Fig. 4. Sand tube groin (Lønstrup at the Danish North Sea Coast).

2. To obtain better knowledge of the applicability of sand tubes in coastal protection works.
3. Measures against a downdrift recession caused by a mole built to protect the Hvide Sande inlet.

The barrier is only about 1 km wide but has a natural protection of dunes.

The coast is exposed towards the west, prevailing winds from W-NW, and the N-S littoral drift is estimated at 400,000 m^3 p.a. Tidal range less than 0.8 m, wind set up may be up to + 3.0 m.

The constructions described in the following were with few exceptions made of three tubes laid out to form a prism. The tubes were permeable made of double layers of black polypropylene monofilament.

Group 1: Four beach groins. (Fig. 5).
35 m long, starting on the dune at a level of + 6-7 m, ending on the beach at level + 2 m.

Group 2: Two artificial beach ridges.
One half-moon shaped with a shingle drain under the middle section. Total length 70 m.
Laid out with top level - 0.2 m at the front and the ends at top level appr. + 1.0 m.
The construction never really worked because the permeable tubes over the drain were washed out by a gale during the construction period.

Fig. 5. Beach groins (Hvide Sande. The danish North Sea Coast).

The other ridge boomerang shaped.
Total length 70 m. Laid out on the beach at level + 1 m. After a short while the structure sank and is now buried in the sand.

Group 3: Two groins going from the dune foot to the still water line, spaced 120 m apart and at an angle of 20° north to the coast normal.

Group 4: As group three, now showing 20° south.

Finally two constructions in the form of dozed sand prisms normal and parallel to the coast covered with a filter sheet stitched on both sides to individual tubes; unfortunately the stitching was not strong enough and the structures failed after a short while.

Experimences:

The material has shown good resistance to the forces acting upon it. The tube structures must be held together by some means: It is essential to pay careful attention to the problem of bottom protection. Some attemps were tried with filter sheet but were not properly executed. Thus the "groins" and "ridges" followed the seasonal beach fluctuations down - but of course never up again.

A extensive measurement program following the experiments will be finished and finally evaluated in the summer of 1971 so far it can be stated that in the period summer 1969 to spring 1970 stabilisation of the beach has been noted.

Fig. 6. Enebærodde (Funen).

On the Enebærodde spit on the north coast of Funen a contractor has been conducting some experiments, that began in autumn 1969.

There was a minor erosion problem in the test field.

The tubes used were made of polypropylene lined with plastic D = 0.70 m.

There have been some interesting features in these experiments especially concerning some groins made of single tubes going to a water depth of approx. - 1.0 m. (Fig. 6).

1. The sand-tube groins in this relatively calm area had a significant traditional groin effect.
2. The groins did not show any damages in the breaker zone.
3. During the severe winter 1969-70 the tubes remained intact, although subjects to rather hard ice attacks.
4. The spit consists mainly of rather coarse material (shingle) but this has not apparently caused extra wear on the tubes,
5. but keeps them from sinking.

Lately - spring 1970 - sand tubes have been used for dune foot protection on an artificial spit along the Lime Inlet on the west coast of Denmark.

Fig. 7. Sydhalen (Thyborøn).

The tubes were laid out on the west beach of the spit and thus face the east part of the southern Thyborøn barrier; the construction is not therefore in a very exposed position. (Fig. 7).

The structure is a 2 x 100 m prism arrangement with three 70 cm diameter tubes made of polypropylene tubes limed with impermeable plastic foil.

On the southern section the tubes are lashed together with ropes while on the northern section the two lower tubes are woven together. Later sand will be dozed up between the eroded dune and the structure.

The tubes were filled very succesfully by the hydraulic principle and had a very high filling degree, a level of about 90 % of the theoretical diameter being obtained.

In June 1970 the first 1 m diameter tube was laid out north of the harbour at the Skaw.

The effective height obtained was approx. 90 cm, the far end of the tube was positioned at a water depth of approx. 3.0 m.

It was build in an old landing stage, and accreted in a short while sand to a height varying from 0.20 cm at depth 1.50 cm to 1 m at the shore end.

Other projects have been carried out, and new are under preparation.

4 MATERIALS

Several types of polypropylene fabrics have been used for the skin of the tubes

White polypropylene very soon appeared to have an unsatisfactory resistance to the influence of ultraviolet sun rays, and the fibres of a black polypropylene monofilament had an unfortunate tendency to slide so the sand grains could be washed out

A woven black fabric, multiplex polypropylene splitfibre, seems to have solved most of these problems and has furthermore proved very resistant to icy conditions and to the effect of human activity, at bathing beaches for more than 1 year When the hydraulic filling method is used the skin is lined with an inner tube of plastic foil to obtain impermeability

Tubes with diameters of up to 1 0 m have been filled to lengths of up to 100 m and at water depts of up to - 3 m The filling material has been natural beach sand with mean grain diameters of about 0 25-0 50 mm A recent small test with hydraulic filling of a tube with a mixture of 1 part cement to 3 parts of sand has worked out well

CONCLUSIONS

On the basis of preliminary experiments conducted hitherto the following conclusions may be drawn

(1) Impermeable sand tubes can be filled above and under the water to almost any length by hydraulic pumping
(2) The selected type of fabric has demonstrated relatively good resistance to the forces acting in coastal environment
(3) The experiments have shown that sand tubes may be used with advantage to solve minor coast problems, as temporary structures and for prototype pilot tests because the sand tubes can be easily removed
(4) If sand tubes are protected from sunlight and from human activity their use may be of a permanent nature
(5) Many problems are still unsolved and the use of tubes is still in the development stage Work is in progress towards development of larger and more economical sizes of tubes

CHAPTER 93

THE PRESSURE OF FLOATING ICE-FIELDS ON PILES

by Joachim SCHWARZ[1)]

SYNOPSIS

In order to determine the maximum ice forces against structures, the compressive strength was investigated by laboratory tests on cubes of several ice species. The results contain the influence of temperature, velocity of deformation and direction of pressure on the cubic strength.

In order to employ these laboratory results for the calculation of structures, a relationship between the strength in laboratory tests and in nature was derived by measuring the pressure of floating ice-fields on a pile of a bridge, which crosses the tidal estuary of the EIDER River.

The investigation leads to an equation, which allows the calculation of ice pressure against piles.

INTRODUCTION

In cold regions the pressure of ice is decisive for the calculation of hydraulic structures. This pressure, however, is still unknown or just in development. It is therefore not surprising that in severe winters hydraulic structures will be destroyed by ice run.

In rivers the danger of ice pressure decreases with time, because the ice run in spring will be controlled by ice-breaker-

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A similar report was given by the author at the 1. Ice-Symposium of IAHR in Reykjavik, September 1970 ships and because the ice formation will be reduced by the heated water of power-stations.

In coastal regions there is no way of keeping the ice forces from structures and just in these locations the question of ice pressure becomes more and more important, for example by the offshore-construction of deep-water harbors, transloading-points for oil, light-houses and bridges.

Intensive ice research was started after World-War II., especially in USA, Canada and Russia with the investigation of fundamental properties of ice (6).

The problem of ice forces on structures has picked up during the last 10 years: KORZHAVIN (3, 1962) developed an equation to calculate the pressure of river ice in spring. This formula is based upon assumptions, which are only derived through laboratory tests. PEYTON (4, 1966) measured the ice pressure on the piles of a drilling-platform in Cook Inlet, Alaska. His qualitative results are in agreement with the investigations of the author. Some experimental work, carried out by oil companies (CROASDALE, 2, 1970) has not yet been published.

A general view about the present situation of research of ice pressure on structures was given by ASSUR (1, 1970) at the 1. Ice Symposium of IAHR, 8 - 10 September 1970 in Reykjavik.

GENERAL CONSIDERATION

The authors investigation (5, 1970) of the pressure of floating ice-fields on piles has been based on the assumption that the maximum pressure of ice is limited by its compressive strength. This strength was first of all ascertained in compression tests on cubes in order to determine systematically the different influences, such as temperature, velocity of deformation and direction of pressure. The received cubic strength can't be immediately employed for designing structures, because in nature the rupture of ice occurs in another way than in our laboratory tests. In nature the contact between ice and structure is, for example, smaller than in the experiments between ice cube and pressure plate. Moreover the shape, the width of the structure and the thickness of ice has an influence upon the strength.

Because the fundamental strength properties nevertheless should be utilized for calculating ice forces, it was necessary to derive a relationship between the strength in laboratory tests and in nature. This was done by measuring the ice-forces on a pile of a bridge.

LABORATORY TESTS

Strength properties were investigated by compression tests on ice-cubes from river, lake and harbor (fresh-water-ice) and from the North-Sea, Baltic-Sea and brackish-water (salt-water-ice).

The edge lengths of the cubes were 10 cm. The tests were performed at ice temperatures of 0°, -10° and -20° C in two different directions (perpendicular and parallel to the growth-direction). The velocity of deformation was varied from $S = 3 \cdot 10^{-3} \frac{1}{sec}$ to $S = 3 \cdot 10^{0} \frac{1}{sec}$. Plywood panels were placed between the cube area and the pressure plate, in order to average out the unevenness on the cube surface, so that the test results scattered only up to ±5 %.

RESULTS

1. By lowering the temperature, the strength of ice increases at a rate of about.

   $\alpha = 4{,}5$ kp/cm²°C with fresh-water-ice and

   $\alpha = 2{,}5$ kp/cm²°C with salt-water-ice.

   This strengthening is nearly linear down to -20° C. The lesser strength of salt-water-ice is attributed to the liquid brine cells within the ice.

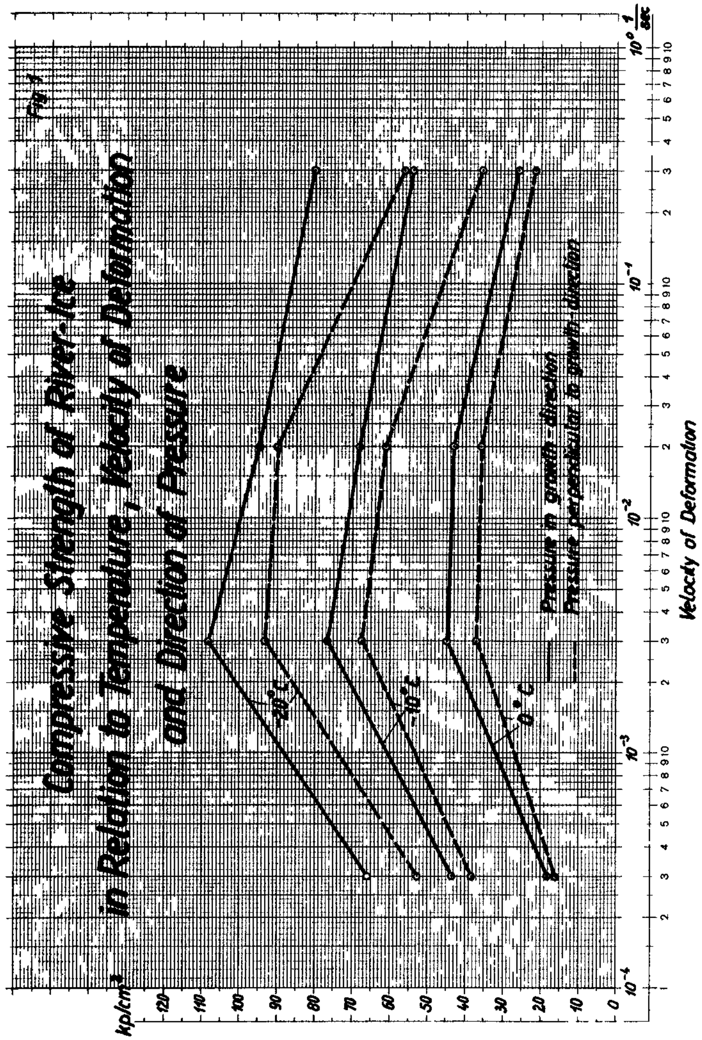
Fig 1
Compressive Strength of River-Ice
in Relation to Temperature, Velocity of Deformation
and Direction of Pressure
-20°C
-10°C
0°C
Pressure in growth-direction
Pressure perpendicular to growth-direction
kp/cm²
Velocity of Deformation

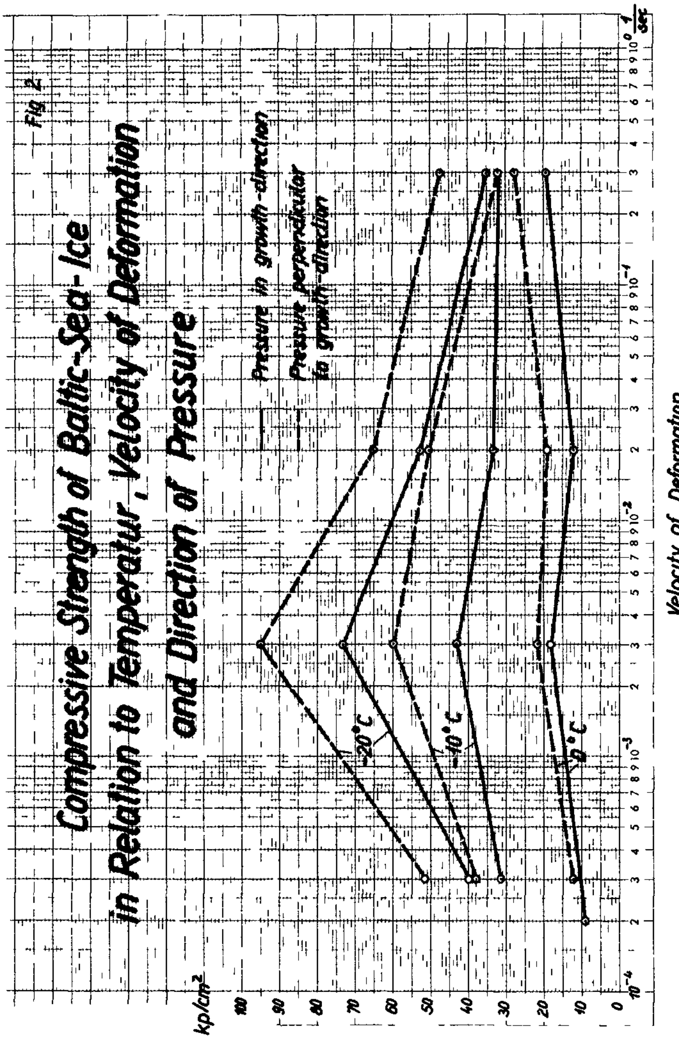
Fig. 2
Compressive Strength of Baltic-Sea-Ice
in Relation to Temperatur, Velocity of Deformation
and Direction of Pressure
Pressure in growth-direction
Pressure perpendicular
to growth-direction
-20°C
-10°C
0°C
kp/cm²
Velocity of Deformation