PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
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COMPARISON BETWEEN SPRAY AND SPLASH AT SOME TYPICAL PERMEABLE COASTAL STRUCTURES AND THE INFLUENCE OF ICE FLOES DEPOSITED ON THESE STRUCTURES ON SPRAY AND SPLASH QUANTITIES

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Abstract - This paper describes the results of some laboratory experiments and is fully empirical. It is published due to the practical interest which has been demonstrated in the results by engineers who build training walls and sea walls along lakes or on open shores in low temperature regions when spray and splash may result in ice covers.

TEST PROCEDURES

The following designs were investigated by laboratory experiments carried out partly at the St. Anthony Falls Laboratory, Minneapolis and partly at the Technical University of Norway. Model scale was 1:30. All figures refer to prototype values.

A) Straight rubble mound with a slope of 1 in 2, and block weight = 8 t.

B) Rubble mound with a berm. Lower slope 1 in 2 up to elevation 0.9 m above water level, slope of berm 1 in 5 up to elevation 2.7 m, then an upper slope 1 in 3 to elevation 6.0 m above water level. The total width of the design was ab. 33 m. Block weight was 8 t.

C) Vertical permeable crib design, consisting of a pile frame surrounded by netting and filled with blocks. Block weight was 3.8 t.

Common for the three designs was crest elevation = 6 m, depth at the toe of the structure = 6 m, and slope 1 in 5 from the toe of the structure at elevation 6 m below water level down to the bottom at elevation 9 m below water level.

Spray caused by wind and wave action was measured behind the three different designs with and without ice floes on the water surface. The tests were carried out in a 26 m wind-wave flume, cross-section was 0.6 m by 1.3 m. Wind flow was provided by a tunnel blower at the end of the flume. A piston type wave generator produced waves of varying period and amplitude. The wind velocity was measured by a V-tube manometer filled with alcohol placed in front of the structure. The velocity was found to be practically constant in the horizontal as well as the vertical cross-section. The wave height was measured at the toe of the breakwater slope.

Plastic spray collectors were placed behind the crest of the structures. The model ice consisted of wax floes with spesific weight = 0.92. Prototype thickness was 0.45 m (1.5 cm in model) 7-11 m^2 prototype floes (80-120 cm^2 in model). As the wave height varied from 3.0 m to 6.0 m, the ratio ice thickness/wave height varied from 0.15 to 0.08.

TEST RESULTS

Fig. 1 shows action by a 5.5 m, 12 sec prototype wave on a 1 in 2 rubble mound (St. Anthony Falls Laboratory, Minneapolis).

Fig. 2 shows action by a 5.5 m, 12 sec prototype wave on a crib (St. Anthony Falls Laboratory, Minneapolis).

Fig. 3 shows action by a 3.9 m, 7 sec prototype wave on a berm wall (Techn. Univ. of Norway).

Fig. 4 shows action by a 3.9 m, 7 sec prototype wave on a berm wall. The upper part of the uprush plunges against protruding blocks (Techn. Univ. of Norway).

Fig. 5 demonstrates the influence of ice floes deposited on a 1 in 2 rubble mound. Uprush height decreases, spray and splash increase. Wave height was 4.8 m, period 7 sec (Techn. Univ. of Norway).

Fig. 6 demonstrates the influence of ice floes on a berm wall (Fig. 3). The ice floes deposited on the berm increase spray and splash (Techn. Univ. of Norway).

The relative spray quantity Q/HL was plotted against the relative crest elevation h/H, where Q = quantity of spray per unit length of structure per hour, H = wave height, L = wave length and h = structures crest elevation.

The straight rubble mound

The results from tests on the straight rubble mound showed that this design was very sensitive to variations of h/H. It may be seen from Fig. 7 that the relative spray quantity Q/HL increased with decreasing h/H. Waves with steepness ratio κ = H/L = 0.08 gave more spray than waves with κ = 0.04, when the relative crest elevation h/H>ca. 1.2, and vice versa, when h/H<ca. 1.2.

As it may be seen from Fig. 8, the test results with ice floes on the water surface showed too much scatter to justify any conclusions. The tendency, however, was that ice floes increased the relative spray quantity by 50-100%. In this connection it must be noted that the ice floes (ab. 100 wax floes) had a slight damping effect on the waves as most of them were concentrated in the breaking zone. Some of them were deposited on the slope.

The berm wall

The results from tests on the berm wall (Fig. 9) showed that Q/HL was nearly independent of variations in h/H within the range h/H = ca. 1.0-2.0. Waves with steepness κ = 0.08 caused more spray than waves with κ = 0.04 when the ratio h/H>ca. 1.2, and vice verca for h/H<ca. 1.2. Tests with ice floes on the water surface (Fig. 10) showed almost the same scatter as the corresponding tests with the straight rubble mound. Also in this case ice increased the relative spray quantity by 50-100%.

The crib

Fig. 11 shows results from tests on the crib. The results show that it is very sensitive to variations in h/H. The relative spray quantity Q/HL increased with decreasing h/H.

Ice floes on the water surface decreased the relative spray quantity by more than 50%, a result of the damping effect by the ice, which had no possibilities for depositing on the structure.

COMPARISON BETWEEN THE DESIGNS

Tests without floes. With relative crest elevation h/H < ca. 1.5 (H/h>ca. 0.7), the berm wall was most favourable with respect to spray. The straight rubble mound caused more spray than the berm wall and the difference increased with decreasing h/H. The crib was the least favourable of the three designs.

When the relative crest elevation $h/H >$ ca. 1.5 ($H/h <$ ca. 0.7), the difference between the three designs was not significant (of the order of the scatter). The tendency was however, that the crib was the most favourable design, next the straight rubble mound. The berm wall was the most unfavourable with respect to spray quantity. This may be seen on Fig. 12 which represents another series of tests.

Tests with ice floes on the water

As mentioned above these results were very scattered. The ice, however, increased spray by 50-100% on the two rubble mounds, while it decreased spray on the crib. The total result therefore was that the relative spray quantity behind the three designs did not differ significantly with ice floes on the water surface.

Acknowledgement - The authors want to express their appreciation to Howard, Needles, Tammen and Bergendoff, Consulting Engineers, Minneapolis, for permission to use Figs. 1 and 2 of report by the St. Anthony Falls Laboratory in this paper. Reference is made to paper by Mr. Bernard H. Rottinghaus, partner H.N.T.B. printed in these proceedings.

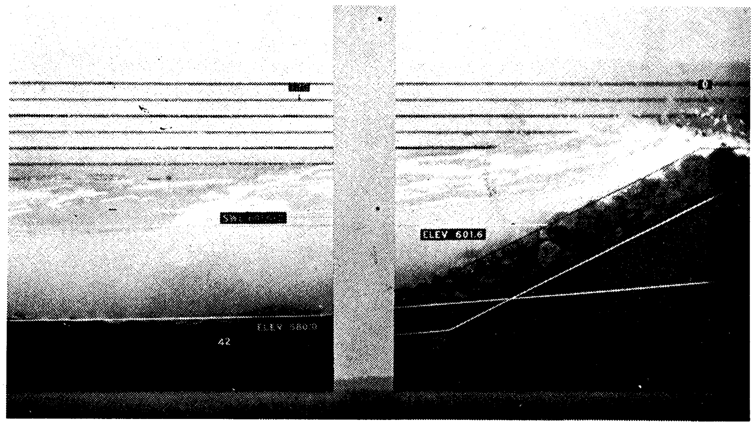

Fig. 1. Uprush on a 1:2 rubble mound by prototype waves 5.5 m, 12 sec.
(St. Anthony Falls Lab., Minneapolis).

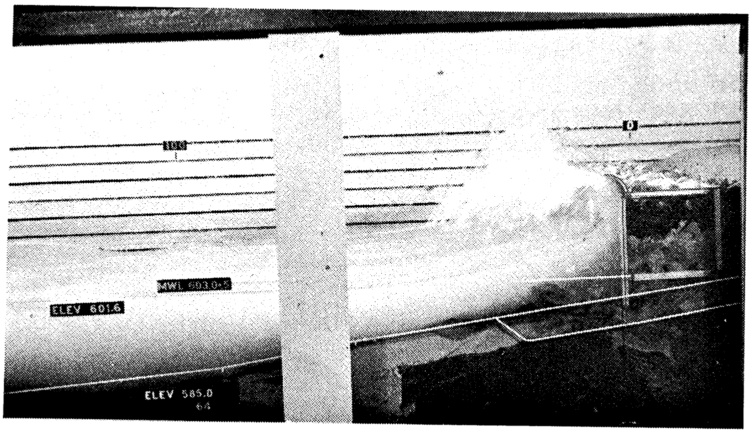

Fig. 2. Action by 5.5 m, 12 sec prototype wave on a crib.
(St. Anthony Falls Lab., Minneapolis).

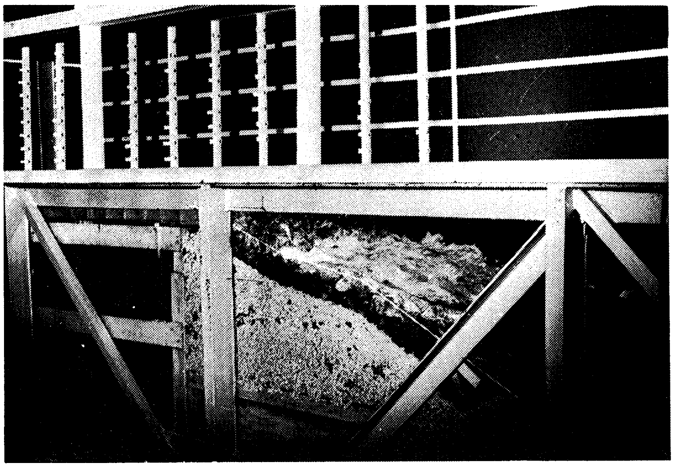

Fig. 3. Action by 3.9 m, 7 sec prototype wave on a berm wall.
(Techn. Univ. of Norway).

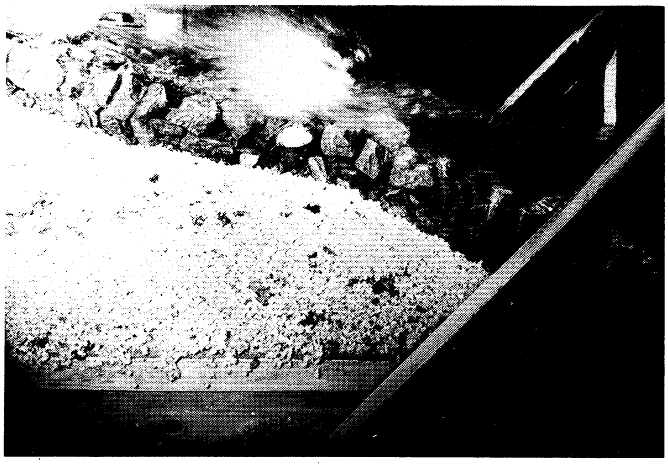

Fig. 4. Action by 3.9 m, 7 sec prototype wave on a berm wall.
(Techn. Univ. of Norway).

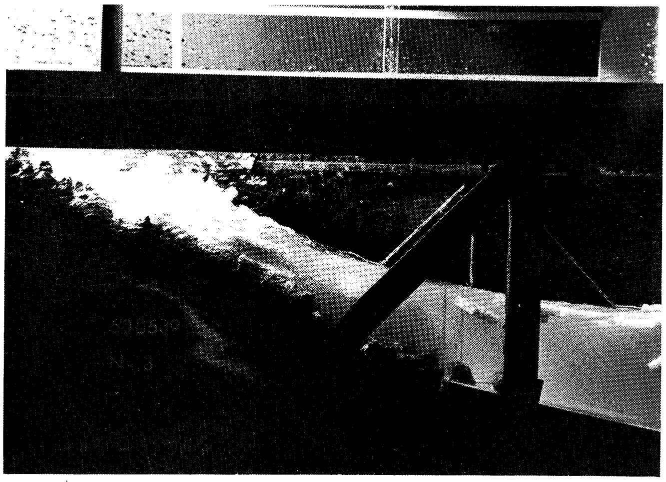

Fig. 5. Influence of ice floes deposited on a 1 in 2 rubble mound on spray and splash. (Techn. Univ. of Norway).

Fig. 6. Influence of ice floes deposited on a berm wall (Fig. 4) on spray. (Techn. Univ. of Norway).

FIG. 7 . RELATIVE SPRAY VERSUS RELATIVE CREST ELEVATION FOR THE STRAIGHT RUBBLE MOUND.
WITHOUT ICE FLOES ON THE WATER SURFACE.

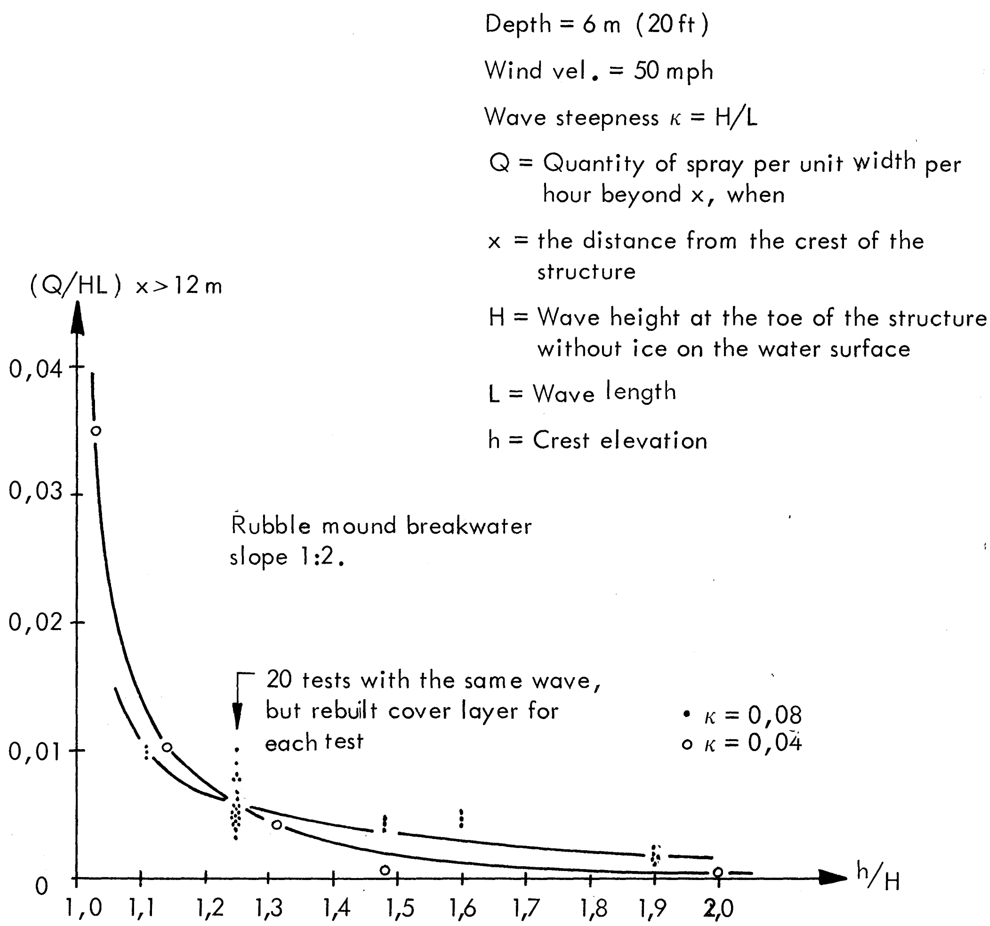

FIG. 8. RELATIVE SPRAY VERSUS RELATIVE CREST ELEVATION FOR THE STRAIGHT RUBBLE MOUND.
WITH ICE FLOES ON THE WATER SURFACE.

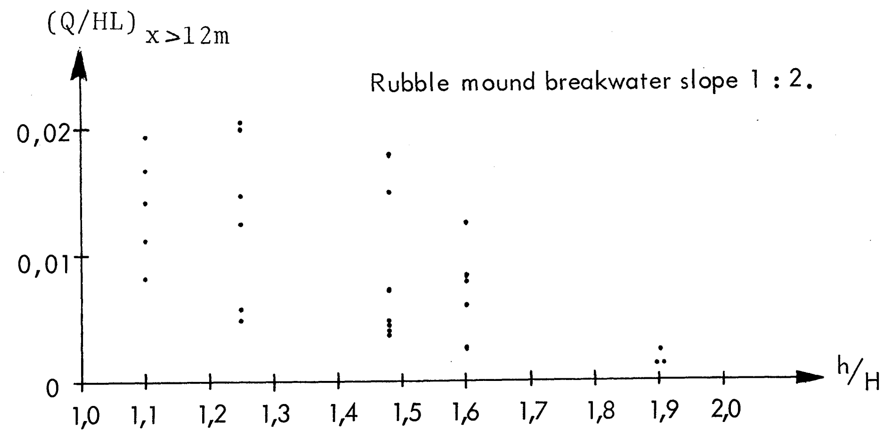

FIG. 9. RELATIVE SPRAY VERSUS RELATIVE CREST ELEVATION FOR THE BERM WALL.
WITHOUT ICE FLOES ON THE WATER SURFACE.

Depth = 6,0 m (20 ft)

Wind vel. = 50 mph

Wave steepness = κ = H/L

Q = Quantity of spray per unit width per hour beyond x, when

x = the distance from the crest of the structure

H = Wave height at the toe of the structure without ice on the water surface

L = Wave length

h = Crest elevation

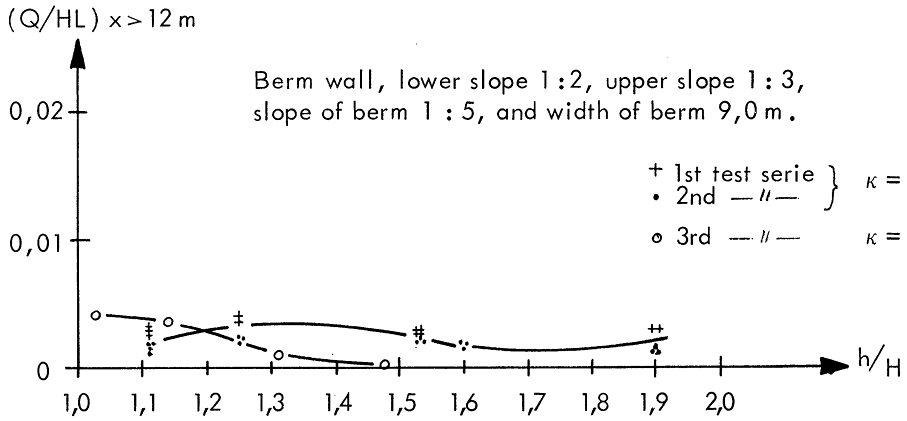

FIG. 10. RELATIVE SPRAY VERSUS RELATIVE CREST ELEVATION FOR THE BERM WALL.
WITH ICE FLOES ON THE WATER SURFACE.

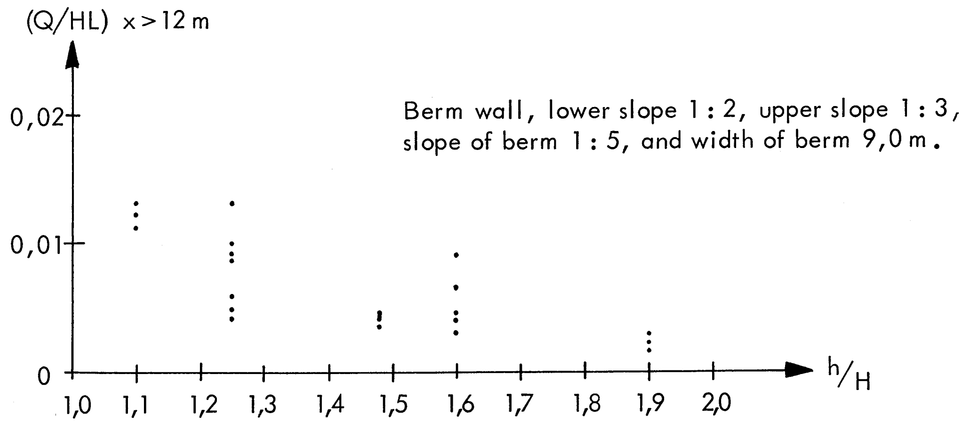

FIG. 11 RELATIVE SPRAY VERSUS RELATIVE CREST ELEVATION FOR THE CRIB DESIGN. WITH AND WITHOUT ICE FLOES ON THE WATER SURFACE.

Wave steepness = κ = H/L ≈ 0,08

— — — Tests with ice floes on water surface

——— Tests without ice floes on the water surface

Q = Quantity of spray per unitwidth per hour beyond x, when

x = the distance from the crest of the structure

H = Wave height without ice on the water surface

L = Wave length

h = Crest elevation

St.A.F. = St. Anthony Falls Laboratory

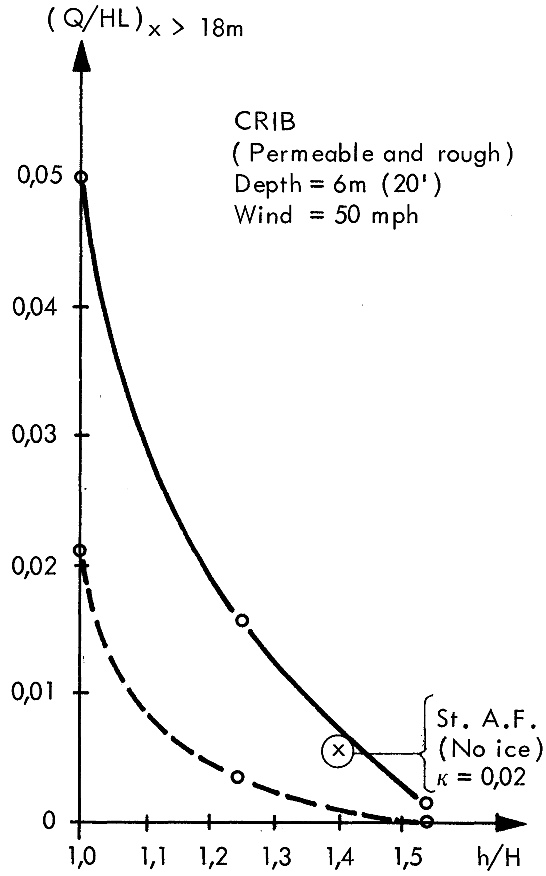

FIG. 12 RELATIVE SPRAY VERSUS RELATIVE CREST ELEVATION FOR DIFFERENT DESIGNS.

Wave steepness = κ = H/L 0,08

——— Tests without ice floes on the water surface

R.M. = Rubble mound slope 1 : 2
B.W. = Berm vall, lower slope 1 : 2, upper slope 1 : 3, slope of berm 1 : 5, and width of berm 9,0 m.

Q = Quantity of spray per unitwidth per hour beyond x, when

x = the distance from the crest of the structure

H = Wave height

L = Wave length

h = Crest elevation