US Army Corps of Engineers

DESIGNING SMALL-BOAT HARBORS FOR ICE CONDITIONS

INTRODUCTION

Each winter, ice damages thousands of small-boat harbors throughout the U.S., both in saltwater and freshwater areas. Ice can lift piles completely out of harbor bottoms, and ice can shove harbor structures off their foundations. Millions of dollars of damage is done each winter, ranging from large losses to minor problems that require repair each year. Everyone connected with small-boat harbors should be aware of the problems ice can cause. And new harbors should be designed and built to control ice's harmful effects.

This pamphlet is not technical, and it will acquaint vou with the problem and several remedies. Sources for further information and help are given at the end. We will begin bv discussing what ice is and what forms it takes.

ICE TYPES

ice is a natural material; however, unlike many materlals, ice exists only part of the time and takes many forms. The differing types of ice are the results of how it was formed and what has happened to it since. Things like temperature, snowfall, sunshine, wind, water level changes, waves and man's actions (ice breaking) all influence how ice forms.

Clear, transparent ice results from slow freezing of calm water bodies, such as ponds or small lakes. This type is called "black ice."

When snow on top of ice becomes saturated by water and then freezes, a milky-colored ice forms. This type of ice is known as "snow ice." Another type of milky ice is formed when air bubbles are trapped in the ice during very rapid freezing. Black ice and snow ice are quite strong.

When ice is broken into pieces by waves or anything else, "brash ice" is formed. The broken pieces can be like flat plates or semi-rounded boulders, and they can refreeze together forming a rough, highly irregular ice cover that can be very strong.

in the spring, as the ice begins to melt, a very weak type of ice forms. Although "candled ice" may be quite thick, it has little strength and is dangerous; you can't walk on it. It is made up of vertical, oblong pieces that are loosely joined to each other.

The temperature of ice affects its strength. Warm weather heats an ice cover on a body of water; snow on the ice will insulate it. Once the ice begins to warm up towards its melting temperature, it will lose strength. On the other hand, a cold spell will strengthen an ice cover. A rapid cold snap will cause the ice to shrink and crack.

Saltwater ice is generally weaker than freshwater ice because pockets of salty brine water get trapped along the crvstal boundaries. Cold sea ice with less salt can be nearIy as strong as freshwater ice.

These are the main types of ice that can form in small-boat harbors. The next factor is the harbor itself.

Broken ice in a marina

HARBOR ENVIRONMENT

Environmental factors are one key for designing marinas to decrease ice problems. A small-boat harbor is constructed on submerged land that is sheltered from the open expanse of a lake, river or sea. We build structures to support the harbor's docks and piers, and ice is just another part of the natural environment that we must adjust to.

The climate of the site and its geology are two of the many factors that you must consider. A small-boat harbor must be designed quite specifically for a particular site. The most important factor, however, is the severity of the winter, characterized by accumulated freezing degree-days, by storm frequencies and by snowfalls.

A freezing degree-day is the amount that the average temperature for a given day is below 32°F, the freezing temperature of water. For example, if the average daily temperature was 17°F, the value would be 32°F minus 17°F or 15 freezing degree-days. These are summed up during the winter months and indicate how "cold" or severe the winter is. The larger this sum is, the more ice you can expect, and presumably, the more problems you face.

You should be aware of water level changes. Water levels fluctuate because of tides, river stages, storms and seiching. Seiches, where the water in the lake basin sloshes back and forth, happen on large lakes such as the Great Lakes because of storms, high winds and barometric pressure changes. This motion produces water level changes, and when an ice cover is present it will move up and down. Piles that are frozen into a moving ice cover may be pulled from the harbor bottom if they are not embedded deeply enough.

Pile uplift

Other factors that vary from place to place and must be thought about in the design include water depths and temperatures, harbor orientation and shape, and bottom conditions. For example, if the harbor is deep, You may choose floating docks because long piles are expensive.

Harbor water temperatures are not the same everywhere. Some things that cause temperatures to vary are harbor bottom springs, water currents, storm mixing, warm water discharges, solar radiation and snow cover. If the water is warm, vou may choose docks that are designed to be ice free by using one of the thermal de-icing methods (to be discussed later). If the water is very cold (within a fraction of a degree of freezing) deicing probabIy won’t work.

The near-surface geology of the harbor bottom is verv important to the choice of docks. An engineering analysis of the harbor bottom by soll borings and tests is recommended. Without good subsurface information, docks and piles may not survive the winter.

After vou have discovered what your harbor’s environment is like, you must pick a type of dock and protect vour docks from ice damage.

Fixed dock structure

HARBOR DESIGN

Choosing docks

Your choices are fixed structures, floating structures and movable or removable structures. Fixed structures are either placed on the bottom of the harbor or are driven into the bottom. Timber poles or piles made of steel or concrete may be used to support horizontal decks and walks. They are driven deeply enough into the bottom to resist ice forces that could either push them over or pull them out. Occasionally, they are wrapped or coated so that the ice can’t stick to them and pull them out. Gravity structures rest on the bottom and are stable because of their weight and size. Examples include sand and rock-filled steel and timber cribs, and stone rubble-mound breakwaters.

Usually, a harbor uses floating docks when the bottom is unsuitable for piles or cribs, when water levels fluctuate over wide ranges, or when you want removable docks.

The most common type of floating structure is the pontoon-supported marine dock. The pontoons are made of polyethylene, aluminum, galvanized steel, wood, Fiberglas, concrete and other materials, and are filled with a foam. They must be anchored to the bottom and shore. If the docks are to remain in place all year round, they must be completely detached from their anchors because ice movements could damage both the docks and the anchors.

Movable docks can be taken out of the water during the winter or are designed to move a certain amount while in the ice; for example, there are telescoping piles that permit up and down motion. Another example, finger docks, have hinges along their lengths and at their shore connections with bulkheads and can be rotated up and back on to the shore with a construction crane for the winter.

Crib

Floating docks

Stored docks

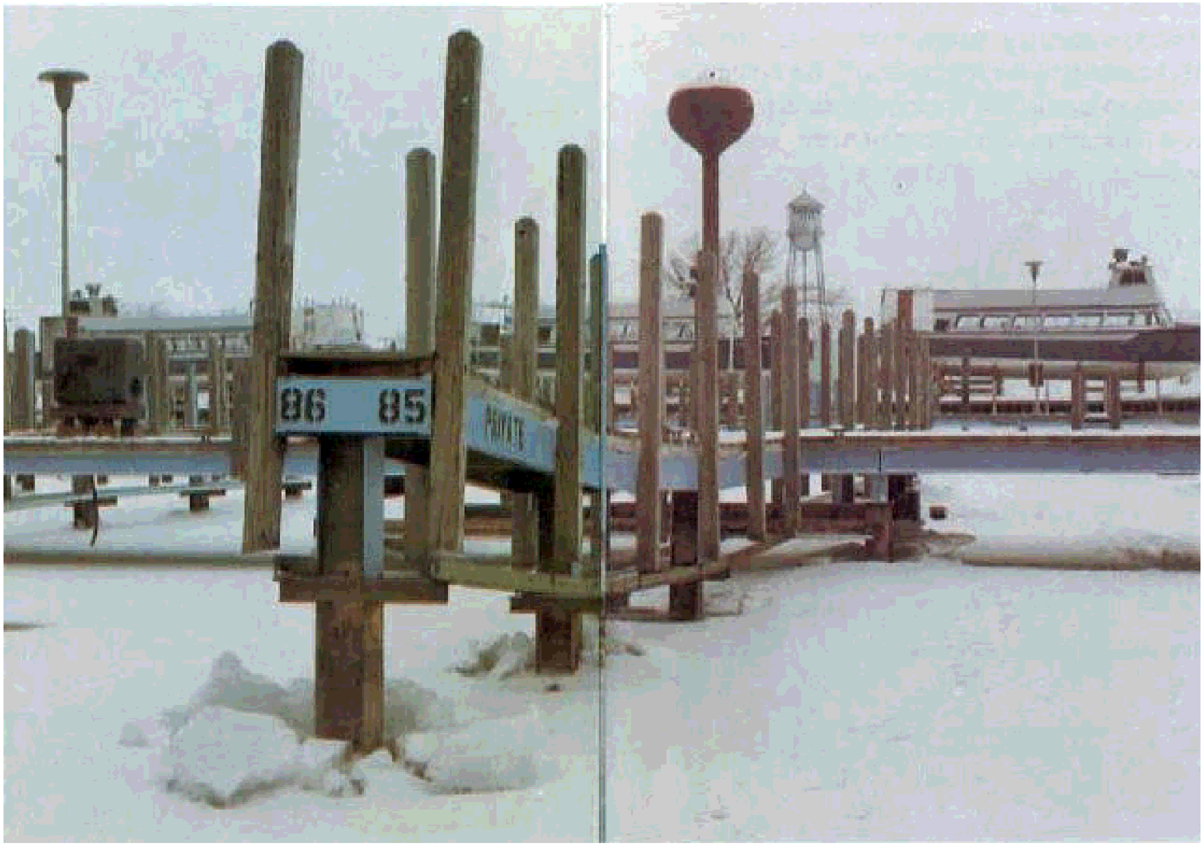
Hinge pier

Protecting docks from ice forces

Estimating the horizontal and vertical ice forces is, at this time, uncertain. We know and can expect that there will be vertical forces from water level fluctuations, and varying horizontal forces from shifting ice and from ice sheet expansion.

Vertical forces on individual harbor piles can be tens of thousands of pounds (both up and down), depending on the thickness and strength of the ice, the size of the piles, the strength with which the ice grips the pile, how close one pile is to another and other factors.

Reducing the surface areas that ice can grip is one design strategy. This can be done by using piles that are narrow at the water surface where the ice grows, using fewer piles by increasing the span of the deck joists, or using piles that are very strong and narrow.



Pile uplift

We know that isolated piles around the edges of the docks experience larger lifting forces than those that are in the more protected center. The central piles share the ice forces with other piles, and through this group sharing, receive less. Therefore, a proper design strategy for isolated piles would be to drive them deeper than other piles. This is an exceptionally effective method if the site geology is amenable to it. On most sites, however, there is a limited depth to which a pile can be driven. Fortunately, on many sites a careful soil investigation will disclose an acceptable soil deposit where the piles can be driven deep.

Ice will expand when warmed. Horizontal forces are produced by this expansion and can range from a few hundred to a few thousand pounds on single, free-standing piles. Expanding ice will move towards open water areas or up sloping shorelines, so you should expect high horizontal forces at sites where the ice is known to move.

The probability of damage from wind-driven ice can be reduced by carefully planning the layout of the marina. If, for example, the entrances to harbors are sheltered, ice from the main water body won’t be as likely to enter the harbor. In the case of an open entrance, an ice control structure (to be discussed later) could be installed during the ice season to intercept the incoming ice.

In addition to exerting forces on harbor structures, ice can be very abrasive or very "rough" on structures, especially wood piles. Fibers from the piles’ surface are peeled away with repeated ice contacts, so much so that the cross-sectional area and therefore the strength of the piles at water level are greatly reduced. Paints and coatings on steel and concrete pilings will be easily stripped through this type of abrasion.

Wood abrasion

Floating docks that are left in the water all winter are threatened by shifting and moving ice. The individual dock members will be torn and abraded and somewhat "groundup" by the ice pieces. When docks are left floating in the ice, they must be free to move with the ice; the dock design must allow them to be disconnected from shore anchors and piles. Not to do so invites damage from ice movement. Docks designed to remain in the ice should also be articulated for flexiblilty to accommodate ice motions, and to aid in replacing damaged sections.

Dock damage

It is sometimes possible to stabilize the ice in harbors through the use of ice booms and other measures, but generally, if the ice movements are from storms and water level fluctuations, not much can be done. In harbors where there is very little vertical or horizontal ice movement, floating clocks do well.

The design to be used will be one that recognizes these forces and actions. The basic design strategies must alleviate and reduce the ice forces.

Floating tire breakwater

Controlling ice

Previously, we have described ice problems and some ways to install marine structures to combat these problems. There are, however, ways of weakening the ice, controlling or guiding its movement, and protective devices that can be used on existing structures.

if a structure can be kept ice free, it won’t have to bear any vertical or horizontal ice loads. Compressed air bubbling systems are an effective way to suppress ice. Compressed air is released from small nozzles on distribution lines run on or near the bottom. The rising, buoyant air bubbles bring up the warmer bottom waters, which, depending on water and air temperatures and the volume of air released, either reduce the ice thickness or maintain open water areas. Bubblers can be used on individual piles or over large areas.

Propellers or pumps are sometimes used to move water and melt ice around structures to be protected. At many locations, warm water from industrial plants or even groundwater is available and can be used to melt ice. To be effective, this water must be brought to the ice surface. There are also other ice protection techniques that are less expensive than bubblers, which consume energy. A low-adhesion material can be placed around wooden piles. Coatings for steel and concrete piles have been partially successful in reducing ice adhesion; however, the coating must be renewed every year.

Horizontal ice forces can be controlled by placing clusters of piles or filled cribs in areas exposed to wind or current-driven ice pieces. These ice-intercepting structures must be placed in strategic locations to satisfactorily control the moving ice.

Ice booms can also be used to stabilize marina ice and to shield docks from moving ice. Booms can be constructed from timbers, used tires and other materials. In tidal areas, booms are used to guide ice past structures.

Horizontal ice forces can also result from expanding stationary ice, as was mentioned earlier. The resulting pressures can be reduced or eliminated by making zones of weakness within the ice sheets, either by freezing soft materials into the ice or bv cutting slots.

Pile protected by bubbler

Pile wrapping

SUMMARY

Before planning marina facilities, you should observe site ice conditions for a few years, then decide which ice protection measures and design approaches should be used. Some areas, like many small lakes, have so little vertical ice movement that uplift damage is not a problem. Some sites are completely protected from horizontal ice movement. This pamphlet gives you a background on many of the problems and what to look for.

For additional help with your marina, check other sources for aid. Specialized consulting engineering firms and contractors may have good field experience. Many states have Waterways Commissions or other agencies that have gained valuable experience through their construction and regulatory activities. Universities with Sea Grant Programs, in particular the University of Wisconsin at Madison, may have practical information for you. Finally, the U.S. Army Corps of Engineers in your area can be of help, and you may call on the U.S. Army Cold Regions Research and Engineering Laboratory.

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