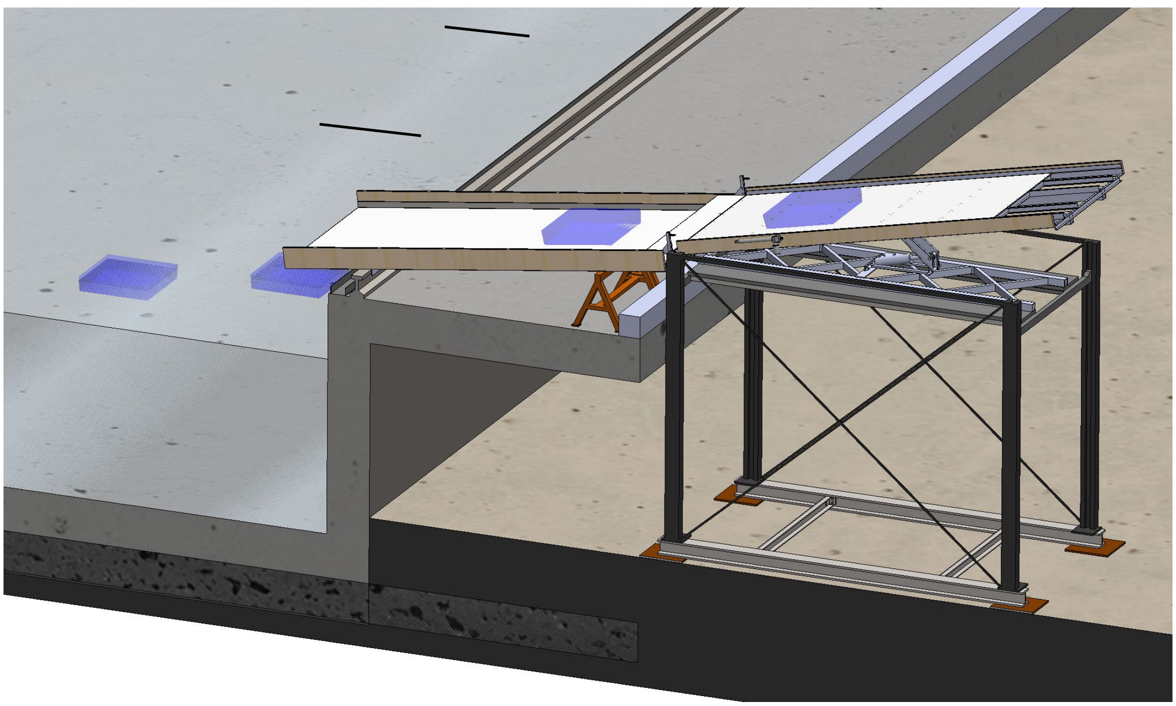
Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division

Enhancements to Ohmsett's Testing Capabilities in a Drift Ice Environment

Final Report

January 2024



(Photo: Applied Research Associates)

Leonard Zabilansky, P.E

US Department of the Interior
Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division

Enhancements to Ohmsett' s Testing Capabilities in a Drift Ice Environment

Final Report

OSRR # 1144

January 2024

Author:
Leonard Zabilansky
Applied Research Associates / Ohmsett

Prepared under 140E0122F0097
Task Order# T171-089
By
Applied Research Associates (ARA)
4300 San Mateo Blvd. NE, Suite A-220
Albuquerque, NM 87110

US Department of the Interior
Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division

DISCLAIMER

Contracts:

Study concept, oversight, and funding were provided by the US Department of the Interior (DOI), Bureau of Safety and Environmental Enforcement (BSEE), Oil Spill Preparedness Division (OSPD), Sterling, VA, under Contract Number 140E0122F0097. This report has been technically reviewed by BSEE, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

The PDF file for this report is available through the following sources. Click on the URL and enter the appropriate search term to locate the PDF:

Document Source	Search Term	URL
Bureau of Safety and Environmental Enforcement (BSEE)	Project Number – **1144**	Enhancements to Ohmsett's Testing Capabilities in a Drift Ice Environment | Bureau of Safety and Environmental Enforcement (bsee.gov)
U.S. Department of the Interior Library	Enhancements to Ohmsett's Testing Capabilities in a Drift Ice Environment."	https://library.doi.gov
National Technical Reports Library	Enhancements to Ohmsett's Testing Capabilities in a Drift Ice Environment."	https://ntrl.ntis.gov/NTRL/

Sources: a) BSEE (2023), b) DOI [2021], c) National Technical Information Service (2021)

CITATION

Zabilansky, Leonard. 2024. Enhancements to Ohmsett' s Testing Capabilities in a Drift Ice Environment. U.S. Department of the Interior, Bureau of Safety and Environmental Enforcement. Report No.: 1144. Contract No: 140E0122F0097.

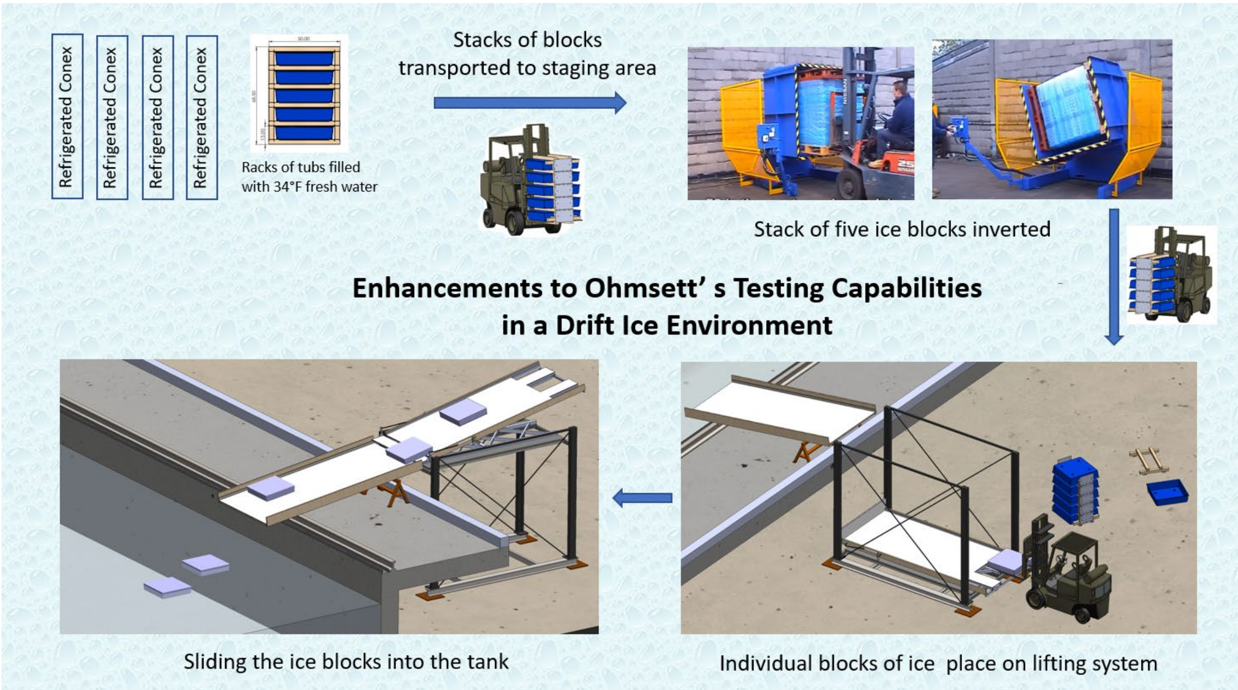
ABOUT THE COVER

Ice Blocks are lifted from the staging area in the parking lot and into the tank using the lifting and sliding system depicted on the cover. Ice blocks are loaded on the tilting slide at the lower level then lifted to the elevation of the tank. The tailgate is lowered to bridge the gap between the slides before sloping the tilting slide and sliding the ice into the tank. (ARA)

ACKNOWLEDGEMENTS

Author would like to thank the Ohmsett team and BSEE staff for their valuable input during the development of the conceptual design, and Sarah Corniea of the ARA Rocky Mountain Division (RMD) for her technical illustrations and drawings that were used to convey the design to shareholders and fabricators.

GRAPHICAL ABSTRACT



EXECUTIVE SUMMARY

Evaluation of oil recovery techniques in broken ice is one of the capabilities at the Ohmsett facility; however, the process of generating ice fields has been historically labor intensive. The objective of this project was to develop a system that could economically manufacture meter by meter ice blocks that are 20-cm thick used to prepare a brash ice field for testing. The project was divided into the following components: manufacturing the ice, rental equipment needed for the test, and the investment in Ohmsett equipment. Manufacturing ice blocks required custom bins to use as forms for the ice blocks. The bins were designed and manufactured using the thermoforming processing technique where heated plastic sheets are pulled into a mold using a vacuum. A racking system of subcomponents was designed that could be quickly assembled to support five bins per stack as the ice froze in the refrigerated Conex boxes. Fourteen stacks were used to freeze 70 blocks of ice in a 20-foot-long refrigerated Conex box. To minimize the refrigeration load, a package refrigeration system with a glycol-water heat exchanger was specified to chill the water used to fill the bins. Components for the bin racks were designed for compact storage during the off-season in Conex boxes. Refrigerated Conex boxes for freezing the water and a pallet inverter to invert the rack of five ice bins were rented for the respective test. The ice management system was designed to move the ice blocks from the staging area in the parking lot and into the tank included a commercially available car lift to lift a tilting slide with the ice payload to the elevation of the tank. Above the elevation of the tank, a tailgate on the tilting slide was lowered to bridge the gap between the tilting and stationary slide with a fixed slope on the west deck of the tank. While tilting the bed, the ice slid across the tailgate and down the stationary slide into the tank. For corrosion control, the slide weldments were galvanized and HPDE sheets were attached to the bed of the slides to increase the ability of the ice blocks to slide. The systems designed for the manufacturing and managing the ice to build the ice field in the tank has enhanced the drift ice testing capabilities of the Ohmsett facility. The methodology is more energy efficient, less labor intensive, and has a short cycle time to manufacture the ice in a safer environment for on-site personal. These improvements to Ohmsett capabilities will allow multiple ice testing programs during a winter. This report also includes the estimated cost of each component and discusses manufacturing sea ice and frazil ice.

Table of Contents

Enhancements to Ohmsett’ s Testing Capabilities in a Drift Ice Environment

1 BACKGROUND

Evaluating oil spill recovery equipment in ice-infested waters at Ohmsett requires creating ice fields with a normal distribution of ice fragments. Historically, one-meter by one-meter ice blocks were harvested from a large, refrigerated tank at the Cold Regions Research and Engineering Laboratory (CRREL) and transported to Ohmsett. The CRREL ice tank, however, is no longer operational. As an alternative, a system to freeze ice blocks using plastic-lined wooden ice forms in refrigerated Conex boxes at Ohmsett was developed. This was a labor-intensive process where the wooden forms had to be constructed, lined with plastic, and filled with water. Once the water froze, the wooden forms were disassembled, and the plastic removed from the ice before lifting the ice blocks into the tank. The wooden forms retained moisture, adding to the refrigeration load as well as insulating the water, prolonging the freezing process.

To streamline the ice management process, the Ohmsett staff developed various ice scenarios with optimization of each process and the interaction between processes using the metrics of cost, safety, manpower, simplicity, resilience, and longevity. The ice management process was divided into the following steps.

1.1 Manufacturing the ice blocks with the following subcomponents

a. Custom-made plastic bins as ice forms
b. Stacking system for the bins in the refrigerated Conex box without compromising air circulation
c. Layout of the stacks in the refrigerated Conex boxes
d. Filling the bins with chilled water to reduce refrigeration load
e. Partitioning the blocks for half and quarter fragments
f. Storing components and equipment in the off-season

1.2 Ice processing including the following steps

a Transporting the blocks to a lifting station
b Inverting the ice blocks
c Lifting the ice blocks from the staging area and into the tank using the following assemblies: tilting slide, vertical lift system, hydraulic system to tilt the slide, and stationary deck slide.

The process within each step is described below.

2 MANUFACTURING THE ICE

2.1 Custom-made Plastic Bins as Ice Molds

An extensive search was conducted to determine if 1-meter by 1-meter bins were available. Nothing was found to be commercially available, and research efforts focused on manufacturing custom bins. Various molding techniques were evaluated including blow molding, rotational molding, and thermoforming, using 500 bins as the delivered quantity. Thermal vacuuming forming was determined to be the most cost-effective for the limited quantity required. In the thermal molding process, the parent plastic sheet is heated to an elastic state before being set on an aluminum mold. A vacuum is used to pull the warm plastic to the profile of the mold. Once the plastic is cooled, excess material is trimmed.

Ohmsett engineering staff discussed the application with thermal plastic manufacturers to capitalize on their manufacturing expertise for designing cost-effective plastic bins. The design process was iterative with the final design shown in Figure 1 having the following features.

- Top edge curved to add rigidity to the side panels
- Dimples on the bottom to provide the unidirectional registration with the supporting framework
- Chamfering the bottom corner to avoid excessive thinning in the forming process
- Parent material ¼-inch thick sheet

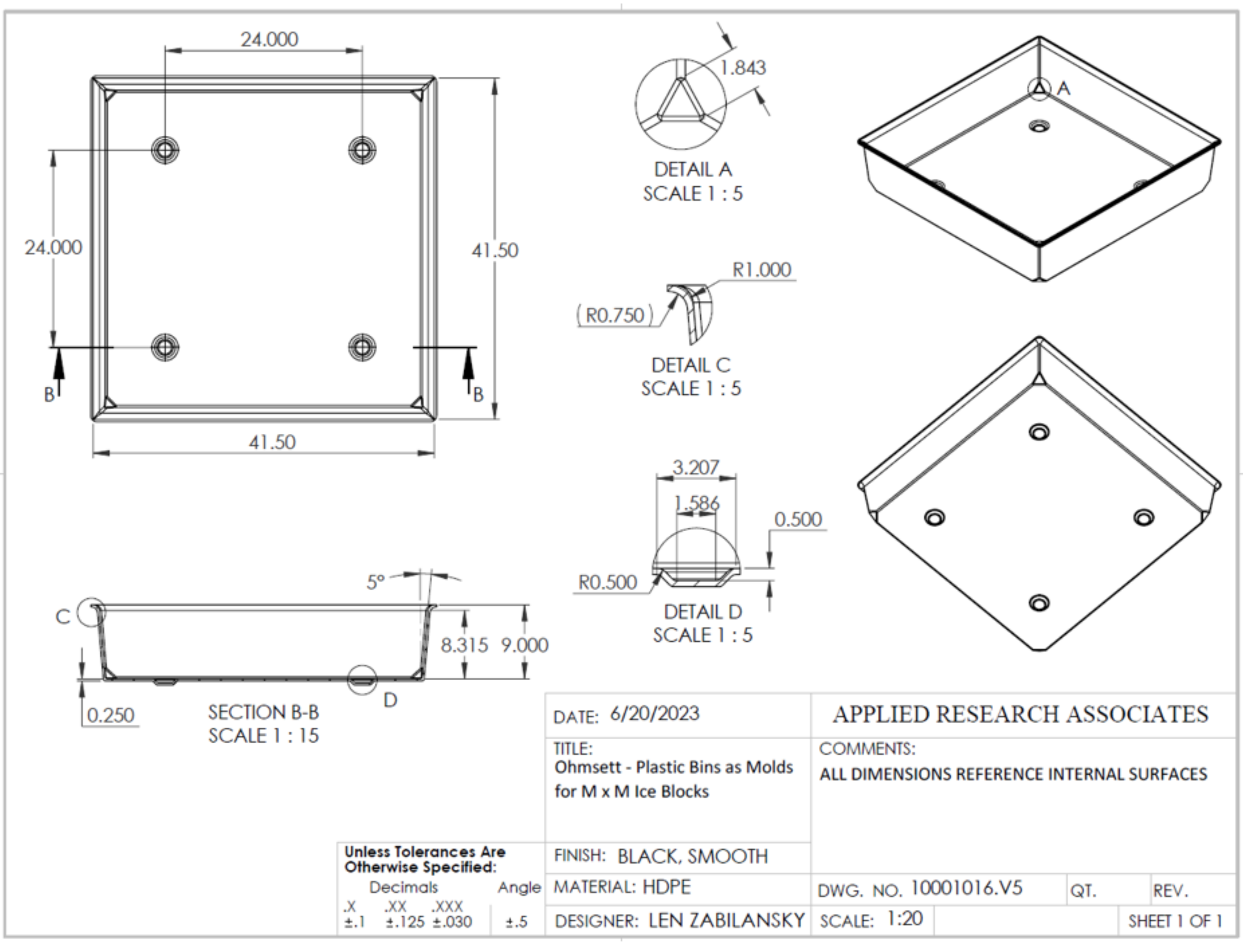


Fig. 1 Design of the 1 meter by 1 meter plastic bins formed using a thermoforming process.

Two plastics were suggested for the ¼-inch parent material: High Density Polyethylene (HDPE) and High Impact Polystyrene (HIPS) with the respective material properties shown in Figure 2 from Ref 1.

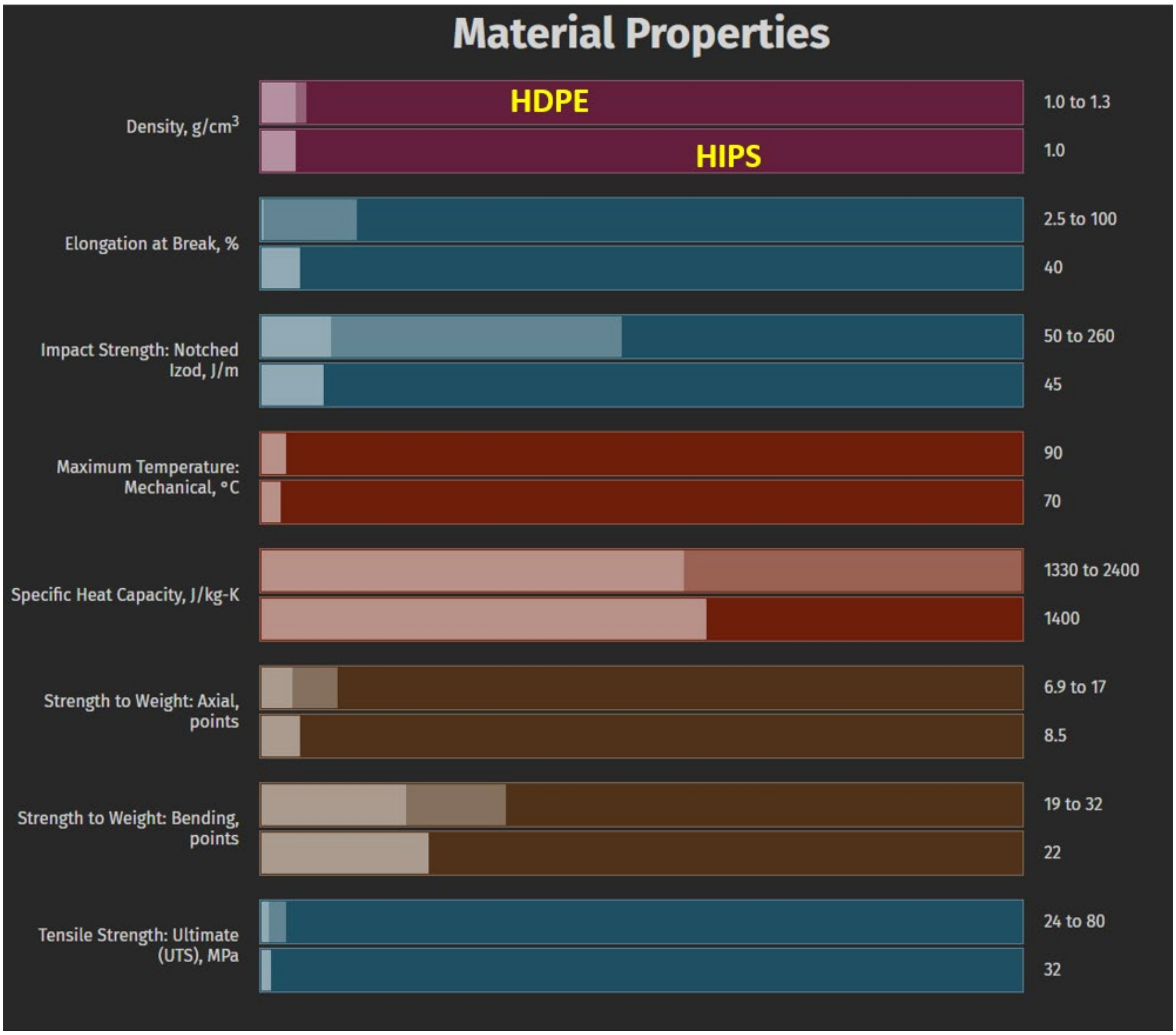


Fig. 2 Material properties of HDPE and HIPS

HDPE material was selected based on the impact strength. This material is typically used to manufacture large trash barrels. HDPE is in the polyolefin family of materials, and is a semi-crystalline thermoplastic material, with a continuous use temperature range of -50° F (-46° C) to 180° F (82° C). It is categorized as a standard material and offers high impact strength, high chemical resistance, and very low water absorption (Ref https://www.polymershapes.com/product/high-density-polyethylene-hdpe/).

To evaluate using plastic molds to create the ice, commercially available plastic mortar tubs were used in previous ice tests to freeze small ice blocks. The tubs were robust with minimal ice adhesion as the ice slid out as the bins were rotated vertically, as noted in Figure 3.

Fig. 3 **Ice blocks slide out of the plastic mortar bins as they are rotated vertically**

Most outdoor trash cans are HDPE and despite taking a beating, they have a long service life. The proposed bins are more durable than the trash cans and combined with limited usage and protection from UV light degradation in the off-season, they should last ten to fifteen years, disregarding handling damage.

2.2 Stacking System

Designing the stack system was also an iterative process with multiple brainstorming sessions with the Ohmsett staff. Each stacking system was evaluated using the following criteria: 1) ease of use, 2) price, 3) ability to forklift a stack of bins, and 4) ease of storing components. Figure 4 shows an expanded view of the final design, with the primary components being 4x4 lumber to support the bins, 2-inch x 6-inch (2x6s) wooden blocking, and aluminum bracing plates for the end panels. The ends of the 4x4s have wood/machine studs with a wing nut to connect the end panels for stability.

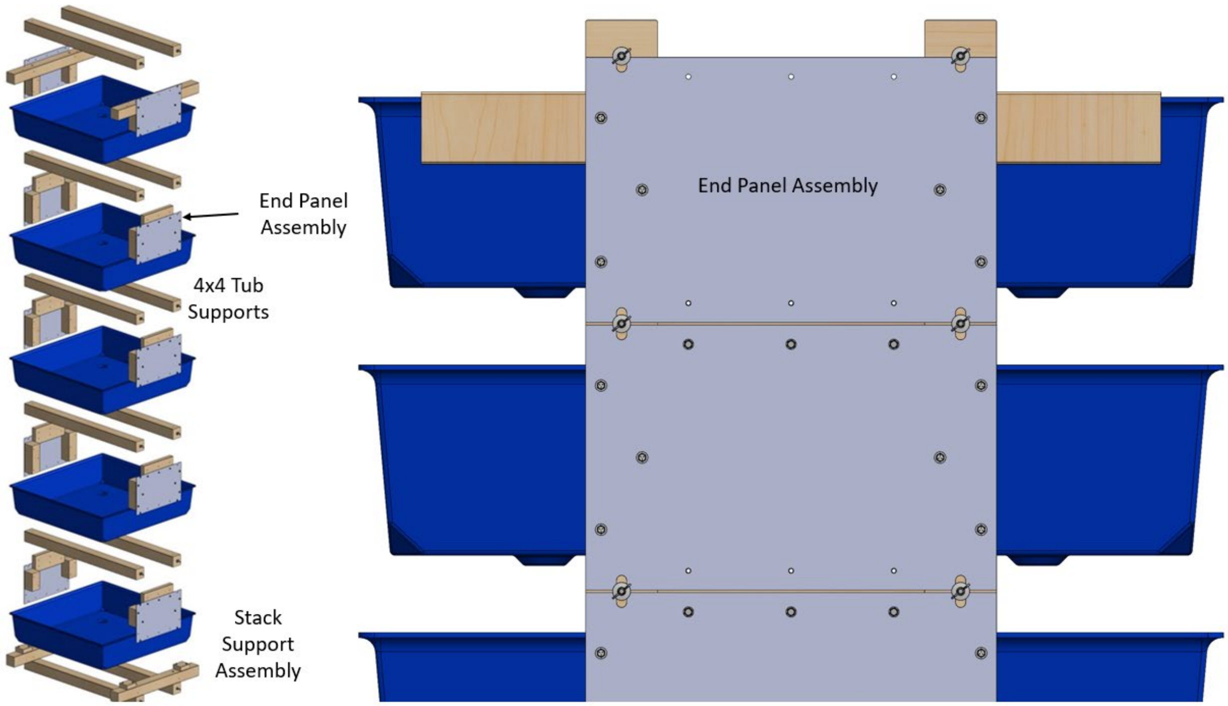


Fig. 4 Exploded view of the stacking system

2.3 Layout of the stacks in the refrigerated Conex boxes

Each stack is limited to five bins to allow air circulation above the stack of bins. Fourteen stacks are configured in two columns in a refrigerated Conex box to freeze up to 70 ice blocks per cycle, Figure 5.

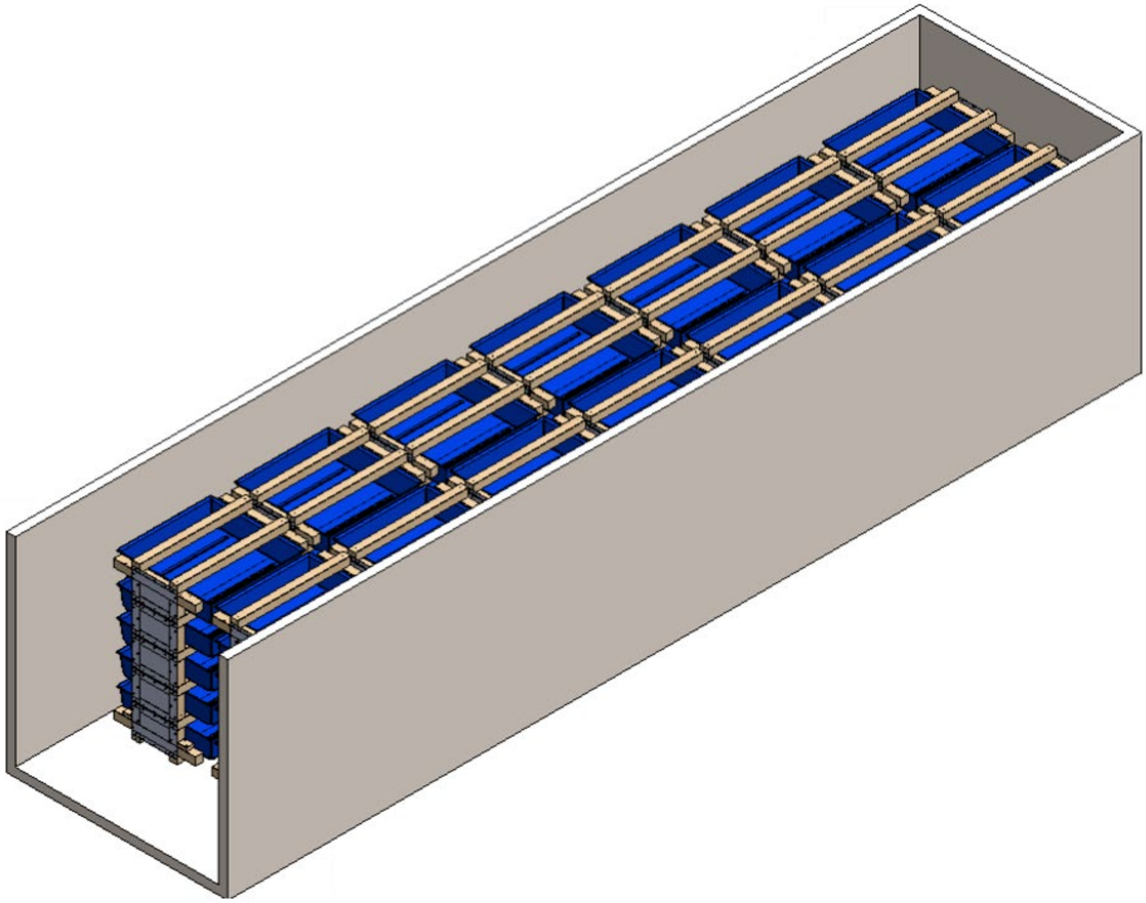


Fig. 5 Configuration of 14 stacks of ice bins in the Conex refrigeration box

2.4 Filling the Bins with Chilled Water

The Conex box refrigeration system is designed to maintain frozen goods, not to freeze them. Also, it is assumed the product has limited moisture, minimizing the number of defrost cycles required. To work within these refrigeration limitations, bins are filled with chilled water reducing the latent refrigeration load associated with tap water. Each bin has a capacity of 55-gal for a total of 3850-gal for the 70 bins per Conex box. Using a fill rate of 10-gpm, it takes 6.4 hours to fill the bins in a Conex box. Ignoring losses, a single-pass chiller system used to precool the water from approximately 55°F to 34°F reduces the refrigeration load on the Conex by more than 56 tons. A package refrigeration with glycol as the cooling media is used with a shell and tube heat exchanger to chill the water. A second benefit of using chilled water is surface ice will quickly form, sealing the water surface limiting moisture in the air and the subsequent number of defrost cycles. Working from front to back, pairs of stacks are filled sequentially until 70 bins are filled with cold water.

As a precaution, Conex boxes were pitched so any spilled water would drain toward the door and not to the back blocking the return air intakes. The freezing process starts by setting the temperature of the unit to just below freezing (28° F) until surface ice forms, stopping the water vapor migration and reduce the frequency of the defrosts. Once surface ice forms, temperature set point (suction pressure) is lowered as much as possible to increase the freezing rate. This procedure minimizes the number of defrost and each defrost will effectively clean the evaporators to maintain efficient heat exchange. The ambient air, air temperature in the refrigerated Conex box and water temperature in ice bins are recorded as a time-series to document freeze up process. Temperature data is supplemented with the performance of the refrigeration system, i.e., suction pressure, frequency, and duration of defrost cycles, etc. Performance data provides feedback and is used to optimize the freezing process, reducing the power requirements and cycle time for this unique application of refrigerated Conex boxes.

2.5 Partitioning the Ice Block

Test plans call for ice fields consisting of a mix of 1-m x 1-m, 1-m x 0.5-m, and 0.5-m x 0.5-m ice blocks. Historically the large blocks were broken using an assortment of tools, i.e., chisels, an electric hammer, axe, etc., to create the half and quarter block sizes. This is a labor-intensive process and alternative methodologies were evaluated to reduce manpower and cost while increasing personnel safety. One of the methods considered uses internal dividers inserted into the full-size bins before freeze-up to partition the block into half and quarter sizes. The half block dividers use aluminum metal plates sandwiched between ¾-inch by 1 ½-inch strips of plywood or spines, mirror the inside of the bins, Figure 6. The wooden spines extend beyond and rest on the edge of the bins parallel with the supporting 4x4s (Figure 4). Due to the limited clearance under the supporting 4x4s, the upper portion of the quarter divider is bent to create a supporting tab that would nest perpendicular with the half block divider and the edge of the bin as shown in Figure 6. Dividers are installed in the number of bins required for the size distribution prior to freeze-up.

When the tubs are inverted, the ice tends to separate from the dividers due to the spine protruding above the blocks of ice and the limited adhesion to the smooth aluminum dividers. Managing the block fragments disrupt the ice management process as trays need to be inserted between the tubs with dividers prior to inverting the bins. This adds an additional step as the trays are inserted in the stack and recovered once the blocks are on the lifting system.

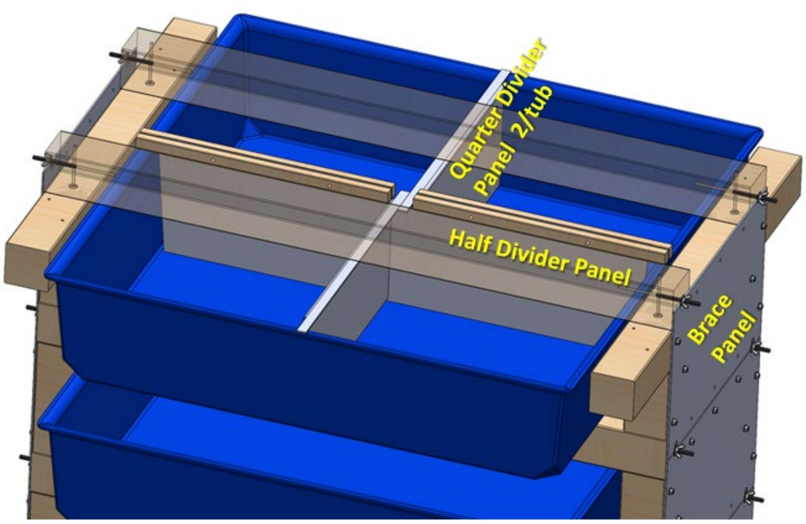


Fig. 6 Half and quarter dividers to partition the full-size blocks

Another technique commonly used to break the ice is to partially cut through the ice to create a zone of weakness while maintaining enough integrity to move the block as a unit. Once the block is in position, an ice chisel inserted in the cut easily propagates the crack, splitting the ice. Both pneumatic circular saws and chainsaws (Figure 7) were used to cut the ice, although a pneumatic circular saw is more efficient and safer, a cordless chainsaw may be more convenient. To increase cutting speed, a circular blade for wood can be used on the pneumatic saw or the raker teeth on the chain blade can be filed to increase cutting depth/speed. The partial cuts can be made while the blocks are at a convenient working height on the forklift as they are moved to or on the lifting system. Once on the slide, an ice chisel inserted in the slot easily snaps the block and all the fragments end up in the tank.

Fig. 7 Saws used for cutting slots in ice

The techniques for dividing the blocks were evaluated using the metrics of ease of use, time, money, and safety using ice frozen in mortar tubs. Aluminum plates were used to simulate the dividers and an electric skill saw with a 7 1/4 -inch diameter blade was used to partially cut the ice block. Ice adhered to the aluminum making removal of the plates problematic. Although the depth of the cut of the circular saw was less than half the ice thickness, the particle cut provided stress concentration for subdividing the block. Giving the effectiveness of the circular saw, a pneumatic circular saw with a 12-in was used to make 5-in deep cuts in the blocks. The pneumatic saw avoids the safety hazard associated with using electrical equipment in a potentially wet environment.

2.6 Storing components and equipment in the off-season

As ice blocks are removed from the stack, end panels and 4x4s will be placed on pallets for storage. Panels will be stacked on 11 pallets and the 4x4s stacked on 10 pallets for a total of 21 pallets, Figure 8. The pallets will be double stacked in two parallel rows, requiring one and a half (1 ½) 20-foot Conex boxes. The 500 bins will be stacked 21 high in parallel rows in two and a half (2 ½) 20-foot Conex boxes. A total of four 20-foot Conex boxes will be required to store the parts for the stacks and bins, Figure 9.

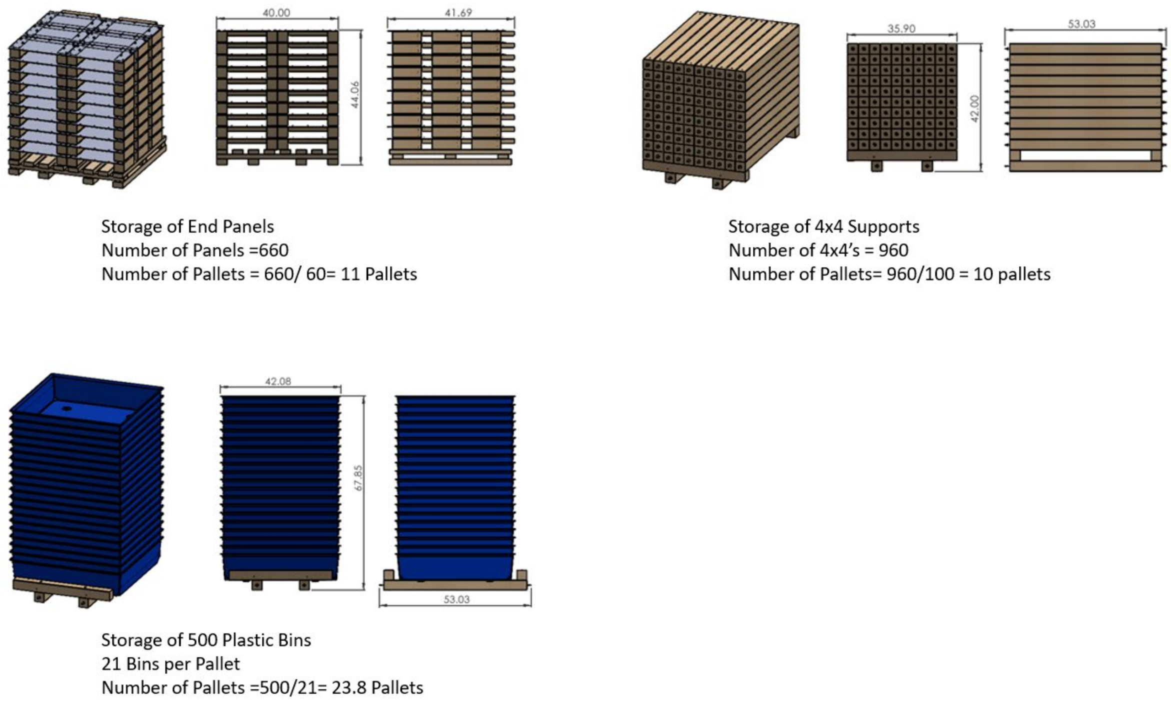


Fig. 8 Pallets for storing components

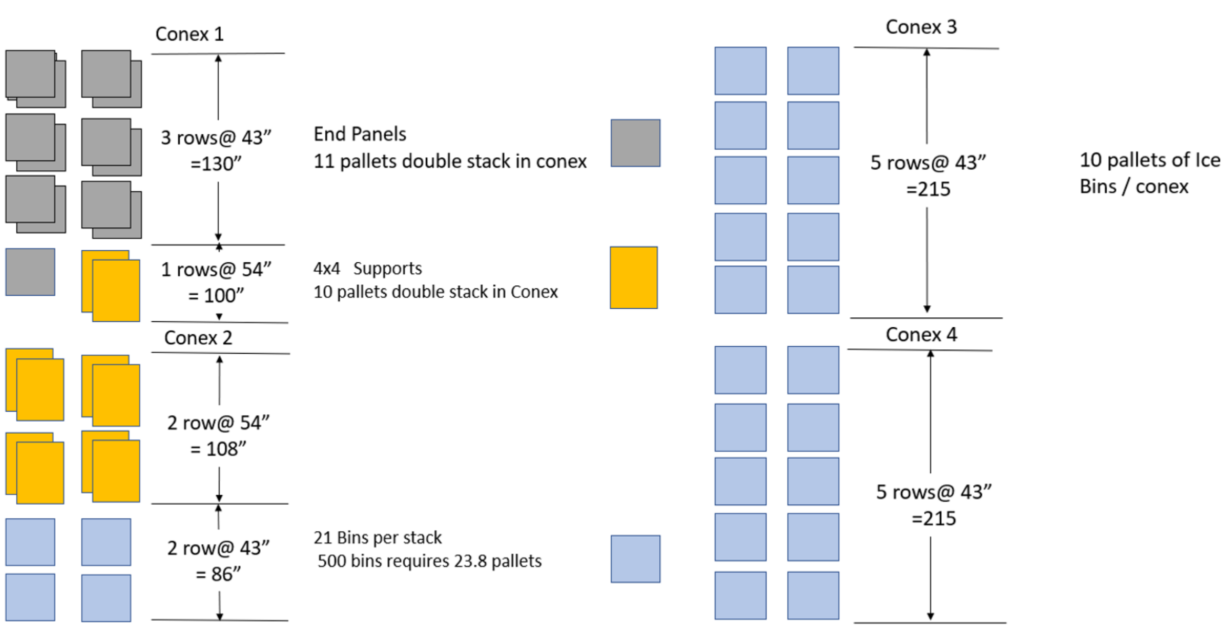


Fig. 9 Layout for storing components for stacks and tubs in Conex boxes

Two additional conex boxes are required to store support equipment in the off season, i.e., package refrigeration system, glycol-water heat exchanger, hydraulic pump system for tilt slides, tailgate actuators, sawhorses, etc.

3 ICE PROCESSING

3.1 Transporting Ice Stack

For efficiency, the stacks of ice blocks need to be transported from the refrigerated Conex boxes to the staging area in the parking lot adjacent to the tank. The stability of the stacks needs to be addressed as the terrain is not smooth asphalt. Each stack can be moved by a forklift or multiple stacks can be loaded and secured to a flatbed trailer. Need to consider the time to load and unload the trailer vs. transporting a single stack with a forklift. The stacks can be moved to a temporary storage area near the staging area prior to test day, closely packed to minimize melting, and covered with an insulated tarp. The process will be refined with experience.

3.2 Inverting the Ice Block

Inverting the blocks individually was considered but was rejected as it required custom equipment, safety concerns, and was labor intensive. Ideally, inverting a full stack is the most effective and safest approach. A pallet inverter, a convenient tool routinely used in the manufacturing and shipping industry was rented at a reasonable cost. This standard equipment safely inverts a full stack of ice blocks, Figure 10. A video of the inverting process is available at https://www.youtube.com/watch?v=5X0RNaoooX4.

Fig. 10 Pallet inverter used to rotate a stack of ice bins

The inverter is staged to allow the forklift loading / unloading stacks to place the inverted stack for easily accessible by the forklift(s) moving the individual blocks to the lifting system described below, Figure 11.

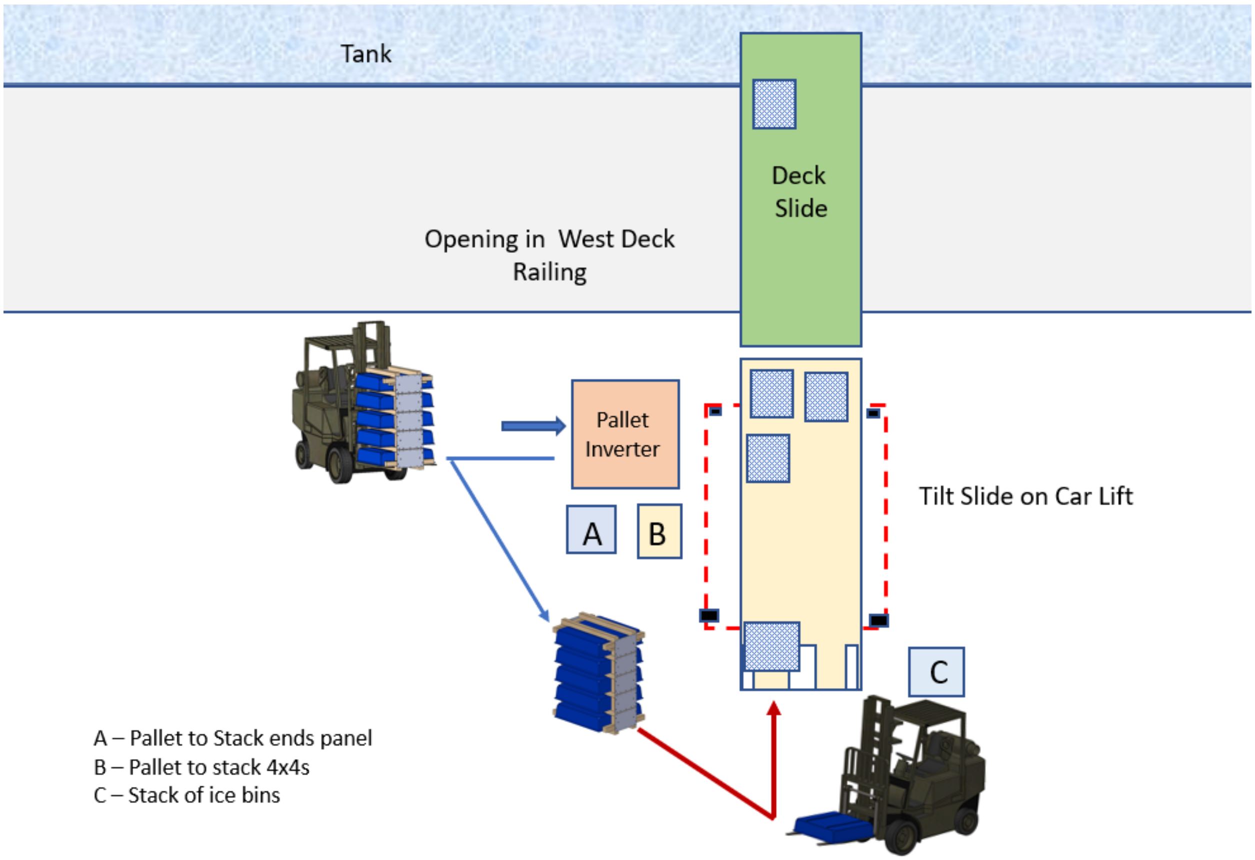


Fig. 11 Layout of staging area

The width between the forks on the forklift is adjustable to allow the fork to slide in adjacent to the 4x4s and lift a block of ice (Figure 12). Tops of the ice blocks dome during the freezing process and are on the bottom of the inverted block and safely center the block between the forks as they are moved to the lifting system. If the block sliding while on the forklift is a concern, each fork can be covered with a strip of plywood or a rug to increase friction. Bins were removed and stacked for storage as the ice was moved to the lifting system. End panels and supporting 4x4s were removed before the next ice block was removed and the sequence was repeated for all the blocks.

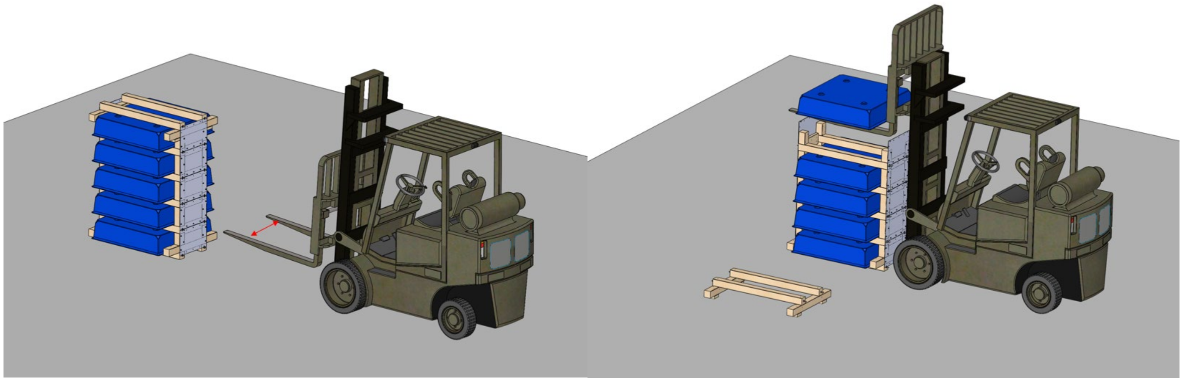


Fig. 12 Sequentially lifting the blocks of ice off the stack

3.3 Lifting System

Initially, a conveyor system was considered to lift the ice blocks from the staging area in the parking lot to the west deck of the tank as a continuous operation. This approach was rejected as the transition from the upslope of the conveyer to the downslope of the slide on the deck to the tank could potentially break the blocks. Other factors for rejecting the conveyor approach were safety, keeping the ice blocks on the conveyor system, and cost.

The alternative solution was a batch process with the ice blocks loaded on a slide where they were lifted to the elevation of the west deck and tilted to deliver the ice into the tank as depicted in Figure 13. The lifting system is comprised of the following assemblies: tilting slide, vertical lift system, hydraulic system to tilt the slide, and stationary deck slide. The respective design considerations for each assembly are described below.

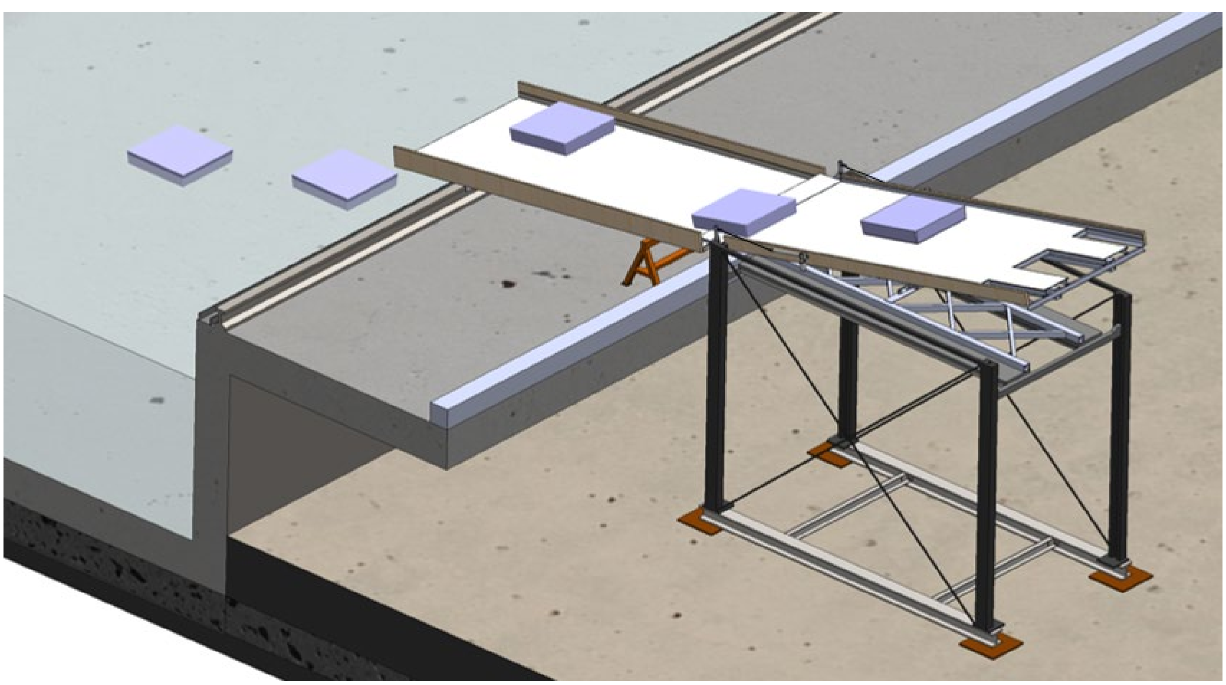


Fig. 13 **Lifting system**

3.3.1 Tilting Slide

The individual ice block was moved from the inverted stack and set on the bed of the tilting slide. The bed is approximately 18 feet long cantilevers off the lift to allow unimpeded access by the forklift loading and extends beyond the lift frame at the opposite end for unloading. The width of the bed is 86 inches and is limited to the distance between the corner post of the lift. The bed has two tongues created by the adjacent fork pockets, (right side Figure 14) to facilitate a forklift setting a block on the bed. With two loading locations, ice was split at one location while ice was loaded at the second location or simultaneously loaded using separate forklifts to expedite the loading process. The bed is hinged to the subframe under the tailgate at the tank end and a hydraulic piston between the subframe and bed to lift and tilt the bed to slide the ice into the tank. While loading ice (Figure 15), the tailgate on the right side was closed and by sloping the bed, ice was easily corralled at the front of the slide. The subframe of the tilting slide is attached to the platform of the lifting system.

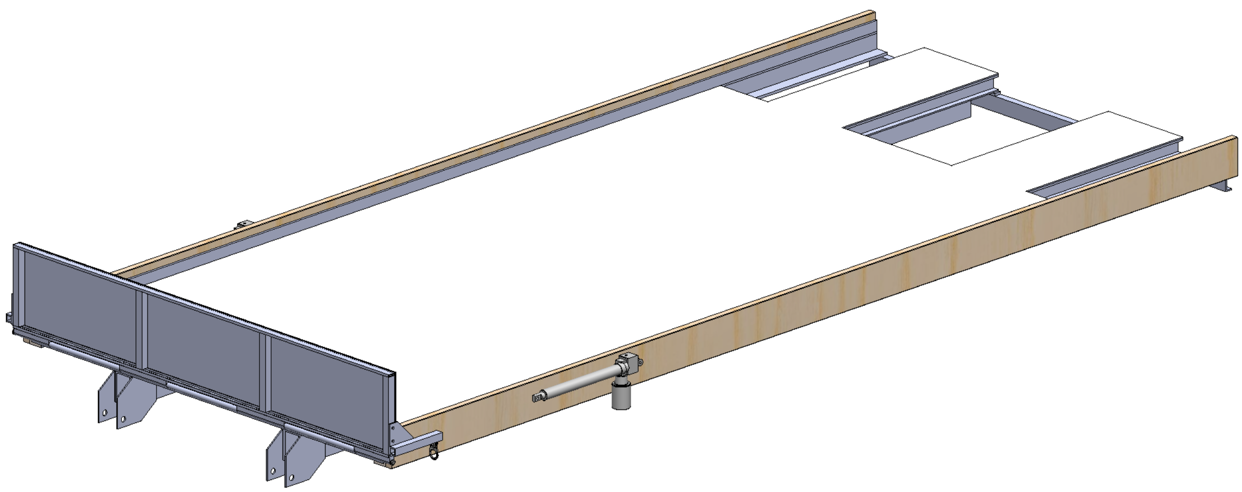


Fig. 14 Tilting slide

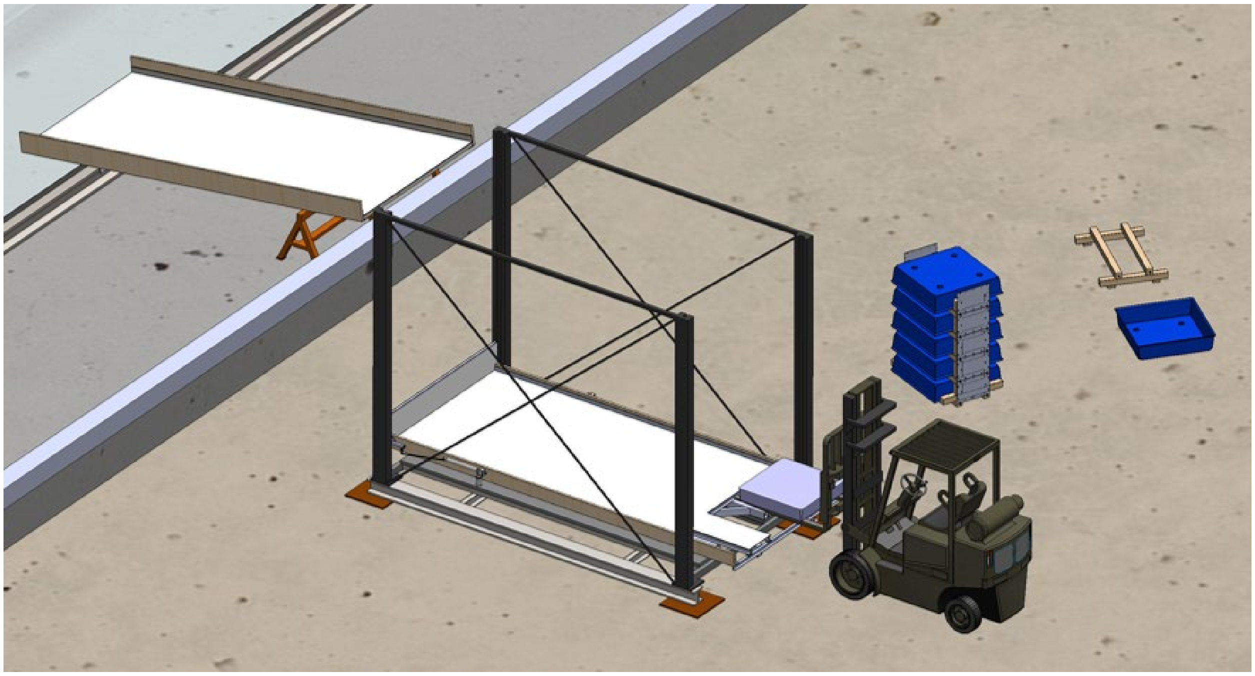


Fig. 15 **Loading the ice on the bed of the tilting slide**

3.3.2 Lift System

The tilting slide is mounted to a commercially available car lift used to lift the loaded slide to the west deck, Figure 16. The freestanding four-post car lift is designed for a lift height of 145 inches, is rated at 7,000-lbs with only vertical loads on the foundation. In a conventional installation, the system is anchored to the concrete floor for lateral stability; however, in this application, a steel subframe was used to provide lateral stability. Loads on the frame are distributed to the parking lot using steel load plate with intermediate shims to level the frame. The number of 550-lb ice blocks that can be lifted per cycle is limited by the capacity of the lift when the weight of the tilt slide system is included. More blocks could be lifted per cycle with a more complex alternative such as a custom-made material elevator rated at 12,000 lb. Due to the significant cost difference, the design is based on a car lift.

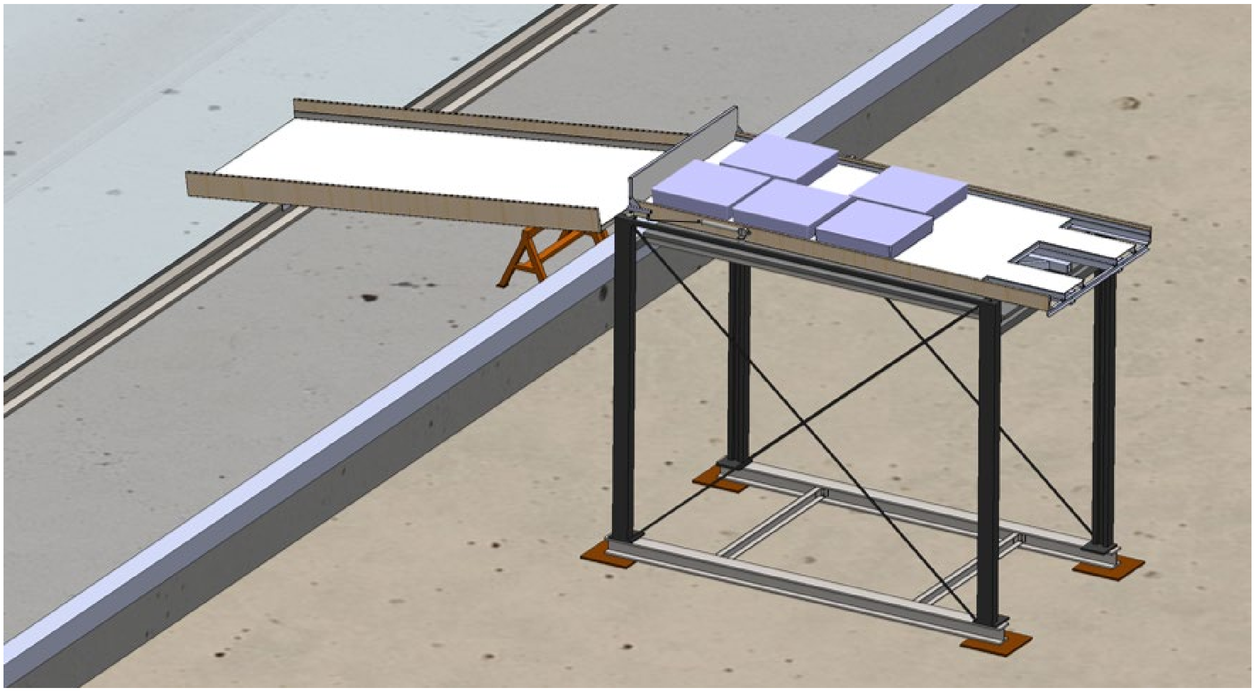


Fig. 16 **Loaded slide lifted to the west deck using a car lift with the bed sloped to keep the ice blocks at the front of the bed**

3.3.3 Hydraulic system to tilt the slide

With the loaded slide lifted to the elevation of the deck slide, the tailgate is mechanically opened using electric actuators. The tailgate rests on the deck slide, bridging the gap between the two slides. A hydraulic piston tilts the bed of the tilting slide (Figure 17) and the ice slides across the tailgate down the deck slide and into the tank. A commercially available hydraulic system designed to tilt dump truck bodies was installed between the subframe and bed to tilt the bed. The hydraulic pump has a remote control to allow the ice lifting and sliding to be control by a single operator on the west deck.

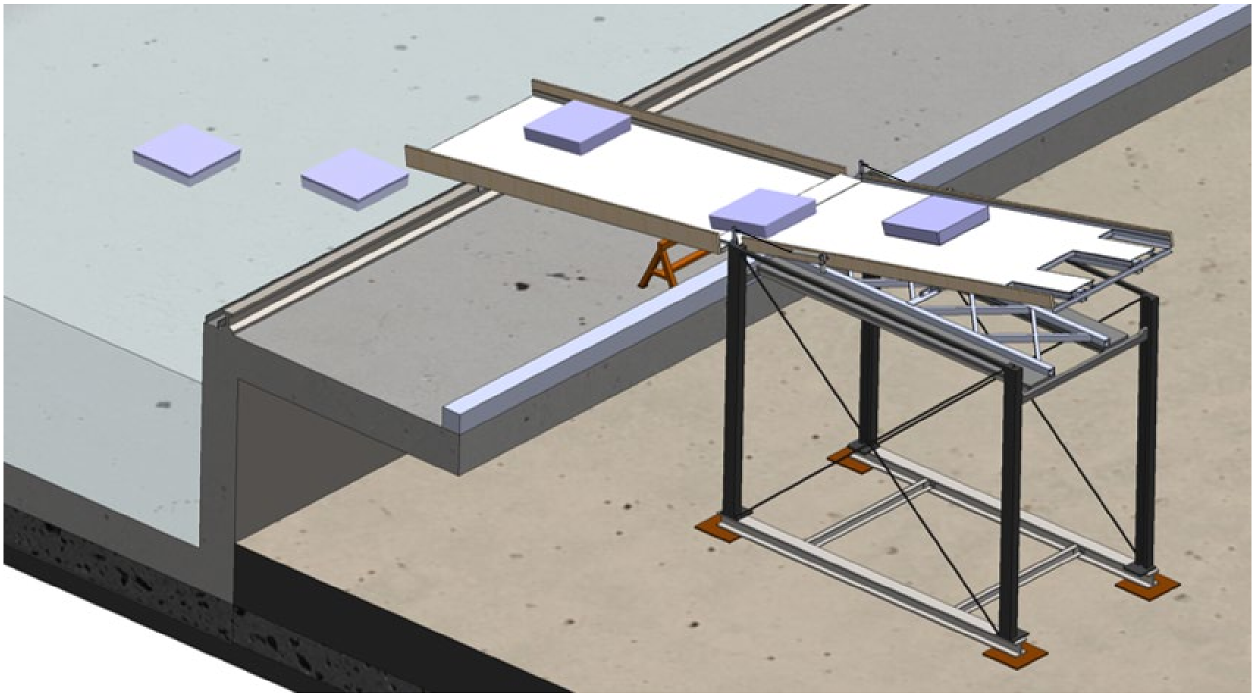


Fig. 17 **Commercially available car lift to tilt the loaded slide**

3.3.4 Deck Slide

The deck slide is 18 feet long by 96 inches wide (Figure 18) to allow the tailgate on the tilting slide to fit within the side rails. The tank end of the slide rests on the bridge rail with a shear block to prevent lateral motion, to maintain the momentum of the sliding ice blocks, the opposite end is supported on 30-inch-high industrial sawhorses for a 12-degree slope (Figure 19). The slide cantilevers over the edge of the tank approximately two feet to reduce the drop height of the block and reduce breakage. The telehandler was used to quickly move the deck slide once the ice field was built, freeing up the deck space for the test.

Fig. 18 Deck slide

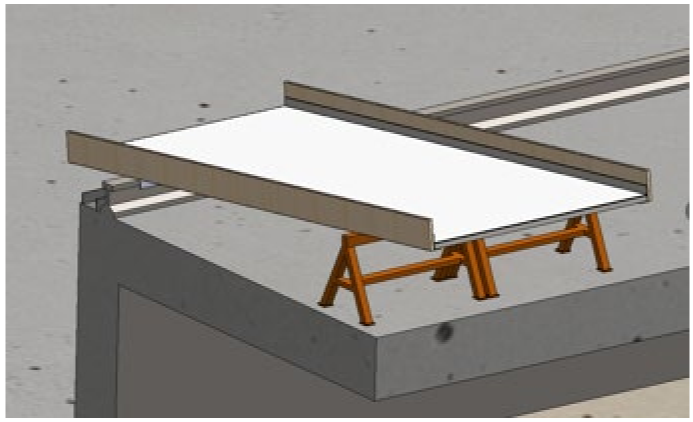


Fig. 19 **Deck slide with a 12-degree slope**

For corrosion control, the structural frames of both slides are galvanized, but to enhance sliding, HDPE plastic sheets are attached to the metal decks. In the off-season, the deck slide can be stored upside down on the tilt slide and wrapped in shrink wrap for environmental and UV protection.

3.4 CYCLE TIME

The staging area, Figure 11, is configured for parallel processing as the time to load the pallet inverter, invert and unload the inverted stack is less than the time to load the individual blocks on the tilting slide, lift the loaded slide, lower the tailgate, slide the ice into the tank and close the tailgate and lower the tilting ice tray. The dimension of the tilting slide is controlled by the dimensions of the car lift, but the number of blocks on the slide is limited by the 7,000-lb load rating of the lift. Accounting for the weight of the tiling slide, only six 550-lb blocks can be lifted using the car lift. A custom freight elevator with a 12,000-lb rating could lift the loaded tilt slide with 10 (or two stacks) of blocks. It is difficult to justify the expensive elevator for the additional capacity with only marginal improvement in the cycle time.

To efficiently build the ice field would take three teams, inverting, ice loading, and unloading, with the respective responsibilities outlined below.

Team 1: Invert Team

1. Set the 4x4 frame on top of the stack that will become the bottom when the stack is inverted
2. If the tub has dividers, install plastic tray to support broken ice blocks.
3. Load stacks of blocks into the pallet inverter with the stack against the solid wall
4. Invert the stack
5. Remove the inverted stack and position it for access by the forklift loading the blocks onto the tilting slide
6. Remove 4x4 supports and end panels to allow access by the forklift to the next block, (Figures 4 and 12) and stack the 4x4s and end panels on respective pallets
7. Repeat 1-6

Team 2: Ice Load Team

1. Assist Team 1 in disassembling the stacks as the ice blocks are removed

2. Palletize 4x4 and end panels on respective pallets
3. Move ice blocks to tilt slide by forklift and, remove and stack the bins
4. Set ice on the tongue of the tilt slide tray and partition blocks as required
5. Repeat the process until the tilting ice slide is loaded

Team 3: Unload the tilting ice slide. This would be a single operator.

1. Lift the car lift
2. Lower tailgate to bridge the gap between the tilt slide and the deck slide
3. Lift the bed of the tilt slide enough to slide the ice in the tank
4. Lower the tilt slide and close the tailgate
5. Lower the car lift

This process of lifting the tilting slide, operating the tailgate, and operating the hydraulic system to lift the bed of the tilting slide is controlled by one operator using remotes. The operator has complete view of the ice management process for coordination and safe operations.

The process of inverting a stack of blocks occurs in parallel with lifting the blocks into the tank which is a sequential process. Lifting the blocks from the staging area to the tank is a longer process with the cycle time being controlled by the transit time for the forklift to move the individual block from the stack to the slide. The estimated round-trip time between the stack and the slide is 1.5 minutes for a total time to load the slide with five blocks being 7.5 minutes. Cycle time for lift and sliding sequences would be 5 minutes for a total cycle time of 12.5 minutes for each stack. It is anticipated that the processing time will decrease as the respective team develops a routine. Since the transient time of loading the forklift is governing the loading process, it may be beneficial to have two forklifts loading the ice, but the tradeoff would be close coordination of the forklift traffic.

Using the conservative cycle time, an ice field of 70 blocks takes three (3) hours to build using equipment with less physical stress on the staff.

4 FUNDING PROCESS

Equipment required for enhanced ice tests at Ohmsett is separated into three categories: ice manufacturing, equipment rental for the test, and capital investment. Each category is described below.

4.1 Ice Manufacturing

Material, equipment, and labor to assemble the system in direct support of the ice manufacturing process that includes the following:

a 500 1-meter x 1-meter custom HDPE bins manufactured using vacuum forming techniques including a custom aluminum mold.

b Material and labor to fabricate stackable frames to support the plastic bins during the freezing process. Eighty stacks supporting five bins each used to freeze 400 bins in six refrigerated Conex boxes per freezing cycle. This includes fabricating 800 aluminum end panels and fasteners to assemble the stacking system.

c The ice field is composed of half and quarter-sized ice fragments. One of the techniques evaluated included bin dividers to partition the required number of blocks to obtain the required size distribution in the ice field. The other alternative is partially cutting the block with a pneumatic circular saw or cordless chainsaw. The task would include the necessary supplies, aluminum dividers, labor, and equipment for the selected system.

4.1.1 Equipment Rental

Rental equipment required to freeze and process the ice blocks to support a series of ice tests.

a Refrigerated Conex boxes (six required)

b Pallet Inverter

Equipment specifications and rental fees will be included in the respective ice test proposal.

4.1.2 Capital Investment

Facility investment that would enhance capabilities in addition the supporting ice tests.

a Independent package refrigeration system for glycol that would be used in conjunction with a heat exchanger, e.g., shell and tube, to cool the water to 34° F used to fill the ice bins.

b Material lifts to move equipment and supplies from the staging area in the parking lot to the west deck.

  i. Commercially available car lift, 12-feet high with a load capacity of 7,000-lbs.

  ii. A 12,000-lb custom freight elevator is an option, with orders of magnitude higher cost.

c Material slides including the tilting slide and fixed slope deck slide and appurtenances.

d Gate in the west deck safety railing to allow equipment on and off the deck without compromising the curb used for delineating the secondary containment area.

Material and labor cost/ ROMs for the respective categories are listed in Table 1 using current pricing.

Table 1 Respective cost/ ROMs for each category.

Component	Material	ARA Labor	Total
Ice Manufacturing - Project Investment			
Material and Labor to Build Reusable Stacking System for Ice Tubs and Pass-Through Water Refrigeration System (PO to DSM Metal Fabrication)	$29,779.26	$93,291.06	$123,070.32
Divider panel for to subdivide tubs in to 1/2 and 1/4 block sizes	$10,215.00	$33,855.55	$44,070.55
Vacuum Thermoforming of 500 HDPE Plastic Bins and Aluminum Mold (PO to C&K Plastic)	$72,130.72	$10,432.61	$84,362.78
		Sub Total	$251,503.65
Equipment Rental for Ice Test			
Pallet Inverter (2 month min rental)	$5,103.00	$1,500.00	$6,603.00
20-foot Refrigerated Conex Boxes (six required for 2 months @ $2,000/ each including delivery fees)	$12,000.00	$2,500.00	$14,500.00
		Subtotal	$21,103.00
Ice Manufacturing - Capital Investment			
Glycol refrigeration system and heat exchanger to cool tap water used to fill the plastic bins to reduce refrigeration load (Refrigeration System $24,895, Heat Exchanger $8,495)	$33,390.00	$7,000.00	$40,390.00
Car Lift with 7,000 -lb capacity 12-ft lift (BendPak HD-7PXW @ $8,055) and support frame (Option 2: custom material elevator with 12,000lb capacity and 12-ft lift American Custom Lift FM4-74338-1 @ $225,123,32)	$11,776.75	$32,525.43	$44,302.18
Contracting Fabrication of Galvanized Tilting Bed Slide and Installing Plastic on Deck Surface	$30,281.59	$28,748.67	$59,030.26
Contracting Fabrication galvanized Deck Slide and Installing Plastic on Deck Surface	$13,753.35	$25,937.71	$39,691.06
Install gate in safety railing to allow access to deck		$5,000.00	$5,000.00
		Sub Total	$188,413.49

5 ICE PRODUCTION: FRESH, SALT AND FRAZIL

5.1 Freshwater Ice

For the longevity of the ice field, it is recommended that freshwater ice be used for the oil tests as the primary objective is ice fragments impeding oil migration to the recovery equipment being tested. Freezing time can be predicted using the freezing degree analysis (White, 2003) an algorithm using the square root of accumulated time below freezing times a coefficient. Although the technique was developed for lake ice, it provides guidance for freezing ice in the bins. To minimize the refrigeration load, bins are filled with cold water (1°C / 34 °F), and the temperature of the Conex boxes maintained just below freezing (-2° C/ 28° F) until surface ice forms. The skim ice significantly reduces the moisture/humidity, and subsequent defrost cycles. Once the water surface is sealed, lower the temperature set point to increase the rate of freezing. Using the AFDD Accumulated Freezing Degree Day (AFDD) algorithm with a temperature of -12°C/ 10° F, the 20-cm / 8-in of ice freezes in less than 12 days. Considering the ice is freezing from all surfaces, unlike natural freezing in a lake, freeze time is on the order of five (5) days once the skim ice forms.

Ice has polycrystalline structure with the impurities trapped in between the crystals. Figure 20 is a horizontal thin section of freshwater ice between polarized filters showing the defined crystal boundaries. Color variations are attributed to the orientation of the C-axis of the crystal, like light through a prism.

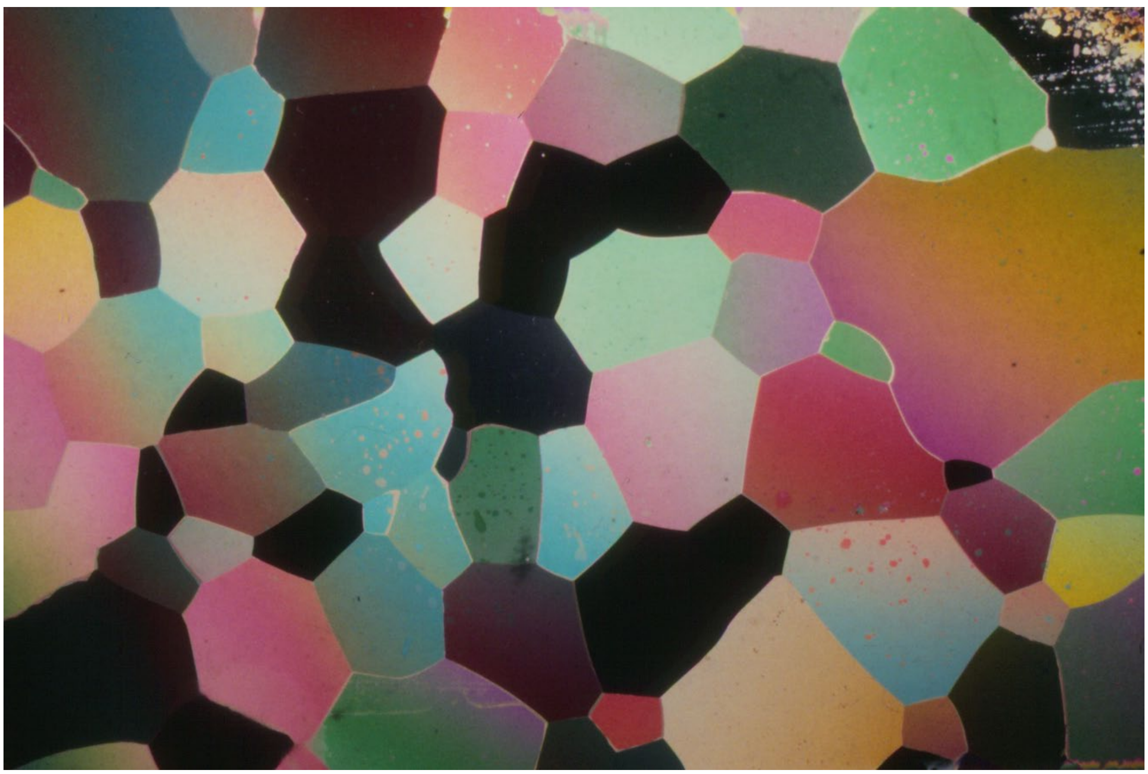


Fig. 20 Horizontal thin section of freshwater ice under a polarized filter

5.2 Sea Ice

By contrast, Figure 21 is a mosaic of vertical (left) and horizontal (right) cross-sections of sea ice at the various depths in a 40-cm / 16-inch ice core showing the erratic crystal boundaries. As a side note, the different crystals structure along the perimeters of the sections is fresh water used to adhere the thin section to the glass slides.

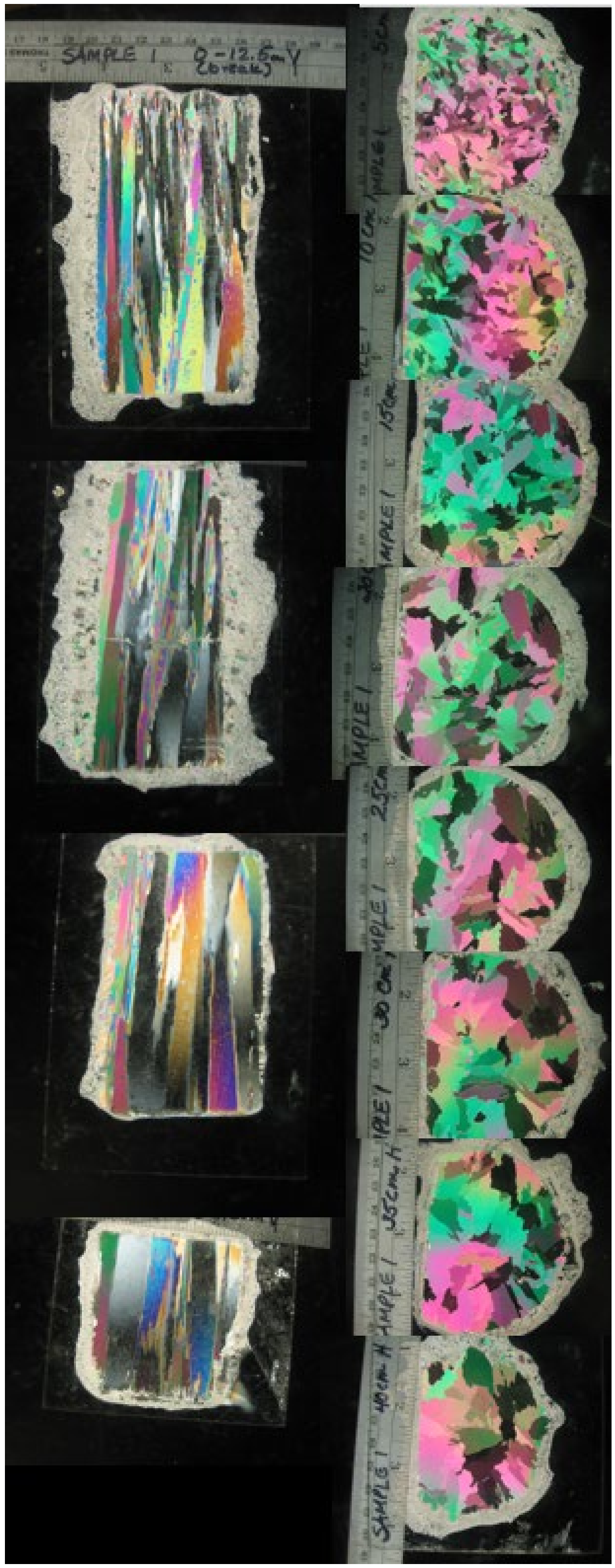


Fig. 21 Vertical and corresponding horizontal thin sections of sea ice under polarized light

As seawater freezes, the bulk of the impurities are rejected at the freezing interface in the skeletal layer, but some are trapped between the crystals, creating brine channels. Oil under the ice will migrate up the brine channels as shown in Figure 22 (Pegau W. G., 2016) (Pegau W. G., 2017).

Fig. 22 Vertical and corresponding horizontal thin sections of sea ice under polarized light

As sea ice freezes in the environment or a large tank, the rejected impurities do not significantly change the chemistry of the parent water. That is not the case in smaller insulated tanks with thermal or top-down freezing. As the ice forms the impurities are rejected into the remaining water, increasing the salinity, and decreasing the freezing point affecting the freezing process and crystal structure. The plastic bin can be used to freeze seawater, but ice formation will start on the interior surface of the bin and the water surface. During the freezing process, all impurities (e.g., salt, air, etc.) are rejected to the freezing interface resulting in near freshwater ice on the outer edges of the block with a steep salinity gradient to the center. Given the limited refrigeration capacity of the Conex units, the centers of the ice blocks will ever freeze, and the blocks will easily break when handled.

5.3 Frazil Ice

Frazil is generated in turbulent supercooled water at cold ambient temperatures, i.e., steep rapids at 28°C (-20 °F). Reproducing frazil ice at Ohmsett tank would be an expensive investment. What is appropriate for evaluating oil recovery equipment would be slush ice manufactured from ice chips, Figure 23 from (Keller, 2006). Chips used for making snow cones would be a suitable surrogate for creating oil-ice slushie for testing equipment in a small tank in a cold room. The water in the tank could be cooled using the package refrigeration system (item 1 in Capital investment) in conjunction with a submerged glycol loop in the tank.

Fig. 23 A view of frazil ice

6 SUMMARY

Recent ice tests conducted at Ohmsett required a labor-intensive process using wooden forms to freeze the meter-by-meter ice blocks and manpower to maneuver the ice into the tank. The proposed ice management system uses custom HDPE bins as molds to efficiently freeze the ice blocks by eliminating the insulating aspect of the wooden form and the excess refrigeration load due to the inherent moisture in the wood. Five bins would be stacked in a wooden assembly with 14 stacks per refrigerated Conex box. To expedite the freezing process, it is recommended the bins be filled with water cooled to 1° C (34 °F) using a glycol refrigeration system in combination with a heat exchanger to reduce the refrigeration load on the conex by 56 tons. Using the plastic bins and precooling the water results in fewer, but more effective defrost of the refrigeration coils improving the freezing efficiencies and decreasing freezing time. Bins stacked five high in an assembled stacking system with 14 stacks or 70 bins per refrigerated Conex box, require six Conex boxes for 400 blocks of ice. A portion of the block are divided for the appropriate size distribution of half and quarter block sizes in the ice field.

The first step in the ice management phase is transporting the frozen stacks of ice blocks to a staging area adjacent to the tank. A complete stack of blocks is inverted using a rented pallet inverter with the inverted stack conveniently placed to allow the stacks to be disassembled as the ice blocks are moved to the lifting system. Bins are lifted off the ice block as they are moved to a batch lifting system that includes a car lift with a tilting slide as a payload. The number of blocks lifted at the 12-feet per cycle is limited by the load capacity of the lift to six. Once the tilting slide is loaded and lifted to the deck slide and the tailgate is opened bridging the gap between the slides, a hydraulic system tips the sloping slide and the ice slides down into the tank.

Although the bins can be used to freeze seawater, the resulting ice blocks are not representative of natural sea ice as the rejected impurities, i.e., salts, are concentrated in the middle of the ice block. The probability of the center of the block freezing is extremely low due to the high salt concentration and depressed freezing point. Due to this delicate crystal structure, the blocks would not have any structural integrity and will easily fracture when moved.

Frazil is generated in turbulent supercooled water and subfreezing ambient temperature that would be difficult to reproduce at Ohmsett. Chipped ice could be used as a surrogate to evaluate the performance of oil recovery equipment, but the test would have to be conducted in a cold room with the tank water maintained near the freezing point.

7 RECOMMENDATIONS

This enhancement to drift ice testing capability needs to be marketed to research community and an animation would be valuable tool in this endeavor. The animation could be posted on the website or the Ohmsett YouTube Playlist and displayed at conferences to trigger discussions with potential clients.

Engineering safety controls were incorporated into the design of the equipment, but forklift traffic remains a safety concern. The layout of the staging area needs to consider forklift traffic and stack of components for the modular stacks. An Standard Operating Procedure (SOP) should be the prepared and updated following every test to incorporate refinement and maintain corporate knowledge between tests.

The equipment is critical to conducting ice tests and it should be operational and properly stored in the off- season. A preventive maintenance plan should be developed that includes inspection of hydraulic hoses, electrical connections, grease fittings, test the concentration of the glycol to determine temperature range, etc.

The component used are commercially available, but due to delivery time critical spares should be considered. One critical component is the hydraulic pump for the tilt slide and options are equipment to retrofit High Pressure Units (HPU) or stock a spare dump body pump.

8 References

(ERCD/CRREL Technical Note 04-3 Method to Estimate River Ice Thickness Based on Meteorological Data)

Pegau, W.S, Garron, J. Zabilansky, L and Bassett, C, (2017) Detection of oil in and under ice International Oil Spill Conference Proceedings 2017(1):1857-18765.

Pegau, W. S., J. Garron, and L. Zabilansky. (2016). Detection of oil on-in-and-under ice, Final Report 5.3, Joint Industry Programme to define the state-of-the-art for surface remote sensing technologies to monitor oil under varying conditions of ice and visibility, London, U.K. 406 pp. 4.

Keller, A.A and Broje, V., BSEE report OSRR-528-Optimization of Oleophilic Skimmer Recovery, (2006)

8.1.1.1.1.1.1 Appendix A: Technical Summary

REPORT TITLE: Enhancements to Ohmsett’ s Testing Capabilities in a Drift Ice Environment

CONTRACT NUMBER(S): E17PC00014 14E0122F0097

FISCAL YEARS(S) OF PROJECT FUNDING: FY2023

CUMULATIVE PROJECT COST: $335,375.10

COMPLETION DATE OF REPORT: 15 January 2024

BSEE COR(S): Kristi McKinny

BSEE CO(S): Darren Ho

PROJECT MANAGER(S):Grant Coolbaugh

AFFILIATION OF PROJECT MANAGER: Dr. Tom Coolbaugh

ADDRESS: 4300 San Mateo Blvd. NE, Suite A-220 Albuquerque, NM 87110

PRINCIPAL INVESTIGATOR(S)*: Leonard Zabilansky

KEY WORDS: Ice, oil drift ice, manufacturing ice block, sea ice, frazil ice

* The affiliation of the Principal Investigators(s) may be different than that listed for Project Manager(s).

9 Abbreviations and Acronyms

AFDD	Accumulated Freezing Degree Days
BSEE	Bureau of Safety and Environmental Enforcement
CO	Contracting Officer.
COR	Contracting Officer’s Representative
CSE	Council of Science Editors
DM	Departmental Manual
DOI	Department of the Interior
NRS	National Response System
NRTL	National Technical Reports Library
OSPD	Oil Spill Preparedness Division
OSRR.	Oil Spill Response Research

Department of the Interior (DOI)
The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Safety and Environmental Enforcement (BSEE)
The mission of the Bureau of Safety and Environmental Enforcement works to promote safety, protect the environment, and conserve resources offshore through vigorous regulatory oversight and enforcement.

BSEE Oil Spill Preparedness Program
BSEE administers a robust Oil Spill Preparedness Program through its Oil Spill Preparedness Division (OSPD) to ensure owners and operators of offshore facilities are ready to mitigate and respond to substantial threats of actual oil spills that may result from their activities. The Program draws its mandate and purpose from the Federal Water Pollution Control Act of October 18, 1972, as amended, and the Oil Pollution Act of 1990 (October 18, 1991). It is framed by the regulations in 30 CFR Part 254 – *Oil Spill Response Requirements for Facilities Located Seaward of the Coastline*, and 40 CFR Part 300 – *National Oil and Hazardous Substances Pollution Contingency Plan*. Acknowledging these authorities and their associated responsibilities, BSEE established the program with three primary and interdependent roles:

- Preparedness Verification,
- Oil Spill Response Research, and
- Management of Ohmsett - the National Oil Spill Response Research and Renewable Energy Test Facility.

The research conducted for this Program aims to improve oil spill response and preparedness by advancing the state of the science and the technologies needed for these emergencies. The research supports the Bureau's needs while ensuring the highest level of scientific integrity by adhering to BSEE's peer review protocols. The proposal, selection, research, review, collaboration, production, and dissemination of OSPD's technical reports and studies follows the appropriate requirements and guidance such as the Federal Acquisition Regulation and the Department of Interior's policies on scientific and scholarly conduct.