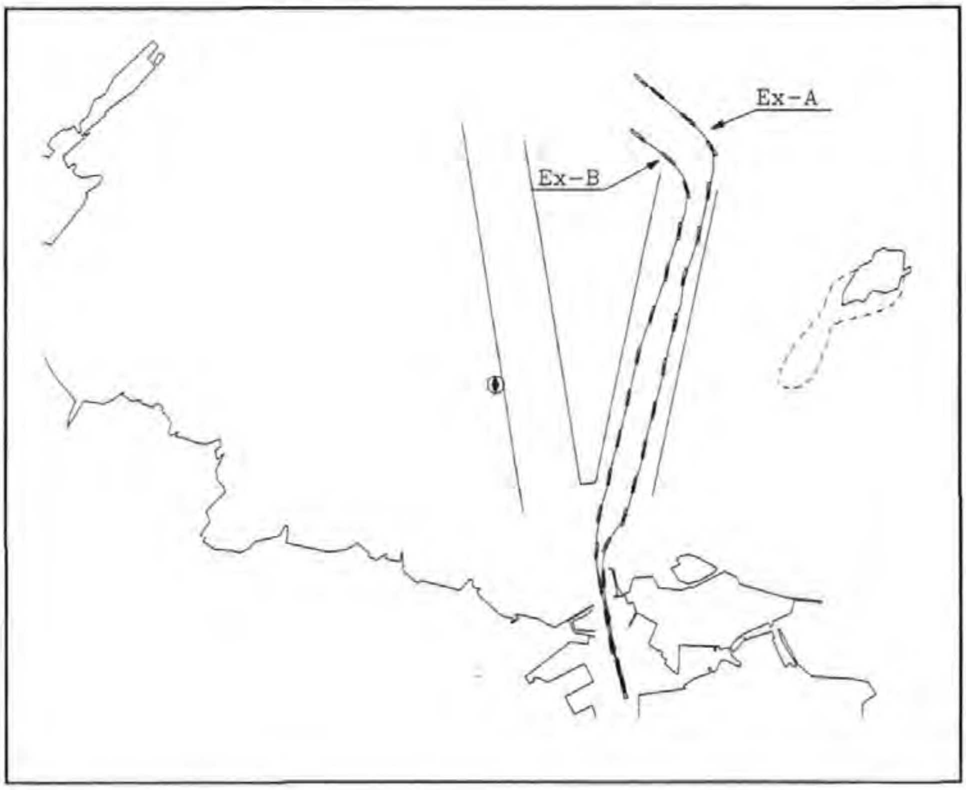

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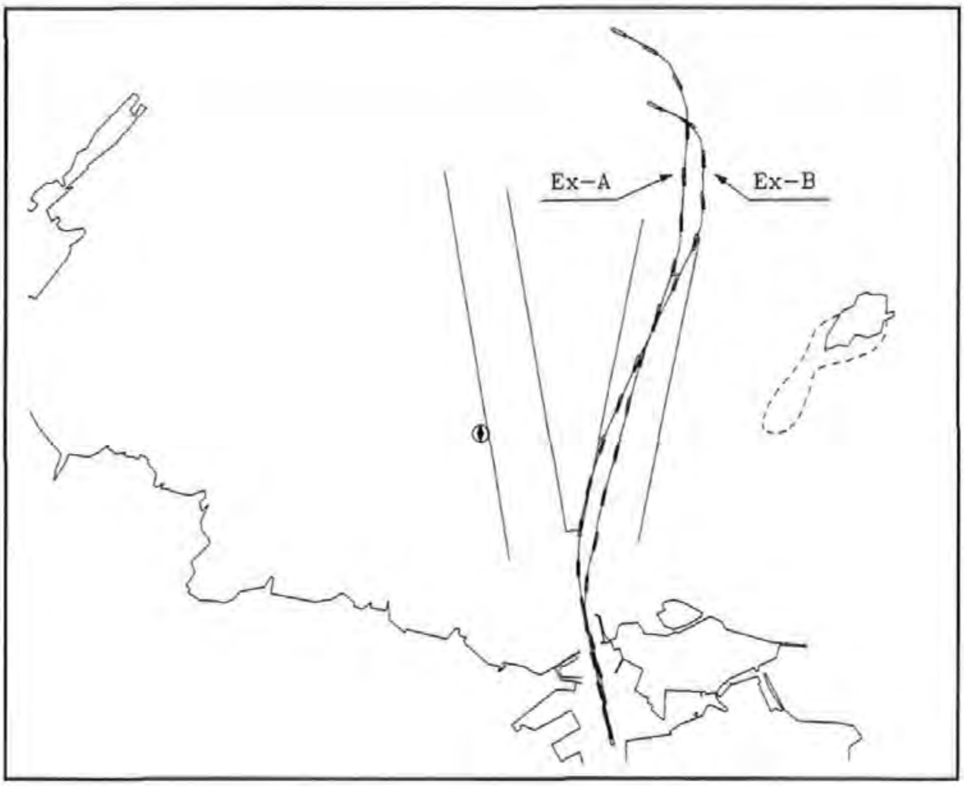

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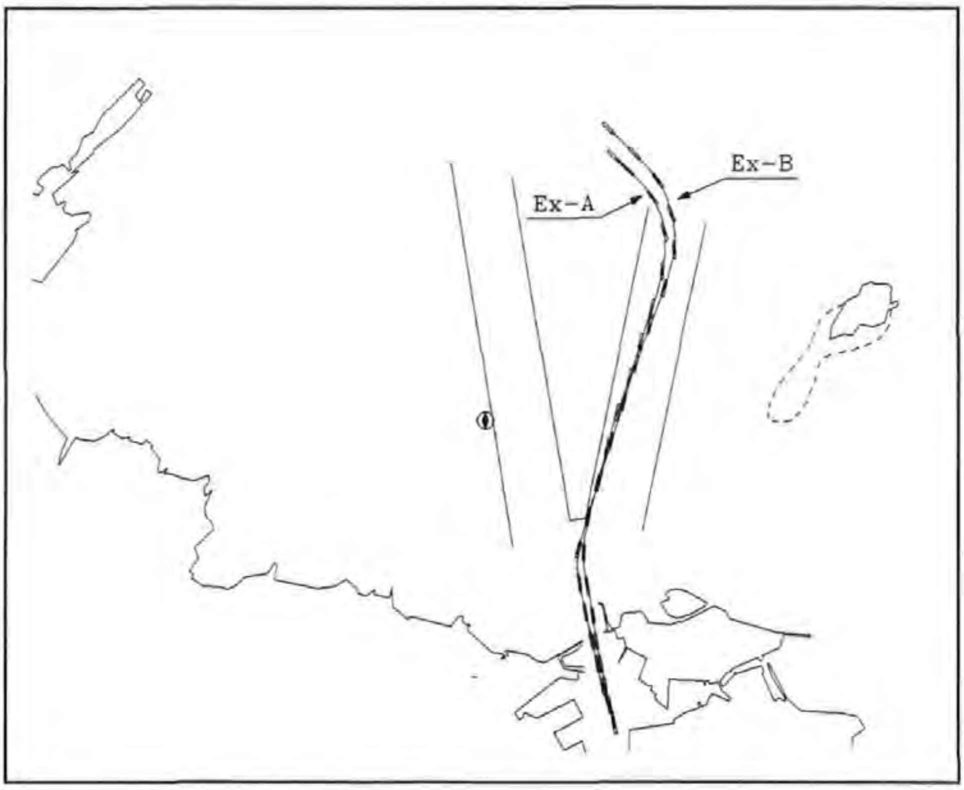

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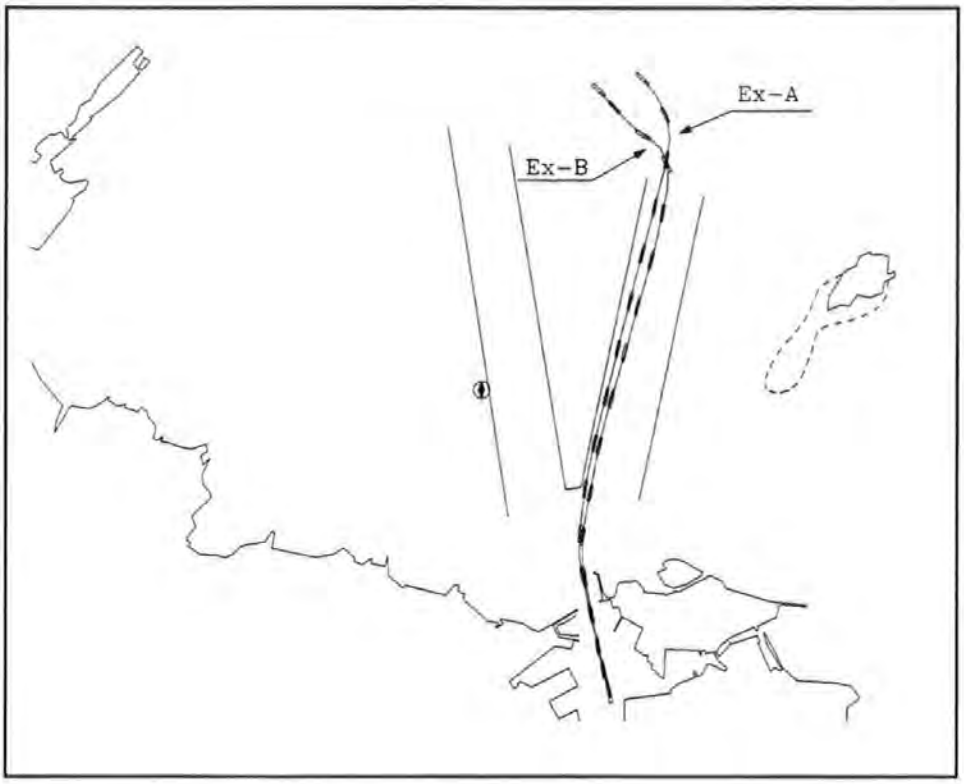

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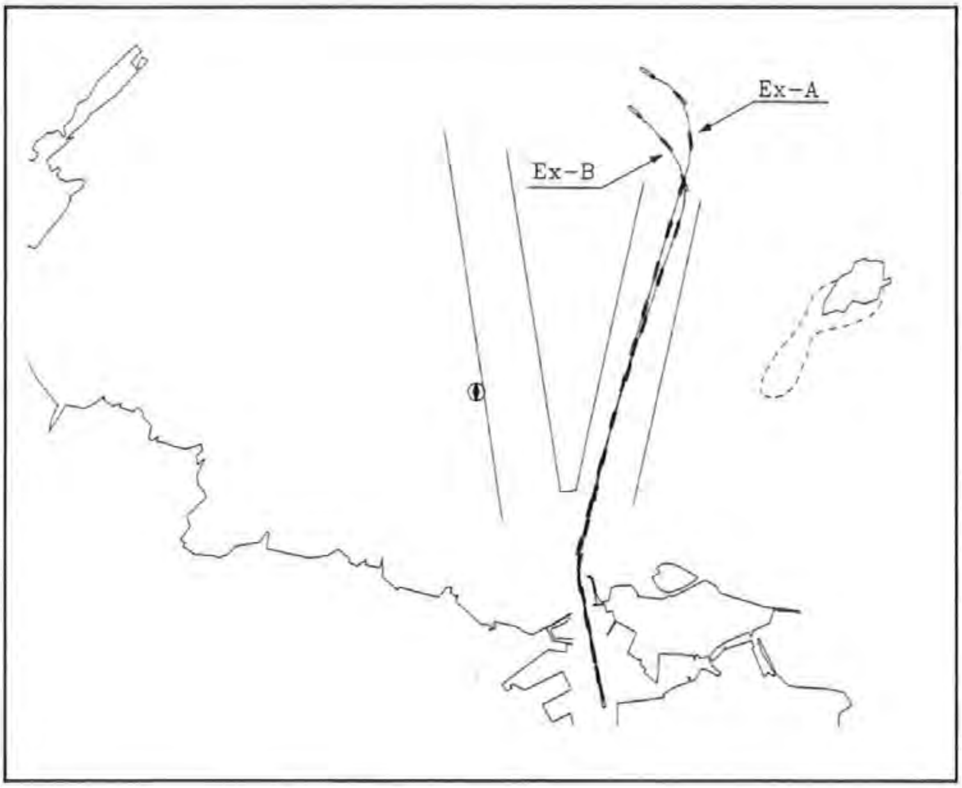

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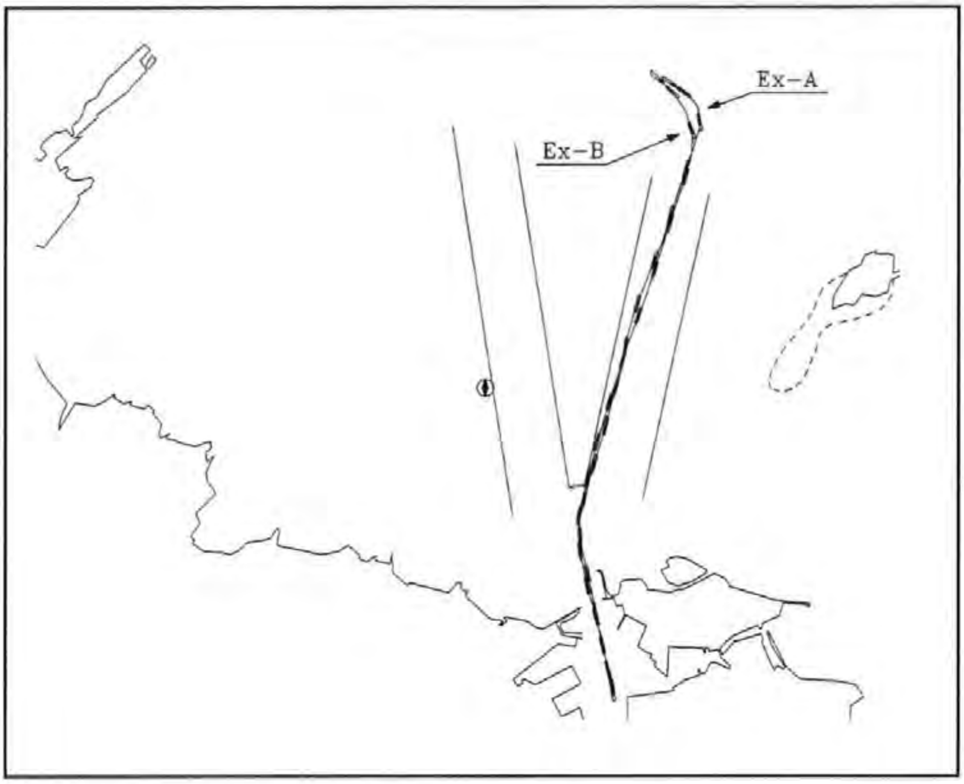

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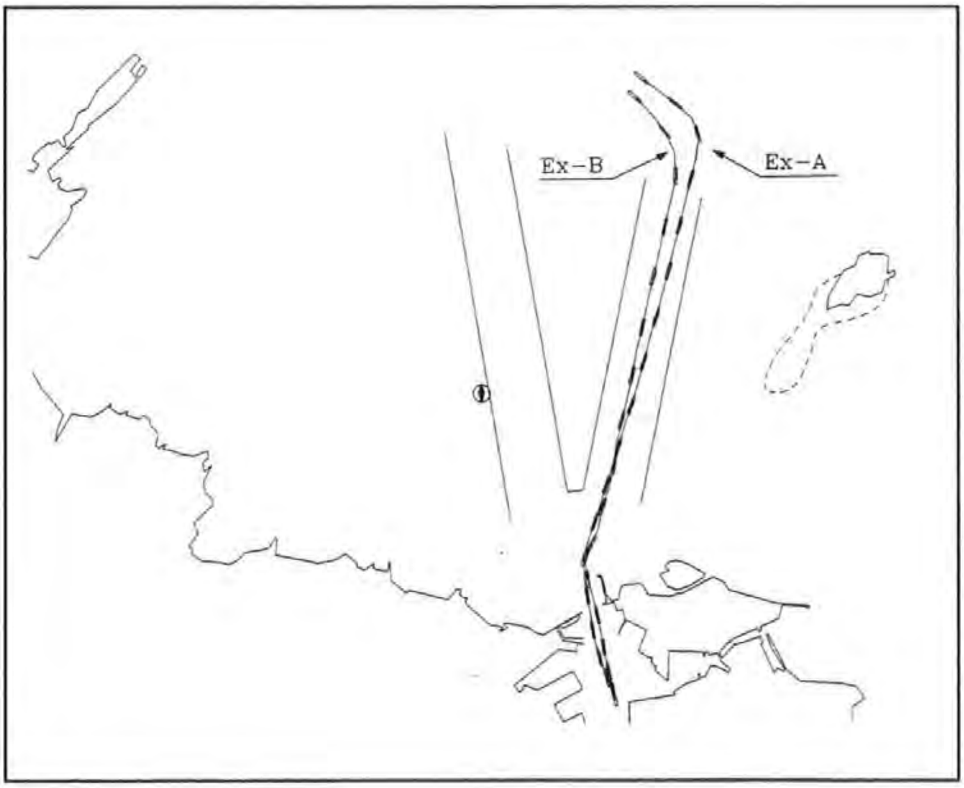

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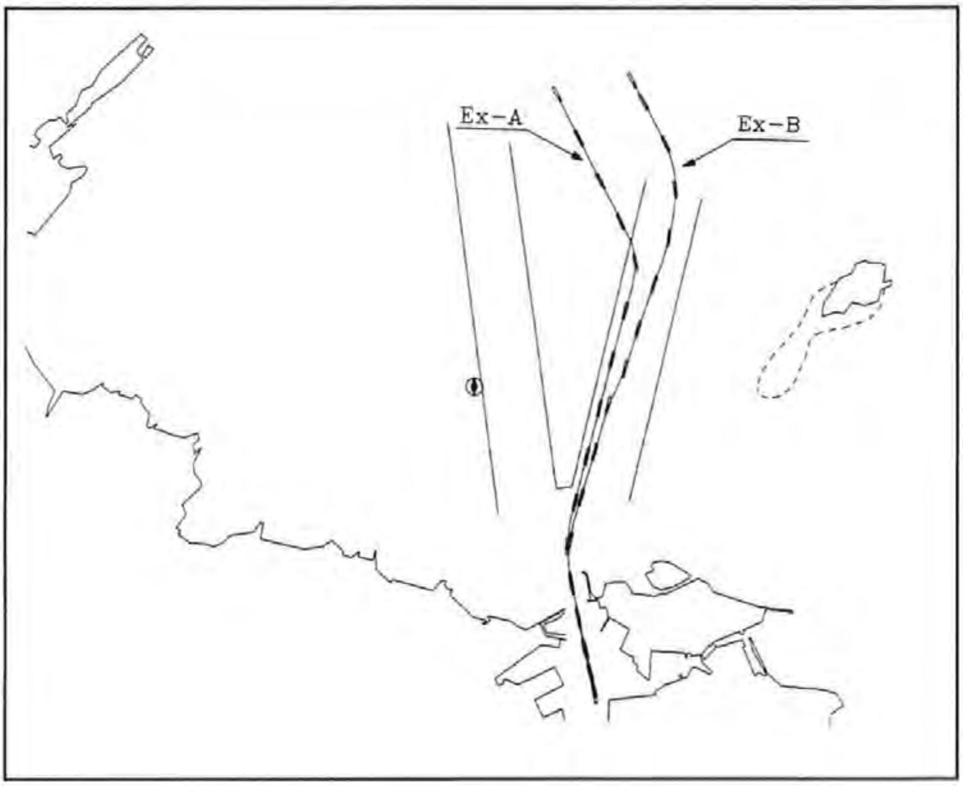

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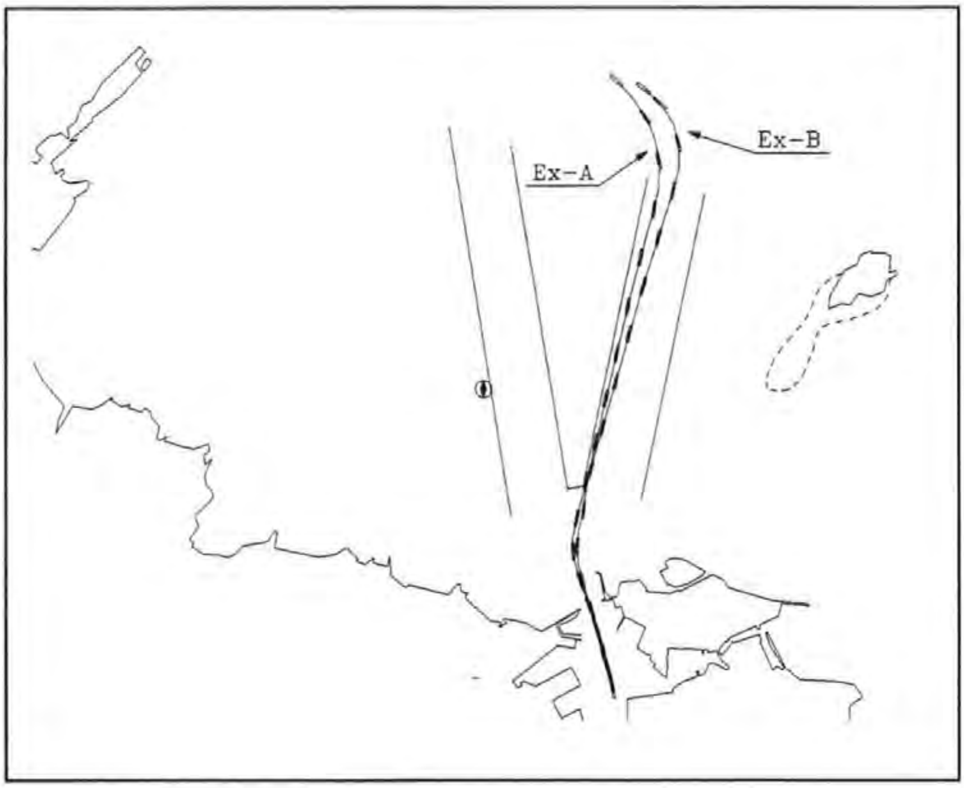

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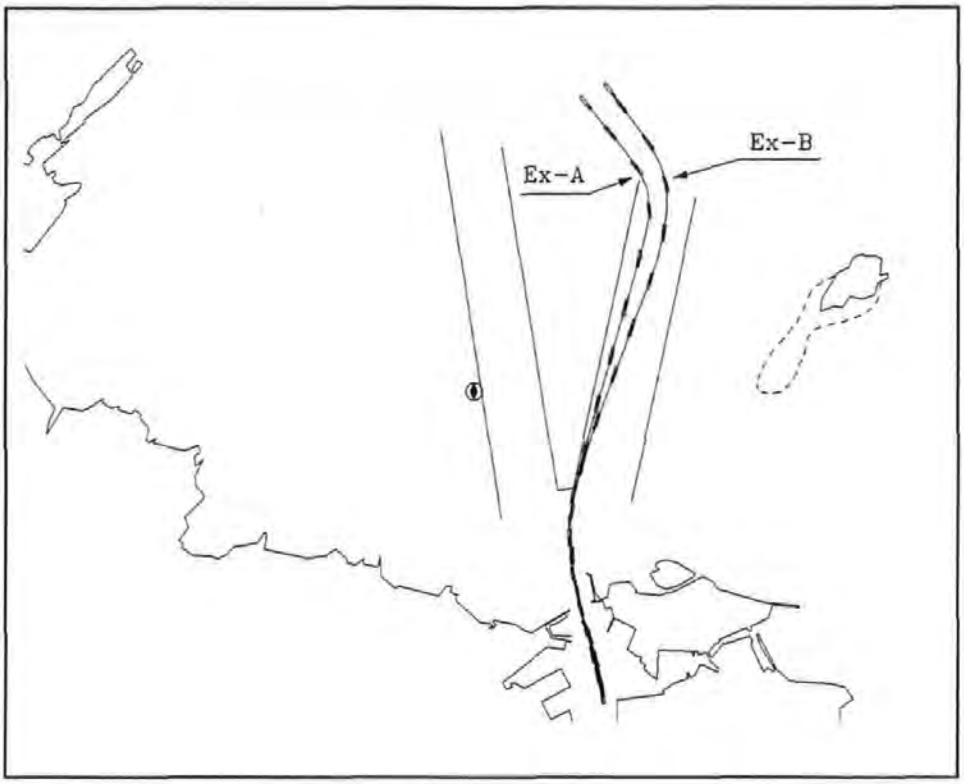

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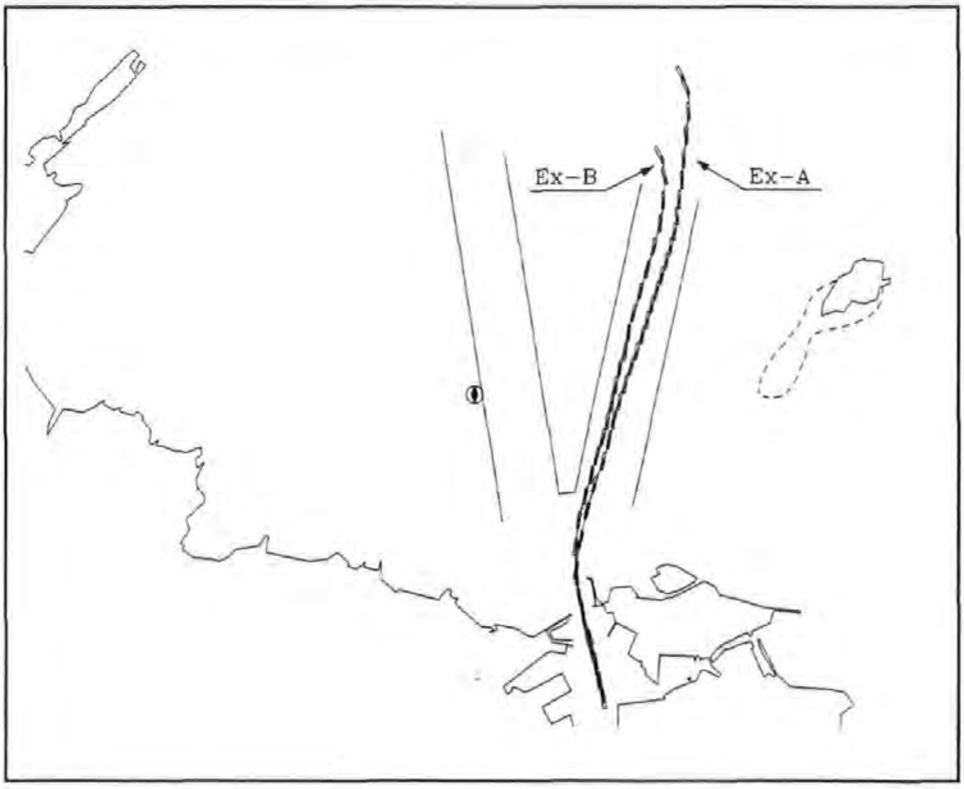

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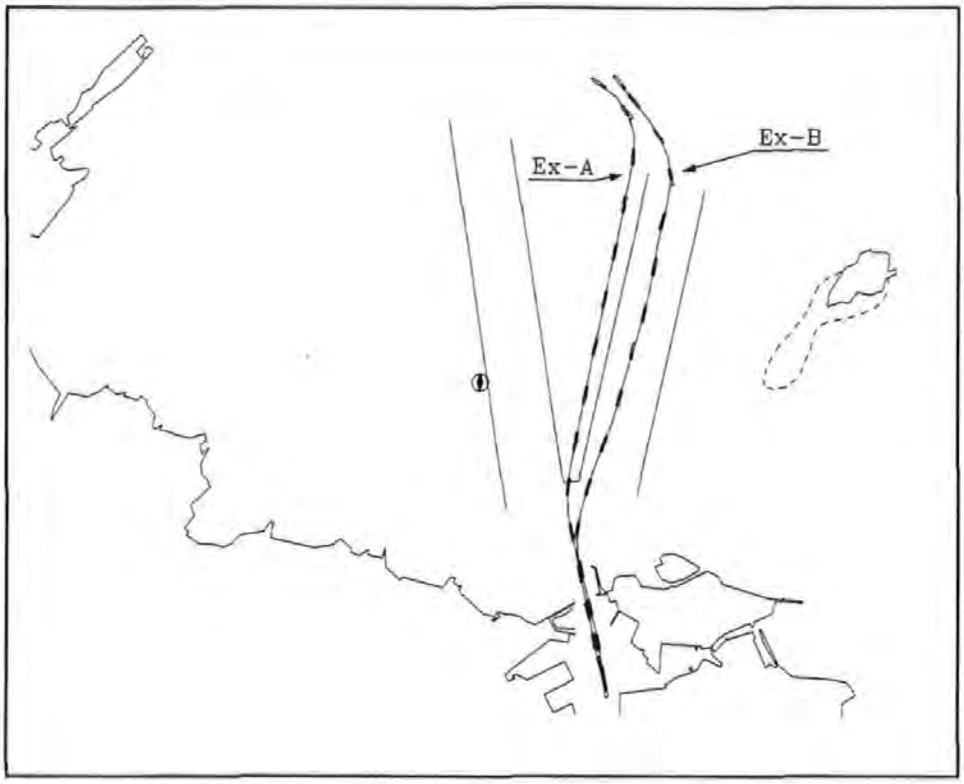

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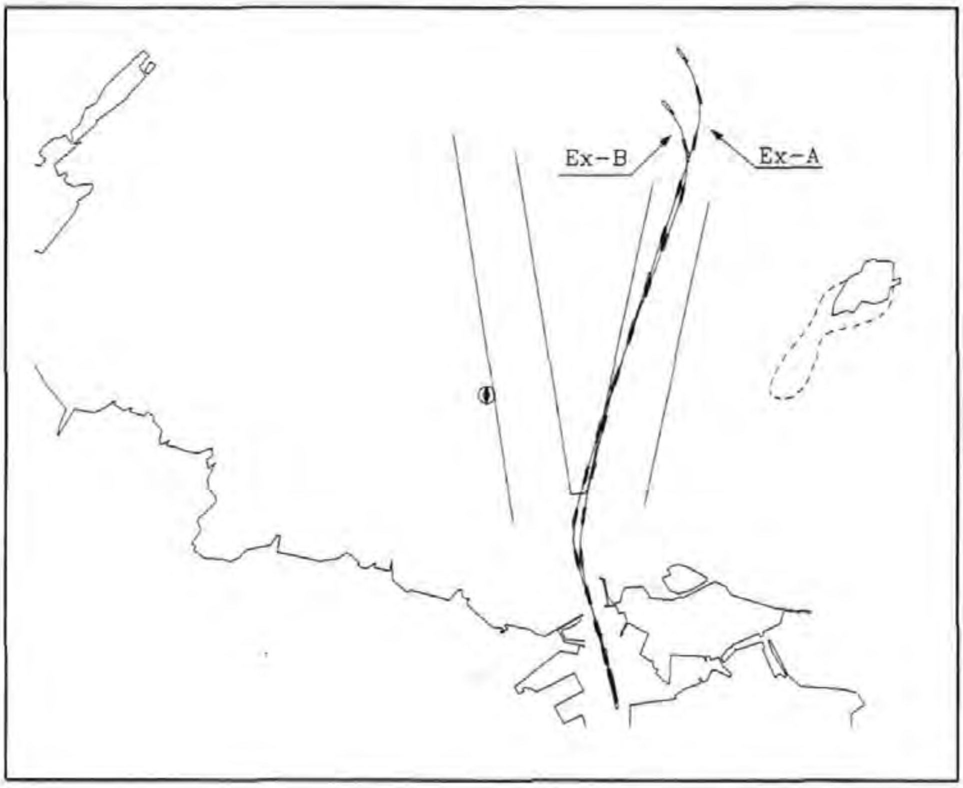

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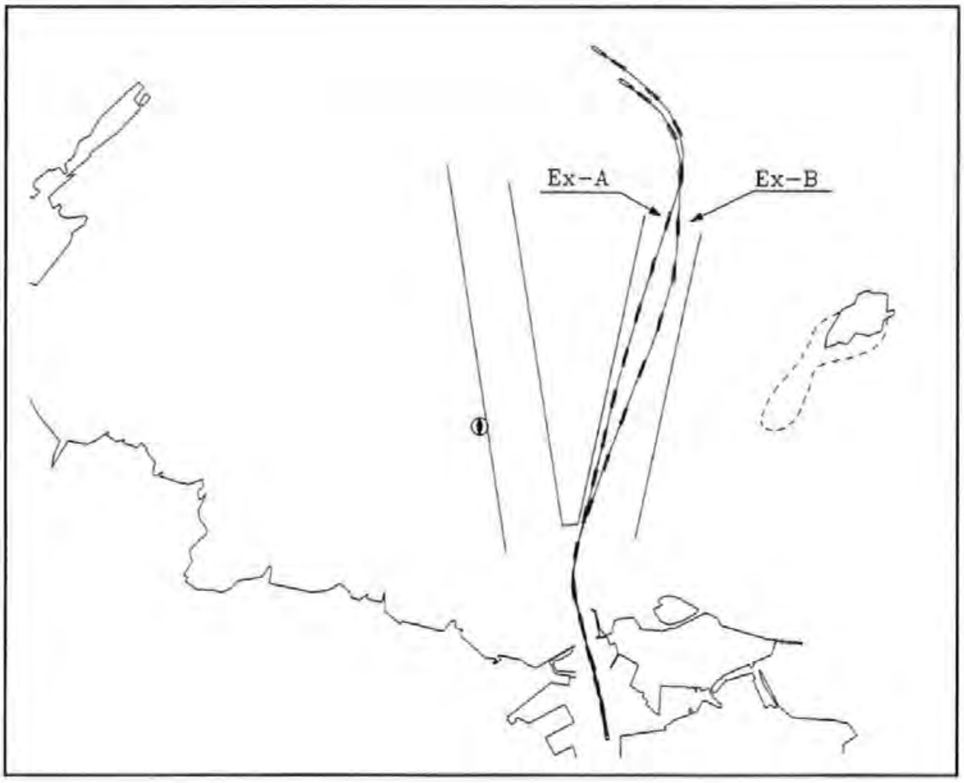

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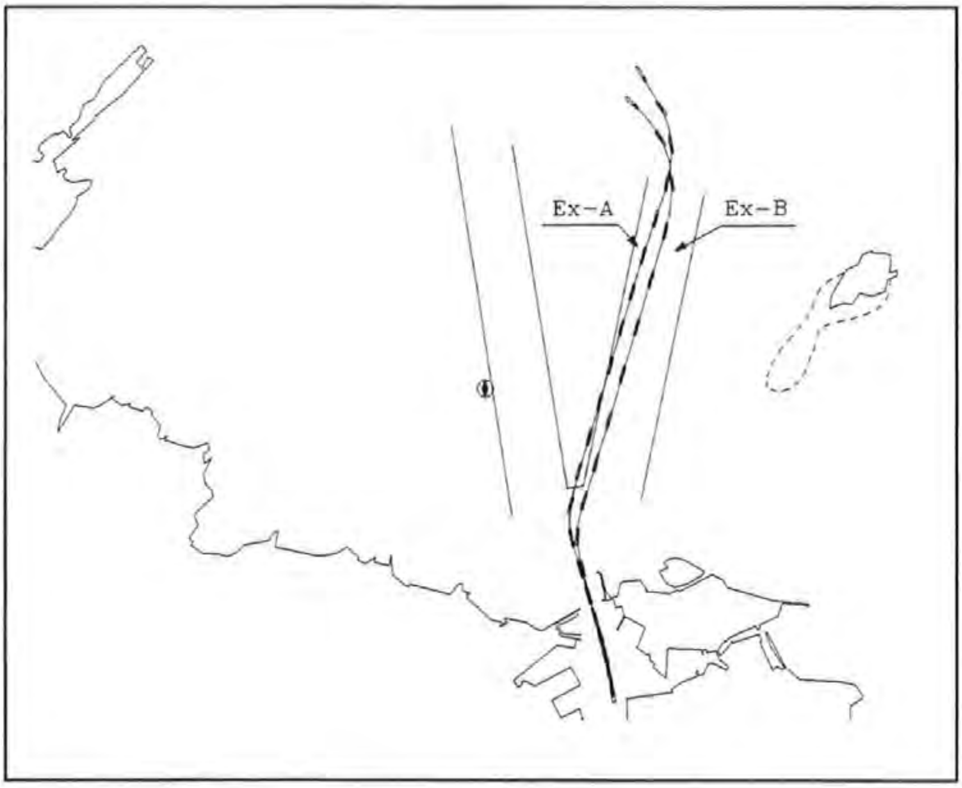

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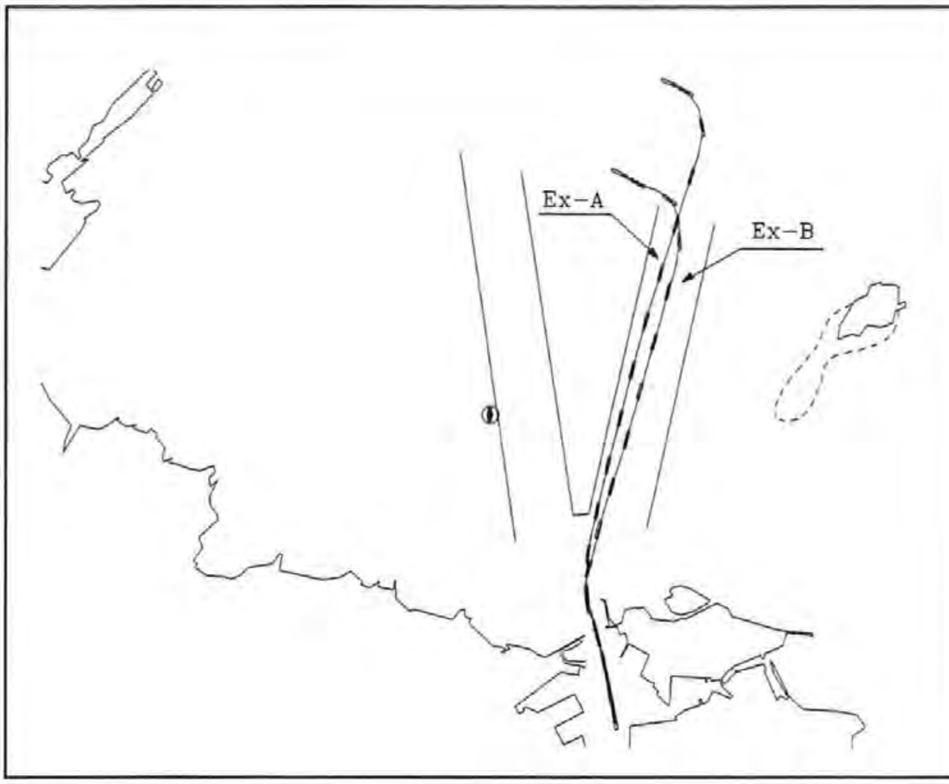

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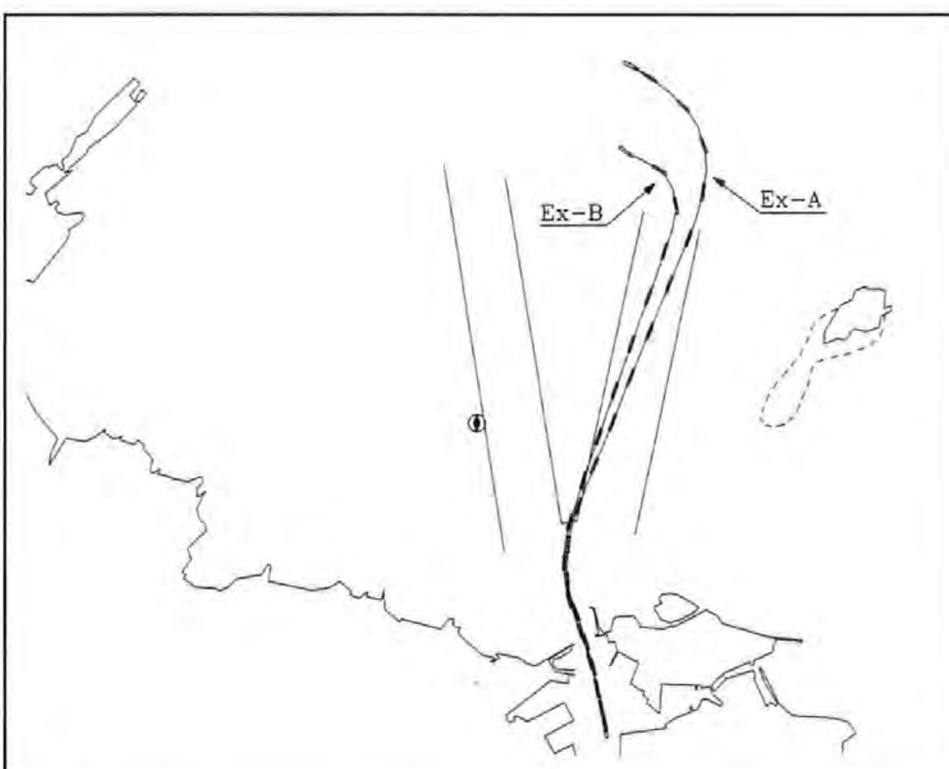

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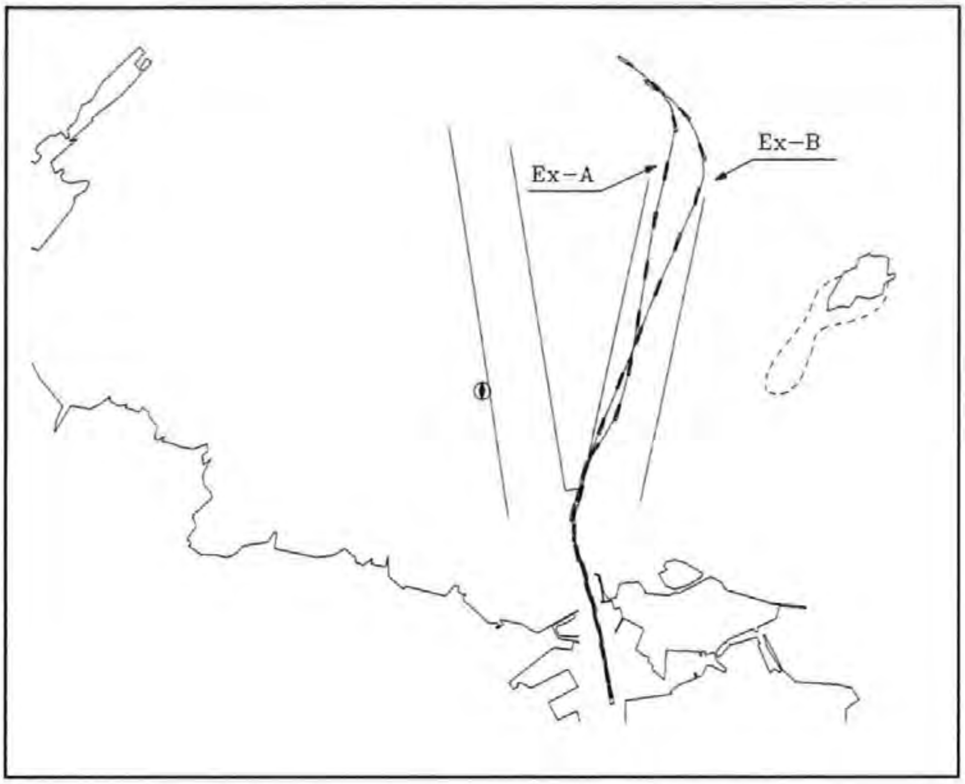

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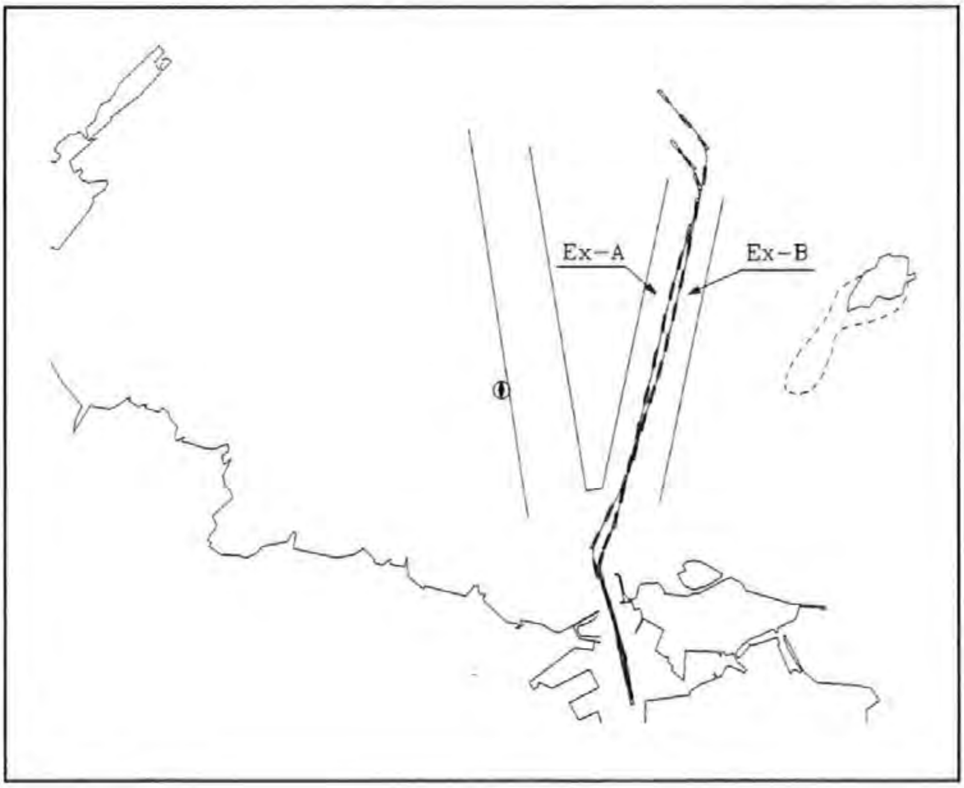

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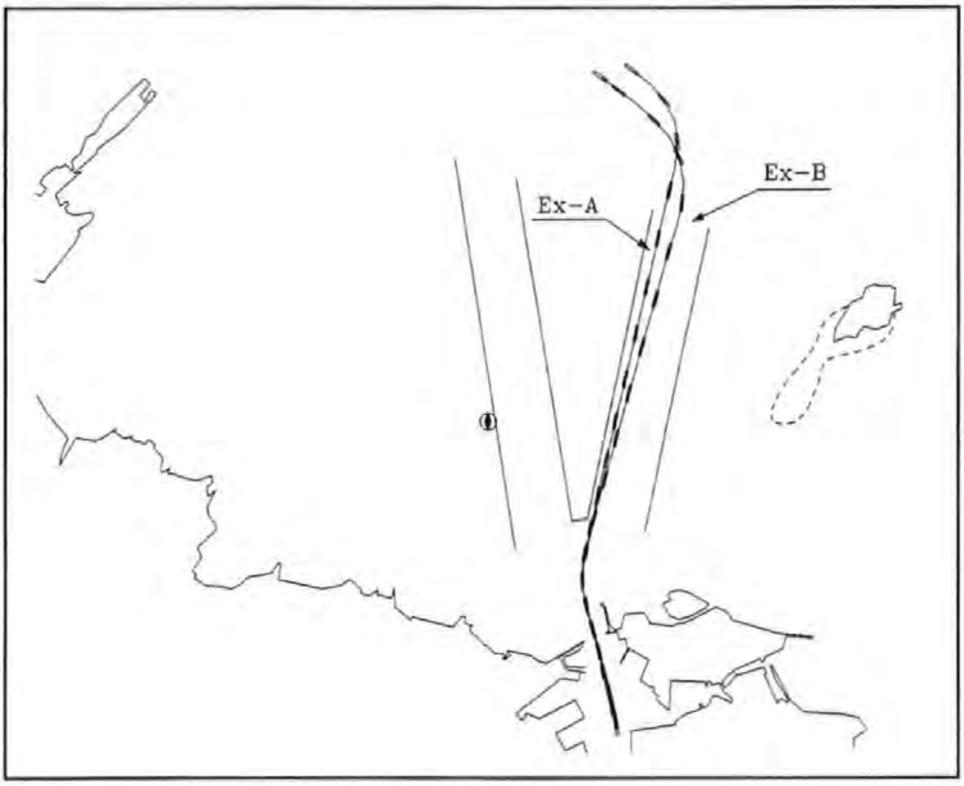

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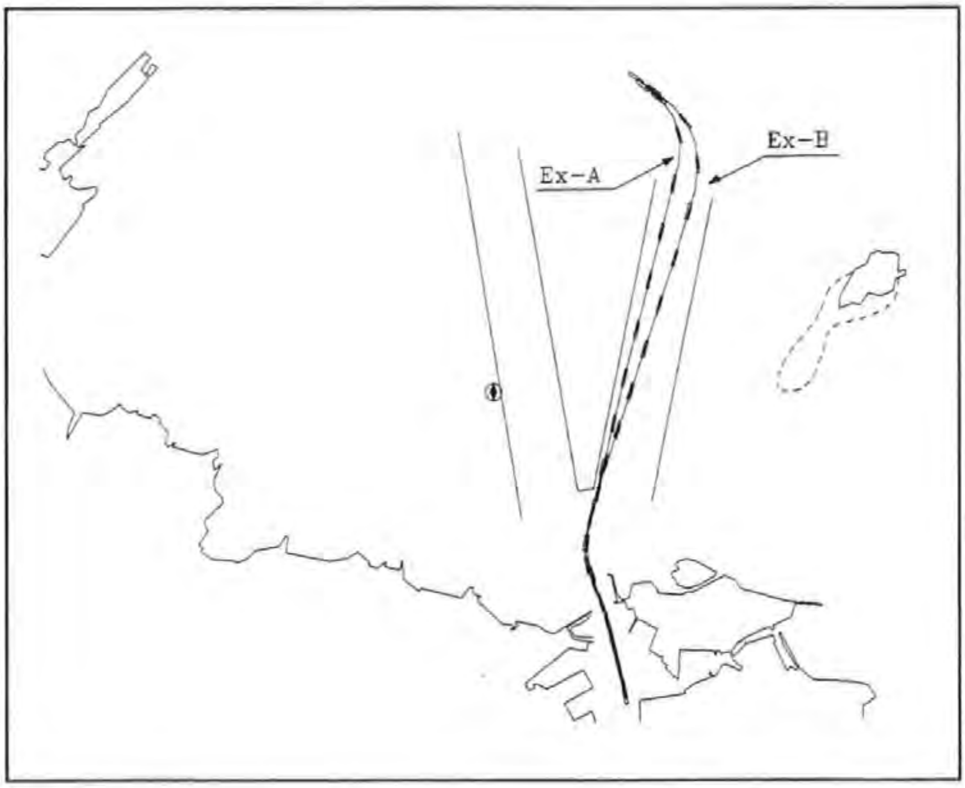

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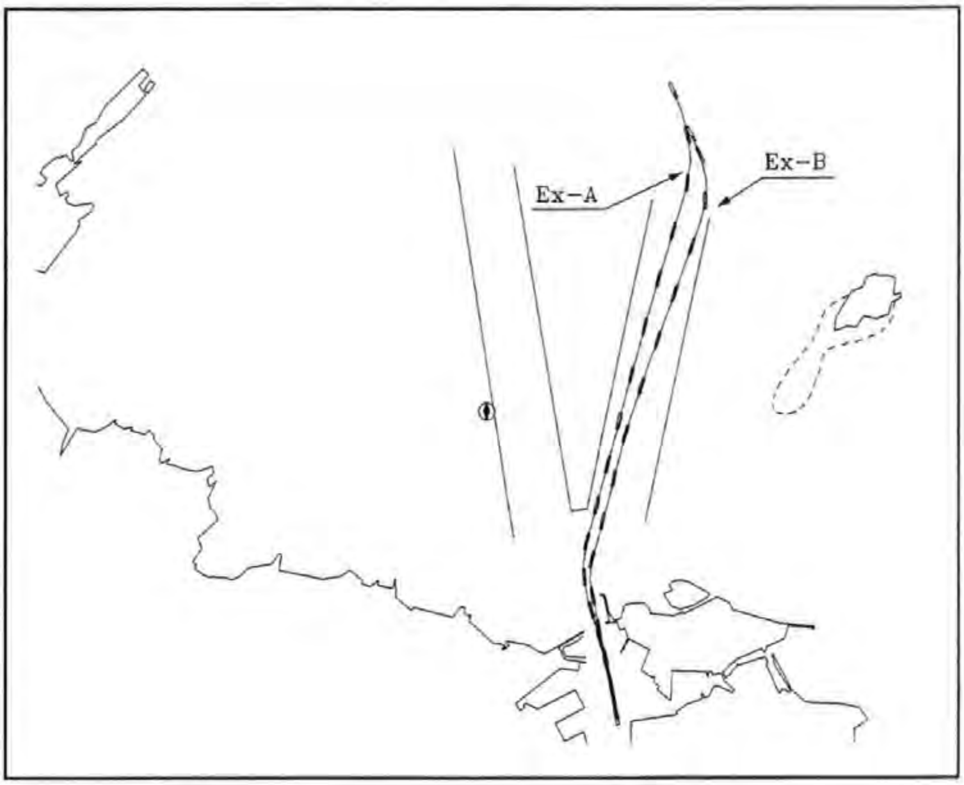

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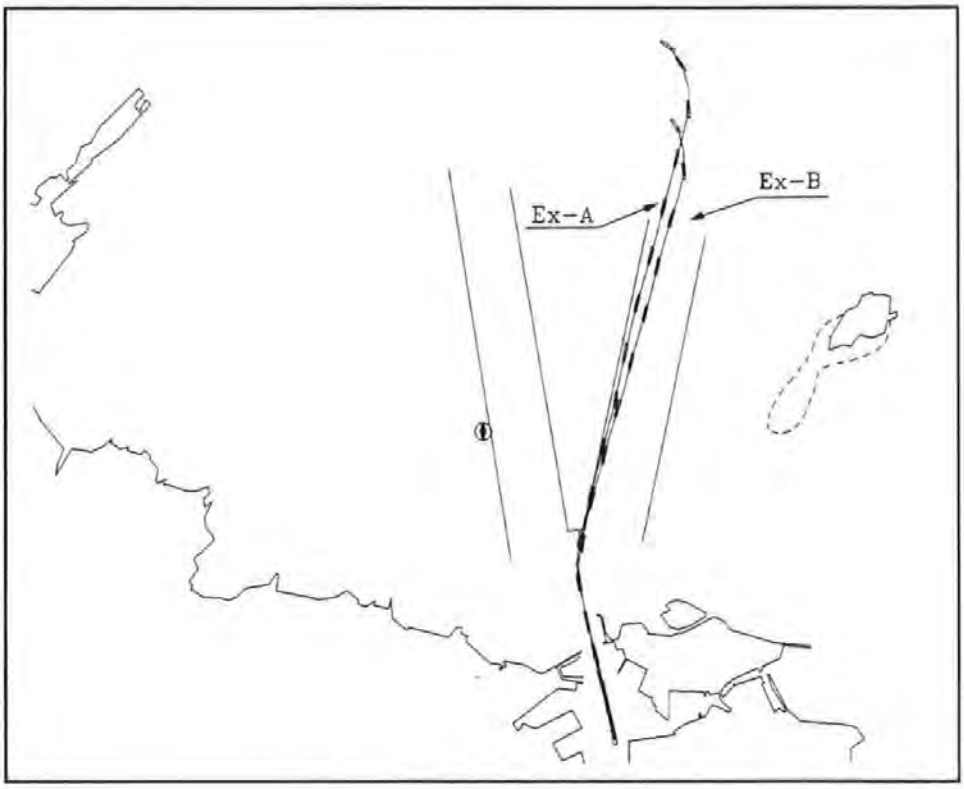

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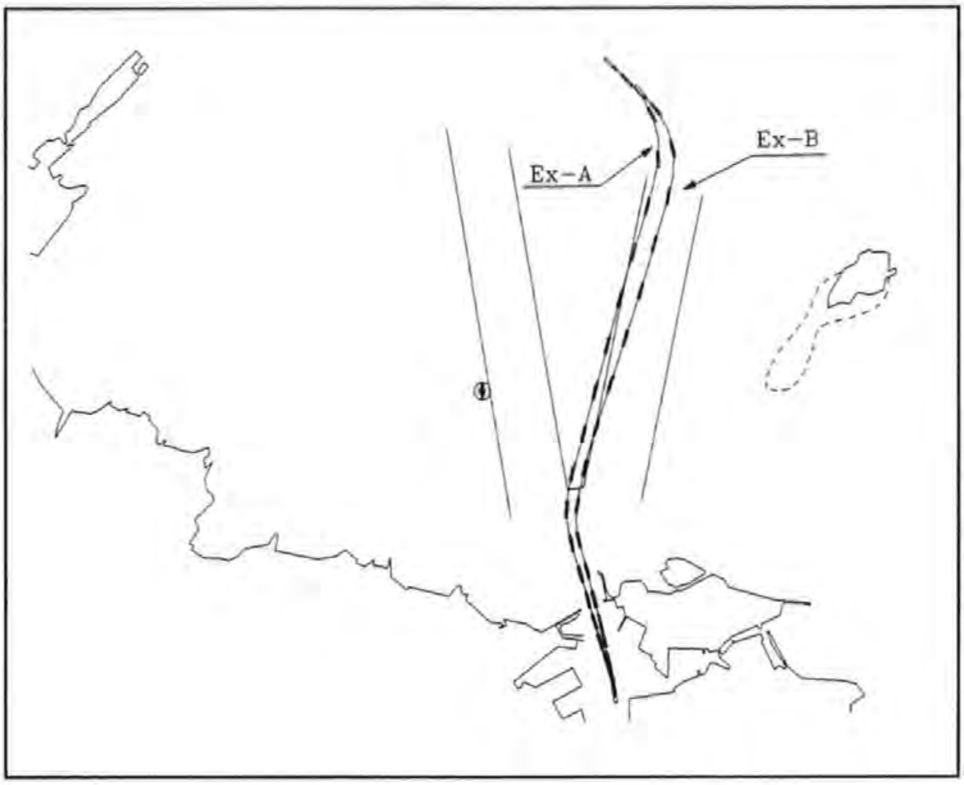

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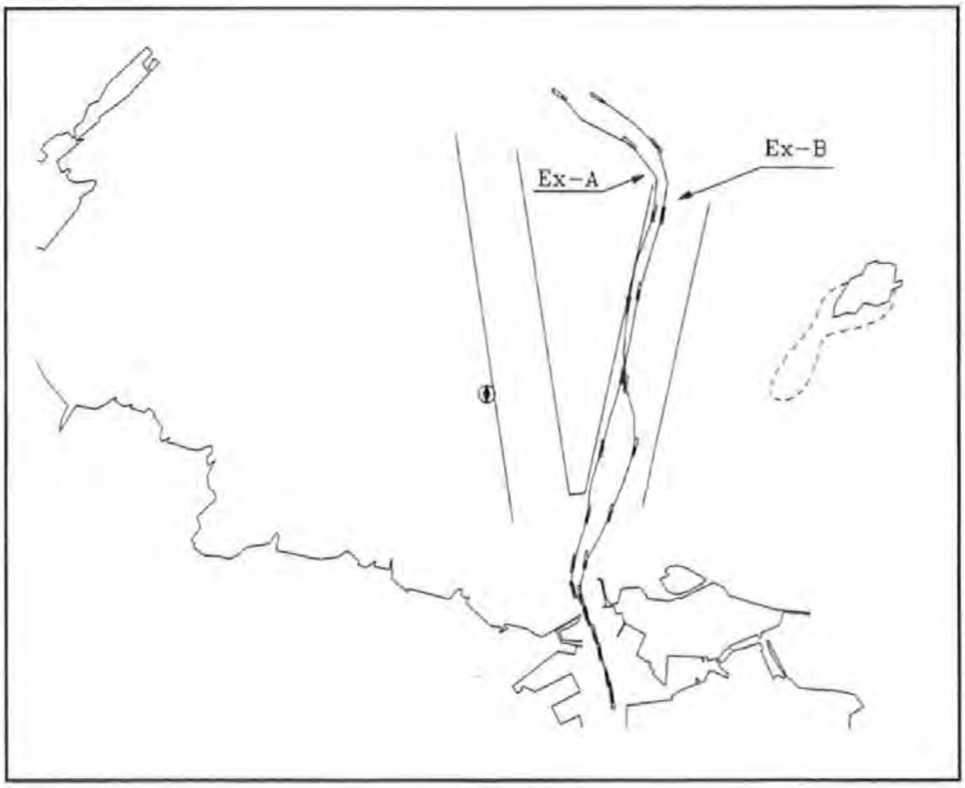

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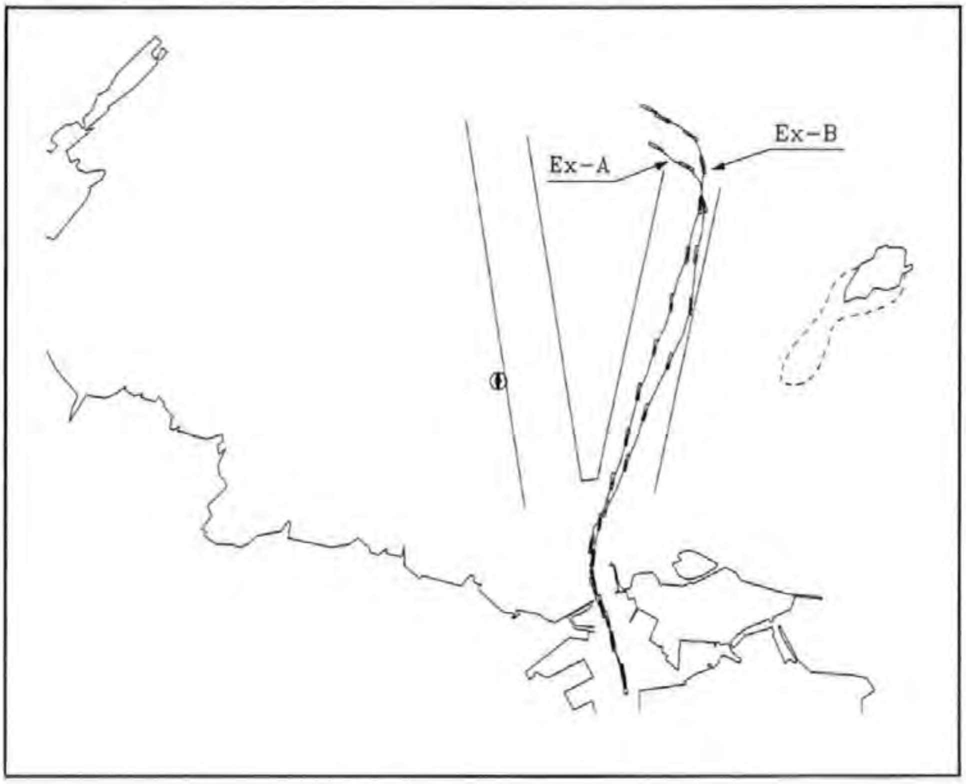

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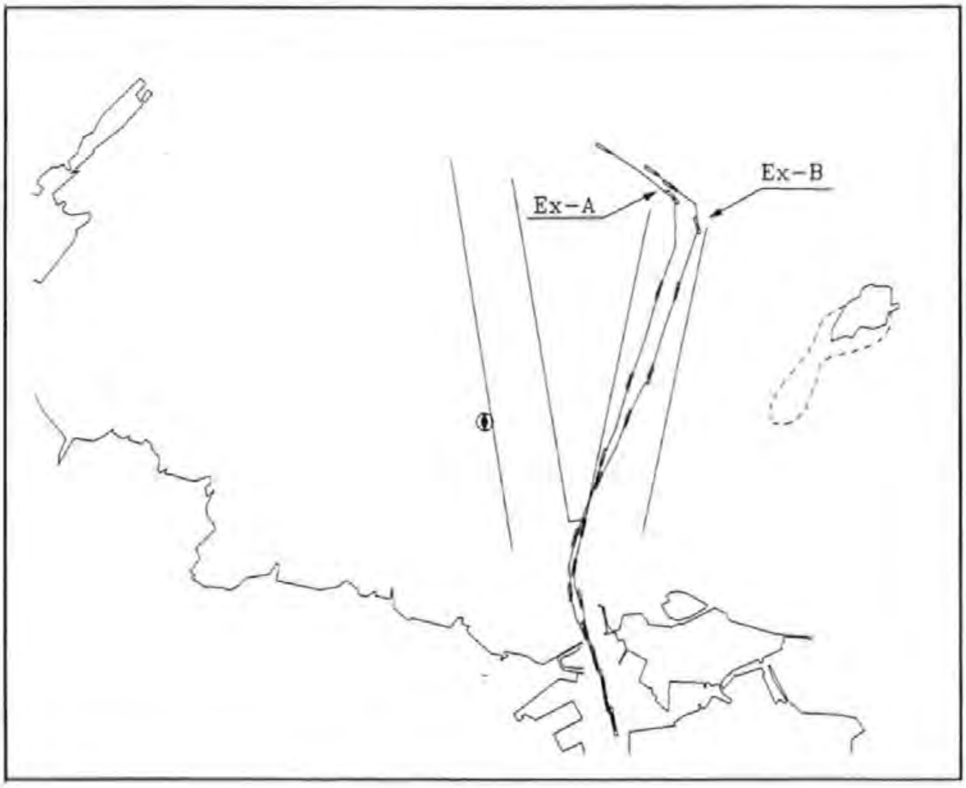
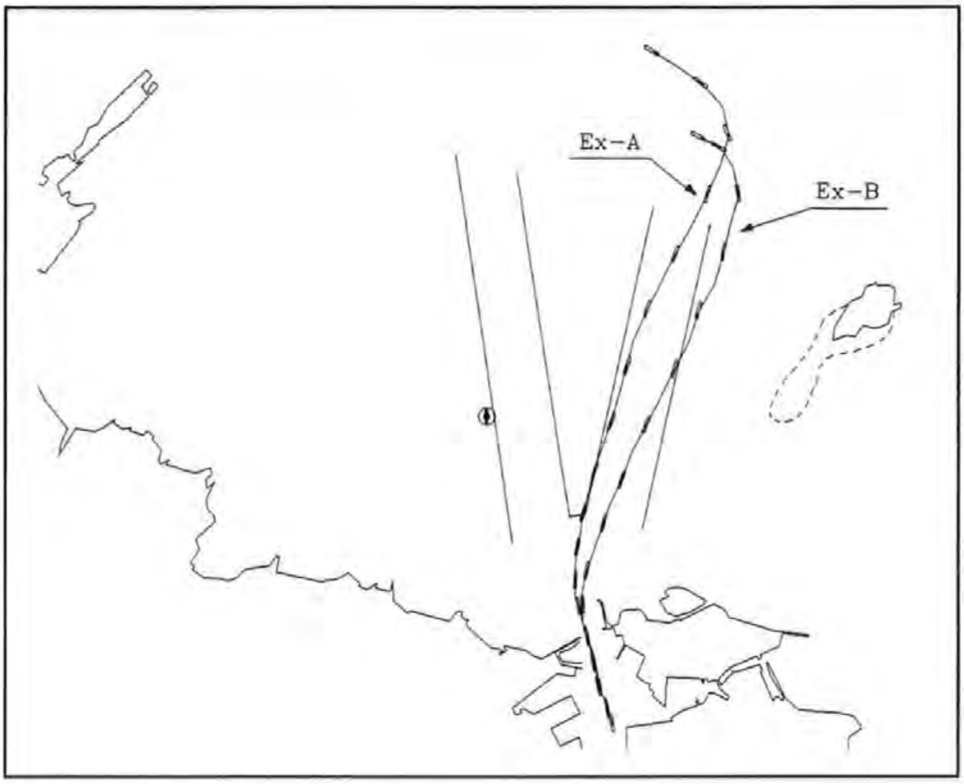
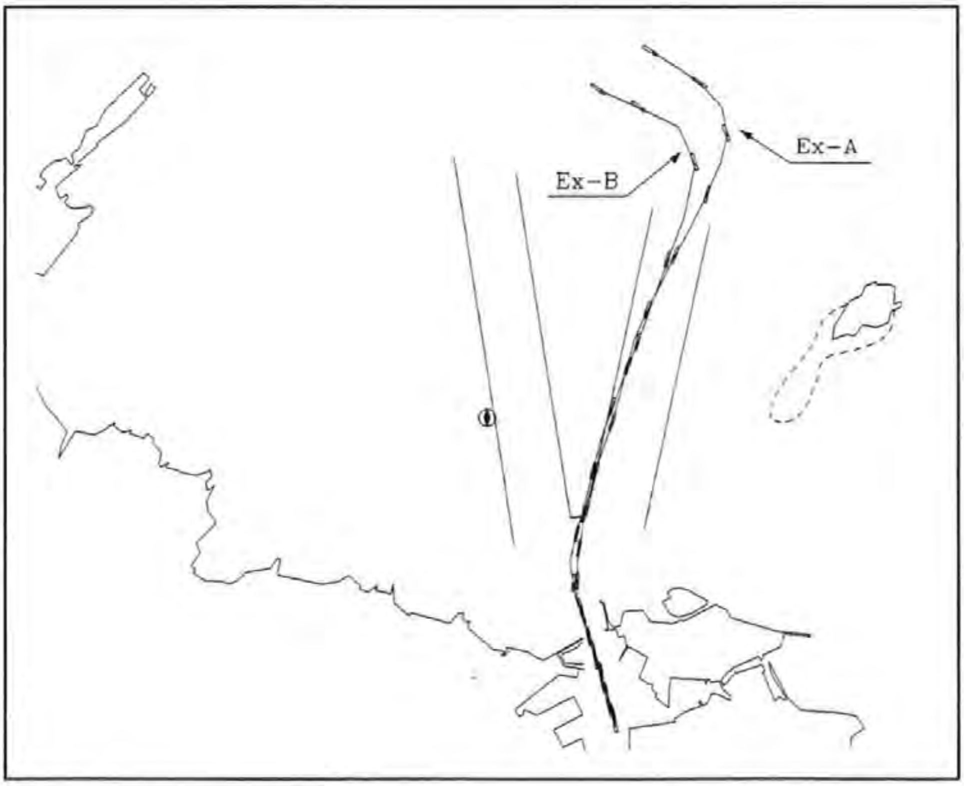


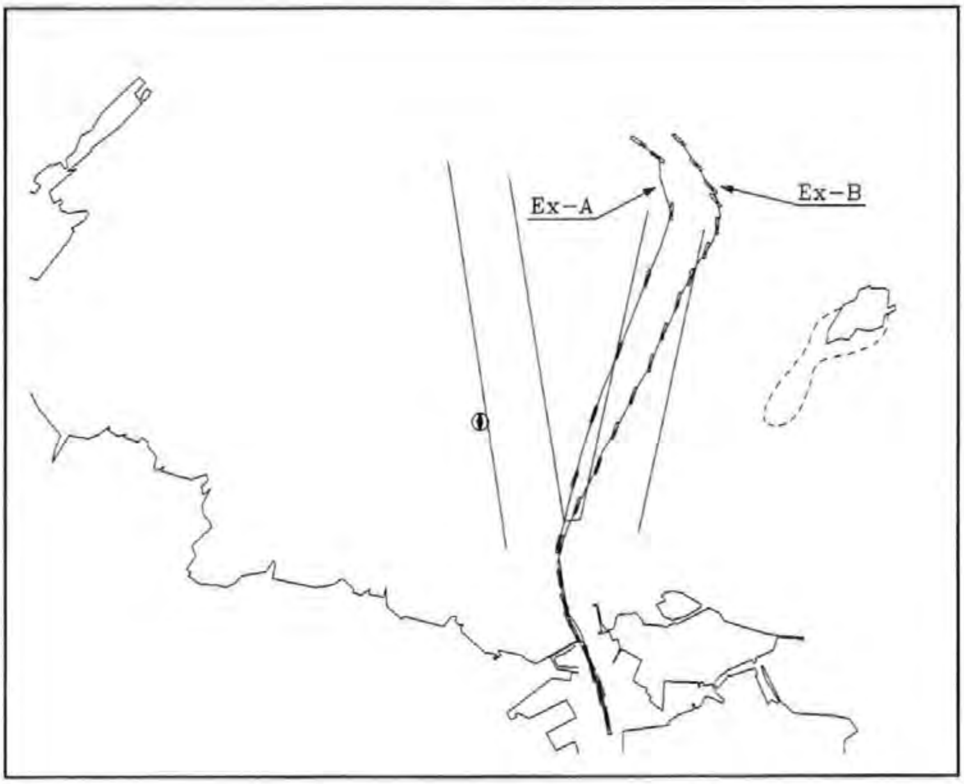
Run 30



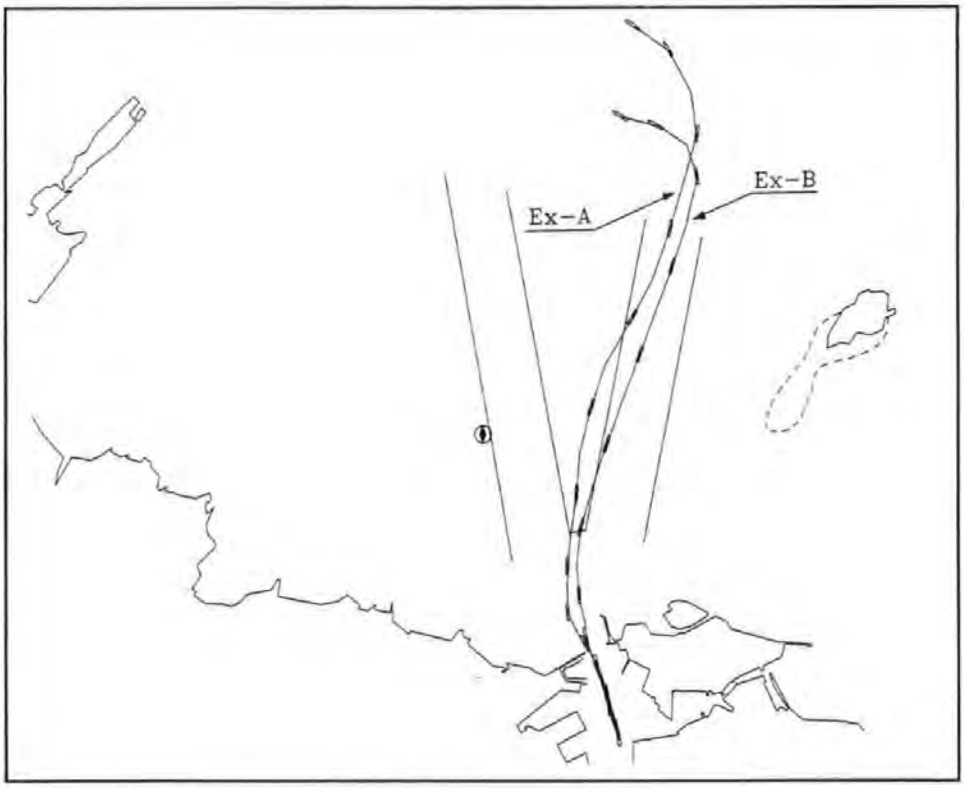
Run 31



Run 32



Run 33



Run 34

APPENDIX - K

Turbo Basic programme for calculation of ship position

```
cls:clear
outfil$="c:\distance.out"     'The result of ship position and distance'
Totalline=20                  'The first data line'
inpfile$="c:\distance.inp"    'All files of ship tracks'

'The first data line as an example'
dim point1(2,Totalline),point2(2,Totalline),point3(2,Totalline)

  point1(1,1)=291
  point1(2,1)=2760
  point2(1,1)=926
  point2(2,1)=1668
  point3(1,1)=609
  point3(2,1)=2214

for i=1 to totalline
  next i

dim coe(3,Totalline)

for i=1 to Totalline          'Equation of the first data line'
  x1=point1(1,i)
  y1=point1(2,i)
  x2=point2(1,i)
  y2=point2(2,i)
  call GetCoeffOfLine(x1,y1,x2,y2,a,b,c)
  coe(1,i)=a
  coe(2,i)=b
  coe(3,i)=c
next i

open inpfile$ for input as #1 'To extract data from ship track file'
k=0
41
if eof(1) then goto 42
  incr k
  input #1,a$
  print a$,k
goto 41
42
close #1
print
dim na$(k)
open inpfile$ for input as #1
for i=1 to k
 input #1,na$(i)
next i
close #1
```

```
totals=k

open outfil$ for output as #3
for file1=1 to totals
  nam$=na$(file1)+".dat"

open nam$ for input as #1
  k=0
  print nam$,
  while eof(1)=0
    line input #1,a$
    incr k
  wend

print k
  close #1

'To find the two connected points on opposite side of the first data line'
dim track1(2,k)
  open nam$ for input as #1
  for i=1 to k
      line input #1,a$
    track1(1,i)=val(mid$(a$,19,5))
    track1(2,i)=val(mid$(a$,27,4))
  next i
  close #1
  xt1=track1(1,1)
  yt1=track1(2,1)
  for i=2 to k

    xt2=track1(1,i)
    yt2=track1(2,i)
    for lineid=1 to Totalline
      l=lineid
      pa=coe(1,l)
      pb=coe(2,l)
      pc=coe(3,l)
      px1=point1(1,l)
      py1=point1(2,l)
      px2=point2(1,l)
      py2=point2(2,l)
      xm=point3(1,l)
      ym=point3(2,l)
      Call GetSignal(xt1,yt1,pa,pb,pc,signt1)
      Call GetSignal(xt2,yt2,pa,pb,pc,signt2)
      if signt1*signt2<0 then

'Equation of the line of these two connected points on track'
        Call GetCoeffOfLine(xt1,yt1,xt2,yt2,ta,tb,tc)
```

```
'To confirm the data line and the above line crossing'
        Call GetSignal(px1,py1,ta,tb,tc,signp1)
        Call GetSignal(px2,py2,ta,tb,tc,signp2)
        if signp1*signp2<0 then

'The point of ship track crossing the first data line'
          intx=(pc*tb-pb*tc)/(pa*tb-ta*pb)
          inty=(pa*tc-ta*pc)/(pa*tb-ta*pb)
          Call GetSignal(intx,inty,ta,tb,tc,sig)
          Call GetSignal(intx,inty,pa,pb,pc,sig1)

'The distance of this point to the base line'
          dx=intx-xm
          dy=inty-ym
          dist=(dx*dx+dy*dy)^0.5*2.92969

'Equation of the base line'
          ptx1=609
          pty1=2214
          ptx2=-580
          pty2=1629
          Call GetCoeffOfLine(ptx1,pty1,ptx2,pty2,d,e,f)

'To find the cross point on which side of the base line'
             sigb=d*intx+e*inty-f
             if sigb>0 then
             dist=-dist
             end if
          print #3,nam$;
          print #3,"    ";
          print #3,using "########.###";dist
       end if
     end if
   next lineid
   xt1=xt2
   yt1=yt2

  next i
  erase track1
  print #3,""
next file1
print #3,""
close
end
```

```
sub GetCoeffOfLine(x1,y1,x2,y2,a,b,c)
 if (x1-x2)=0 then
 a=1
 b=0
 c=x1
 else
 a=(y1-y2)/(x1-x2)
 b=-1
 c=a*x1-y1
 end if
end sub


sub  GetSignal(x,y,a,b,c,sign2)
    if abs(a*x+b*y-c)<0.0001 then
       sign2= 0
    else
       if a*x+b*y-c>0 then sign2= 1
       if a*x+b*y-c<0 then sign2=-1
    end if
end sub
```

APPENDIX - L

Means and standard deviation of ship tracks

The distance between inbound ship tracks and base line in outside area in Ex-A (in metres)

Data line	Day-time(NTOU) mean / st.dev	Night-time(NTOU) mean / st.dev	Night-time(UP) mean / st.dev.	Total mean / st.dev
1	-1.5/ 4.9	1.3/ 4.1	-10.0/ 9.5	-2.4/ 8.0
2	-15.6/ 22.4	-4.5/ 17.1	-31.3/ 28.8	-15.6/ 23.7
3	-41.3/ 53.0	-17.5/ 35.5	-66.3/ 42.7	-39.4/ 48.4
4	-58.3/ 82.6	-23.4/ 50.4	-106.7/ 45.7	-58.0/ 72.5
5	-70.2/ 109.7	-30.3/ 64.0	-151.4/ 39.2	-75.2/ 95.3
6	-73.1/ 134.7	-34.2/ 77.1	-189.3/ 42.1	-85.6/ 117.9
7	-72.7/ 160.6	-39.8/ 92.1	-215.7/ 60.3	-92.5/ 140.5
8	-64.2/ 193.4	-40.3/ 110.2	-237.5/ 80.7	-92.8/ 168.3
9	-50.7/ 232.6	-38.2/ 129.7	-249.1/ 111.2	-87.9/ 200.1
10	-38.0/ 276.6	-41.3/ 144.9	-260.0/ 132.5	-84.7/ 232.9
11	-27.6/ 321.3	-47.1/ 159.9	-255.4/ 169.2	-80.3/ 265.5
12	-16.0/ 365.6	-48.6/ 175.7	-233.4/ 227.0	-70.3/ 299.8
13	-11.5/ 405.2	-51.1/ 193.3	-200.5/ 292.3	-62.1/ 332.8
14	-9.5/ 443.0	-54.6/ 214.6	-147.1/ 353.0	-51.1/ 365.0
15	-18.1/ 485.9	-67.0/ 239.8	-124.8/ 407.3	-54.5/ 402.6
16	-34.9/ 539.8	-82.2/ 262.5	-140.6/ 441.6	-70.6/ 444.1
17	-53.1/ 581.0	-110.9/ 287.6	-145.4/ 512.1	-89.1/ 485.2
18	-78.5/ 611.5	-168.3/ 330.3	-124.5/ 609.5	-114.4/ 529.3
19	-117.1/ 634.2	-253.1/ 442.6	-97.2/ 676.2	-153.0/ 579.6
20	-197.7/ 644.6	-347.0/ 576.3	-76.9/ 750.6	-216.8/ 635.6

Remark: The positive mean distance is on the right side of the base line.

The negative mean distance is on the left side of the base line.

The distance between inbound ship tracks and base line in outside area in Ex-B (in metres)

Data line	Day-time(NTOU) mean / st.dev	Night-time(NTOU) mean / st.dev	Night-time(UP) mean / st.dev.	Total mean / st.dev
1	-2.7/ 4.4	-1.9/ 3.3	-19.0/ 5.4	-5.8/ 8.0
2	-15.8/ 17.4	-13.3/ 13.6	-58.7/ 15.8	-23.9/ 23.8
3	-31.6/ 36.7	-28.1/ 28.5	-86.6/ 30.0	-41.9/ 39.7
4	-29.3/ 56.7	-26.6/ 42.2	-101.5/ 49.6	-43.4/ 58.3
5	-11.8/ 76.8	-9.5/ 61.7	-117.8/ 83.4	-32.9/ 84.2
6	20.0/ 101.7	22.2/ 95.5	-111.5/ 158.3	-6.4/ 122.5
7	53.2/ 133.2	54.1/ 134.9	-72.8/ 235.5	27.5/ 162.3
8	100.8/ 172.4	90.3/ 178.6	-19.2/ 316.9	73.0/ 209.0
9	157.0/ 223.7	135.2/ 230.7	57.5/ 400.2	130.1/ 263.4
10	211.4/ 278.8	183.3/ 283.9	124.6/ 463.7	185.3/ 316.0
11	263.7/ 333.1	236.6/ 341.3	209.6/ 529.1	244.6/ 370.1
12	314.2/ 371.9	300.4/ 399.9	303.5/ 559.2	307.9/ 409.3
13	358.1/ 401.2	356.1/ 446.6	401.6/ 584.5	366.5/ 441.5
14	339.3/ 425.6	402.0/ 483.9	495.0/ 594.3	419.8/ 466.3
15	431.3/ 443.7	438.9/ 508.1	587.6/ 611.6	465.7/ 487.7
16	459.6/ 454.8	475.0/ 517.7	694.1/ 638.9	512.4/ 506.4
17	474.1/ 460.3	501.4/ 516.3	775.5/ 674.5	544.2/ 522.1
18	471.1/ 457.8	521.9/ 512.5	835.1/ 696.4	561.3/ 531.0
19	457.3/ 444.9	535.9/ 504.3	884.7/ 718.6	568.4/ 535.8
20	418.5/ 424.1	538.4/ 485.9	906.4/ 737.3	554.2/ 535.1

Remark: The positive mean distance is on the right side of the base line.

The negative mean distance is on the left side of the base line.

The distance between inbound ship tracks and centre line in lane area in Ex-A (in metres)

Data line	Day-time(NTOU) mean / st.dev	Night-time(NTOU) mean / st.dev	Night-time(UP) mean / st.dev.	Total mean / st.dev
1	-684.7/ 797.8	-672.7/ 476.8	-864.4/1023.0	-718.2/ 752.7
2	-476.3/ 693.6	-424.9/ 491.0	-600.7/ 849.5	-486.8/ 658.9
3	-306.9/ 607.8	-275.2/ 468.9	-296.0/ 669.4	-295.3/ 566.4
4	-195.3/ 552.7	-158.3/ 453.9	115.9/ 520.0	-120.3/ 518.3
5	-120.7/ 509.8	-109.9/ 448.9	222.3/ 451.5	-46.9/ 487.0
6	-70.4/ 475.2	-93.6/ 443.2	251.3/ 444.4	-11.0/ 466.3
7	-35.2/ 437.0	-95.8/ 437.6	253.5/ 456.3	6.4/ 446.8
8	-27.0/ 415.2	-120.6/ 435.8	242.1/ 458.3	0.9/ 436.8
9	-8.5/ 407.4	-126.8/ 418.3	214.8/ 461.3	2.7/ 426.1
10	-2.3/ 404.4	-138.7/ 391.2	214.0/ 437.0	2.1/ 413.9
11	-8.6/ 407.1	-52.3/ 363.8	175.3/ 433.8	-13.0/ 405.1
12	-18.7/ 391.9	-151.7/ 347.6	170.6/ 412.3	-18.8/ 388.9
13	-8.8/ 350.0	-164.1/ 343.0	171.0/ 373.4	-17.5/ 361.8
14	24.3/ 306.5	-144.0/ 338.6	250.7/ 281.3	14.1/ 332.3
15	23.5/ 326.5	-46.5/ 430.3	259.8/ 246.1	65.1/ 344.1

Remark: The positive mean distance is on the right side of the centre line.

The negative mean distance is on the left side of the centre line.

The distance between inbound ship tracks and centre line in lane area in Ex-B (in metres)

Data line	Day-time(NTOU) mean / st.dev	Night-time(NTOU) mean / st.dev	Night-time(UP) mean / st.dev.	Total mean / st.dev
1	140.7/ 336.4	239.5/ 296.9	309.3/ 196.5	204.5/ 301.2
2	251.7/ 332.6	297.7/ 259.2	351.7/ 231.4	285.8/ 288.6
3	304.2/ 336.8	306.1/ 247.9	369.7/ 280.7	318.3/ 294.6
4	321.7/ 338.4	287.4/ 242.5	370.0/ 324.7	321.6/ 302.6
5	317.0/ 336.0	251.7/ 236.2	328.2/ 361.4	300.1/ 307.8
6	295.6/ 333.8	206.3/ 232.6	270.6/ 380.0	264.2/ 310.8
7	266.1/ 338.1	165.4/ 230.3	228.3/ 386.9	228.7/ 314.7
8	224.0/ 346.2	126.3/ 226.8	179.3/ 319.7	186.0/ 319.1
9	159.7/ 340.8	87.6/ 225.0	147.0/ 400.9	135.9/ 316.8
10	144.6/ 347.5	49.3/ 225.7	125.8/ 412.0	112.7/ 324.2
11	110.4/ 349.8	15.4/ 222.3	119.6/ 434.5	84.3/ 330.4
12	74.7/ 359.4	-12.8/ 217.9	101.9/ 451.5	54.6/ 338.7
13	37.4/ 368.3	-47.1/ 213.0	95.6/ 480.2	24.5/ 350.0
14	2.7/ 391.4	-65.3/ 217.6	108.8/ 510.8	-0.2/ 360.7
15	-50.1/ 439.7	-43.5/ 228.2	81.0/ 501.8	-20.9/ 390.7

Remark: The positive mean distance is on the right side of the centre line.

The negative mean distance is on the left side of the centre line.

The distance between outbound ship tracks and centre line in lane area in Ex-A (in metres)

Data line	Day-time(NTOU) mean / st.dev	Night-time(NTOU) mean / st.dev	Night-time(UP) mean / st.dev.	Total mean / st.dev
1	-256.7/ 146.3	-327.9/ 115.8	-322.2/ 206.9	-291.1/ 151.8
2	-254.3/ 149.3	-320.9/ 115.3	-312.7/ 221.5	-285.9/ 156.2
3	-246.8/ 153.0	-306.1/ 110.8	-300.6/ 234.5	-275.3/ 159.8
4	-240.9/ 157.4	-289.4/ 108.1	-290.5/ 247.5	-265.4/ 164.2
5	-236.3/ 161.6	-270.9/ 108.1	-283.2/ 252.1	-256.1/ 166.8
6	-228.4/ 167.0	-250.9/ 110.9	-275.9/ 246.8	-244.8/ 168.2
7	-221.9/ 173.5	-237.0/ 113.0	-264.4/ 237.6	-235.1/ 169.2
8	-214.6/ 179.6	-225.1/ 114.6	-261.7/ 228.8	-227.4/ 170.6
9	-206.1/ 184.8	-211.1/ 115.0	-250.3/ 230.8	-216.7/ 173.7
10	-199.3/ 190.7	-201.5/ 115.9	-236.9/ 236.0	-207.7/ 177.9
11	-188.7/ 196.9	-190.3/ 118.5	-213.9/ 243.6	-194.4/ 183.1
12	-179.5/ 203.0	-181.8/ 121.1	-195.5/ 240.5	-183.5/ 185.9
13	-168.0/ 209.8	-171.4/ 125.3	-173.4/ 233.3	-170.1/ 186.5
14	-154.2/ 214.8	-157.8/ 130.6	-150.6/ 217.3	-154.5/ 188.7
15	-143.4/ 220.3	-153.6/ 135.6	-129.8/ 200.9	-141.3/ 189.5
16	-132.0/ 230.0	-131.8/ 141.9	-109.7/ 183.9	-127.4/ 193.3
17	-122.4/ 242.4	-115.1/ 148.0	-77.4/ 173.2	-111.0/ 200.6
18	-121.1/ 262.7	-100.4/ 153.9	-49.3/ 163.8	-100.2/ 213.5
19	-123.5/ 283.8	-85.4/ 159.9	-25.5/ 151.8	-92.1/ 227.3
20	-131.9/ 307.8	-69.2/ 165.1	-15.7/ 135.3	-89.5/ 242.7
21	-150.5/ 336.0	-61.8/ 167.8	-18.7/ 122.1	-97.3/ 261.3

Remark: The positive mean distance is on the right side of the base line.

The negative mean distance is on the left side of the base line.

The distance between outbound ship tracks and centre line in lane area in Ex-B (in metres)

Data line	Day-time(NTOU) mean / st.dev	Night-time(NTOU) mean / st.dev	Night-time(UP) mean / st.dev.	Total mean / st.dev
1	-252.6/ 90.0	-289.3/ 102.5	-317.0/ 129.2	-276.7/ 102.5
2	-247.5/ 91.2	-275.7/ 108.1	-303.8/ 129.2	-267.4/ 103.7
3	-237.4/ 90.4	-258.9/ 109.9	-275.0/ 131.0	-251.5/ 103.0
4	-228.1/ 87.0	-244.7/ 107.7	-246.2/ 132.8	-236.7/ 100.6
5	-217.4/ 85.4	-229.4/ 103.7	-220.0/ 128.8	-221.5/ 97.5
6	-203.4/ 82.7	-211.5/ 110.7	-192.7/ 130.5	-203.6/ 96.0
7	-190.1/ 80.7	-195.5/ 99.7	-160.6/ 137.6	-185.6/ 97.4
8	-176.0/ 78.9	-178.5/ 99.7	-128.2/ 149.9	-166.9/ 101.1
9	-157.7/ 78.5	-158.4/ 99.2	-95.3/ 161.8	-145.1/ 105.3
10	-143.5/ 79.0	-140.6/ 98.3	-66.7/ 175.7	-126.8/ 110.6
11	-124.3/ 81.6	-121.8/ 97.8	-29.9/ 192.7	-104.1/ 118.6
12	-108.2/ 85.3	-106.6/ 99.1	-5.5/ 208.2	-86.6/ 125.9
13	-88.7/ 89.5	-89.7/ 100.1	16.6/ 220.6	-67.3/ 131.7
14	-68.0/ 92.0	-70.6/ 101.7	40.6/ 223.4	-46.4/ 134.2
15	-50.8/ 94.7	-55.0/ 103.2	67.2/ 221.5	-27.8/ 136.3
16	-34.2/ 98.2	-37.7/ 107.4	100.3/ 229.5	-7.6/ 143.2
17	-17.0/ 102.4	-19.5/ 112.2	133.3/ 239.7	13.2/ 151.1
18	-4.1/ 106.4	-5.7/ 117.7	160.0/ 238.0	29.2/ 155.3
19	3.4/ 109.2	6.9/ 124.1	191.1/ 239.4	43.1/ 162.0
20	5.0/ 133.6	17.2/ 248.4	214.0/ 248.4	51.6/ 172.2
21	-12.8/ 126.1	11.6/ 147.8	220.6/ 254.8	42.4/ 184.6

Remark: The positive mean distance is on the right side of the centre line.

The negative mean distance is on the left side of the centre line.

APPENDIX M

The results of Wilcoxon test and M-W test to ship tracks

M - 1 The significance level of distance at outside area for inbound tracks

Data line	Wilcoxon test	M-W test			
		Ex-A		Ex-B	
	Ex-A / Ex-B	day/night (NTOU)	night (NTOU/UP)	day/night (NTOU)	night (NTOU/UP)
	34/34 tracks	17/10 tracks	10/7 tracks	17/10 tracks	10/7 tracks
1	**0.0032**	0.1509	**0.0127**	0.6321	**0.0006**
2	**0.0268**	0.2379	**0.0404**	0.4215	**0.0006**
3	0.4519	0.3401	**0.0248**	0.3795	**0.0025**
4	0.3471	0.3932	**0.0084**	0.6879	**0.0047**
5	**0.0196**	0.3153	**0.0006**	0.8408	**0.0147**
6	**0.0042**	0.3153	**0.0006**	0.9600	0.0510
7	**0.0012**	0.3933	**0.0013**	0.9200	0.1432
8	**0.0004**	0.6156	**0.0025**	0.9200	0.2831
9	**0.0002**	0.8018	**0.0047**	0.9200	0.4350
10	**0.0001**	0.8018	**0.0063**	0.8408	0.4945
11	**0.0001**	0.8803	0.0510	0.8408	0.5582
12	**0.0001**	1.0000	0.1432	0.7632	0.9223
13	**0.0000**	1.0000	0.4350	0.8408	0.6963
14	**0.0000**	0.9600	0.5582	0.9600	0.6963
15	**0.0000**	0.9600	0.7697	0.9600	0.6256
16	**0.0000**	0.9200	0.4350	0.9600	0.5582
17	**0.0000**	0.8803	0.3798	0.9600	0.3291
18	**0.0000**	0.6879	0.4945	0.8018	0.2046
19	**0.0000**	0.5139	0.7697	0.7632	0.2046
20	**0.0000**	0.6514	0.6963	0.6156	0.2046

M - 2 The significance level of distance at lane area for inbound tracks

Data line	Wilcoxon test	M-W test			
		Ex-A		Ex-B	
	Ex-A / Ex-B	day/night (NTOU)	night (NTOU/UP)	day/night (NTOU)	night (NTOU/UP)
	34/34 tracks	17/10 tracks	10/7 tracks	17/10 tracks	10/7 tracks
1	**0.0000**	0.9200	0.3291	0.4514	0.1917
2	**0.0000**	0.8018	0.2046	0.5468	0.6256
3	**0.0000**	0.8803	0.5582	0.8018	0.7697
4	**0.0002**	0.7632	0.4945	0.9200	0.6961
5	**0.0017**	0.8408	0.3798	0.7252	0.7697
6	**0.0064**	0.9600	0.2831	0.6514	0.7697
7	**0.0196**	0.9600	0.2046	0.5807	0.6963
8	**0.0410**	0.8408	0.2046	0.5139	0.9223
9	0.0955	0.6156	0.2046	0.5807	1.0000
10	0.1852	0.4218	0.0971	0.2693	1.0000
11	0.2628	0.3401	0.1432	0.3401	0.9223
12	0.3515	0.3401	0.1432	0.9661	0.8453
13	0.5553	0.3152	0.0637	0.2693	0.8453
14	1.0000 (28/28 tracks)	0.3703 (16/10)	**0.0393** (10/6)	0.3135 (14/9)	0.7389 (9/5)
15	0.4460 (18/18 tracks)	0.8148 (12/6)	0.2623 (6/6)	0.8658 (12/7)	0.9353 (7/5)

Remark: 1. There were 24 ship tracks reached the 15th data line in both exercises.

2. Among those tracks, 18 pairs of tracks were performed by the same subjects.

M-3 The significance level of distance in lane area for outbound tracks

Data line	Wilcoxon test	M-W test			
		Ex-A		Ex-B	
	Ex-A / Ex-B	day/night (NTOU)	night (NTOU/UP)	day/night (NTOU)	night (NTOU/UP)
	34/34 tracks	17/10 tracks	10/7 tracks	17/10 tracks	10/7 tracks
1	0.3515	0.3661	0.6256	0.3401	0.5582
2	0.1998	0.3933	0.4945	0.4821	0.4945
3	0.1138	0.3933	0.4945	0.5807	0.6963
4	0.1303	0.5468	0.4350	0.5807	0.8453
5	0.1218	0.8408	0.4945	0.6695	0.6963
6	0.0990	0.9600	0.5582	0.7632	0.6963
7	0.0955	0.9800	0.6256	0.7632	0.6256
8	0.0577	0.9200	0.4945	0.8018	0.5582
9	**0.0235**	0.9200	0.3291	0.7441	0.4350
10	**0.0135**	0.9600	0.3798	0.8018	0.3798
11	**0.0078**	0.8803	0.4350	0.8018	0.3798
12	**0.0078**	0.7252	0.4945	0.7632	0.3291
13	**0.0075**	0.7632	0.4945	0.7632	0.3291
14	**0.0049**	0.8018	0.6963	0.6879	0.2416
15	**0.0027**	0.6879	0.9223	0.6514	0.2416
16	**0.0021**	0.6514	0.9223	0.6879	0.1463
17	**0.0028**	0.7632	0.6963	0.8018	0.1432
18	**0.0032**	0.8018	0.4350	0.8803	0.1184
19	**0.0042**	0.7632	0.3291	0.8408	0.0971
20	**0.0041**	0.8403	0.3291	0.8408	0.0791
21	**0.0064**	0.8803	0.3798	0.9600	0.0791

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