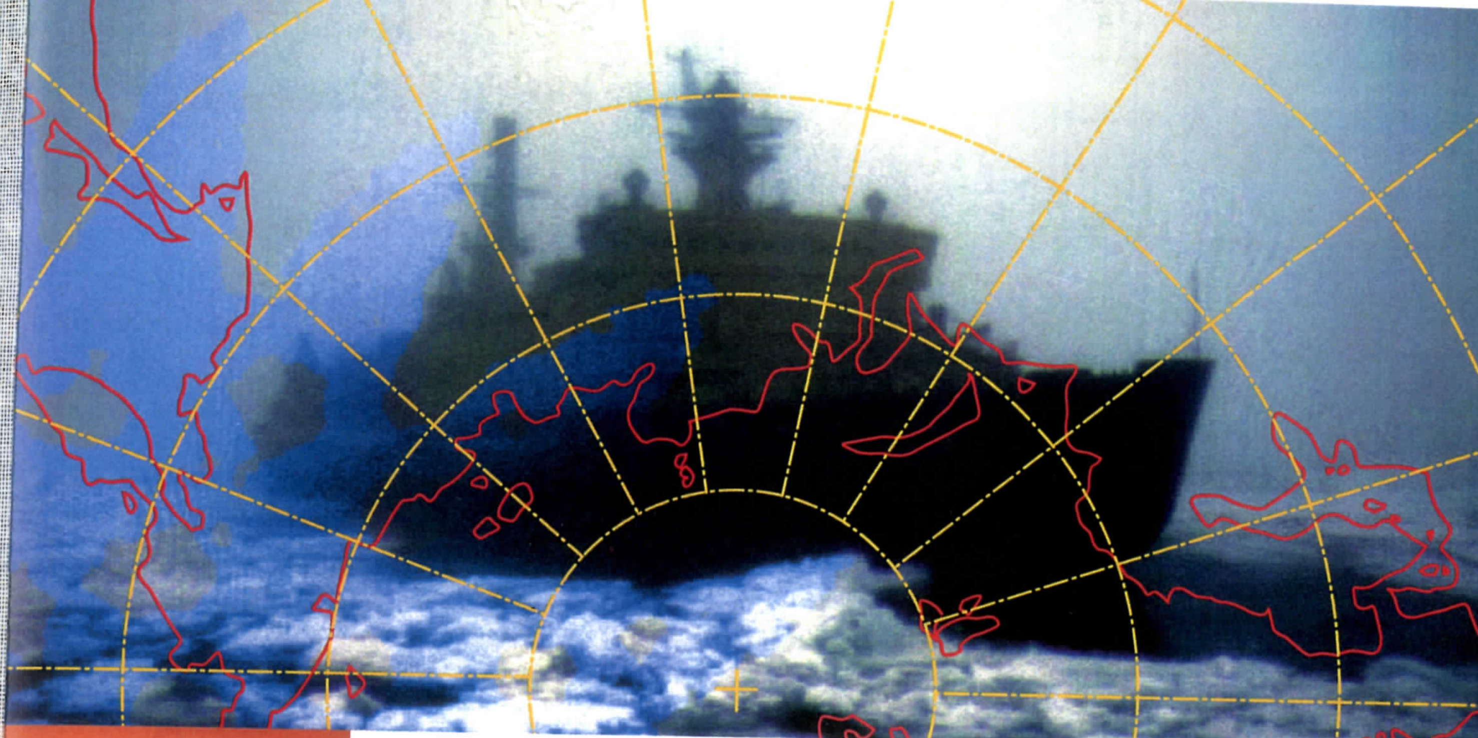

INSROP WORKING PAPER
NO. 115 - 1998, I.5.4

Oil Spilling from a Grounded Mid-deck Tanker

By Hiroshi Tamama

INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

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What is an INSROP Working Paper and how to handle it:

FOREWORD - INSROP WORKING PAPER

INSROP is a five-year multidisciplinary and multilateral research programme, the main phase of which commenced in June 1993. The three principal cooperating partners are **Central Marine Research & Design Institute (CNIIMF)**, St. Petersburg, Russia; **Ship and Ocean Foundation (SOF)**, Tokyo, Japan; and **Fridtjof Nansen Institute (FNI)**, Lysaker, Norway. The INSROP Secretariat is shared between CNIIMF and FNI and is located at FNI.

INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

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Contents

ABSTRACT

The changes in the scale of oil operations still stem from an ever increasing demand for energy. Import of natural energy resources has been vital to Japan and Far East Asian countries. One of the possible major commodities via the NSR in future would then be crude oil and natural gas, in particular along the eastern half of the route to these countries. Operations of tankers and LNG carriers along the NSR undoubtedly involve a latent possibility of increasing marine pollution. Petroleum oil is one of the most widespread pollutants in the marine environment. Although there have been remarkable improvements in the case of vessel-source pollution, the increased number of ships and the rising tonnage of oil carried is still threatening to cause disastrous oil pollution. After the Exxon Valdez accident, regulations demanded considerable improvements in the structural design of tankers.

The mid-deck tanker concept has thus been developed in Japan as an alternative to the double hull design to meet the requirements of OPA 90 and IMO. The mid-deck tanker will have a significant potential in operations via the NSR. The basic features of oil spill caused by grounding of a typical mid-deck tanker were studied by the model tests at a large circulation channel in the SOF Technical Institute and the pollution prevention capability was discussed.

1. INTRODUCTION

Valuable lessons have been gained from recent major oil pollution incidents, in particular, the Exxon Valdez one, and an oil pollution response methodology, which is to be a flexible, dynamic, successful system, should be fashioned. The basis for the success of the oil spill response can be established through full understandings of characteristics and behaviour of spilling oil.

The Exxon Valdez oil spill is the most studied ever. The prediction of spreading of spilled oil from the vessel and the cleanup involved application of technology not previously applied to large spills. Many of these applications are now the subject of ongoing international research programmes aimed at improving the ability to respond.

In general, the oil spilling scenario can be divided into four stages. They are local or near field, intermediate field, far field, and coastal issues. At the first stage, near field oil spilling is discussed with close attention to oil spilling behaviour from a damaged vessel. Spreading spilled oil on the sea surface is discussed as an intermediate field problem at the second stage, transitional one leading to far field spilling. At this stage oil release on the sea surface changes gradually in properties. Large-scale spilling is discussed at the third stage, dealing with far field spilling problems, such as a prediction of the direction and speed of drift of oil on the sea surface. Spilled oil reaching and polluting shorelines gives rise to various troublesome issues, which are discussed at the fourth stage of oil spilling.

In the INSROP a few projects have dealt with general pollution issues, such as oil pollution of the Arctic ocean, environmental problems, biological effects, pollution responses, preparedness, etc. This paper deals with the near field issue of oil spilling from a ship hull with mid-deck, which will be expected to be in service via the NSR in future. In this case it can be assumed that oil released into water does not change much in properties.

Oil spill accidents should be avoided along the NSR, because the environment along the route is extremely fragile and sensitive to any pollution. Even in the waters free from ice, prevention of oil pollution from ships is an urgent subject to be solved, and under a strong influence of the IMO guidance several new structure systems have been studied and developed for oil tankers. Among them, a mid-deck tanker design has been developed in Japan as an alternative to the double hull design concept and proposed at the 30th MEPC in 1990. This design is excellent for purposes of preventing oil outflow from a vessel even in high energy grounding and collision, which will satisfy the basic requirements for the NSR oil tanker design.

This paper presents a summary of the model test results carried out on a VLCC with mid-deck to study the near field oil spilling and to clarify fundamental behaviours of spilled oil from a mid-section part of the vessel in ice-free conditions. VLCCs might not be appropriate for the NSR vessel in future, but the test results with the model of the VLCC can be utilized to tankers of smaller size.

2. STATISTICS OF COLLISION AND GROUNDING ACCIDENTS

Despite the wider use of greater sophistication of navigational aids both of shore and on board ship in addition to advanced technology in shipbuilding, shipping accidents remain at a high level. There are clear black spots, particularly for collisions and groundings, which are located in narrow channels, around headlands and in areas where shipping density is high. The NSR has the latent possibility of becoming another black spot for collisions and groundings due to the severe natural conditions.

The Lloyd's Register published a report on statistical analysis of the classification society records for oil tanker collisions and groundings[1]. For a reference, relative frequency of length of breach, distribution of breach location along ship length, and relative frequency of penetration in collisions and groundings is shown in Figs. 1, 2 and 3, respectively. In Fig.2 the centre of

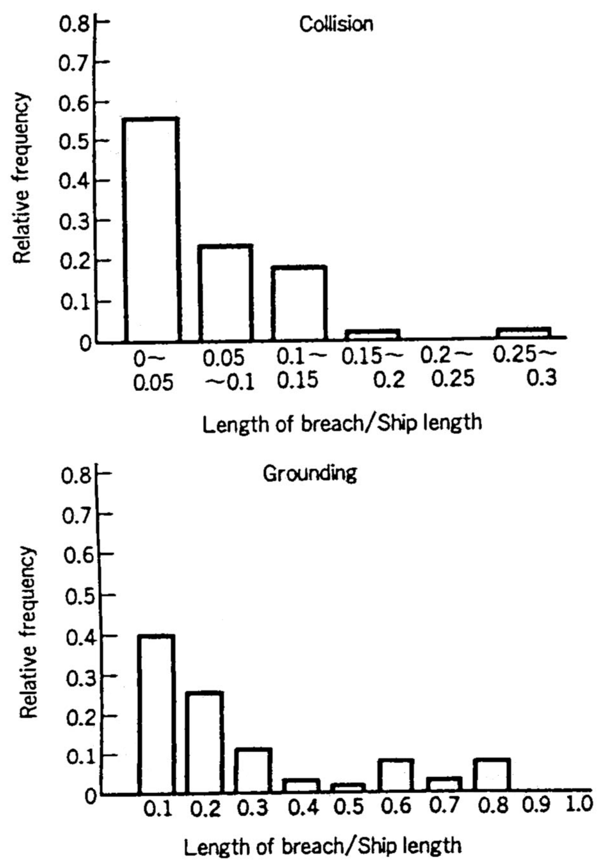

Fig. 1 Relative Frequency of Length of Breach[1]

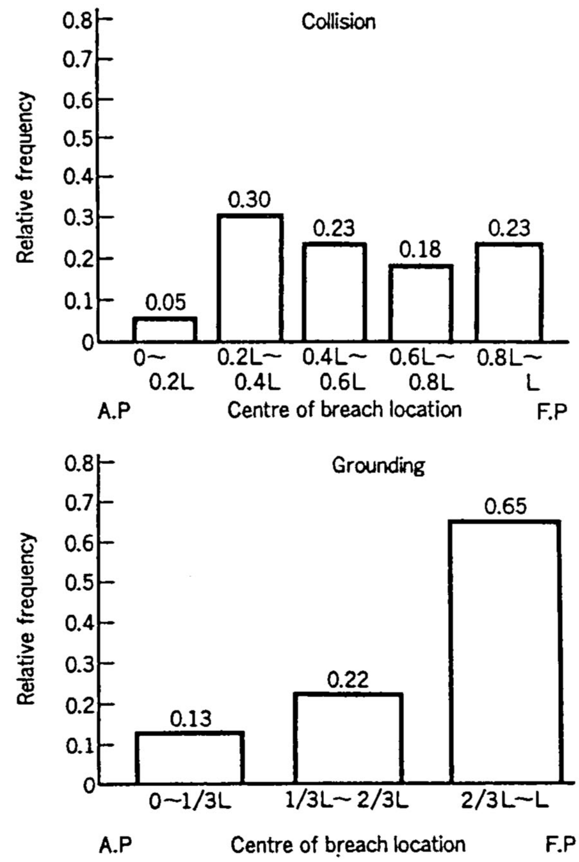

Fig. 2 Distribution of Breach Location along Ship Length[1]

breach locations were measured from the stern. Fig. 3 indicates the fact that actual penetrations mostly occurred in relatively small area in both cases of collision and grounding, i.e., narrower than 5% of ship breadth.

3. MID-DECK TANKER

Since 1993, the double hull structures for tankers have been obligatory in response to the ever present problems of oil spill These double hull structure requirements caused a few new problems, such as an increase in hull maintenance area troublesome inspections and maintenance work in a cramped and unfavourable environment of the double hull space, etc. and with a consequent increase in operating cost.

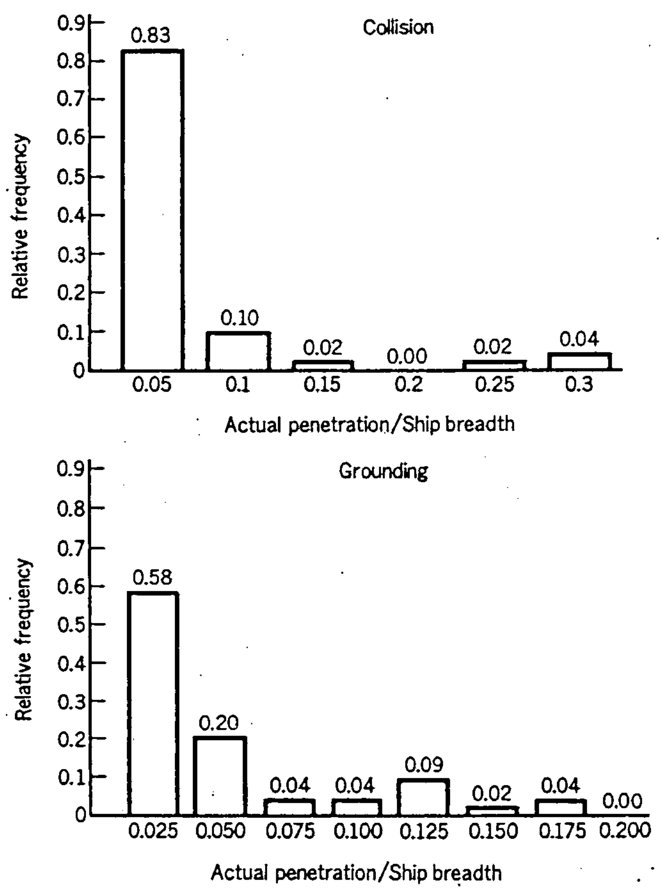

Fig. 3 Relative Frequency of Penetration[1]

An effective solution of these problems would be found in a mid-deck structure concept. The basic concept of the design of a mid-deck tanker is shown in Fig. 4[2].

The wide double side structure and a mid-height deck can effectively protect cargo oil tanks from oil outflow in case of collision and grounding. The cargo oil tank part with longitudinal and transverse bulkheads to satisfy the tank size limitation and the requirements of the hypothetical oil outflow quantity specified in the MARPOL 73/78. The design concept of the mid-deck tanker was submitted to the IMO, and is recognized as having the capability better or at least equivalent to common double hull tanker to minimize the volume of spilled oil, through a comparative study between a mid-deck and a double hull tanker[3].

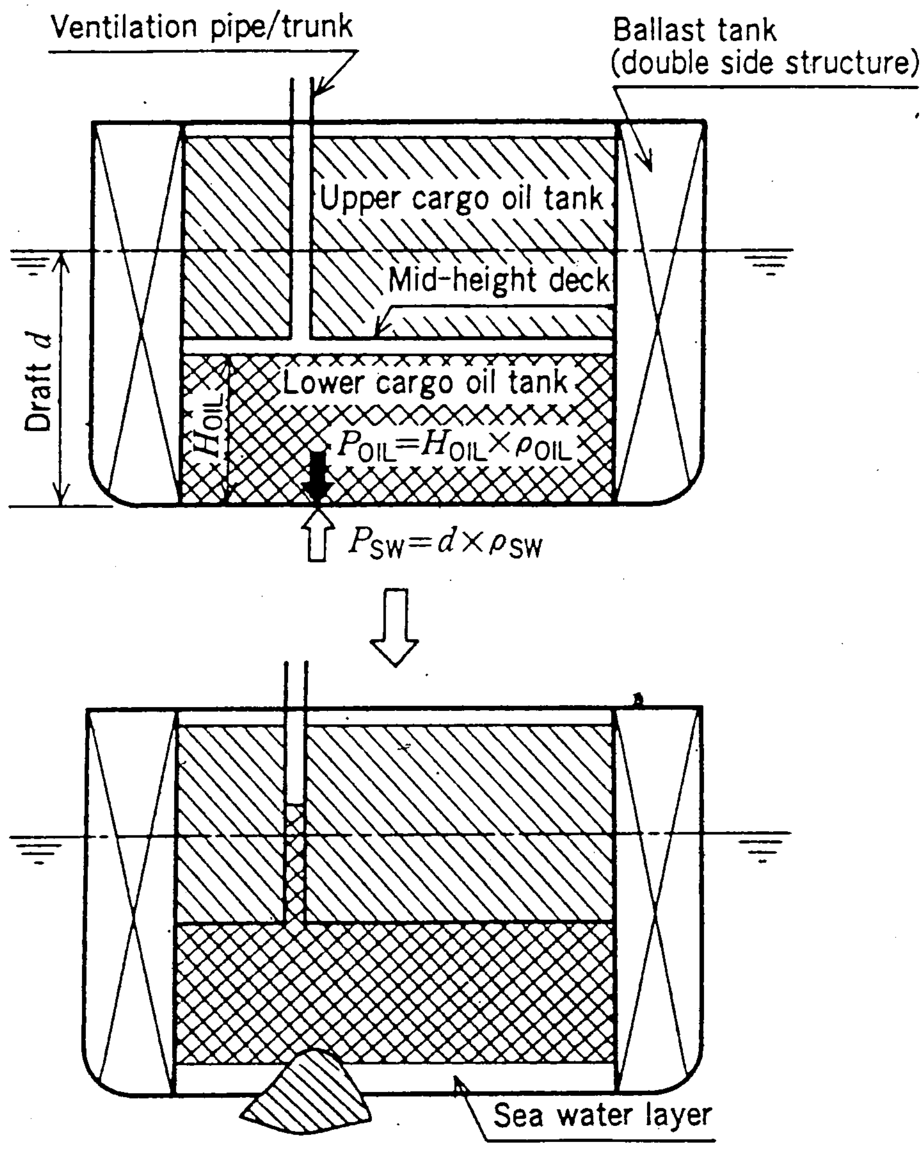

Fig. 4 Basic Concept of Mid-deck Tanker

The Germanischer Lloyd carried out a collision resistance test and confirmed that the mid-deck tanker has greater deformation energy to be absorbed in a collision than the general double hull tanker, as shown in Fig.5[4].

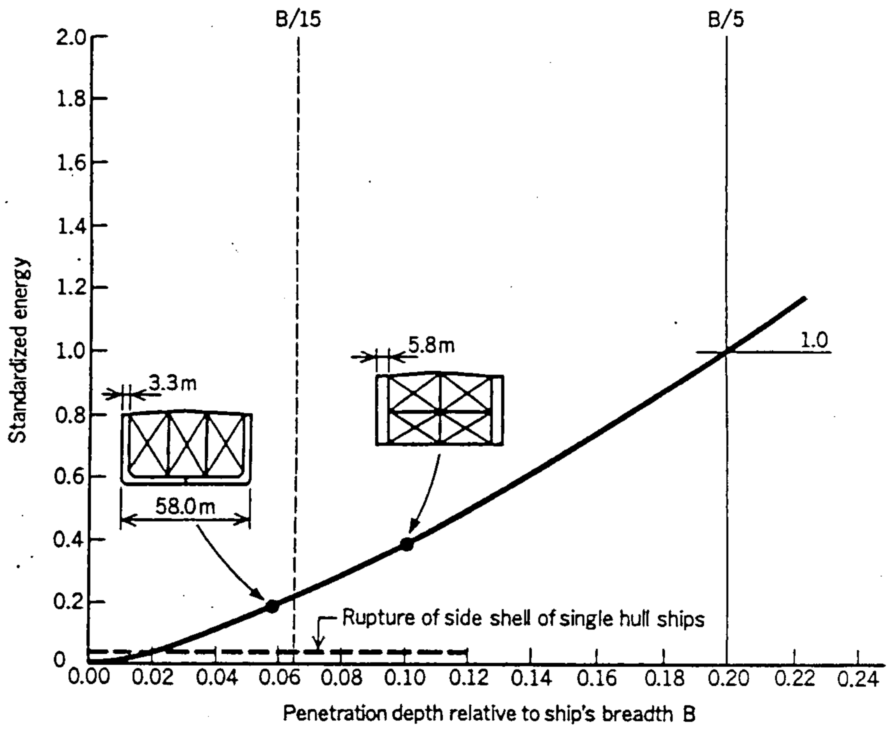

Fig. 5 Standarized Function of Deformation Energy Absorbed in a Collision[2]

4. MODEL TEST

4. 1 Outline of Model Tests

To investigate a near field issue of oil spilling, model tests were carried out with a midship section model of a VLCC with mid-deck at the SOF Tsukuba Institute.

The primary objective of the SOF Tsukuba Institute was to perform various investigations of pollution prevention at sea, and has a large circulating channel for basic study of oil spilling and other technical issues on pollution.

The outline of the channel is illustrated in Fig.6. The facility consists of a measurement section, which is marked by ① in the figure, circulating channel ②, wave-maker ③, wave absorber ④, flow pump ⑤, measuring carriage ⑥, sub-carriage with blowers ⑦, sub-carriage with surface-current-generator ⑧, machinery space ⑨, water-cleaning pit ⑩ and mono-rail hoist ⑪. The wavemaker of a flap-type can generate waves of 0.3m in amplitude and 10m in

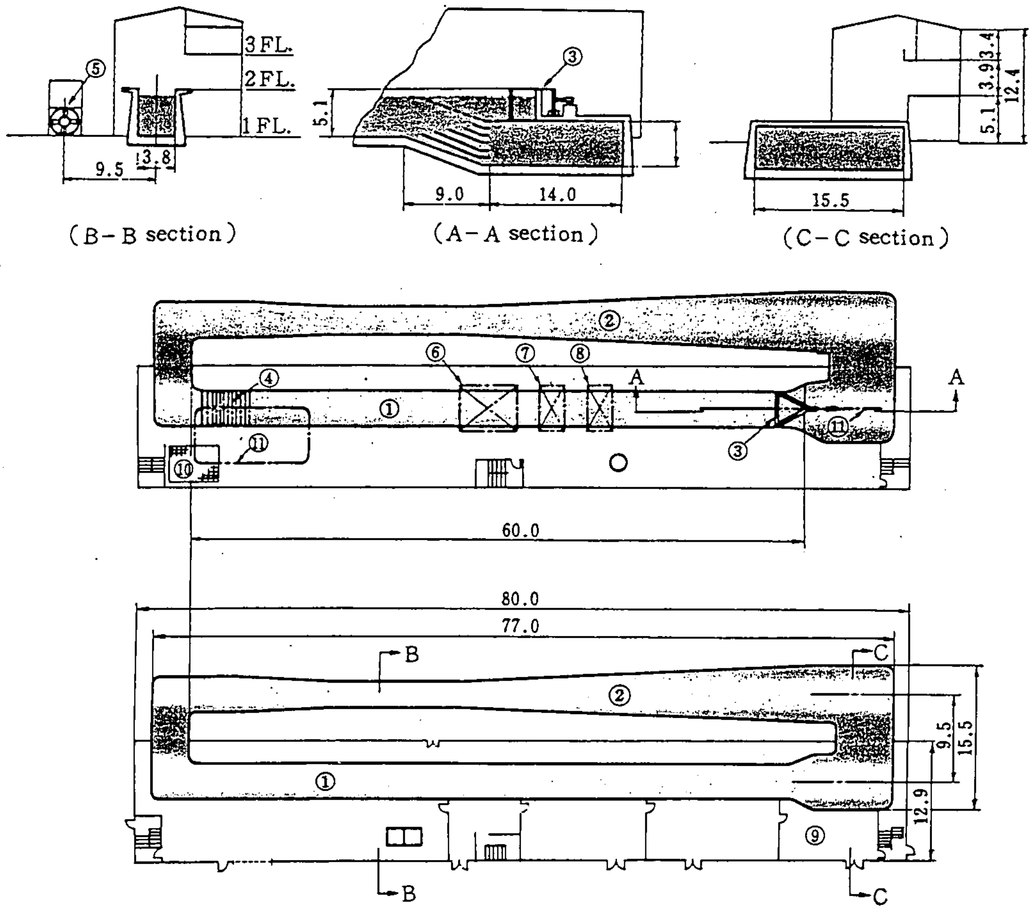

Fig. 6 Outline of the Circulating Channel, SOF
SOF Tsukuba Institute

wave length. The measurement section of the channel is 60m long, 3.8m wide and 4.3m deep. Water velocity varies from 0.1 to 1.5m/s, while wind velocity varies from 5 to 20m/s, generated by wind blowers installed on a sub-carriage ⑦.

The model tests were conducted at the large circulating channel, with particular attention to

(1) incipient spilling of oil from a damaged bottom due to grounding,
(2) dynamics of spilled oil affected by current and waves.

A model of midship section of the VLCC was used to examine effects of damaged area and initial speed of ship before grounding.

4.2 Incipient Spilling

4.2.1 Spilling Scenario

When a mid-deck tanker is grounded in shallow water at a cruising speed or at a certain speed slightly slower than the cruising one, cargo oil in the ship would spill out through an opening in the ship bottom gouged by grounding, decreasing the ship speed drastically due to grounding. This sharp decrease in the ship speed would prevent cargo oil from spilling out furthermore.

This type of spilling is designated as initial exchange loss due to grounding.

4.2.2 Model

The scale model of 1/30 which represents one section of a VLCC tank was used in spilling tests. Main particulars of the model is shown Table 1.

Table 1 Main Particulars of 1/30 Scale Model

	MODEL	SHIP
Length of tank	1.3 m	39 m
Width of tank	1.8 m	54 m
Depth of tank	1.0 m	30 m
Mid-deck height	0.45 m	13.5m

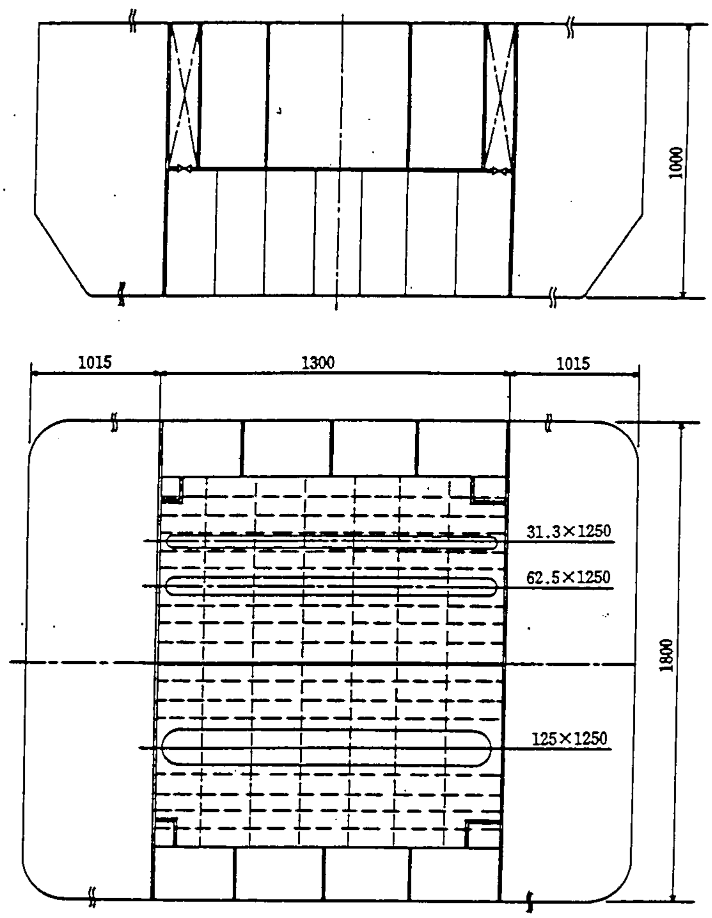

Fig. 7 1/30 Scale Model

The model has an opening at the bottom, which is imitating a rupture due to damage in case of grounding, as shown in Fig. 7. The length of the opening is 1.25m in model and 37.5m in full scale. Fig. 8 shows a scheme to simulate an effect of an opening due to damage. The extent of damage of the ship bottom, or in other words, length of the opening is adjustable by means of the sliding cover. The sliding cover has a conical protuberance on its front edge to simulate a disturbance effect due to grounded reef.

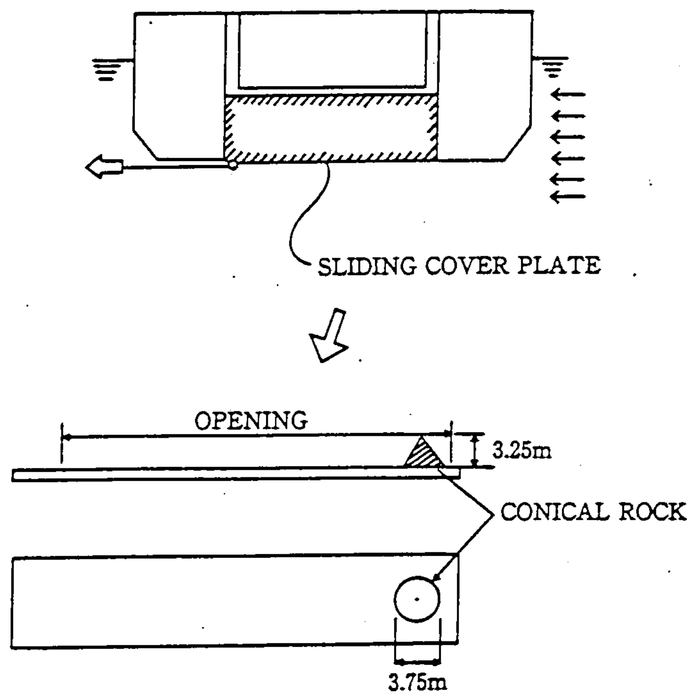

Fig. 8 Mechanism of Opening Adjustment

4.2.3 Test Conditions

The draft of the mid-deck VLCC was assumed to be 20m in full scale and cargo oil was filled up to 98% of full volume in the lower tank. In the model tests lubricant with density of 0.89 and viscosity of 42cSt was used, being effectively substituted for a typical crude oil. No other types of oil were tested due to limitation of time and funding.

The model was clamped on the measuring section frame of the circulating channel. Incipient spilling of oil was simulated by decreasing current velocity rapidly and simultaneously by swiftly removing a sliding cover for the imitated opening due to grounding, and consequently oil was flow out from the opening.

The test conditions are summarized in Table 2.

Table 2 Test Conditions

in full scale

WIDTH OF OPENING	0.94m	1.88m	3.75m
LENGTH OF OPENING		37.5m	
INITIAL SHIP SPEED	5kts,	7.5kts, 10kts,	15kts

4.2.4 Simulation of Ship Speed Drop

Decrease of ship speed after grounding can be estimated from conservation of kinetic energy as follows:

$$\frac{1}{2}\frac{aW}{g}V_0^2 = Fs$$

Decrease of ship speed is then expressed by

$$V = V_0 - \frac{Fg}{aW}t$$

where

F: force acting at the interface between hull and reef in Kgf,
g: acceleration of gravity in m/sec^2,
s: penetration distance in m,
t: time in sec.,
V: ship speed in m/sec,
V_0: initial ship speed before grounding in m/sec.,
W: volume of displacement of a ship in m^3,
a: coefficient of added mass.

The rate of ship speed decrease has a linear relation to an opening or rupture width[5].

If the current velocity can be controlled to decreases by this equation, it would be possible to simulate the spilling reasonably. In this test, however, such a velocity control was not possible at the circulating channel. The decrease of current velocity in the test was then simulated to ship speed drop when a rupture width of 1.1m was caused by grounding.

4.2.5 Test Results

The test results are summarized in Figs. 9 and 10.

Fig. 9 indicates clearly that outflow volume of cargo oil from the opening decreases rapidly with decrease of rupture width. There exists a critical rupture width which does not spill out oil from the opening, though the critical width will depend on basic characteristics of crude oil.

Kinetic energy of a ship will play a major role in grounding damage, and it is quite natural that oil outflow increases with increase of initial ship speed, as shown in Fig.10. The lower curve in Fig. 10 corresponds to the case where

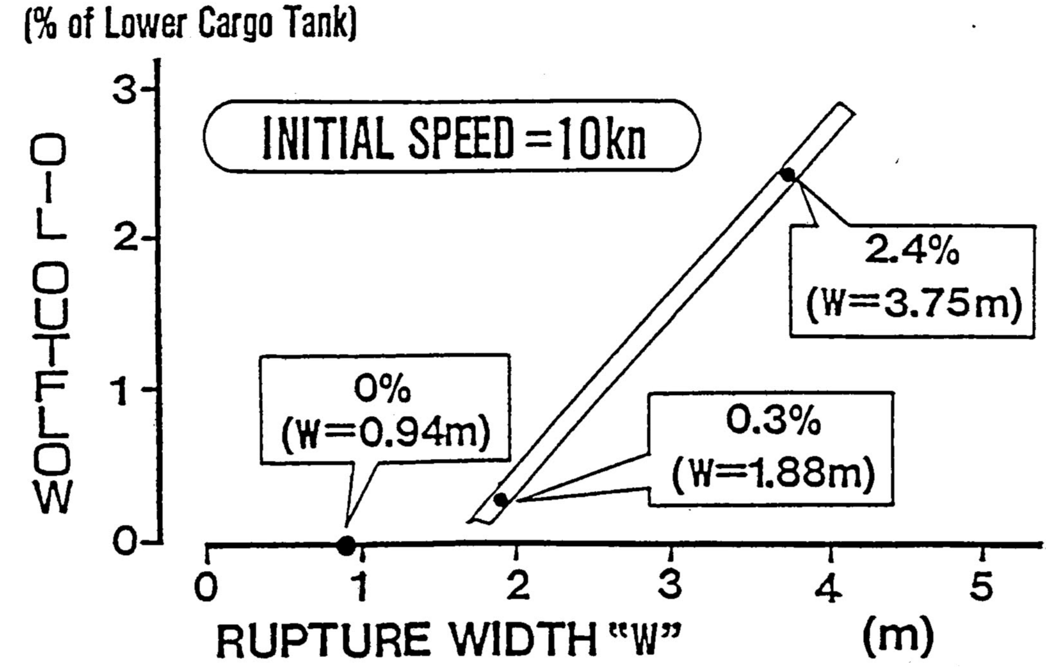

Fig. 9 Effect of Rupture Width on Oil Outflow

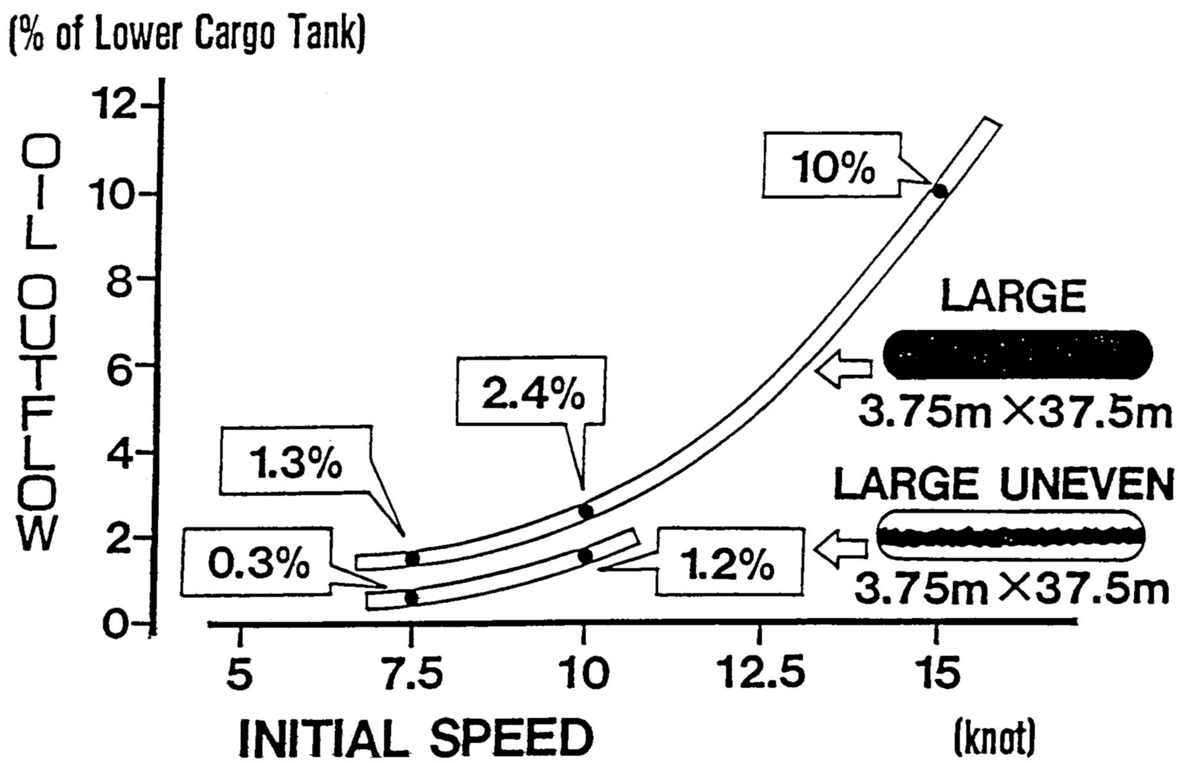

Fig. 10 Effect of Initial Ship Speed on Oil Outflow

large uneven rupture with dents occurred in a ship bottom. The uneven rupture seems more realistic in full scale accidents.

4.3. Effects of Waves and Current on Oil Spilling

4.3.1 Spilling Scenario

Soon after grounding, balancing between isostasy between oil and sea water results in inflow of sea water into a damaged cargo oil tank, pushing cargo oil upwards. When the layered sea water in a damaged tank is not thick enough to stabilize disturbances caused by current and waves, the disturbances induce oil spilling from a damaged opening.

4.3.2 Model

1/15 scale model of a mid-deck VLCC was used in the test. The outline of the model is shown in Fig. 11. In beam waves, however, the aforementioned 1/30 scale model was used, due to the test facility restriction. Main particulars of the model are shown in Table 3.

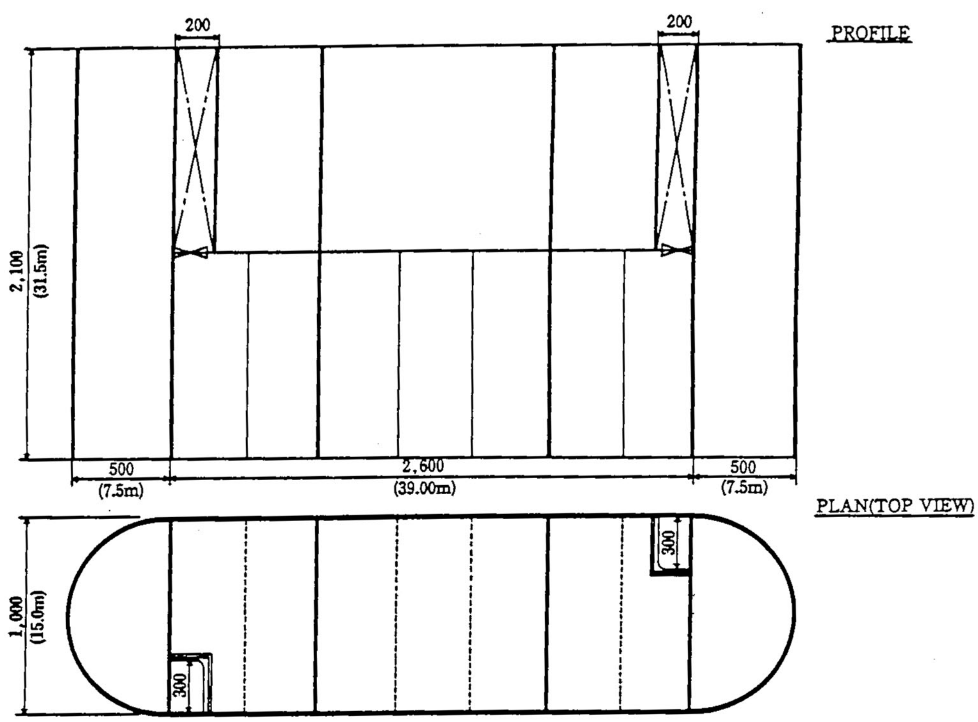

Fig. 11 1/15 Scale Model

Table 3 Main Particulars of 1/15 Scale Model

	MODEL	SHIP
Tank Length	2.6 m	39.0 m
Tank Width	1.0 m	15.0 m
Tank Depth	2.1 m	31.5 m
Mid-deck Height	0.95 m	14.3 m

The model has two types of opening in the bottom; the larger one is 2.5m long and 0.25m wide and the smaller one is 0.3m long and 0.03m wide. The larger opening can be half closed and has an attachment to simulate an uneven rupture with dents.

4.3.3 Test Conditions

The same lubricant was used to imitate crude oil as in the case of the initial exchange loss. The test condition of waves and current is summarized in Table 4.

Table 4 Test Conditions

		in full scale
THICKNESS OF SEA WATER LAYER	300mm	(at draft 17m)
	600mm, 900mm	(at draft 20m)
CURRENT VELOCITY	3kts, 5kts, 7kts	
BEAUFORT SCALE	4, 8 (head and beam waves)	

Through the preliminary experiments little oil was observed to spill out after two hours from the beginning as shown in Fig.12. The dynamic effects of waves and current on oil spilling was evaluated by the volume of spilled oil in two hours from the beginning.

4.3.4 Test Results

The effect of current velocity on oil spilling is shown in Fig.13. There is a critical value of current velocity at which oil commences to flow out, and the critical current velocity slightly depends on the thickness of sea water layer. Naturally the volume of oil outflow increases with incease of current velocity. The volume of oil outflow was found to have a linear relation with the volume of sea water.

Fig. 14 shows effects of rupture size and shape on the oil outflow. The volume of oil outflow has a direct dependence on size and shape of rupture. The test results showed that in the case of small size rupture there was no oil outflow observed if the sea water layer is thicker than 600mm even when the current velocity is 7kts. Uneven rupture reduces amount of oil outflow.

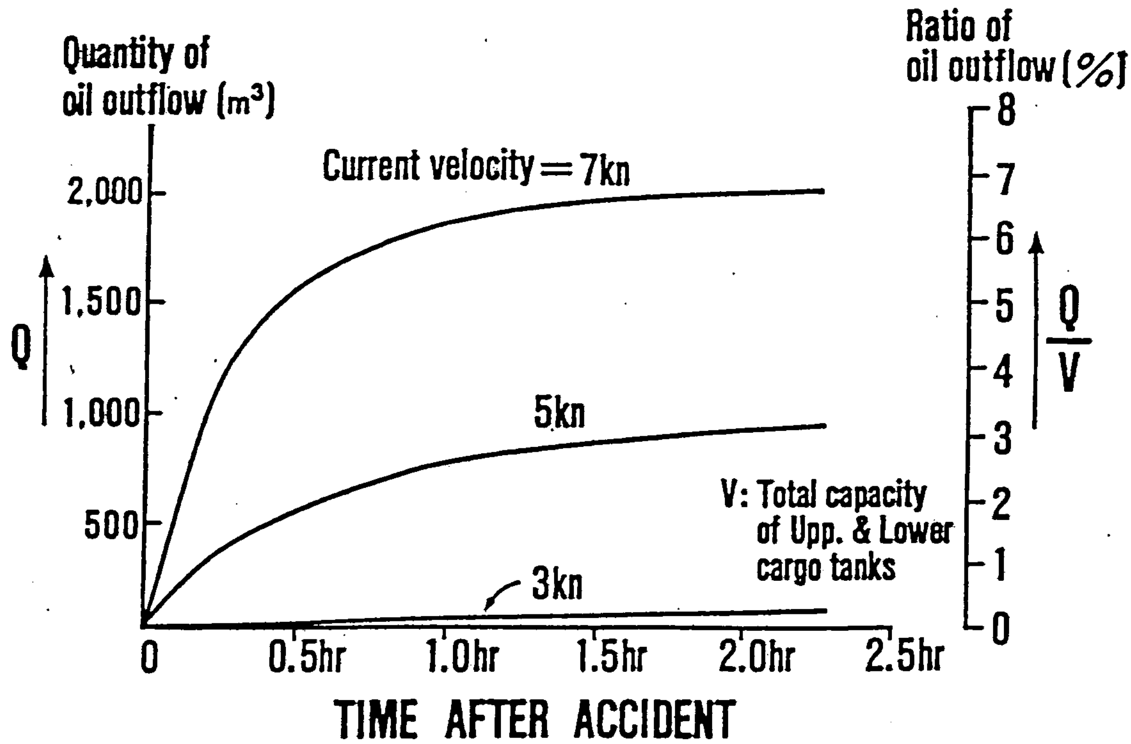

Fig. 12 Increase of Oil Outflow after Accident

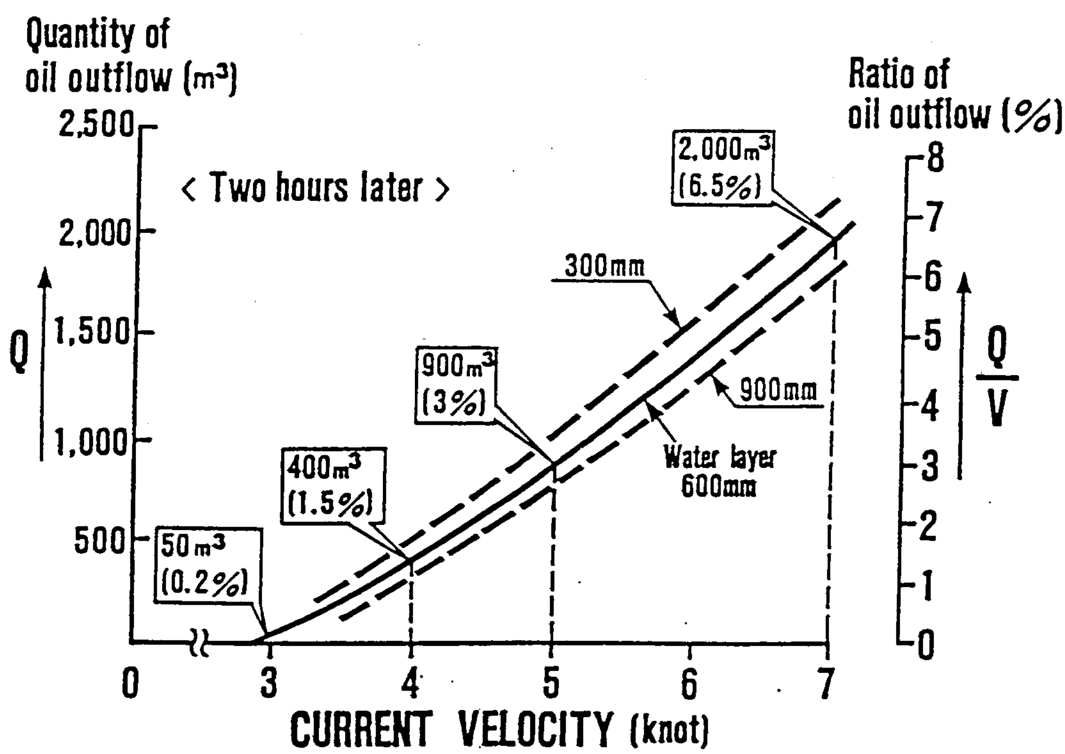

Fig. 13 Effect of Current Velocity on Oil Outflow

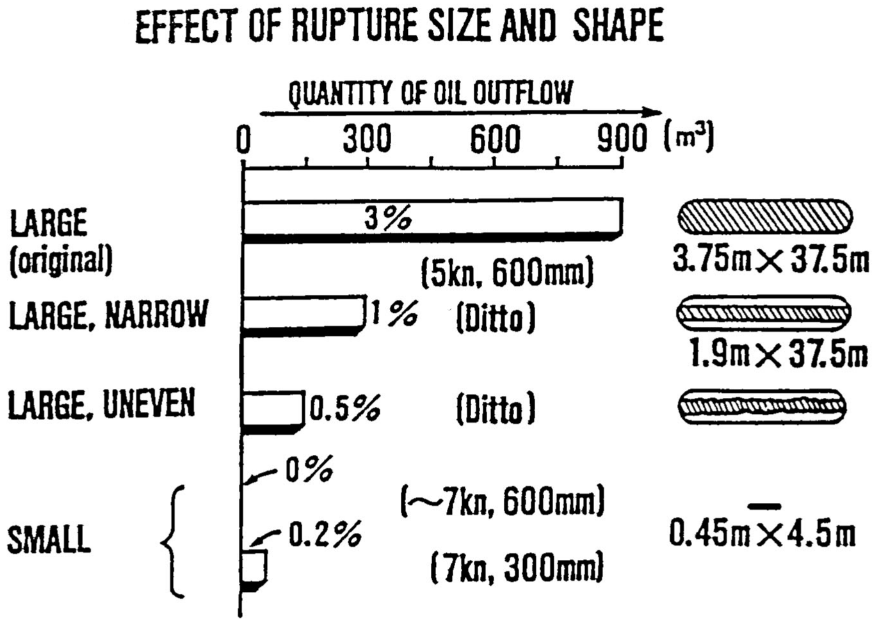

Fig. 14 Effect of Rupture Size and Shape on Oil Outflow

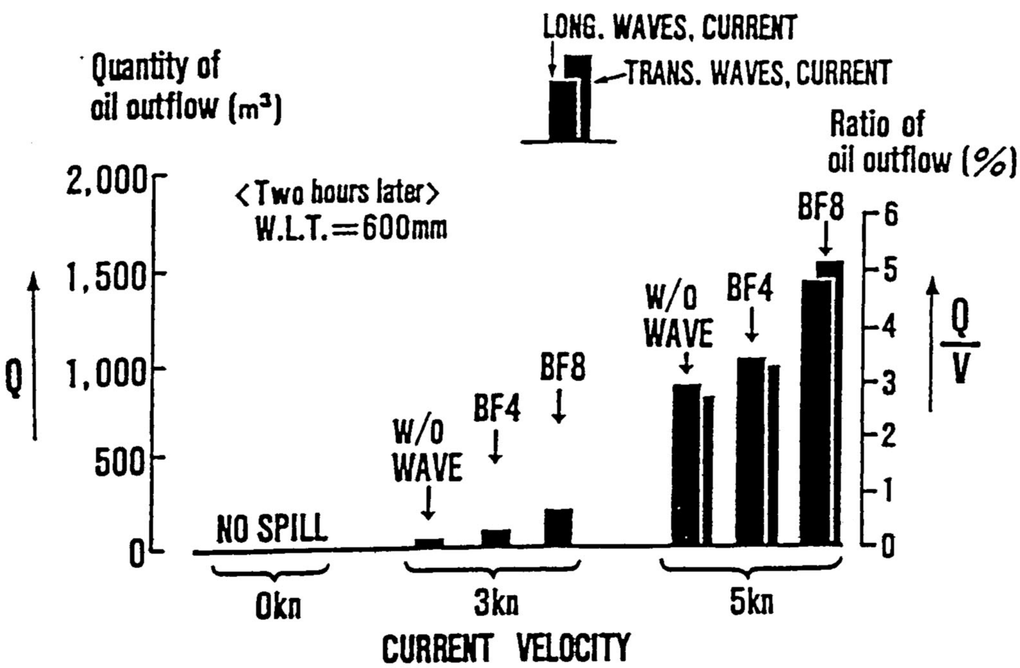

Fig. 15 Effects of Waves and Current on Oil Outflow

Fig. 15 shows multiplex effects of waves and current on oil outflow. In moderate sea states, the oil outflow would not be induced by ship motions or wave actions alone. The current velocity greatly facilitates the oil outflow in waves.

The ship motions, however, might be a significant factor to oil outflow in the case of the synchronized ship motions in beam seas.

A diagram was made by summarizing the test data to roughly estimate the amount of oil outflow induced by waves and current. The diagram, as shown in Fig. 16, has two scales for two cases of large and large uneven ruptures.

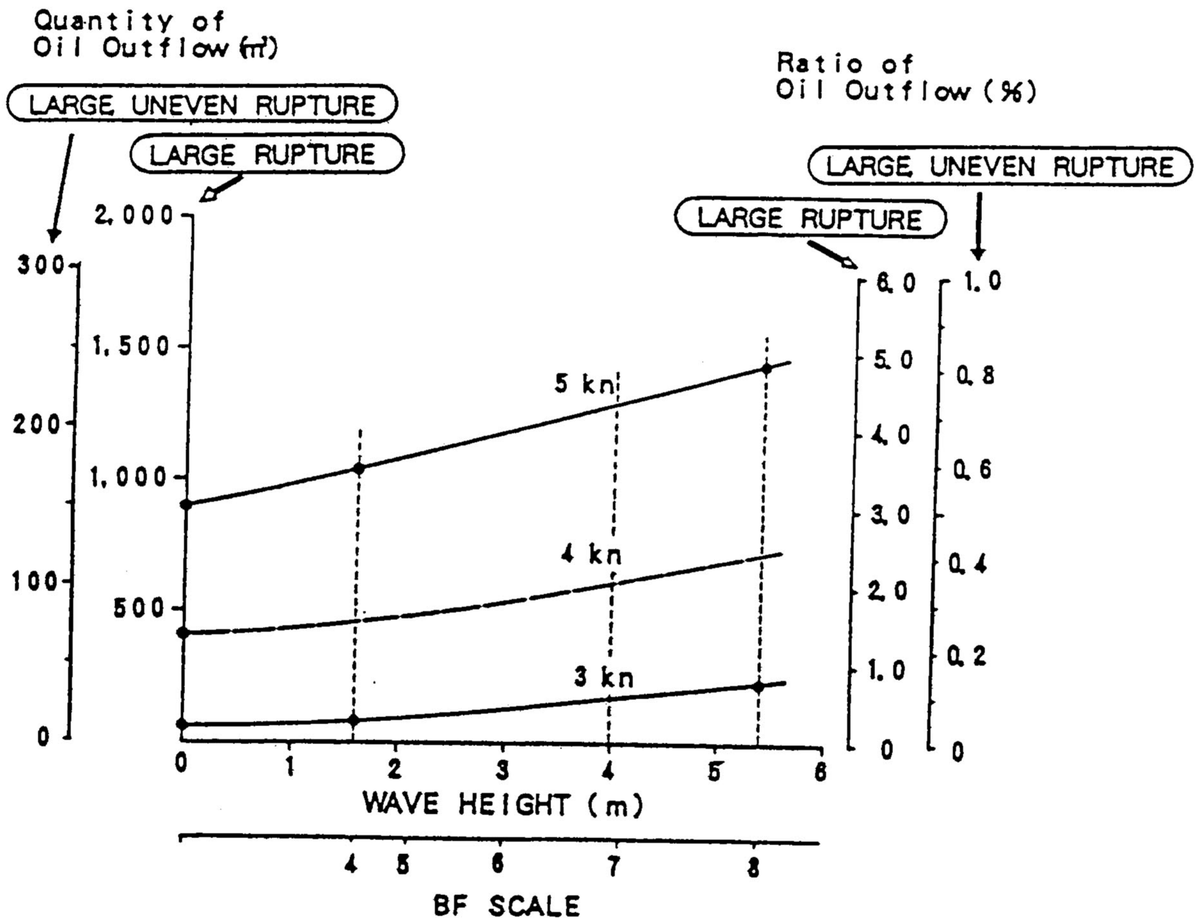

Fig. 16 Diagram for Estimation of Amount of Oil Outflow Induced by Waves and Current

5. EVALUATION OF OIL OUTFLOW OF MID-DECK TANKER

Fig. 17 shows a typical example of estimation of ship speed drop, crack length, and amount of oil outflow from each tank of a mid-deck VLCC, when the ship has an initial speed of 10 kts before grounding. The crack length extended to 44% of the ship length and oil outflow occurred at the four tanks. Total amount of oil outflow, however, was 1.2% of total volume of cargo oil, which was close to the IMO hypothetical value of 1%. It should be noted that the estimation based on test results with large rupture would give a greater amount of oil outflow, because ruptures of uneven complex shape are much more realistic in actual grounding.

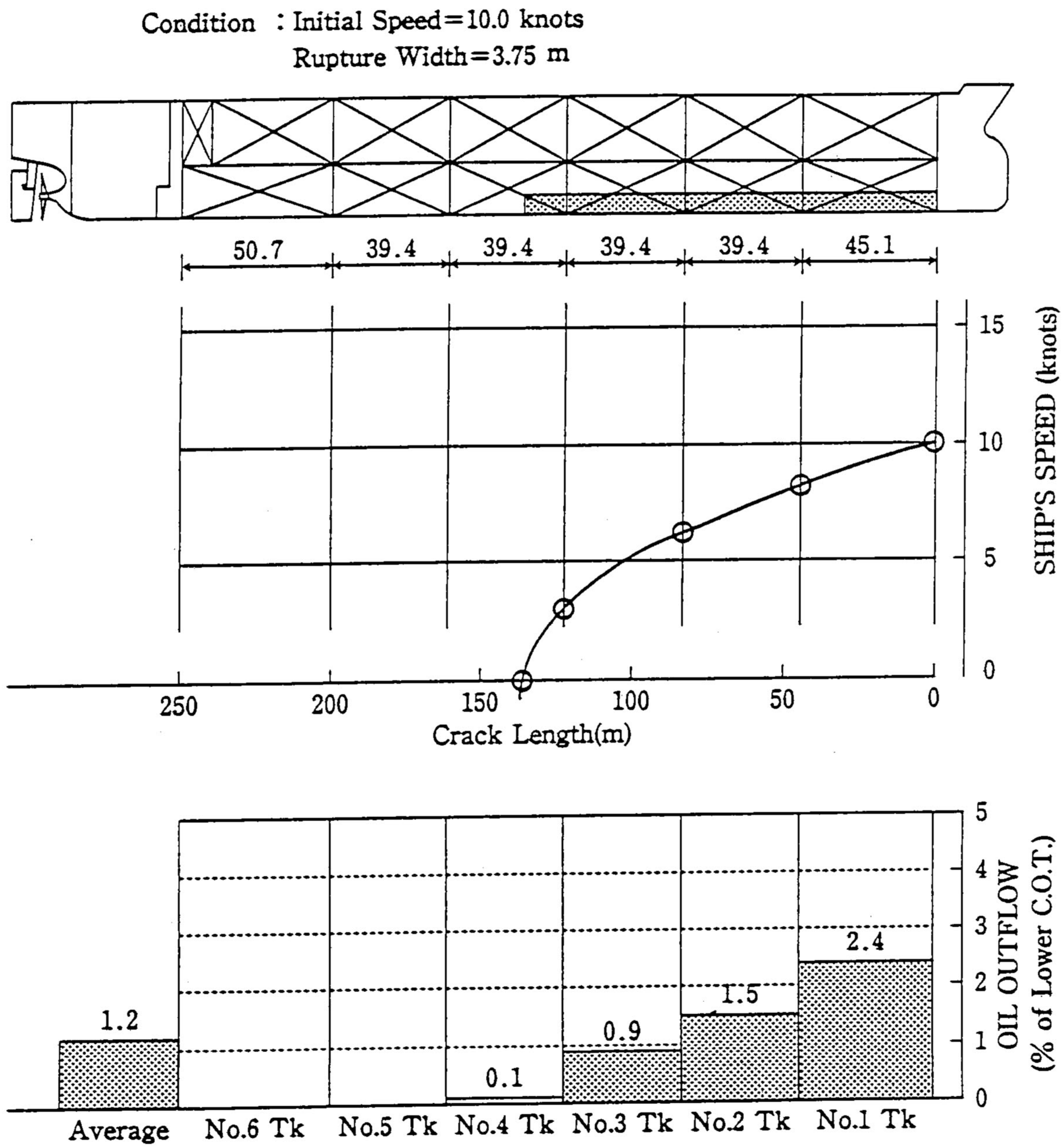

Fig. 17 Estimation of Ship Speed Drop and Oil Outflow due to Grounding

The IMO Oil Tanker Design Comparative Study has accepted the test results conducted at the SOF Tsukuba Institute.

6. CONCLUDING REMARKS

The model tests were carried out at the SOF Technical Institute. The test results provided useful information of oil outflow in grounding, although only one type of oil was tested due to lack of time and funding. The fundamental effects of ship speed before grounding, waves, and current were clarified and summarized in a diagram for estimation of amount of oil outflow. The properties of oil will affect spilling out behaviours of oil from damaged tankers, and to somewhat quantitatively different conclusions might be obtained. Further spilling tests with the other types of oil will be carried out in future.

Unfortunately no experiment was conducted in the case of ice-infested waters, as the SOF has not an appropriate facility, and the size of the tested ship might be too large for the NSR tanker.

The mid-deck is located below the water-line so that the hydrostatic pressure inside the bottom tank is lower than for the water outside. In case of the bottom tank ruptures, water will push its way into the tank, thus creating a seal between the oil and the ruptured skin. The mid-deck tanker has bigger double sides to accommodate water ballast than those of a double-skinned tanker and could protect more effectively against collision, collisions with ice and vessels. Most of the test results will be useful as basic data for the future NSR vessel design.

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5. The Shipbuilding Research Association of Japan, "Marine oil spill responses(in Japanese)", Report 186R, 1991.

REVIEW OF PAPER

Title of Paper: Oil Spilling from a Grounded Mid-deck Tanker

Author: Hiroshi Tamama

Reviewed by Hans V. Jensen, Research Scientist, SINTEF Civil and Env. Eng., Norway

Scope: The paper presents a summary of results from physical model tests of groundings of a Very Large Crude Carrier (VLCC) with mid-deck, to study oil spilling and to clarify fundamental behaviour of spilled oil from a mid-section part of the vessel in ice-free conditions.

Comments:

In general the paper would be easier to read if the language is brushed up a bit.

Chapter 1

- The four different oil spill scenarios (near field etc.) should be defined.

Chapter 2

- Is the "centre of breach location" in Fig. 2 measured from the bow or the stern?
- Without reading reference 1 it is difficult to know what Fig. 3 is showing

Chapter 4

- A little more description of the test tank would be preferable. Items 1 through 11 have not been identified.
- The drastic decrease in the ship speed is stated to be caused by the spilling of oil through the bottom (Section 4.2.1). Is this what the author wants to say? In that case it should be further explained.
- Description of model (Sec. 4.2.2) is very good.
- It seems that only one test oil has been used. This is surprising since the properties of crude oils vary over so wide ranges. As an example, if the wax content is high, the pour point of the oil would also be high. For a spill of such oil in cold water (like the NSR), the viscosity of the oil when reaching the water temperature could be compared to the viscosity of a piece of butter right from the refrigerator. It is easy to see that the fate and behaviour of a crude oil with such properties would be quite different from the fate and behaviour of a crude oil with pour point at -20 C.

  Since the paper is stating that the test were focusing especially on the "dynamics of spilled oil affected by current and waves", more attention on the oil properties would have been appropriate.

- Another question is whether the physical properties of the test oil have been altered to account for the model scale of the experiments. If this has been done, it should be described in the paper. If this is not considered to be of importance, it should be discussed why.
- All the parameters in the equations (Sec. 4.2.4) have not been defined.
- It is stated that "aft tanks will have the possibility of less oil outflow from a rupture than fore tanks (Sec.4.2.5). Explain why.

<u>Chapter 6</u>

- No conclusions are found in this chapter.

Conclusive remarks:

The paper is very interesting, also for a person that is mainly working with problems related to oil after it has been spilled.

The sparse comments about the test oil indicate that the project has not focused on this issue. The reviewer believes that the variations in the physiochemical properties of the cargo oil would highly affect the results.

At last a question about the use of a mid-deck tanker: Since the seawater layer at the bottom of the lower cargo oil tanks would prevent more oil to flow through a rupture in the bottom of the hull, could such a layer in the bottom be pumped into the tanks during loading of the VLCC to further reduce the risk of oil spills (or reduce the volume of spilled oil) caused by a grounding? At least if the VLCC will be transiting very sensitive areas?

Trondheim 5 July 1998

Hans V. Jensen

Dear Dr. Jensen,

As Mr. Tamama was transferred to a different department in the recent personnel changes, I do appreciate your kind review of Mr. Tamama's INSROP Paper, and I am sure that in general the comments you made on his paper are very useful.

We have been recognized that the properties of oil have important role in the spilling behavior. We should recognize the scale effects on the behavior of spilled oil form a ship.

Model tests in relatively large scale always cost much. To his great disappointment he could not find any fund to pursue his primary plan on oil spilling from a mid-deck tanker, which included experiments with larger scale models.

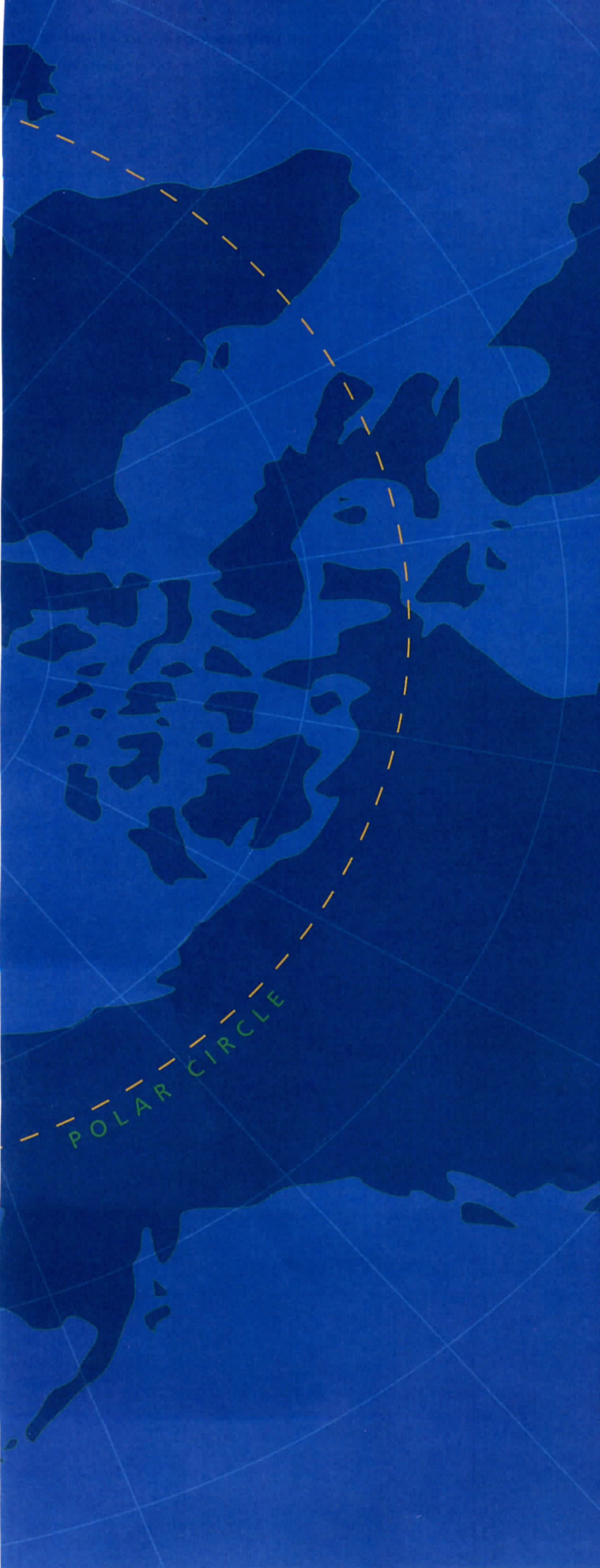
I will make necessary corrections in his paper on behalf of him, after discussing with him via telephone conversation.

Best wishes,

H. Kitagawa

H. Kitagawa, PhD.

Hokkaido University



The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.
SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Sasakawa Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.
CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; shipping safety; technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stockholding company.

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.
FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multidisciplinary approach, entailing *extensive* cooperation with other research institutions both at home and *abroad. The INSROP* Secretariat is located at FNI.