DEVELOPMENT OF SEA ICE CONSTRUCTION TECHNIQUES

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In man's effort to develop the Arctic and Antarctic, it has been found to his advantage to utilize ice and snow to their ultimate in accomplishing his construction needs. Considerable study, therefore, has gone into the development of the natural ice sheet towards this goal.

The U. S. Naval Civil Engineering Laboratory first started to develop a technique for increasing the strength of the natural ice sheet in 1950-51. These early trials were conducted for two consecutive seasons in the vicinity of Point Barrow, Alaska. The first season saw construction of an ice pad 150 by 400 feet. It was located in a sheltered pass between Elson Lagoon and the Arctic Ocean. During the second season, a 160 by 3000 foot ice block was constructed on the floating ice sheet off the coast from the Point Barrow military encampment. Each season the ice sheet was thickened at a considerably faster rate than that taking place through natural growth. Using control flooding, salt water was pumped from beneath the ice sheet and confined within diked areas. Construction of these ice blocks was performed in 3-inch lifts of flood water. A freezing period was allowed between each lift. Using this construction technique, the ice was thickened on the average of 10 feet during each of these seasons.

Many of the basic data collected during these trials were used to form the basis in planning a new series of trials in 1959. These trials were also conducted off the coast of Point Barrow. Location of the test site was approximately 3000 feet off shore on a relatively smooth portion of the floating ice sheet, lying between the first and second pressure ridges. At the start of the two-month trial period, the ice sheet was approximately 3 1/2 feet thick; at the conclusion, through natural growth, it had increased 8 to 10 inches.

The principal piece of construction equipment was a pump wanigan. It housed a 1000-GPM pump rated at 135 ft head. To augment special pumping needs, smaller pumps were on hand. The flood water was delivered to the selected areas through 2 1/2-inch hose lines.

Greater experimental emphasis was placed on these trials than had been the previous case, and as a result the pads constructed were smaller in size but greater in number. Basically, three techniques for ice production were studied. Ice was produced in pads constructed by ponding sea water within confined areas, by spray and sprinkler flooding, and by a technique termed free flooding in which the water is ponded but not confined to a specific area.

Confined Surface Flooding Technique

Construction by ponding the flood water within confined areas requires dikes for retaining the water. These dikes were constructed of cheesecloth and coated with

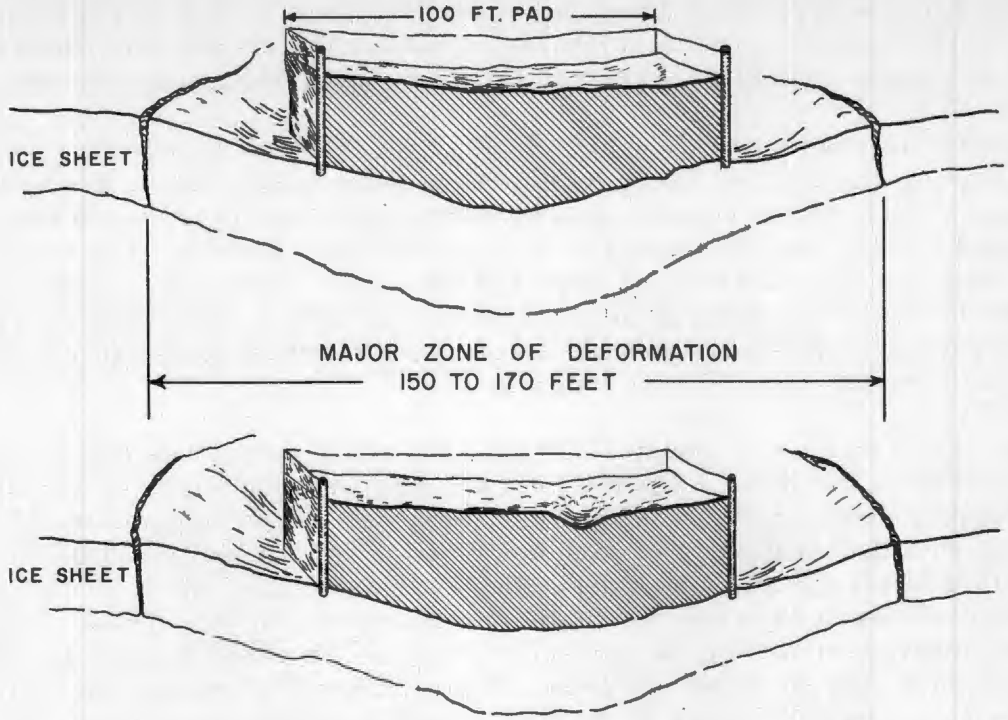

Fig. 1. Typical profiles through 100-foot square test pads. Shaded areas depict flood ice.

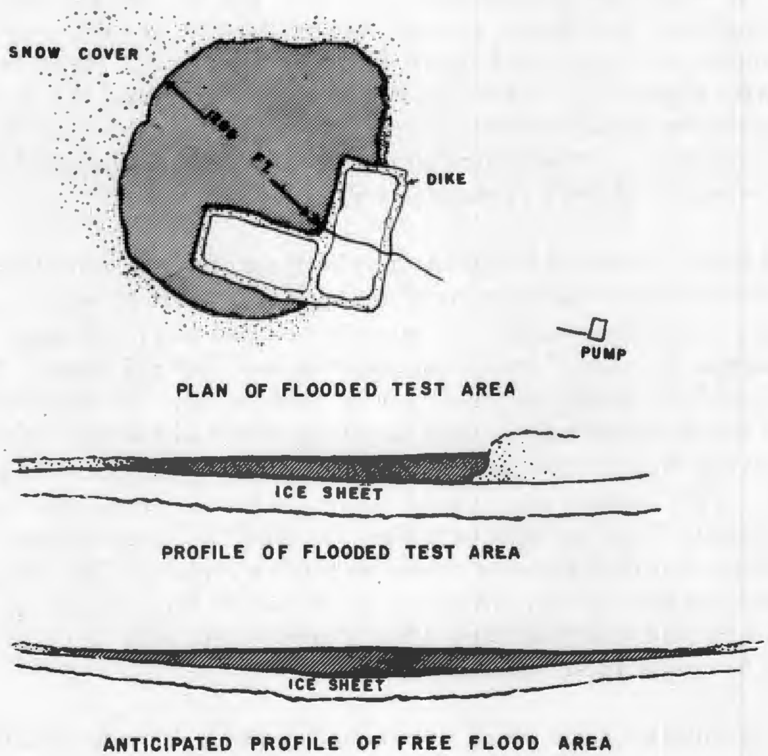

Fig. 2. Free flooding test area plan and profile. Shaded areas depict flood ice.

ice from water spray. This dike, with a wall thickness of 3/8 to 1/2 inch, gave satisfactory performance if air temperatures remained below freezing. However, the amount of construction effort required for this type of dike handicaps the operation.

Six pads 100 feet square and one circular pad 300 feet in diameter were constructed using cheesecloth diking to retain the flood water. Since during the two previous trials a 3-inch construction increment had been used, two additional, a 5-inch and a 7-inch, were selected to gain comparative results. The build-up of ice on the pads was achieved through repeated floodings. Two square pads were constructed in each of the three flood increments while the circular pad received only 3-inch floodings. The average build-up of ice on all of the pads ranged from 2 to 4 feet at the completion of the test program.

The major problem encountered during the construction was that of maintaining a flat surface on the pad. After the first two or three floodings, saucer-like depressions were found to develop in the central area of the pad. This deformation of the surface continued with the application of each new flood layer. In analyzing the condition, plastic flow of the ice sheet best describes what was taking place. This sinking could have been the result of cracks developing in the under surface of the ice sheet under the pad; however, there was no evidence to support this theory since the only cracks observed were outside of the pad area. A profile taken of the ice after each pad was completed indicated the under surface had developed an inverted dome shape. In the depressed areas, the thickness of the ice build-up was found to be 30 to 50 percent greater than near the edge of the pad. This surface deflection or deformation was believed caused by a combination of the static load of the flood water and a temperature rise in the ice sheet. Thermocouples placed in the ice sheet indicated the temperature at some locations within the cross-section had been increased as much as 25 degrees Fahrenheit from that recorded prior to flooding. However, if one accounts for the temperature rise had the natural ice sheet achieved the same total thickness as that of the built-up area, and had it occurred under the same boundary temperatures, then the average temperature rise resulting from the surface flooding would be in the neighborhood of only 10 degrees F.

To effect a better control over the surface flatness in constructing the final three square pads, the point for measuring the depth of the flood water was relocated. In the earlier pads, the flood depth had been measured near the edge of the pad; however, in this latter group, the point was relocated to the central area. This method essentially reduced both the static and heat loads as now only the depressed area would receive the full flood increment. The depth of the flood water near the edge of the pads which received the 3-inch and 5-inch floodings averaged only half that of their central portion. Throughout the construction of these pads, the depression that developed after each flooding was between one and two inches deep. Occasionally in a localized area it would deepen to three and four inches. The two pads constructed by the first method which received the 3-inch and 5-inch floodings had average depressions of 5 inches and 6 inches when completed; and in localized areas, the depression was 9 and 10 inches deep.

Two 100-foot square pads were constructed using 7-inch floodings. This depth of flooding was found to exaggerate the surface irregularity. To illustrate that deep flood increments can be a real source of trouble, on one occasion when a 9-inch flooding was accidentally made, the resulting surface depression after the layer had

Fig. 3. Scene of test area. Cheesecloth diking is seen in foreground. Dark area in background is free-flooding test site.

Fig. 4. Aerial view of test site. Square pads are 100 ft X 100 ft. Circular pad is 300 ft in diameter.

frozen was between 16 and 17 inches. Needless to say, it took several shallow floodings to build the depressed area up before the entire surface could again be flooded.

The deflection of the natural ice sheet surrounding the pads was found to be maximum next to the pad--occurring at the center of the side dimension. At this location, the ice sheet had deflected on the average of 12 inches below a point some 35 feet out. If this point is considered on the circumference of a circle with the pad at its center, then the major deflection caused by the pad will have occurred within this area. This was further evidenced by the circular crack pattern that developed in the ice sheet, around four of the square pads, at about this same location. Such cracks were the result of a stress relief from the negative moment (tension top fibers). At no time did visible radial cracks develop from the center of the pad. This would have indicated danger of failure in the ice sheet. Some deflection of the ice sheet was measured as far as 250 to 300 feet from the pads. There was some indication that in this general area there was a reverse deflection (point of inflection) as some elevations beyond were measured to be less. No circumferential cracks developed around the circular pad.

Tests performed to determine the physical properties of the ice produced by the three flood depths indicated there was no real difference in the strength or salinity. However, the ice produced by 3-inch floodings appeared to have a more uniform cross section. The flood-produced ice was found to have about 50 percent less compressive strength than the natural ice. This comparison is made between uncured flood ice and relatively young natural ice. Vertical test holes, both 9 and 12 inches in diameter, drilled through the flood layer of four of the pads, indicated the presence of unfrozen brine. This solution would start draining almost as soon as the hole was opened. From a limited study of the feasibility of brine removal, it was estimated that the inflow from some of the more productive holes was six to eight gallons per hour. That the solution was a highly concentrated brine was indicated by the fact that during an over-night period when the air temperatures were as low as -29°F, it would not freeze in the hole.

The fastest construction rate for building up the ice thickness appears to be accomplished by the 3-inch floodings. However, the length of set-up time required between floodings for producing the best quality ice is still an area needing considerable future study. The final solution to this problem should be a calculation in degree days of frost, coupled with some factor for wind effect. In this year's operation, the average set-up time allowed between floodings was 24 hours for the 3-inch lifts, 48 hours for the 5-inch lifts, and 72 hours for the 7-inch lifts. It should also be pointed out that in speaking of ice produced by some specified flood depth, that the ice produced will show a wide variation from the actual water depth.

Spray and Sprinkler Technique of Producing Ice

These trials were of a brief duration. In the spray and sprinkler technique, fire hose spray nozzles and rotating sprinkler (Rainbird) were used to produce the ice. The structure of this ice was found to differ considerably from that produced by surface flooding. This ice was formed of very small round crystallites, giving it an opaque or milky appearance.

The ice formed by the spray method was produced in banks ranging up to 2 feet deep. For this work, the spray nozzle was elevated about 4 feet above the surface and pointed so that the discharge spray had a slight elevation. An effort was made to produce fresher ice by removing some of the unfrozen brine solution. This was done by drilling holes in the ice sheet and allowing it to drain back into the ocean. This technique, however, did not prove effective in lowering the salinity of the ice even though the runoff water had a higher brine content than natural sea water. Tests showed there was a considerable variation in the salinity throughout the cross-section, indicating the higher brine concentration was settling to the bottom layer before solidification of the mass.

The sprinkler equipment produced ice very similar to that produced by the spray technique in the central section of its distribution pattern. This was due to the faster rate of build-up and lower projection of the spray resulting in less heat removed by the air. Beyond this area, the ice surface took on a characteristic of small interlaced globular-shaped particles, indicating the water was in a more nearly frozen state before settling to the surface. The salinity of the ice was found to be more consistent throughout the cross-section at this location.

Densities of the ice produced by both the spray and sprinkler methods averaged about 7 percent less than natural ice. This figure, however, was derived from a wide scatter in density measurements. Strength tests indicated this ice had a slightly better tensile strength than the flood-produced ice but a weaker compressive strength.

Free Flooding Technique

In an effort to simplify ice construction by surface flooding, the technique of free flooding was experimented with. In this technique, no dikes are required since the flood water is allowed to establish its own distribution pattern. In theory, the built-up ice mass produced would be circular in shape if the flood water is discharged from the central point of the intended build-up area. This assumes the natural ice sheet is reasonably level at the start. Also, as illustrated from the previous surface flooding trials, the thickest section of ice build-up would occur at the central part of the area. If both were true, then the build-up mass would be circular in plan and have a wedge or lens-shaped cross-section. This has been considered as probably the most ideally shaped ice structure.

To evaluate the feasibility of this theory, an area of the natural ice was selected adjacent to the initial test site. This area was located within a reasonable hose run from the pumping station and had previously constructed dikes lying between it and the pump. Such dikes were necessary to prevent the flood from over-running the pump station. Though this would limit the flow to only a sector of the expected circular pattern, it was felt to be sufficient to demonstrate the feasibility of the technique.

A construction increment of 3 to 4 inches was tentatively selected since this had produced the best results during previous surface flooding. Another criterion established was that the flood water would always be discharged from the same point. This left only one other immediate unknown to the criteria, how to determine when the proper flood depth had been reached. This determination was made through general observation of the actual water distribution. It was found that the flooding operation could be continued as long as the water depth at the discharge point stabilized at 3 to 5 inches. The longer the pumping operation, of course, the wider the distribution pattern. In this year's trials, an effort was made continually to widen the distribution pattern. There is a tendency for the water to pile up in the central part of the flood pattern. This can be attributed to the constant retarding of the water flow at the outer reaches of the pattern due to freezing of this thinner layer. It can be seen from this that there will be a sort of balance established between the individual flood depth and the corresponding air temperature. It is not yet known but speculated that this may produce the best quality ice, since on the warmer days when it is more difficult to freeze the water, the layer will automatically be thinner. Flooding of the selected area by this technique was observed for only seven lifts of approximately 4 inches each. At the completion of the operation, the build-up pattern was a sector of a circular area having a radius of about 280 feet. A profile of the built-up ice mass, as expected, had assumed a wedge-shape with the thickest part occurring at the point of water discharge. At this location, the total ice thickness was measured to be 79 inches, while near the outer fringe of the pattern it varied between 63 and 68 inches. The actual build-up was about 31 inches at the thick section and 15 to 18 inches at the thin section. Surface elevations indicated a differential from the high point, located at the thickest cross-section, to the lowest, located at the thin section, of 1 1/2 to 2 inches. From this, it was apparent that the wedge effect was developing along the under surface as a result of a gentle sinking of the ice sheet.

This flooded area was much like that of any snow-free part of the natural ice sheet in appearance. In this operation the snow was not removed from the area before flooding, and, as a result, there was a smooth transition from the ice to the snow surface.

Though this trial period was too brief to formulate definite conclusions, the results do indicate the technique has considerable promise. None of the construction problems that were experienced by confining the flood water occurred in this technique of flooding.

Summary

In summing up, since it does not appear likely that a technique can be developed which will duplicate the natural process of ice growth, the technique developed for producing this artificially-formed ice will have to cope with the problems bypassed in the natural process.

Present data indicate that to accomplish a major thickening of an ice sheet, the technique of surface flooding has the best prospect for success. The successful development of this technique will have to be achieved through a series of experimental adjustments until the ice produced has the best combination of physical properties and construction characteristics. It is within this overlapping area of engineering and science where most of this development will take place.

This year's trials indicate that (1) thinner flood layers, approximately 3 inches deep, produce a slightly better quality ice with fewer construction problems than the deeper flood increments, and (2) the technique of free flooding appears feasible and potentially offers many advantages over present surface flooding techniques. It is within this scope of thought that immediate future trials are being planned.