



# **Winter Bridging Exercise on Thick Ice**

## **Fort McCoy, Wisconsin, 1988**

Barry Coutermarsh

April 1990

# Special Report 90-10



**U.S. Army Corps  
of Engineers**  
Cold Regions Research &  
Engineering Laboratory

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Prepared for  
OFFICE OF THE CHIEF OF ENGINEERS

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## **PREFACE**

This report was prepared by Barry Coutermarsh, Research Civil Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by DA Project 4A762730AT42; Task, *Army Mobility*; Work Unit CS001.

Technical review was provided by Major Randy Hill and Paul Richmond, both of CRREL.

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**CONVERSION FACTORS:**  
**U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT**

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

<i>Multiply</i>	<i>By</i>	<i>To obtain</i>
inch	25.4	millimeter
inch <sup>2</sup>	0.00064516	meter <sup>2</sup>
foot	0.3048	meter
foot <sup>2</sup>	0.09290304	meter <sup>2</sup>
pound (mass)	0.4535924	kilogram
ton (short)	907.1847	kilogram
pound/inch <sup>2</sup>	6894.757	pascal
pound/foot	14.59390	newton/meter

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## INTRODUCTION

One of the most vexing situations encountered by an army on the move in winter is the need to cross an ice-covered river. If this ice cover is not thick enough to support the anticipated loads, yet is thicker than what can be easily removed (less than 8 in.), the problem becomes very difficult.

This report describes a winter bridging exercise undertaken by CRREL and the 2nd Combat Engineer Battalion, 2nd Marine Division FMF, on 22–26 February 1988 at Fort McCoy, Wisconsin. The exercise investigated the difficulties of bridging a waterway with a substantial ice cover present and experimented with some options that were chosen to be compatible with equipment normally found with a Ribbon Bridge unit. The only special equipment or materials considered were those that could be easily fabricated or procured if found effective.

## BACKGROUND

It has been shown that ice covers up to 8 in. thick can be removed relatively easily from a crossing zone to provide a clear deployment area for the

Ribbon Bridge. Stubstad et al. (1984) suggest that the Combat Support Boat can break up the ice cover in this thickness range. Additionally, chain saws can cut 8 in. of ice relatively quickly. The ice blocks can then be removed from the waterway by bulldozer if the topography allows it to work from the water onto the shore. Mellor and Calkins (1988) detail an exercise in South Korea that used this technique after the ice had been both cut with chain saws and broken up by blasting. Blasting is not recommended unless special techniques are employed that clear some of the ice from the crossing zone. Coutermarsh (1987) details another exercise in South Korea that demonstrated the very difficult conditions caused by fractured ice after blasting a crossing zone by conventional techniques.

In the initial planning of the Fort McCoy exercise, we expected the ice to be 18 to 20 in. thick. However, the weather before the bridging exercise was very cold, which resulted in an average 24.5-in.-thick ice cover at the bridging site. We planned to use chain saws to cut the ice into floes of manageable size, with one saw using a chain modified for faster ice cutting. The blocks were then to be removed by various techniques to assess the relative speed and effectiveness of each. Bull-

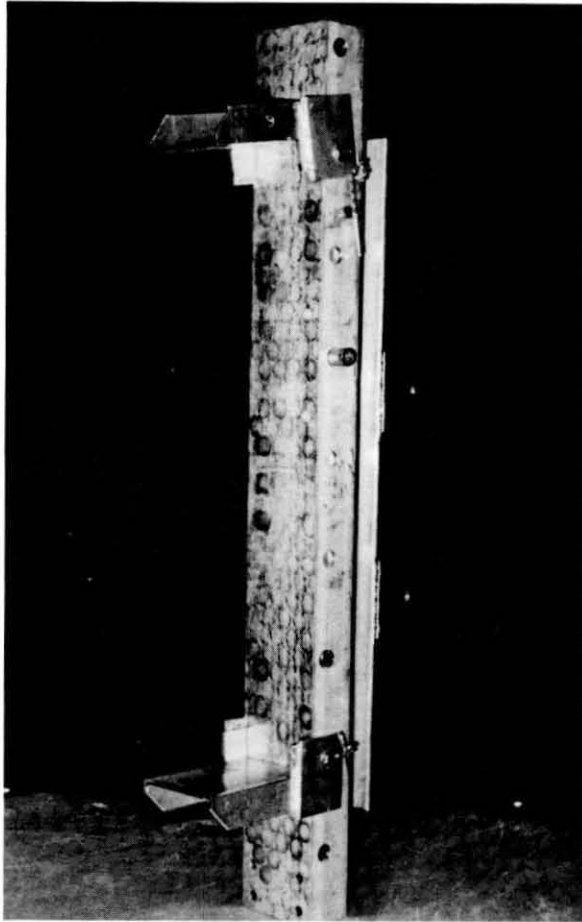


Figure 1. Ice push knees fabricated for the prop-driven Combat Support Boat.

dozers were to be employed near shore to move the blocks onto land, the bridge transporter truck booms were to be used to lift blocks out and a Combat Support Boat with modified push knees was to be used to push ice under the adjoining ice cover. However, the ice being substantially thicker than expected made the operation very difficult and prevented us from using some techniques.

## ICE CUTTING

### Equipment

We thought that the Marines had 24-in. chain saws available to use for cutting the ice, but at the exercise we discovered that they were in fact 18-in. saws. CRREL brought a 24-in. and a 30-in. saw to the exercise and, as it turned out, the 30-in. saw was the only one capable of reaching the water

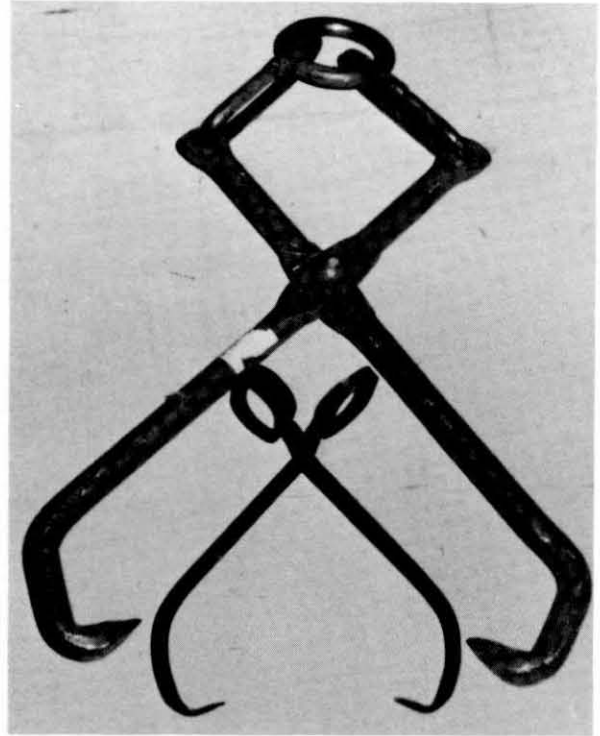


Figure 2. Small hand-held ice tongs inside large timber tongs.

surface. The 18-in. saws were equipped with unmodified skip-tooth chains. CRREL's 24-in. saw had a skip-tooth chain modified by filing the gauge down by about 1/16 in. The 30-in. saw had a standard chain, which provided a slow ice cutting rate.

CRREL-fabricated push knees for the Combat Support Boat (Fig. 1) were supplied to be evaluated for pushing floating ice out of the crossing zone. These push knees were designed to fit on the older style, prop-driven Combat Support Boat, but if they worked they could be easily modified for the newer MKI and MKII versions. Additionally, we brought to the test site timber tongs, ice tongs (Fig. 2) and a short aluminum I-beam with a shackle attached (Fig. 3) to use when lifting ice with a transporter boom.

The other equipment available at the site consisted of bulldozers, bridge transporters, Ribbon Bridge sections, axes, tanker bars, hand ice drills and other miscellaneous equipment normally found with a bridge company.

### Test site

The crossing zone was on Alderwood Lake, at Fort McCoy, Wisconsin. Figure 4 shows the bot-

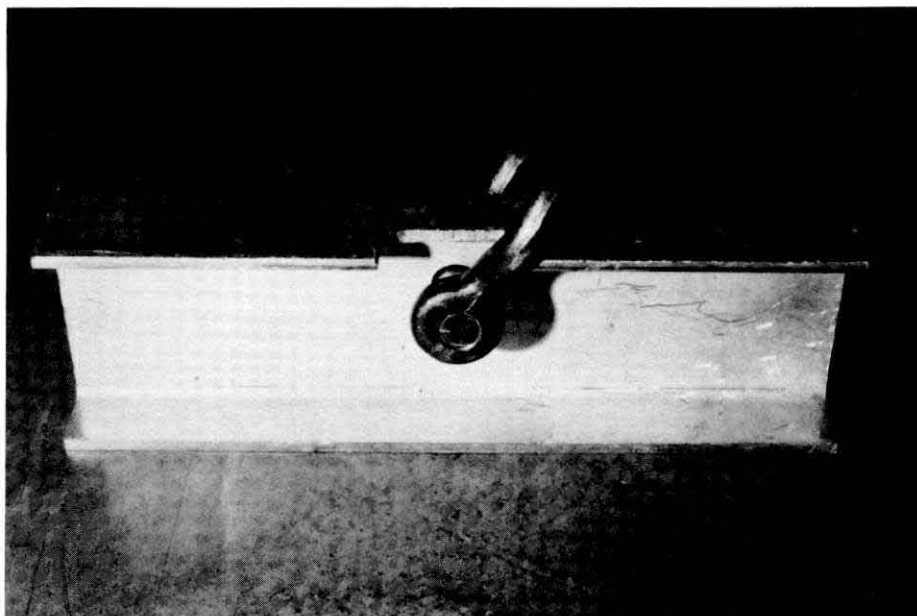


Figure 3. I-beam and shackle used for lifting ice blocks from the water.

tom conditions and ice thickness from an ice reconnaissance by Company A 10 days before the exercise. The ice thickness varied from 17 in. in one spot at the south shore to 29 in. at one spot near the north shore of the lake. The weather may have moderated between the time of this reconnaissance and the exercise date, as the thickest ice that was measured during the exercise was 24–25 in.

Snow was cleared from the south crossing approach by bulldozer. The snow on the ice at the

south end was cleared by hand before the ice cutting began, although the ice was thick enough to support a bulldozer if necessary.

#### Cutting and removal

First, we decided to ascertain if a bulldozer could be of any use for breaking and removing ice of this thickness. Two slots were cut through the ice parallel to the working line of the bulldozer, with the distance between them slightly more than

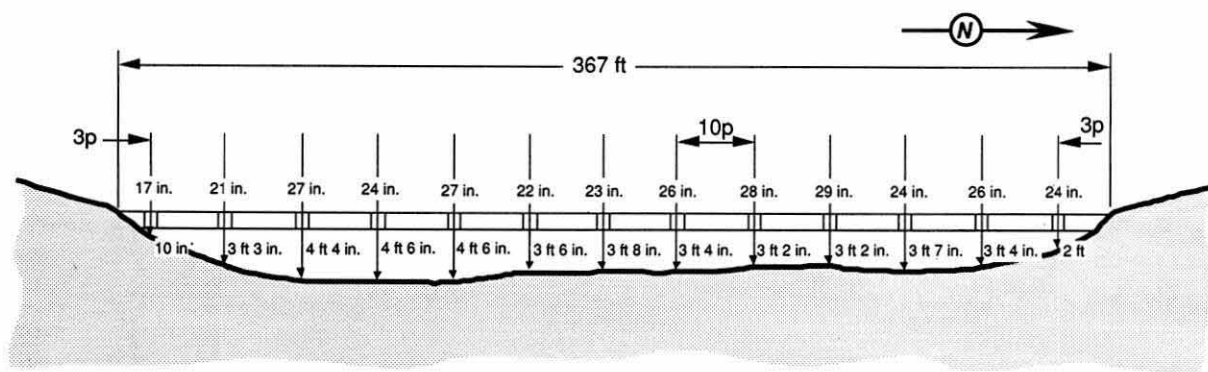


Figure 4. Profile of Alderwood lake on 10 February 1988 (p = paces; values above the ice are ice thickness; values below the ice are depth below the ice cover).



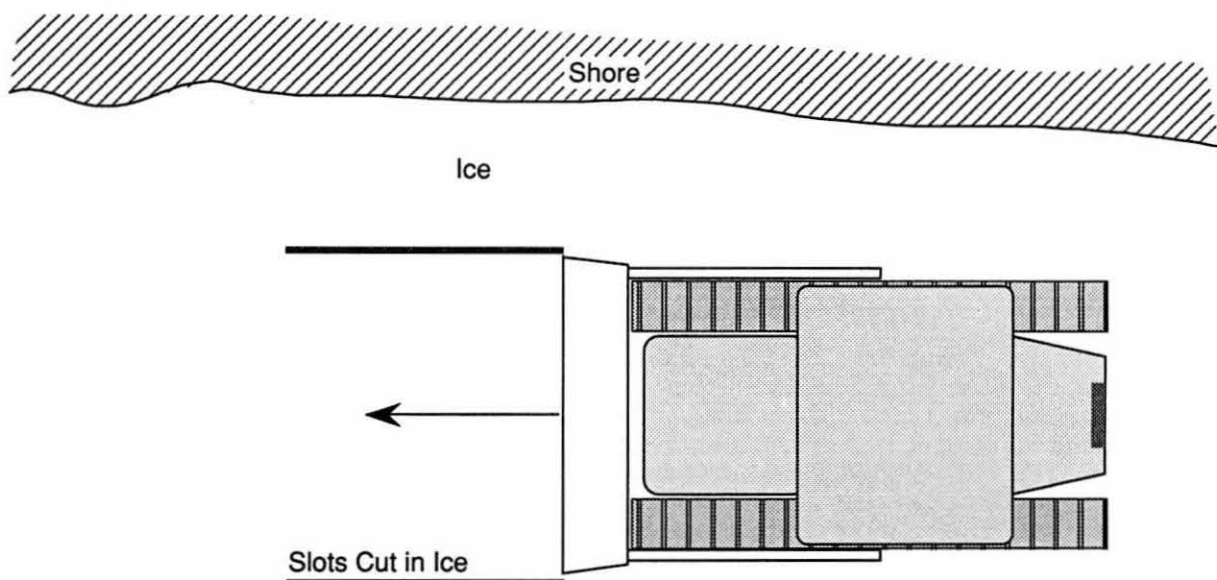


Figure 5. Ice removal by bulldozer. Slots were cut parallel to the bulldozer's direction of travel and just outside the edges of the blade.

the width of the bulldozer blade (Fig. 5). We hoped that these would weaken the ice enough so that the dozer blade could break out sections of ice. A V-notch was then cut into the ice, perpendicular to the working axis of the bulldozer, connecting the previously cut slots, to give the blade a purchase in the ice. In the initial attempts to lower the blade

into the notch, we discovered that the blade support arms contacted the ice surface behind the blade, preventing us from lowering the blade enough to get it under the bottom edge of the ice in front of it. Several attempts to lift the ice failed because the blade would ride up over the ice, scraping off a small amount at the surface. A notch



Figure 6. Ice cut into three sections, showing the lifting hole in the righthand block.

much wider at the top would have been needed to allow the bulldozer blade to get under the ice to lift it up.

We tried shaving the ice off behind the notch with the bulldozer but the blade had little effect upon the ice. After several attempts, this technique was given up as being impractical. We considered cutting the notch back with the chain saw, but with the thick ice that was present it was evident that a very long chain saw blade held at a low angle would be necessary. This would be difficult, if not impossible, for a human operator to handle.

We were curious about what could be accomplished with rippers on the back of a bulldozer, but were unable to obtain them. Perhaps if the teeth could break the ice, the blade could then be used to clear the debris. This procedure could of course only be used where the river topography allowed the bulldozer to work in the water.

Next, we tried using the transporter to remove ice blocks cut by chain saws. The ungrounded ice away from the shore was marked off into approximately 5- x 8-ft sections. Any grounded ice near shore can remain in place and be used as the shore itself when deploying a bridge. Each section had a rectangular lifting hole outlined, off-center, towards the shore end of the section (Fig. 6). It was sized to allow the aluminum I-beam and shackle, with the cable from the transporter boom attached, to be lowered through it. Once under the ice, the I-beam was rotated 90°. This prevented the I-beam

from slipping back out the hole and created a convenient way of lifting an ice section.

The ice cutting was extremely slow and was easily the limiting factor during this procedure. When using chain saws to cut ice, the cutting rate is highly dependant upon ice thickness and chain design. Skip-tooth chains cut ice faster than conventional chains, but are still substantially slower than chains with the gauge filed down (Coutermarsh 1989). Furthermore, when the ice thickness approaches or exceeds the length of the bar, the cutting rate is further reduced. Our cutting operations were seriously hindered from the beginning by saws incapable of penetrating the full ice thickness. This added the problem of how to finish the cut to the water to free the ice floes.

The 18-in. chain saws were used to initially cut the ice down as far as they could. The saws did not perform well in the ice and stoppages for various reasons slowed the cutting down even beyond the expected poor performance. A V-cut was made to open up the ice surface in an attempt to allow the saw to cut deeper than what would normally be possible. This increased the amount of ice that had to be cut, slowing down the process even more. A relatively large V allowed us to cut only about 2 or 3 in. deeper.

The 24-in. saw that CRREL provided was proficient in the ice, but it too was unable to reach the water. The 30-in. saw was used to finish the cuts to the water surface. This saw with its regular chain

*Figure 7. Ice block lifted by a transporter and being laid against the boom as it is lowered to the cradle.*





*Figure 8. Lifting ice blocks with timber tongs. The edge of the ice shown here has already spalled off once from a previous attempt to lift it using the timber tongs; the points of the tongs are only gripping at the edges of the ice.*

was slow at cutting the ice and was susceptible to stalling when it threw water up onto its engine. This was not a problem with the 24-in. saw.

After a section of ice had been cut free, a cable was attached onto the I-beam's shackle. The beam was then dropped through the lift hole and rotated to lock it in place. Sections of ice weighing over 5000 lb were lifted by the transporter trucks using this method. Setting the lifting hole off-center allowed the ice block to rotate and lay flat against the transporter boom as it was raised (Fig. 7). The boom would then be lowered and the ice would come to rest on the back of the truck, ready to be carried away. This proved to be a quick and very neat method of ice removal. By use of this technique, the approach to the crossing area can be kept clear of ice. It will also work in areas where there is only a narrow approach to the crossing zone, since it does not require lateral movement of equipment as in bulldozer operations. The trucks

can approach and depart on the road that will be used for the bridge itself.

The size of the block that can be lifted by this method may be limited by the ice thickness. As the ice gets thinner, it is less able to support its own weight and may fail in bending as it is lifted out of the water, so the block-size-to-ice-thickness ratio should be determined to define what size block should be cut in ice of various thicknesses.

We also experimented with using a pair of timber tongs to lift the ice blocks. These proved difficult to use because they were not wide enough to fully grip the thick ice that we were handling, except at the very edge of the block (Fig. 8). This frequently resulted in the ice block breaking apart at the edge as it was lifted. We did remove some moderate-sized blocks from the water, but found it took several attempts before the procedure was successful. Properly designed and sized ice tongs could potentially speed up the removal process by eliminating a lifting hole. It can be difficult, however, to attach tongs to a large, horizontal block of ice floating in water.

### Summary

The ice we encountered in this exercise was at, if not over, the upper limit of what could be removed in a timely manner with chain saws. The decision to remove or use the ice must take into account the bearing capacity of the ice (24.5-in.-thick ice can support approximately a 37.5-ton load when used as a bridge [U.S. Army Corps of Engineers 1982]), as well as the time available to clear the ice from the crossing zone to deploy the bridge conventionally. The problems encountered in our exercise showed that thick ice removal can be a formidable problem.

### BRIDGE DEPLOYMENT ON THE ICE

Conventional thinking holds that the Ribbon Bridge can not be practically deployed on an ice surface. Because of the initiative of the Marines' 2nd Combat Engineer Battalion, we were able to test this, and we feel that it holds promise under certain conditions.

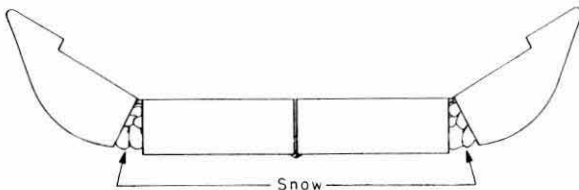
The snow on the approach to the crossing zone and on the north end of Alderwood Lake was cleared away by bulldozer in preparation for the deployment (Fig. 9). The ice was cleared to avoid having snow build up between the pontoons as the bridge unfolds, thus keeping the pontoons from opening fully (Fig. 10).



*Figure 9. Bulldozer clearing the snow from the north side of the crossing lane at Alderwood Lake.*

We did not plan on deploying a complete bridge since the south end of the crossing zone had been weakened by the previous ice cutting exercises. We therefore decided to start deploying bridge sections in the interior of the lake and work towards shore. This would allow us to investigate the feasibility of working a ramp bay onto the completed interior sections as the bridge approached shore.

The first section deployed was an interior bay. It was placed on the ice in the same manner as the bays would be placed in a maintenance yard. The transporter was positioned on the centerline of the crossing zone and the cradle was raised to gently lower the rear end of the interior bay onto the ice.



*Figure 10. Snow buildup between the bow and roadway pontons can prevent the pontons from being latched.*

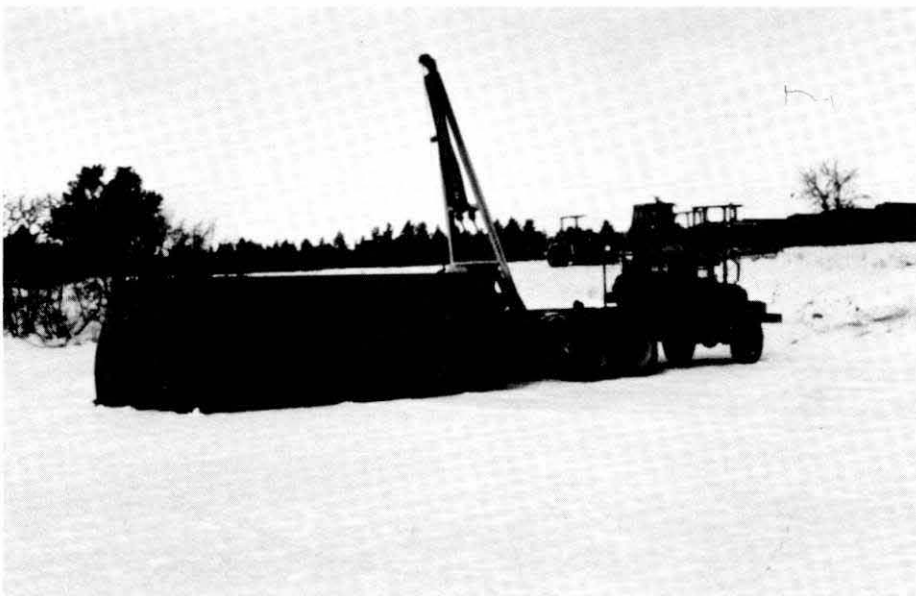
The transporter boom was then used to steadily lower the opposite end onto the ice (Fig. 11).

The bay did not unfold by itself as it would in a water launch and therefore had to be coaxed into opening. A transporter was moved around to the side of the bay where its cable was attached to a bow ponton. The truck then drove slowly away from the bay, pulling the bow ponton down, which unfolded the bay (Fig. 12a). However, the bow pontons did not unfold completely, as the tiedown pins prevented the ponton on one side from rotating fully into position (Fig. 12b). A small bulldozer was positioned at one end of the bay and used its bucket to lift one end of the bay up at a roadway ponton (Fig. 12c). This lifted the tiedown pin up out of the groove it had dug in the ice (Fig. 12d) and allowed the bow ponton to swing into place at both ends.

The second bridge bay was unloaded in line with the first and pulled open using a transporter (Fig. 13). However, the section jumped out of alignment as the pontons unfolded (Fig. 13d), and a cable pulled by the bulldozer was used to slide the section sideways back into alignment with the first. The roadway pontons opened fully but, as before, the bow pontons on this section did not unfold completely. In this case the roadway pontons were latched into place and a transporter and its boom were used to lift the end of the bay up to allow the bow pontons to rotate into place. The



*a. One end of the interior bay is slowly lowered off the truck to the ice.*



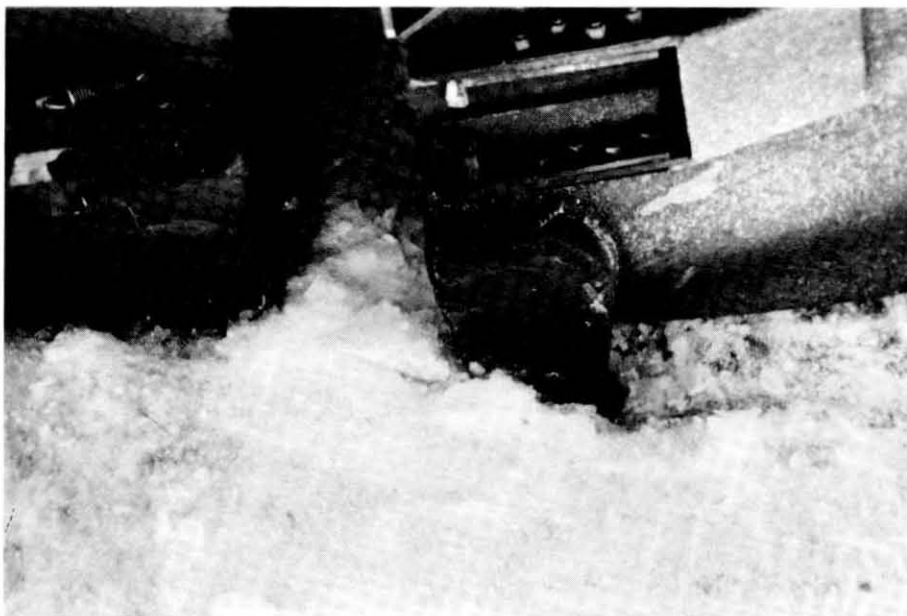
*b. The remaining end of the bay is attached to the transporter boom and lowered off the truck to the ice surface.*

*Figure 11. Deploying an interior bridge bay section.*





*a. The cable from the transporter slowly pulled the bow ponton to start the bay unfolding.*

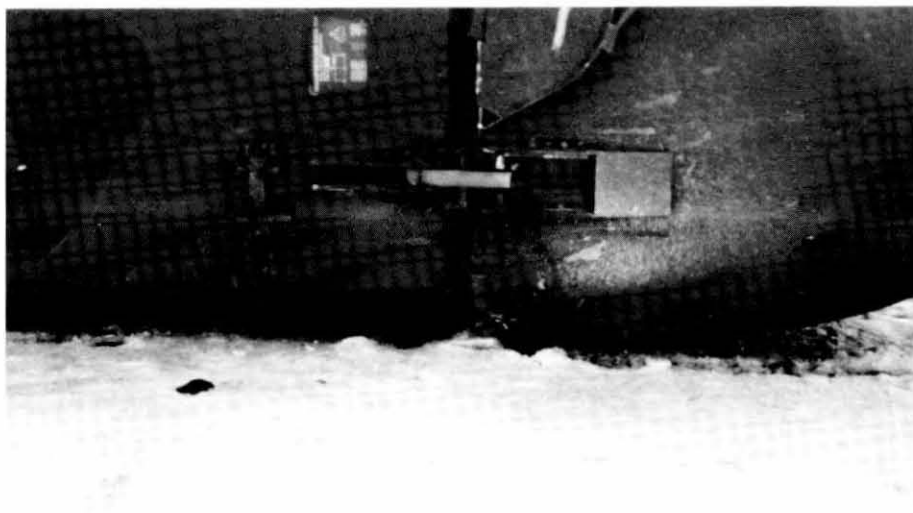


*b. The tiedown pins on the bow pontons would dig a groove in the ice, sometimes preventing the ponton from rotating into its fully opened position.*

*Figure 12. Opening a bridge bay.*

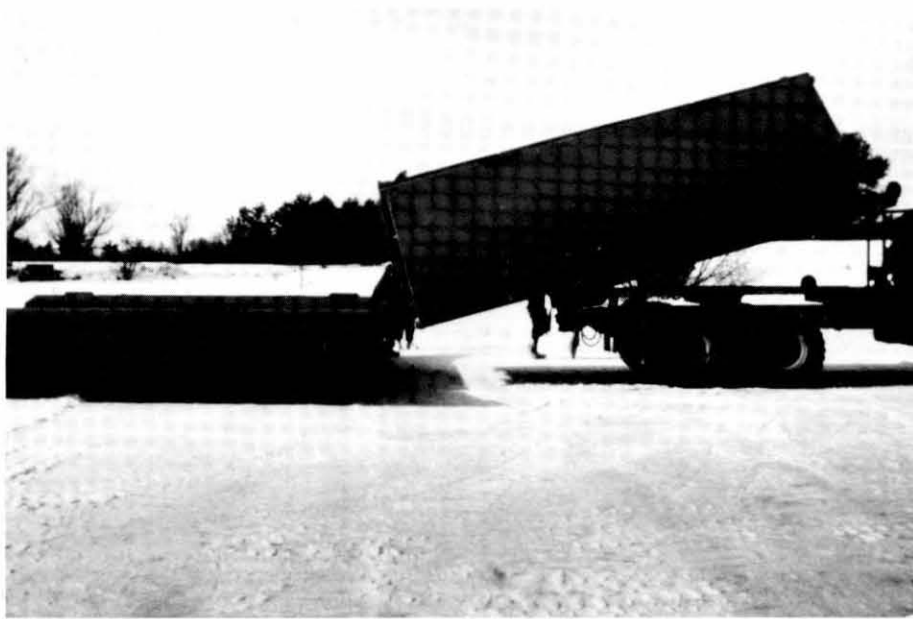


*c. The bulldozer blade was used to carefully lift the bay to allow the bow ponton to swing into position.*



*d. Fully closed bow ponton latched into position. Note the groove in the ice left by the tiedown pin when the ponton rotated downward.*

*Figure 12 (cont'd). Opening a bridge bay.*



*a. The second interior bay was unloaded in line with the first.*



*b. A transporter was again needed to start the bay unfolding.*

*Figure 13. Opening a second bridge bay.*



cable can be attached at the lifting eye, making this a safer procedure than the bulldozer method, where there is a risk of damage to the pontons from a bulldozer blade.

The two bays were closely aligned but were not locked to each other. This would have been possible given the smooth ice conditions present, but the precise movements necessary to do this were

difficult with only transporters and bulldozers available. It might be beneficial to use ratchet hoists to make the final adjustments. The ratchets could be attached to the ends of each bay and used to pull the sections together the last few inches needed to lock the dogbone connectors.

The ramp bay was the last section to be deployed. It was unloaded alongside the bridge

*c. The bay unfolding as the transporter is pulling the bow ponton.*



*d. The bay jumped out of alignment from the inertia of the pontons falling into their open positions.*

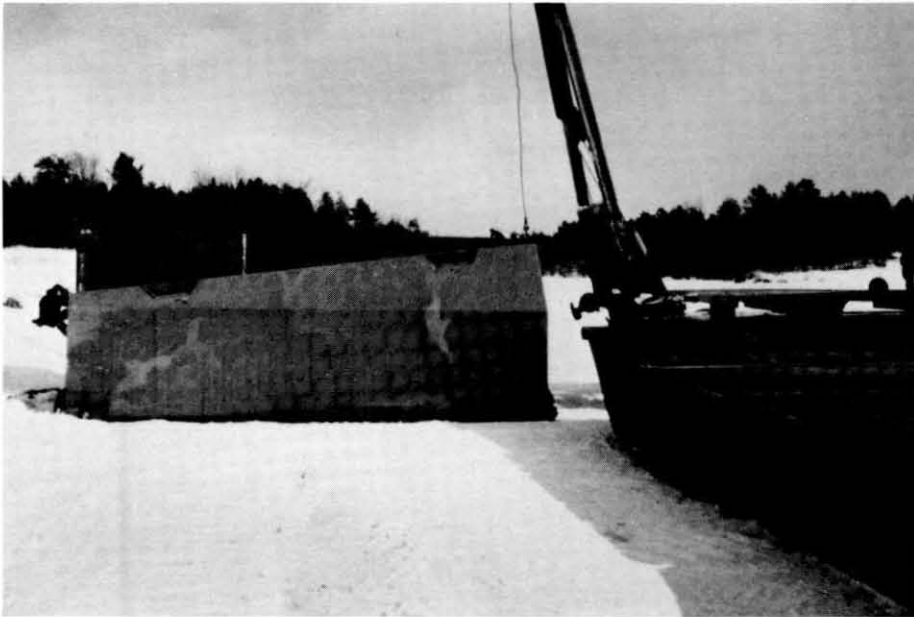


*Figure 13 (cont'd). Opening a second bridge bay.*

centerline between the last roadway section and the shore. It was unfolded by the same technique as the roadway pontons, with both bow pontons requiring an assist from a transporter to unfold. Once unfolded with its pontons locked in place, the ramp bay was moved sideways into position by a transporter (Fig. 14).

Each bridge bay was aligned to the other to

within approximately 3 to 4 in. This was more than close enough to provide an essentially continuous surface for travel between the sections, but it did not allow the bays to be locked to each other. A HMMWV (class 4), transporter (class 28) and an AAV (class 26) were driven onto and off from the sections individually to determine the reaction of the bays and ice to the loads (Fig. 15).



*a. The ramp was unloaded alongside the last interior bay.*



*b. A transporter was used to align the bay with the previously placed sections.*

*Figure 14. Deploying the ramp section.*



*c. Once aligned, the ramp bay was moved sideways into position at the end of the interior sections.*



*a. HMMWV.*

*Figure 15. Loads applied to the assembled bridge bays.*



*b. Transporter.*



*c. AAV.*

*Figure 15 (cont'd).*



*a. The ramp bay with both transporters attached. Lifting up both ends of the bay allowed the bow pontons to rotate closed.*

## BRIDGE RETRIEVAL

To retrieve the bays, we reversed the deployment sequence. A transporter slid the ramp bay sideways away from the interior bays. It then backed up to the end of the bay and lifted it with its boom, as in a normal recovery. One bow ponton did not fold up into its travel position as the bay was raised up to the truck. So, a second transporter backed up to the ponton, attached a cable to it and lifted upwards until the ponton folded (Fig. 16a). The ramp bay was then loaded onto the transporter.

The first interior bay was loaded from the end closest to shore and thus it was not necessary to slide the bay sideways away from the remaining section. Both bow pontons on this interior bay failed to fold up during the initial lift to the transporter. One ponton was coaxed into closing by raising and lowering the end of the bay with the transporter (Fig. 16b and c). It was necessary to use a second truck to lift the remaining ponton, similar to the procedure used on the ramp bay ponton, to rotate it into its travel position (Fig. 16d). The bay was then loaded onto the transporter in a relatively straightforward procedure (Fig. 16e).

Both of the bow pontons on the remaining interior bay refused to fold up during the initial lift and had to be individually lifted by a second trans-



*b. As the interior bay was initially lifted to the transporter, both bow pontons failed to rotate closed.*

*Figure 16. Retrieving the bridge.*



*c. One bow ponton was coaxed closed by cycling the bay up and down.*



*d. The second bow ponton was closed by lifting it with a second transporter.*

*Figure 16 (cont'd).*



*e. Once closed, the bay was routinely loaded onto the transporter.*

*Figure 16 (cont'd). Retrieving the bridge.*

porter before being loaded onto the truck. Apart from the reluctance of the bow pontons to close, the sections were loaded back onto the transporters without much problem.

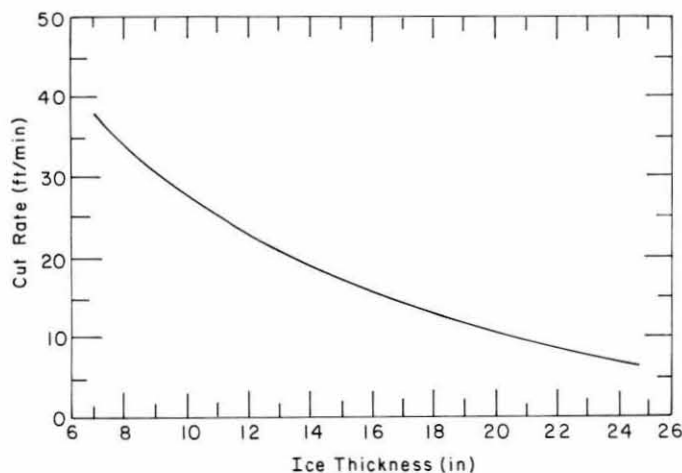
## DISCUSSION

Removing thick ice from a crossing zone can be very labor intensive and time consuming. Figure 17 is a graph of cutting rate vs ice thickness attained with a 24-in. chain saw and a chain modified for cutting ice. As the ice thickness increases, the cutting rate attainable with chain saws falls exponentially. It is evident that cutting the ice

away from the crossing site can quickly become impractical.

There are unanswered questions as to the best method of crossing ice that is relatively thick (i.e., 18–35 in.), yet perhaps not thick enough to support potential loads of class 30 to class 70 and above. It has been thought that it was far too difficult to deploy the Ribbon Bridge on an ice cover to form a usable bridging surface. This exercise clearly shows that it is possible, but not necessarily desirable.

During the deployment sequence, the ice developed radial cracks originating from the area where the bridge sections were placed (Fig. 18). Not long afterwards, what appeared to be portions of two



*Figure 17. Cutting rate vs ice thickness using a 24-in. chain saw with a skip-tooth blade modified for ice cutting (after Coutermarsh 1989).*



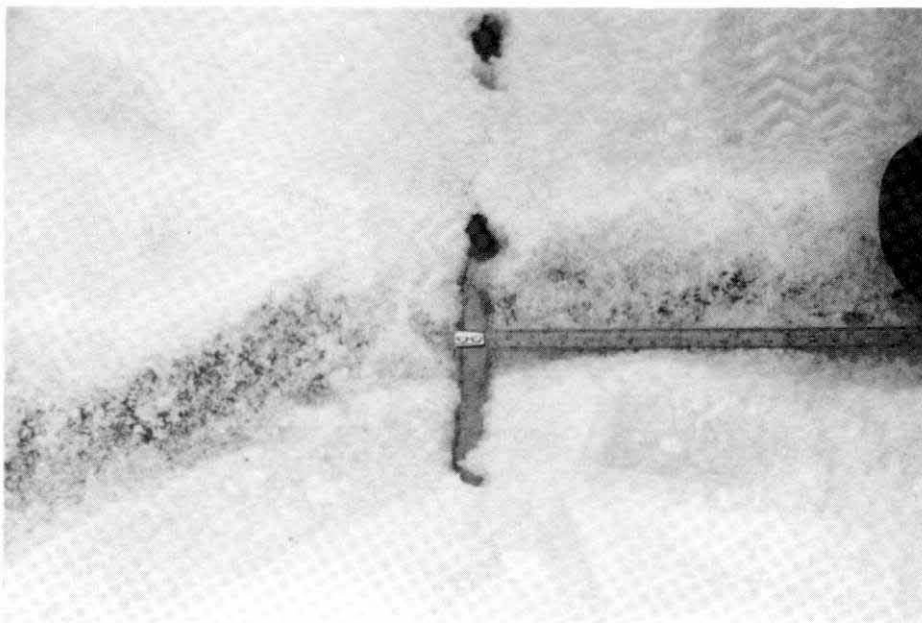


Figure 18. A portion of one of the  $\frac{1}{2}$ -in.-wide circumferential cracks that developed in the ice around the Ribbon Bridge.

circumferential cracks also appeared, centered around the bridge sections. The closest crack was about 10 ft from the end bridge section and had a top width of  $\frac{1}{2}$  in. The next crack was about 69 ft from the bridge and it too was  $\frac{1}{2}$  in. wide. The pattern of the visible portion of these cracks suggested that they would form a semicircle around the bridge, but the snow on the ice made it impossible to confirm this.

At the heaviest loading, the ice held three bridge sections and a transporter, for a total weight of nearly 46 tons. This weight was spread out by the Ribbon Bridge over both grounded and free-floating ice. As mentioned before, an ice thickness of 24.5 in. is capable of carrying a wheeled vehicle of about 37 tons (class 37). It is impossible to say from our experience if the bridge increased or decreased the bearing capacity of the ice.

A thick ice sheet is required to support the loads present when deploying the Ribbon Bridge on top of the ice. This approach may provide an alternative when ice removal becomes impractical.

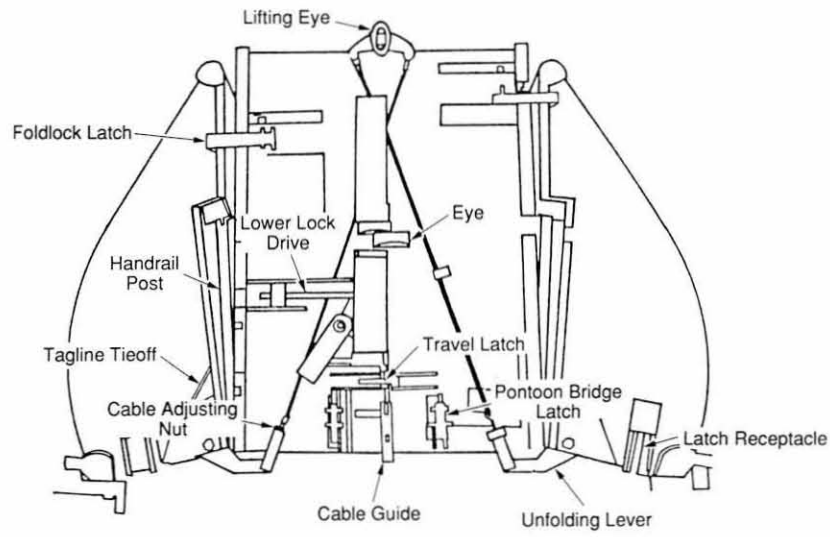
When the Ribbon Bridge is set on an ice cover, there are some components that might be harmed during deployment or trafficking. When the bays are unloaded, the ponton bridge latches must be pulled up to prevent them from being damaged when the bay contacts the ice (Fig. 19a). These should remain in this position during any subse-

quent positioning of the bay. Figure 19b shows the lifting eye and bell crank for the cables connected to the unfolding levers resting on the ice. The bell crank or its shaft might be damaged by repeated forcing against the ice when the bay is being moved into position or when vehicles use the roadway pontons.

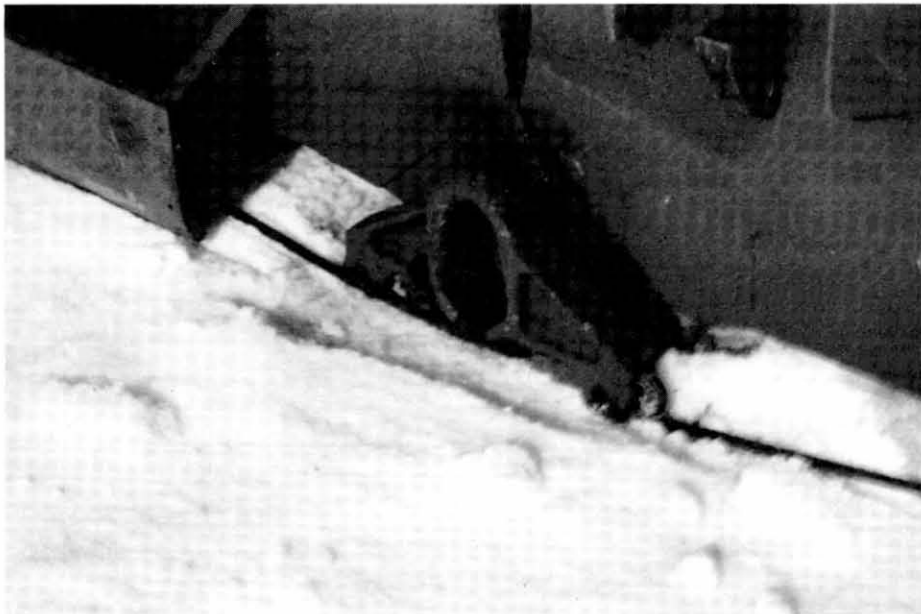
The travel lugs project out from the surface of the bow pontons and therefore take the majority of the load from the bridge when it is resting on a hard surface (Fig. 19c). This will cause a stress concentration in the corner of the ponton where the travel lugs attach to the bow pontons. As shown earlier, dragging a bay into position will cause the lug to dig into the ice (Fig. 12b). This drag resistance from the lug is a major impediment to moving the unfolded bays on the ice and also causes a torque to be transmitted via the lug into the corner. Trafficking the bridge will put a vertical load onto the lug, possibly punching the lug further into the ponton.

A fairing that could be attached to the lugs to prevent them from digging into the ice might be beneficial. The fairings would slide over the ice, reducing the torque transmitted to the corner, and the bays would slide easier because of the reduced drag from the lugs. A fairing would not diminish the punching force transmitted by the lug to the corner unless it could be designed to transmit the





*a. The pontoon bridge latches should be secured in their travel position, as shown here, before unloading the bay onto the ice (after U.S. Army 1980).*



*b. The bell crank on the bay projects down enough to contact the ice surface with the bay unfolded.*

*Figure 19. Potential damage to bridge bay components.*



*c. The folded bridge bay showing the travel lugs projecting out from lower surface of the ponton.*

*Figure 19 (cont'd).*

load from the lug to the adjacent ponton. A fairing might also help during the recovery of the bays by reducing the drag of the travel pins as the bow pontons are rotating into their closed position. This could make the recovery a bit faster, although some time would probably be necessary to remove these before the bays could be locked onto the transporters.

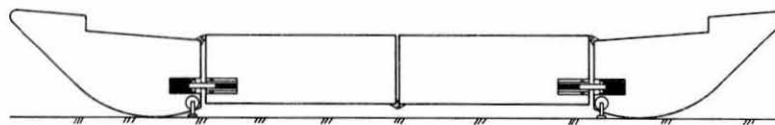
When deployed in water, the bridge has a relatively low unit area loading because of the large surface area of the bays available to spread the load. However, design blueprints for the interior bay show that the lower rounded bow ponton sections project approximately 4.25 in. below the bottom surface of the roadway pontons (Fig. 20). When the bay is deployed on a hard surface, this curved section may receive more concentrated

stress loads than it normally does. The effect of repeated trafficking on this lower surface needs to be determined before the bays receive extended use on a hard surface.

The mere fact of deploying the Ribbon Bridge on an ice sheet does not in itself solve the problem of moving heavy loads across the ice sheet. However, it does offer more flexibility in determining how the rest of the operation could be accomplished, as discussed below.

The first step in the bridging procedure would be determined by the anticipated loads vs the thickness and quality of the ice, as well as by what can be determined as a feasible and practical use of the Ribbon Bridge.

For example, let's assume the crossing scenario requires the transport of class 60 loads across an ice



*Figure 20. Rounded portion of the bow pontons project below the bottom of the adjacent roadway pontons. If the bay is resting upon a hard surface, the roadway pontons are held above the surface by both the bow pontons and travel lugs.*

thickness of 25 in. A class 60 load requires approximately 39 in. of good quality ice (U.S. Army Corps of Engineers 1982). The ice is therefore not thick enough to use as the bridge. If the tactical situation dictates that there is not enough time to cut and remove the ice in the crossing zone, then on-ice deployment of the bridge can be a possibility. The Ribbon Bridge can be supported by 25 in. of good quality ice, and a substantial time savings could be achieved by deploying the bridge on the ice. Once the bridge bays are in place, the crossing possibilities would be determined by how much damage the bridge bays can withstand, how much the ice bearing capacity would be increased by the bridge's load spreading features, as well as how safe the operation would be, as discussed below.

### Dropping the bay into the water

After the bridge is deployed on the ice, it may be desirable to cut the ice along each side of the bridge. This would create a continuous ribbon of ice under the bridge that would still be attached at its ends to the shore-fast ice. The weight of the bays might then be sufficient to submerge the ice, settling the bridge into the water and creating an essentially normal use of the bridge.

The weight necessary to submerge the ice can be estimated by calculating the weight necessary to submerge a free-floating ice block as outlined in EM 1110-2-1612 (U.S. Army Corps of Engineers 1982). The limiting load bearing capacity  $P$  of an ice block is defined by

$$P_{\max} = Ah (\rho_i - \rho_w)$$

where  $A$  is the horizontal surface area of the block,  $h$  the block thickness,  $\rho_i$  the ice density and  $\rho_w$  the water density. In our example we could assume  $A$  would be an area of ice sufficient to allow the bridge to clear the edges of the adjacent ice cover. A 30-ft-wide cut would suffice and would result in  $A$  being equal to 30 ft<sup>2</sup> if the calculation is done on a unit length basis. The ice thickness  $h$  is 25 in. or 2.1 ft,  $\rho_i = 57.3 \text{ lb/ft}^3$  and  $\rho_w = 62.4 \text{ lb/ft}^3$ . On a unit length basis  $P$  is therefore

$$P = (30) (2.1) (5.1)$$

or

$$P = 321.3 \text{ lb/ft}$$

An interior bridge bay is 22.5 ft long and weighs 12,000 lb or approximately 533 lb/ft. It is evident

that the bridge alone would be capable of submerging the ice if it were free-floating. However, the ends of the ice ribbon would still be attached to the grounded ice near shore, unless the ice could be cut before the ramp bays were deployed or the total weight of the bridge was great enough to break the ramps free.

If the ice remained underneath the bridge, it is unclear what effect this would have. If the ice remained perfectly aligned beneath the bays then the buoyancy of the bridge would be increased by the added buoyancy of the ice. However, it is doubtful that the ice would remain directly under the bridge. As traffic moves over the bridge, it pushes it down, which might shift the ice around. A strong current might also cause the ice to shift to one side of the bridge. If the ice shifted more to one side than the other, the bridge would be unevenly supported and might exhibit a tendency to roll towards the less buoyant side during trafficking.

### Employing the bridge as a load spreader

If the Ribbon Bridge can be used when it is grounded along its entire length, then it might be possible to use the bridge as a load spreading device on top of the ice. Although a bridge bay weighs a considerable amount, it has a large surface area that the load would be spread over, thus minimizing the unit pressure. The unfolded roadway pontons are about 13.5 ft wide and 22.5 ft long. The total surface area here is about 304 ft<sup>2</sup> or 43,740 in.<sup>2</sup>; the single bay's weight spread over this area gives a unit loading of 0.27 lb/in.<sup>2</sup>; the weight of a bay plus a class 60 load would be about 3 lb/in.<sup>2</sup>, a conservative estimate that does not include the added area of the bow pontons that would also bear on the ice and lower this further. Load spreading has the potential of allowing heavier loads for a given thickness of ice. It also has the desirable feature of avoiding the very slow and labor intensive ice removal procedure.

The travel lugs and the bow pontons' shape might present the biggest obstacles to this option. As discussed earlier, if the roadway pontons are held above the ice surface by the bow pontons or travel lugs, the traffic load on the bridge would be concentrated at these areas, possibly resulting in failure of the bridge.

Hutchinson (1977), in on-ice deployment trials of the Ribbon Bridge, suggests unlatching the bow pontons and allowing them to rotate upward until the roadway pontons contact the ice. This would allow the full area of the roadway pontons to bear against the ice. However, if the ice were to fail

during trafficking, the unlatched bow pontons could rotate into the path of oncoming traffic as the roadway pontons sunk through the ice. As suggested, some kind of latch modification would be required to prevent the bow pontons from rotating in this situation.

### Creep failure of ice

While a load spreading scheme may allow larger dynamic loads to cross than what the ice alone could bear, the long term loading of ice introduces concerns about creep failure, which is a function of how the ice is loaded, the magnitude of the load and the length of time the ice is loaded. For instance, a load that might be acceptable in motion across a given thickness of ice may fail the ice if that load is stationary for any length of time. The longer a load is applied to the ice, the higher the possibility of creep failure of the ice. This is not a well understood area and a reliable method is not available for predicting this without either performing several measurements of the ice as it deforms or by doing a laboratory analysis of the material.

Figure 21 is a graph from EM 1110-2-1612 (U.S. Army Corps of Engineers 1982) predicting creep failure based upon the load  $P$ , ice thickness  $h$  and the length of time the ice is subjected to the load. This graph is valid for a concentrated load, which may or may not apply to the strip load the ice experiences from a Ribbon Bridge. Experience with this manner of loading is scarce, if it exists at all, and appropriate analysis and confirmation would be needed to obtain a definitive answer.

### Cyclic ice failure

Another area of concern is the degradation of ice strength attributable to cyclic loading. A bridging operation would involve repeated dynamic loads to the ice surface as vehicles traverse it whether or not the bridge is used to spread the load. There is concern that ice will become weaker when it is loaded cyclically, which might necessitate using the ice only for a specified time limit and then moving to a new crossing zone.

## CONCLUSIONS AND RECOMMENDATIONS

As stated earlier, cutting thick ice with chain saws becomes very labor intensive and slow. This makes the procedure less viable for tactical bridging where fast deployment times are crucial.

There are many unanswered questions about both deploying and using the Ribbon Bridge on an ice sheet. Some modifications to prevent damage to the bridge should be made as well as some to increase the safety of an on-ice deployment.

It should be evident from the discussion that more work is necessary on the bearing capacity of ice before the practicality of the bridge as a load spreader can be determined. Empirical studies do offer valuable guidance with the more conventional methods of trafficking and the need to make a winter tactical crossing should not ignore the potential of ice as a bearing surface, especially in light of the difficulty and time involved in removing thick ice from the crossing zone.

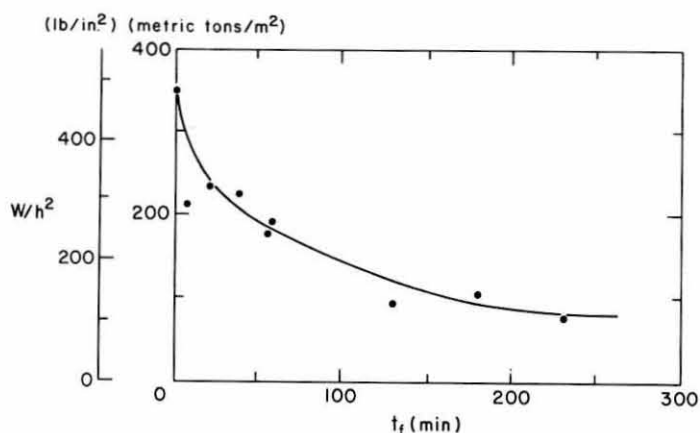


Figure 21. Bearing capacity chart for loads of long duration (from U.S. Army Corps of Engineers 1982).

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