Field Measurements of Anchor and Frazil Ice

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ABSTRACT

We have carried out field measurements of anchor ice for 3 years in a small stream in Hokkaido. Conclusions from the measurements are follows:

(1) Anchor ice formed mainly by frazil crystals.
(2) Anchor ice is observed when air temperature is below about -10 ℃.
(3) When air temperature becomes lower, the volume of the anchor ice masses increases.
(4) Critical condition of anchor ice formation depends on Froude number and air temperature.
(5) Coarseness on the surface of the objects influences the occurrence of the anchor ice.

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1 INTRODUCTION

It is well known that the appearance of frazil ice is the first stage of ice formation in waters. In rivers frazil flocs and small ice floes are then produced on the flowing surface. These result in ice cover initiation when reasonable weather and flow conditions are attained. In the rapid section the turbulence of the flow is sufficiently strong to bring supercooled water to river bed, and ice crystals may nucleate or frazil particles adhere on under water objects to produce anchor ice. When the solar radiation or external heat sources are sufficiently supplied to release the bond between ice and bed material, flocs of anchor ice may float up to the surface. These massive flocs will accelerate ice cover formation, and may transport the bed material by their buoyancy. Solid anchor ice stays on the bed and grows an anchor ice dam. Growth and decay of anchor ice dam sometime control the water discharge to the power station, and is a big concern for the stable power generation. Also adhesive frazil on the trash rack of water intakes impedes its proper function.

In the last decade little are studied about anchor ice as well as the adhesive properties of frazil ice. This paper will describe the results of field observation of anchor ice in a small stream in Hokkaido.

2 FIELD OBSERVATION

Field observation was performed at Niuppu river (catchment area A=159km ^{2}), which is a tributary of Tesio river in Hokkaido.(see Fig.1) The basin of this river is one of the most snowy and coldest regions in Hokkaido, where the annual freezing index exceeds -1000 ℃ day. Water discharge of Niuppu river during observation period was 1.5 ~ 2.2m ^{3}/sec and water depth of observation site was 30 ~ 60 cm. This site with rather uniform channel has a slope of 1/50. River bed is covered with gravels, whose maximum diameter is about 40 cm, and only a narrow portion along the shore has sand bed.

Measurements of anchor ice were performed of a selected reach of the river . This reach of 16m long and 6 ~ 9m wide was covered with a grid of 2 m interval in the direction of the flow and 1 m interval in the perpendicular direction (as shown in Fig.2). And at each grid point, flow velocity, water depth, anchor ice thickness were measured. Time of measurements was about 7:00 a.m. when the anchor ice has its maximum development. And after the measurement all existing anchor ice was removed artificially and let the new anchor ice grow till next morning.

About 100 m downstream of the grid, experiments of adhesive property of frazil particles on different materials were planned. We installed the test materials of 1 cm x 5 cm x 30cm on the river bed as shown in Fig3, and anchor ice volume on the test materials were measured in the morning. Different materials such as iron, mortar, acrylic fiber and wood are tested.

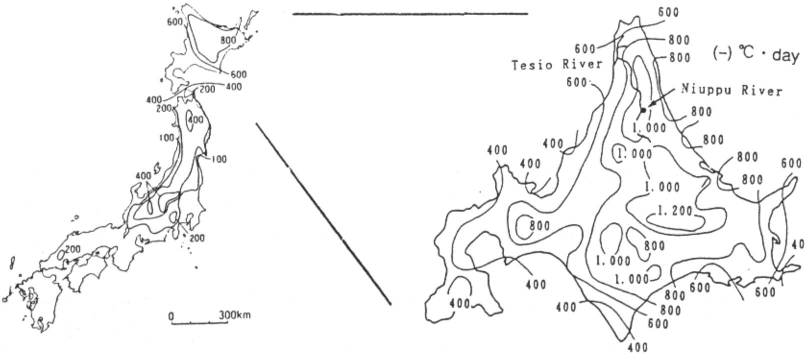


Fig. 1 Distribution of Freezig Index in Japan

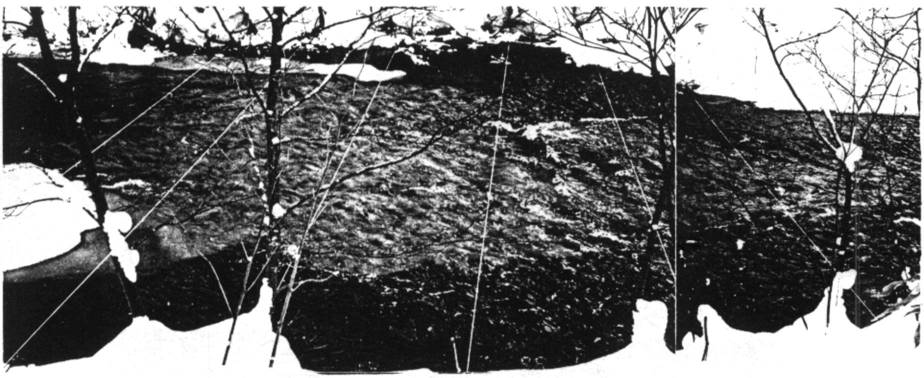


Fig. 2 Observation site

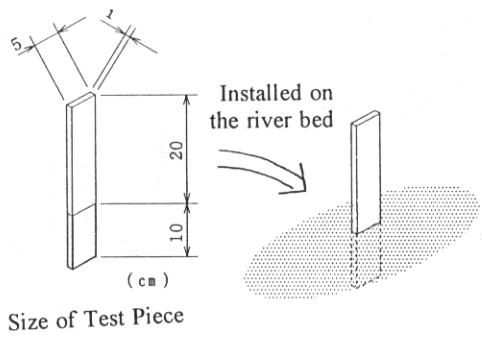
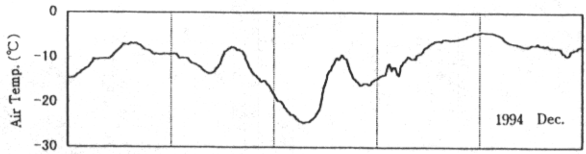


Fig. 3 Size of Test Piece and Installation on the river bed

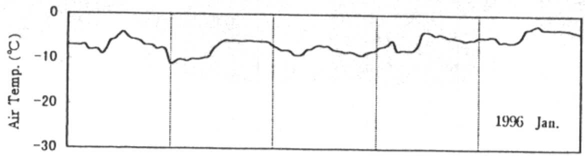
3 RESULTS OF OBSERVATIONS

3.1 Anchor ice formation

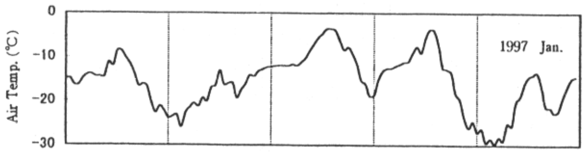
Air temperature and ice condition during the observation periods are shown in Fig.4. This figure shows that when air temperature is less than about -10 ℃, anchor ice appeared in this reach. In the winter of 1994-1995, air temperature was low, and the production of the ice was frequent and large. Winter of 1995-1996 had a rather high air temperature. Due to the warm climate the ice production was less than the previous winter. Winter of 1996-1997 has the coldest air temperature in 3 years and the most active anchor ice production was observed. In these three winters water temperature during the measurements stays close to the freezing point.



Date	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec
Weather	cloudy	snow	cloudy	snow	snow
Ice condition	fully covered	fully covered	fully covered	no ice	no ice



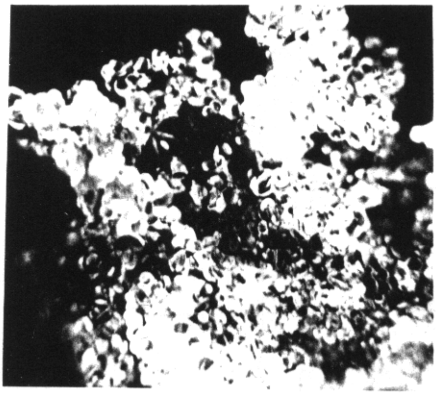
Date	7-Jan	8-Jan	9-Jan	10-Jan	11-Jan
Weather	cloudy	snow	cloudy	snow	snow
Ice condition	fully covered	fully covered	fully covered	no ice	no ice



Date	8-Jan	9-Jan	10-Jan	11-Jan	12-Jan
Weather	cloudy	fine	cloudy	fine	fine
Ice condition	fully covered	fully covered	fully covered	no ice	fully covered

Fig. 4 Air Temperature and General ice Condition for 3 years

The anchor ice masses in Niuppu river consist of platelets or needle-like ice crystals (Fig.5) and grow by trapping flowing frazil into the masses. Fig.6 shows anchor ice masses whose diameter iwas about 100cm, and a boulder of 30cm was found inside of the ice. Anchor ice can grow either toward upstream or downstream depending on sharp of a boulder, which controls the flow pattern around the boulder. Frazil laden flow was confirmed in the daytime by underwater video camera. From the present observations it is concluded that the anchor ice is only initiated in a rapid section and can not exist in milder and deeper streams as well as in a reach of sand bed material.



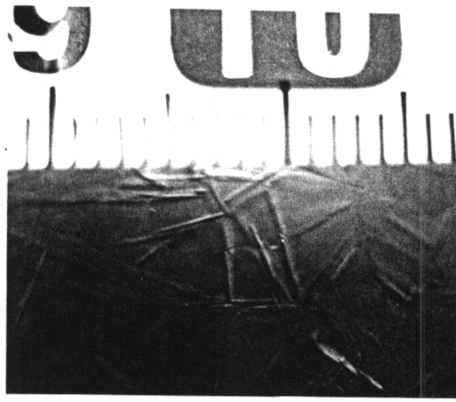


Fig. 5 Platelets crystals and Needle-like crystals

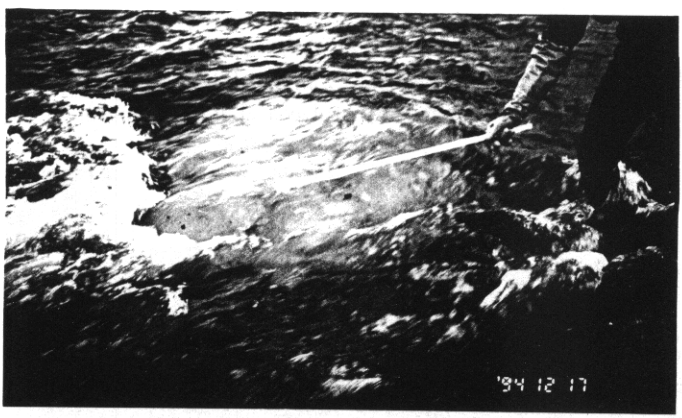


Fig. 6 Anchor Ice formed on a Boulder

3.2 Amount of Anchor Ice Production

Volume of anchor ice masses in the grid, which has an area of 120m ^{2}, was shown in table.1. The freezing index for 6hrs, from 0:00 a.m. to 6:00 a.m., which is called 6-hour freezing index (℃ hour), is calculated, and the anchor ice volume is compared with this index as shown in Fig.7. The dependency of the volume on the 6-hour index is observed.

Table. 1 Volume of Anchor Ice Masses

	Volume(m^3)	Thickness(cm)	6-hr Freezing Index(℃·hour)
7-Jan-96	4.035	5	-50.6
8-Jan-96	5.146	6.6	-72.9
9-Jan-96	2.868	4.1	-56.5
10-Jan-96	1.963	3.7	-50.4
11-Jan-96	1.941	3	-36.5
12-Jan-96	no ice	no ice	-29.6
8-Jan-97	16.97	11.1	-105.7
9-Jan-97	29.48	17.9	-163
10-Jan-97	2.576	3.6	-83.9
11-Jan-97	no ice	no ice	-102.9
1997/1/12	30.128	17	-193.9

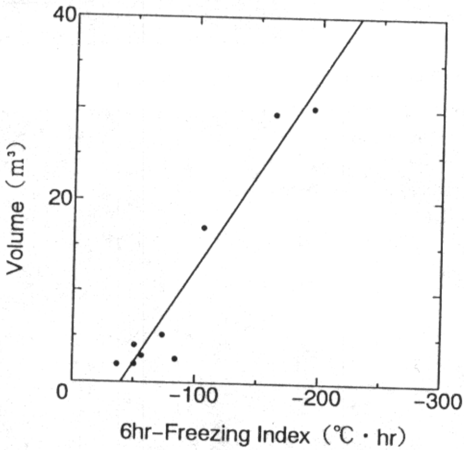


Fig. 7 Volume of Anchor Ice Masses and 6-hr Freezing Index

3.3 Density of Anchor Ice Masses

Relation between density of anchor ice masses and flow velocity is shown in Fig.8. Fig.8 shows an increase of density with the velocity. Scattering of data is caused by a very annoying procedure of removing the water content in the sample to obtain the net weight of ice.

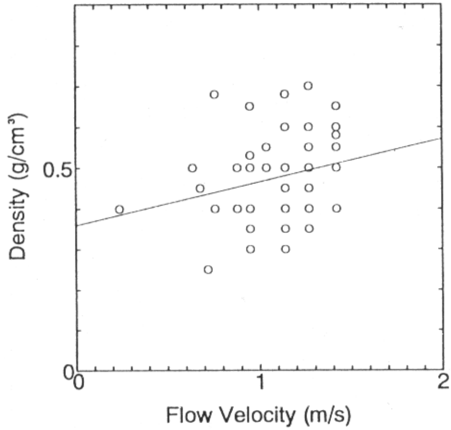


Fig. 8 Density of Anchor Ice Masses and Flow Velocity

3.4 Sediment Content in the Ice Masses

It was often observed that many gravels stayed on the surface of anchor ice as shown in Fig.9. The maximum diameter of these gravels was about 8 cm. It is assumed that this is caused by the buoyancy of the ice. However this procedure was not clear in the present observations. We also measured the sediment content in the ice masses. It was less than 1 % of the weight of the ice, and it is concluded that the effect of anchor ice formation on sediment transportation is trivial in this reach.

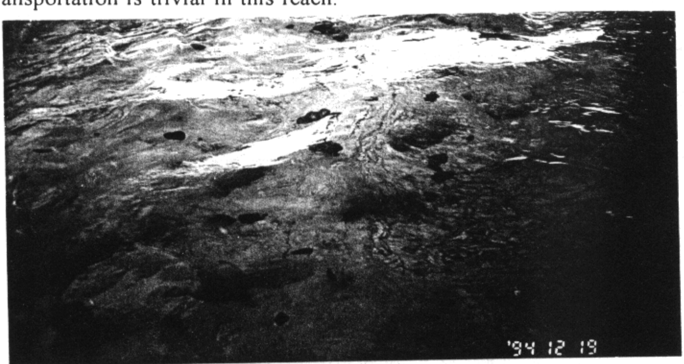


Fig. 9 Gravels on the Carpet of Anchor Ice

3.5 Critical Condition for Anchor Ice Formation

It is clearly observed that the area of anchor ice formation has a close dependency on water depth and flow velocity distributions ; anchor ice was hardly observed in deeper portions of river and grew thicker in portions with high flow velocity. Flow depth and velocity are chosen as control parameters of heat flux to initiate the anchor ice. It is assumed that Froude number represents the combined effects of these parameters. Fig.10 shows a distribution of Froude number and area of anchor ice formation. The area of anchor ice formation and a line of Fr.=0.6 is very similar in shape. It is therefore concluded that one of the control parameter of anchor ice formation is Froude number.

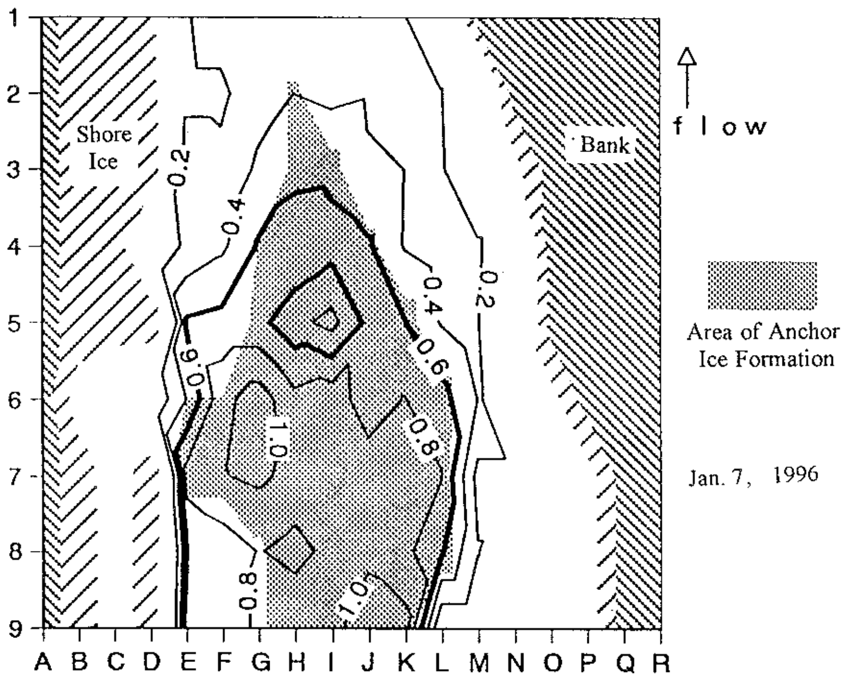


Fig. 10 Froude Number Distribution and Area of Anchor Ice Formation

Fig.11 is a histogram of Froude number, which shows for both frequencies of points where the anchor ice exists, and points where it doesn't exist. It is see from the histogram that foude number of anchor ice formation is in a range between 0.2 ~ 1.5. And for cases where Froude number is less than 0.2, no anchor ice is observed.

Another important parameter for the anchor ice formation, of course, is air temperature. To explain the wide scattering of Froude number for cases of anchor ice formation, influence of air temperature, expressed by 6 hour freezing index, is considered. A relation between Froude number when anchor ice exists and the freezing index is depicted in Fig.12. From the figure it is observed that when the freezing index is large, the minimum Froude number for the anchor ice existence becomes smaller. From the present observation, it was found that the critical condition for the formation of anchor ice depends on the freezing index and Froude number. A line in Fig.12 shows the average critical condition of anchor ice formation.

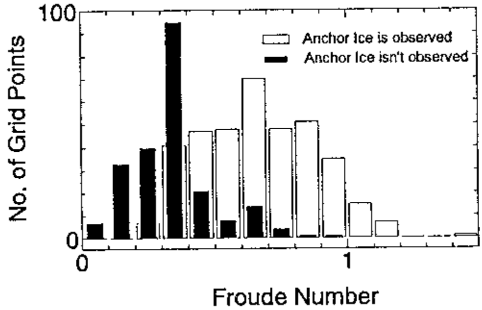


Fig. 11 Histgram about Froude Number

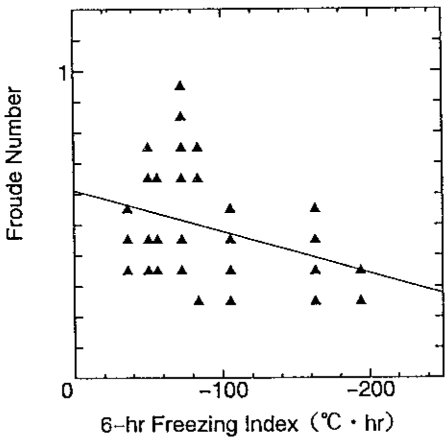


Fig. 12 Freezing Index and Froude Number when Anchor Ice is observed

3.6 Adhesion of Frazil Ice on Different Materials

Fig.13 shows amount of anchor ice adhered on the specimen for 24 hours. There was a very large amount of ice adhesion on mortar while no ice on acrylic fiber. It is clear from present observations that there is a difference in easiness for ice to adhere to materials. During experiments temperature of materials was the same and was the water temperature. We assume that this difference is related to the surface condition of the materials. Among many parameters, we choose the simplest parameter, static friction coefficient. Measuring the static friction coefficient by placing a test piece on a inclined plate, Fig.14 is obtained, which shows a correlation between average of static friction coefficients and volume of anchor ice masses. From this figure it is understood that the volume of the anchor ice masses becomes bigger as the frictional resistance is larger.

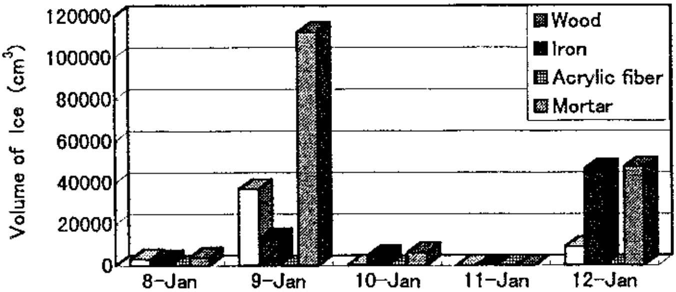


Fig. 13 Volume of ice masses on different materials

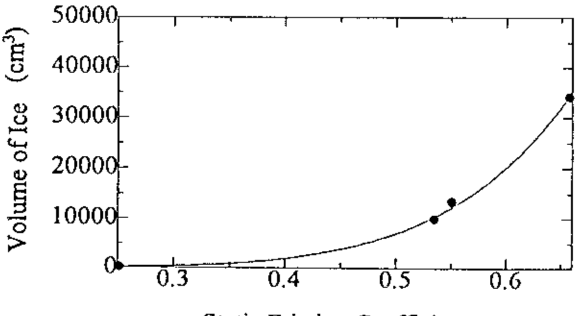


Fig.14 Static Friction Coefficent and Volume of Ice

4 SUMMARY

From the present measurements the following conclusions are obtained ;

(1) Anchor ice formed mainly by frazil crystals.

(2) Anchor ice is observed when air temperature is below about -10 ℃.

(3) When air temperature becomes lower, the volume of the anchor ice masses increases.

(4) Critical condition of anchor ice formation depends on Froude number and air temperature.

(5) Coarseness on the surface of the objects influences the occurrence of the anchor ice.

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