An Interview with Professor T. Tabata, the Institute of Low Temperature Science, Hokkaido University

Sea Ice and Offshore Structures

On 15 April, 1912, the "Titanic" was hulled and sunk in the North Atlantic. Even today, there are ships and offshore structures damaged or destroyed by various forms of the same powerful natural enemy—sea ice. How and where does this menace exist, and what can science do to alleviate the dangers? An interview with Professor T. Tabata of the Institute of Low Temperature Science, Hokkaido University, provides many of the answers to this chilling problem.

NK: Please give us a little information on the sea ice distribution on the earth.

Tabata: Sea ice, or the ice formed from seawater, is seen in the central parts of the Arctic Ocean and in the periphery of the Antarctic Continent even in the summer. During the winter, it is seen in other places as well, such as in the seas around the outskirts of the Arctic Ocean or around the Canadian Archipelago. In Europe, the Baltic Sea, the Gulf of Bothnia and the Gulf of Finland are frozen in winter. It can also be found in the northern edges of the Pacific Ocean such as the Bering Sea and the Sea of Okhotsk.

NK: How is seawater frozen into ice and how do more layers form?

Tabata: When seawater is cooled, its density increases and then vertical convection takes place. Thus, the seawater is cooled from the surface to some depths or ultimately to the ocean floor. The convection stops when its temperature reaches the freezing point. If cooled further, the seawater begins to freeze from the surface.

Sea ice is a poor heat conductor, and so once the sea surface is frozen, it is as though the sea were covered with a heat insulator. A new layer always forms beneath the first layer of ice. If the air temperature does not change, the more the thickness of the ice layers increases, the less the formation of new layers. Because of this, sea ice does not grow to an unlimited thickness.


Prof. T. Tabata

NK: What is the sea ice in the Arctic Ocean like?

Tabata: The Arctic Ocean is firmly surrounded by Siberian, Alaskan, Canadian, and other lands, preventing free motion of the sea ice. The ice in the Arctic Ocean is therefore very stable. Sometimes, blocks of ice crash against each other to form hammocked ice fields, or pressure ridges, which are of a far greater height and number than in the Antarctic Ocean.

The annual average temperature at the North Pole is −18°C, and snowfall in the Arctic Ocean is small.

Sea ice is formed to a thickness of about two metres in the coastal areas of the Arctic Ocean during the winter season as compared with 40 to 50 centimetres in the coastal areas of Hokkaido, Japan, or 120 to 130 centimetres in the northern part of the Sea of Okhotsk.

By the time the sea ice has reached that thickness, it is usually spring. The Arctic Ocean feels a strong sunlight 24 hours a day in June, July and August, and the ice begins to melt. Water runs in streams or forms puddles on the ice. Thick ice layers are reduced by about 40 to 50 centimetres, while thin ones are melted down to open water. Thus, about 25 percent of the frozen area in the Arctic Ocean melts during the summer.

Then, winter comes around, and new ice forms beneath the remaining blocks. This unmelted, remaining ice is known as second-year ice, and the ice which has survived over two summer seasons is called multi-year ice or polar ice.

In the central Arctic Ocean, the ice thickness gets to about three metres, on the average. In summer, 40 to 50 centimetres melt away from the surface, and the new ice of the same thickness is formed beneath the surface in winter. The surface of the ice is trimmed year after year while new ice builds up beneath, and so the block is completely renewed in about seven- to eight-year cycles.

NK: What about the sea ice in the Antarctic Ocean?

Tabata: It differs from that of the Arctic Ocean in several points. In the first place, the Antarctic Ocean is wide open, allowing for free motion of ice. Secondly, the temperature is much lower. The yearly average temperature at the South Pole is -45°C, and therefore the sea ice around the continent is thicker than that in the Arctic Ocean.

In the third place, the Antarctic Continent consists of plateaus roughly 3,000 metres high, from which strong downward winds, known as katabatic wind, blow in all directions. They often blow ice blocks away from the continent. The breaking up of ice fields creates open water where new ice forms. The wind also blows a lot of snow into the ocean, which triggers the formation of even more ice. Additionally, ice floes sometimes sink under the weight of piled up snow, and seawater rises to the surface of the ice and mixes with the snow to form even more. As a result, 4 to 5 metres of ice is formed.

Although it occupies a far larger area than in the case of the Arctic Ocean, the sea ice in the Antarctic Ocean is much easier to melt, and so nearly 85 percent of the total is melted in summer. Such sea ice is called first-year ice. On the other hand, multi-year ice, or winter ice, accounts for only 10 to 15 percent.

NK: Would you tell us something about icebergs?

Tabata: Snow accumulates in the mountains and is pressed to hard ice over a long period of time, say 500 or 1,000 years. The ice forms glaciers while it slowly descends into the valleys. The glacier drops into the sea and is broken into floating blocks of ice. These are what are known as icebergs.

The number of icebergs in the Arctic Ocean is rather small, as is their size. Greenland is an ice continent. Icebergs break off of the glaciers on the eastern coast and are caught by the East Greenland current, being carried away to the south while melting.

An international ice patrol was jointly set up by the United States and Canada. Once this patrol discovers icebergs, they follow them until they are completely melted.

Icebergs form at the north-western tip of Ellesmere Island, which lies at the northern end of Canada. They float around in the Arctic Ocean, and occasionally drift as far as northern Alaska. They are about 30 metres thick, and large ones can measure 10 kilometres in both length and width. Even pieces of icebergs have a thickness of a few metres, and how to avoid a collision with them is a big problem for offshore structures built in the area.

Icebergs are mostly formed during the summer. In winter, the seawater freezes together with icebergs, and sometimes the icebergs slowly drift around together in ice floes.

NK: What about the structure and strength of sea ice?

Tabata: Seawater contains approximately three percent salt. For this reason, seawater begins to freeze at about -1.8°C. Generally, the salt content in sea ice is below 1 percent. The salt remains in sea ice as brine in liquid form, in a narrow tubular or cellular pocket. The volume of liquid brine changes with the temperature of ice and also with the lapse of time.

When a piece of sea ice is cut, many brine pockets are seen. Because of these cavities, it has less bending and compressive strength than ice formed from fresh water. Although strength varies with temperature, the freshwater ice has a compressive strength of 100 kilograms per square centimetre, more or less, and that of sea ice is about one-third as great.

As the temperature of sea ice drops, the strength of pure ice itself increases, and the volume of brine decreases. Because of these two phenomena, the strength of sea ice increases with the decrease in temperature. If the temperature rises, the sea ice loses its strength. Its surface melts in summer, and part of the water seeps downward through cracks or brine pockets washing some more of the brine in the ice away.

So first-year ice is relatively weak, but ice which has survived one or more summer seasons has a strength more

A vast ice field off Point Barrow, Alaska.

or less equal to that of icebergs.

Various offshore structures are currently being planned or constructed within 10 kilometres from the coast, and fortunately the ice in this area is mostly first-year ice. However, in the northern districts, multi-year ice may occasionally drift down to the construction sites. The multi-year ice is thick and strong, calling for special attention when an offshore structure is to be built in a danger zone.

The temperature of the bottom surface of the sea ice is equal to the freezing temperature of the sea water there, i.e., -1.8°C or -2.0°C at the lowest. However, the surface of the sea ice is exposed to the cold, and when the wind blows its temperature drops to -30°C or even to -40°C. The upper portion of the ice is therefore stronger than the lower portion. This difference in strength with the depth of the ice sheet makes it more difficult to calculate the total force applied to the offshore structure due to the movement of the sea ice.

NK: What is the current situation and problems associated

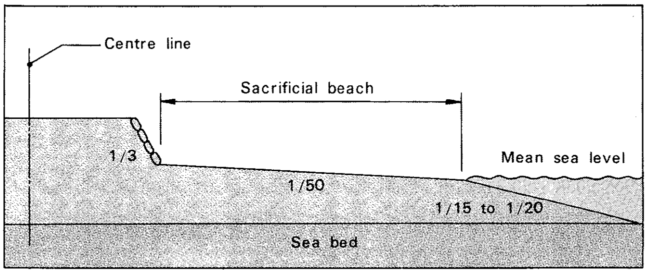


Fig. 1. Typical sacrificial beach island

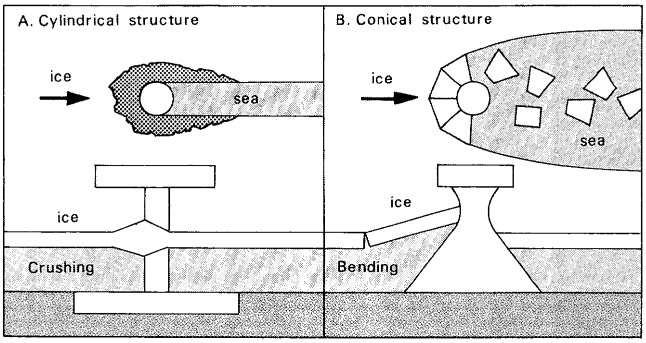


Fig. 2. Mode of ice force

with offshore structures in ice floes?

Tabata: Let's talk about artificial islands first.

Since the North Slope oil field was discovered in Alaska, the production base has gradually moved offshore, and exploratory wells are now being drilled at sea in a water depth of about 15 metres. Using gravel available there, artificial islands having a side length of 100 to 150 metres have been built for oil production. Ice floes in this area are about two metres thick, and the islands are constructed on a wide base to protect production facilities from the threat of these encroaching ice floes (see Fig. 1). It's reported that nearly 20 islands of this type have been constructed so far. Now, I will turn to oil production platforms.

Currently, there is no oil production platform in operation in the ice floes. Basic factors which have to be considered in designing ice floe-resistant platforms are known to us, but exact values of coefficients and variables remain to be clarified, at least, as far as we know.

However, we can assume the most basic form to be a single cylindrical installation built upright in the ice floes (see Fig. 2, A). From experience, we can obtain the magnitude of force which applies to the installation.

The formula is:

$$F = Imk\sigma$$

where F = *force applied to the cylindrical installation;*

I = *indentation factor, which is a coefficient necessary to force the cylinder into the ice and a function of the diameter of the cylinder and the thickness of the ice (it is 2.5 for slim cylinders or 1.0 in the case of structures having flat faces);*

m = *shape factor, which is 1.0 for flat structures such as quay walls, or takes different values in the case of cylindrical or conical forms;*

k = *contact factor, which is 1.0 when the structure is fully in contact with ice or takes different values if partially in contact with ice; and*

σ = *ice strength in crushing.*

This σ is the problem. Usually it is 20 to 50 kilograms per square centimetre. This value was obtained by crushing pieces of ice cut into a diameter of 7.5 centimetres and a length of 15 centimetres. However, samples having a diameter two times as great show a lower strength, about two-thirds of the said value. In the case of still larger sections having a diameter of around five metres, i.e., equivalent to the actual size of the structures, the exact strength is unknown.

Besides, ice floes are not always flat, and σ also varies with their flow speed.

Various ice field experiments have been carried out in America and Canada, but no experiment with actual installations has ever been made.

Besides the cylindrical type, conical structures have been conceived. This is based on the following idea.

The surface of the platform foot is inclined at a given angle. Ice will ride upward along this inclined surface and will be broken due to bending moment and carried away. The next piece of ice will come along and then be broken in the same manner. When viewed from above, cracks occur in the ice in a radial form spreading from the foot outwards (see Fig. 2, B). And, even if blocks of ice are tightly jammed around the foot, they will be broken when the water level lowers with the tide. Since the bending strength of ice is approximately one-third of its compressive strength, ice can be broken more easily with less force.

This design, however, has some problems. One question is whether the ice can be forced to ride upward along the slope of the foot as smoothly as conceived. Specifically, this is a question of friction. And there is no assurance that the broken piece of ice will always be carried away downstream. There is a fear that the ice might bend back upon itself. Another problem is that, because the area of ice on the foot of this structure is greater than on the foot of the cylindrical structure, the force may be greater as well. The best angle of the slope is said to be in the neighbourhood of 45°, but that is also yet to be clarified.

Currently, planned platforms of this type are either self-supporting or of a fixed type construction.

NK: What about research in Japan on these platforms in icy waters?

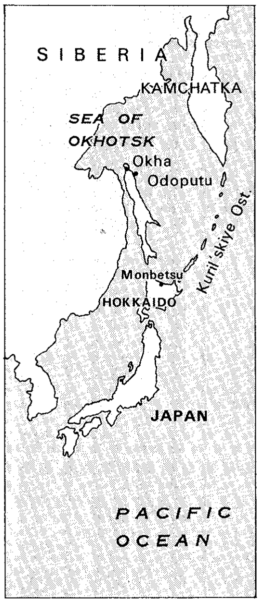
Tabata: An agreement was concluded in 1975 between Japan and the Soviets. The agreement calls for a joint exploration, development and production of oil and natural gas in the continental shelf of Sakhalin.

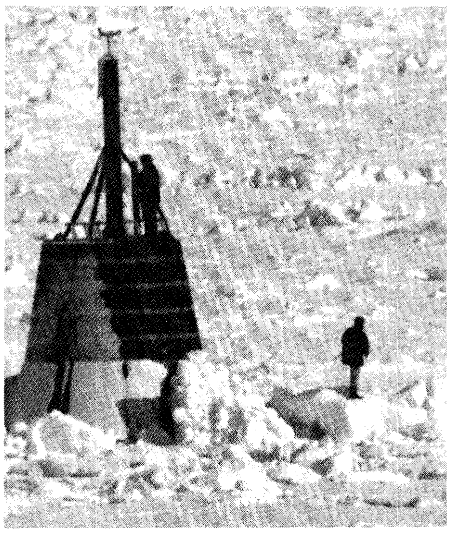
In 1977, oil and natural gases were discovered in the Odoputu structure of the northeastern shelf of Sakhalin, and evaluation wells are being drilled there at present. This oil and gas field has a water depth of 25 to 30 metres, and the thickness of ice floes comes to over one metre in winter. Countermeasures for the prevention of interference on oil development from these ice floes are now being studied jointly by Japan and the Soviets.

Meanwhile, an experimental tower was constructed by Mitsui Engineering & Shipbuilding Co., Ltd. in 1976 at a depth of 6.5 metres and about 600 metres off the coast of Monbetsu, Hokkaido to measure the force of ice floes.

A cylindrical tower having a diameter of about 2.5 metres was built first, and then a conical capsule was placed on the tower. Research with this installation is still being continued.

This is the world's first experiment in this field. The results will contribute to the progress in research and development by the people coping with ice floe problems, and in fact can be effectively utilised for the Sakhalin project.





Experimental tower constructed by Mitsui Engineering & Shipbuilding Co. off Monbetsu, Hokkaido.