PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
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ICE BREAKAGE WITH EXPLOSIVES

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Breakup of ice with the use of explosives as the breaking medium is as old as the use of explosives themselves. In general, little research outside special laboratories has been done to bring this method of ice breaking into the realm of practicality. The state of training of most persons dealing with explosives, especially in the United States, precludes a truly scientific approach to the problems involved, and too often ice breaking is assumed to be of much the same complexity as breaking rock for quarry or highway blasting.

While it is true that ice breaking can be accomplished economically with the use of explosives, the actual structure of ice does not allow for the same procedures as rock breakage.

There are any number of areas in which blasting can be used for ice breaking. Among these are:
Breakup of ice in channels into ports, for deep and shallow draft vessels.
Ice breakup in frozen areas, for water intake and outlet systems.
Ice breakup in rivers to prevent flooding in areas behind ice formations.
Breakup of ice to allow ships to navigate in ice locked areas.

All of these present the same basic problems, and can be approached in much the same manner.

Current procedures call for explosives charges to be laid on the ice, or loaded into the ice after drilling. These result in breakage and cracking immediately around the charges, but little actual displacement.

Actual displacement is necessary to effectively break up ice in any form other than very thin sheets. This displacement cannot be successfully obtained, as it is in rock, with low velocity, high gas production explosives. On the other hand, ice is brittle and light, which in rock would call for a very high order velocity, with density of explosive irrelevant. The use of such explosives, (including all forms of military and commercial explosives, ranging from the famous "Plastic" explosive "C-4", to liquid explosives such as that made by my own parent company called "Astrolite",) does not perform in ice as would normally be expected when one considers that Astrolite has velocities in excess of 8000 meters per second.

Experimentation has shown that the type explosive used for displacement of ice is unimportant vis a vis other considerations. The first of these is the thickness of the ice. Beyond a certain point of thickness, and density, a factor of weight becomes extremely important, though its exact effect can only be determined by experimentation. Whenever the thickness of ice exceeds six feet, an explosive with high gas producing properties is absolutely necessary.

In determining the factors necessary to break up large areas of ice, one factor is paramount. Displacement of the ice, in total, must occur, and must occur over a large area, all at the same time. Placement of the charges in or on top of the ice causes only a radial breakage, and camoflots of cracking from area of charge to area of charge. The ice, by its very nature brittle and cohesive, will not break up.

In compression the ice will withstand tremendous forces, and distribution of the weight, or forces, will tend to increase the ability of the ice to withstand these forces. Just as a person standing on thin ice will break through, and a person stretched out on ice, with weight distribution, can traverse it, so the explosive charge laid on the surface will break through the ice, but will not effect surrounding areas. Displacement of the ice under tension is then obviously necessary.

The method of displacement is relatively simple. Charges placed in the water, at a depth sufficient to lift the water and transmit the shock waves attended upon a detonation in the water, will displace ice throughout the entire area of the blast. Thus, instead of the shattering and "throw" normally associated with ice breakup, a lifting action is applied, in such force as to reduce the ice to small pieces, and return it to the surface of the water. Breakup occurs through three phases. First the cracking due to shock fronts supplied by the initial detonating wave as it travels through the relatively incompressable water. Second, through the lift generated by the upheaval of the water after venting of the bubble formed by the expanding gases, and last, due to breakup upon re-entering or hitting the water on the way down from the initial lift by the water.

Though the idea is simplicity itself, the actual physics remains somewhat speculative. In theory, and it would appear in practice, a detonation in water causes a shock front to travel throughout the water, with a decreasing amplitude and frequency as the waves travel out from the epicenter of the blast. At the same time, though slightly behind, a gas bubble is generated. This bubble is formed by expanding gases from the rapid change of chemicals into a gaseous state. The bubble will form to a volume of approximately 110 to 150 times the volume of the original container of explosives, depending upon the chemistry inherent in the explosives used. Thus, if a one cubic foot charge of explosives with a density of 1.4 were detonated, the resultant gas production would be approximately 110 cubic feet, and a bubble of approximately 3/4 of that volume would be formed, provided the pressures exceed the actual pressure of the water in atmospheres.

If the charge is set near or on the surface, no bubble would form, and the immediate effect would be a venting of all gases to the surface, with a resultant loss of lift from the force of the water which is necessary to break the ice formations.

When charges are placed directly beneath the ice, or immediately beneath the ice cap, little more effect can be expected than if the charges were placed in boreholes drilled for the purpose of placing explosives. The effect of the detonating wave and resultant tensile, or reflected and rerafracted waves would act much as if the charges were placed beneath a ledge of rock, such as slate. Immediate cracking and violent throw would occur, with a definite cratering effect apparent. In short, a large hole would be blown in the ice in the immediate vicinity of the charge.

As the charge is lowered into the ice water beneath the ice, greater effect from a given size charge will be realized, until that point of maximum effect is reached. Beyond this point diminishing returns are realized until, at great depths for minimal charges, no actual lift of the water can or will occur.

Charge size is not the only consideration. Obviously, the thickness of the ice is equally important. Both factors must be considered before calculation can be made.

There appears to be empirical data concerning thickness of ice, size of charge, and depth of placement. Experimental data shows that charges should be placed twice the distance into the water as the thickness of the ice. Thus, five feet of ice can be broken when charges are placed ten feet into the water, or a total of 15 feet beneath the surface of the ice. Charge weight should equal twice the distance of the charge from the surface, or as above, thirty pounds, placed every thirty feet will give excellent breakage of ice. Fairly good breakage will occur in a channel of thirty feet in width. Beyond that point diminishing results will be encountered.

There must of course be allowances made for different types of circumstances, and there is little to suggest that more than approximately fifteen feet of ice can be broken and scattered with a sub-surface charge.

All charges should be fired instantaneously, so as to gain the maximum effect from the movement of water. Delayed charges will probably be displaced by earlier charges. In circumstances where delayed charges have been anchored, (a time consuming and costly operation), little or no appreciable advantage was gained.

Thick ice, in excess of four or five feet will require that holes be punched through the ice to place charges. These can easily be obtained with a simple "Shaped" charge. It is not necessary to use a precast shaped charge utilizing the "Munore Effect" of a jet and slug. Any cone of explosives, with a bottom diameter twice the height of the coe, detonated from the apex of the cone will give the desired results. The weight of these charges should equal the thickness in feet. Thus, a six pound charge will give excellent results through six feet of ice.

Charges can be lowered to the required depth, or the bottom, whichever is encountered first, with the addition of fishing weights, or other heavy objects tied to the bottom of the charge. Where currents are running and may move the charges out of position, a quick mathematical calculation can determine how much additional length of supporting line must be added to the charge to bring it to proper depth.

All charges can be lowered on "Prima-Cord", which is a strong, reinforced detonating fuse. The actual technique of tieing in and placing charges deserves little place in the paper. This is a matter of procedure, and can be done by almost anyone familiar with the normal tools and equipment of blasting operations.

In summary, experimentation has shown that different concepts of blasting must be used when dealing with ice break up. Shattering effective explosives will not necessarily give desired results. Water heave, and bubble collapse are the key features in Ice Blasting, except in massive formations, where standard drilling and blasting are more liable to be used.

Ports and sea lanes now closed to shipping for many months of the year can, with careful planning and foresight be made accessible with the intelligent and advanced use of explosives. "Sleeper" charges could be placed during open water months, with detonation reserved until necessary. These would be absolutely safe until needed, and could even be replaced from time to time as circumstances dictate. Further, present technology could well supply fail safe detonation methods and loading methods to keep ports and shipping lanes permanently available to supply goods and services to those areas which now do without them for long, cold periods of time.