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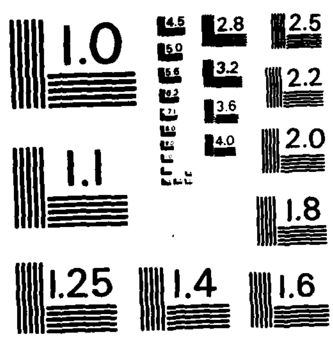

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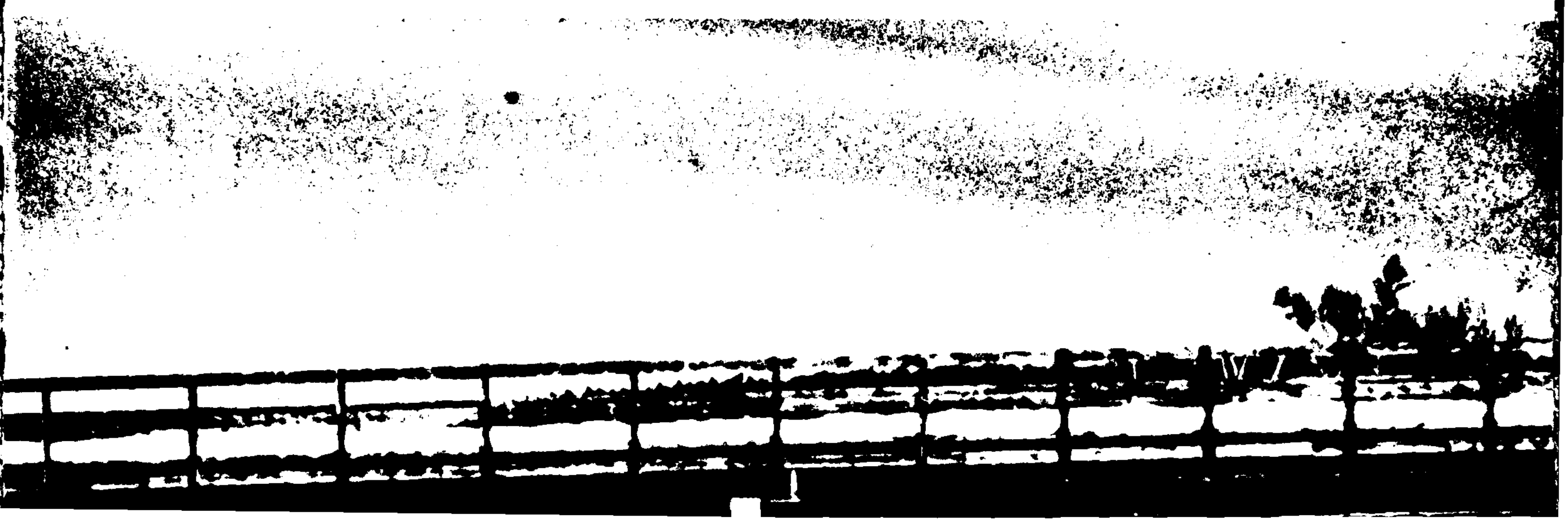

Cover: Load panels installed on pier of Quechee, Vermont, golf course bridge. Photo taken prior to breakup.

CRREL Report 83-32

December 1983

Ice force measurements on a bridge pier in the Ottauquechee River, Vermont

D.S. Sodhi, K. Kato and F.D. Haynes

Prepared for
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Ice forces on a bridge pier in the Ottauquechee River, in Quechee, Vermont, were measured by installing four panels—each capable of measuring forces in the normal and tangential direction—on both sides of a vertical V-shaped pier nose. The measured forces are presented for a short period during an ice run. After the ice run, the thickness and sizes of the ice floes were measured and the compressive strength of the ice was determined in the laboratory from the ice samples collected along the river banks. The water level measurements made at several locations along the river are also presented for the period of the ice run.

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PREFACE

This report was prepared by Dr. Devinder S. Sodhi, Research Hydraulic Engineer, F. Donald Haynes, Research Mechanical Engineer, both of the Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory, and Kazuyuki Kato, Visiting Research Engineer, Ishikawajima-Harima Heavy Industries, Tokyo, Japan. Funding for this research was provided by Civil Works Information Project, CWIS 31723, *Model Studies and Ice Effects on Structures.*

Steven L. DenHartog and Darryl J. Calkins of CRREL technically reviewed the manuscript of this report. The authors are grateful to the following people for their help in conducting this project: Calvin Ackerman, James Morse, John Bayer, Gordon Gooch, Charles Schelewa, Carl Martinson and Anthony Lozeau. The authors are also thankful to Darryl Calkins for providing the data on water level variations in Figure 7.

ICE FORCE MEASUREMENTS ON A BRIDGE PIER IN THE OTTAUQUECHEE RIVER, VERMONT

D.S. Sodhi, K. Kato and F.D. Haynes

INTRODUCTION

For rational design of structures subjected to ice action, the results of theoretical studies, small-scale experiments and full-scale measurements of ice forces have to be synthesized to develop guidelines and recommendations in the form of design codes to be used by practicing engineers (Neill 1976). The field measurement of ice forces forms an important part of this process. Ice forces depend to a large extent on the properties of ice, the geometry of the structure and the mode of ice failure or action. The application of theoretical analysis and the results of small-scale experiments are complicated by the complex and highly variable properties of ice. The interaction of ice with a structure may result in one of or a combination of the following: bending, crushing, impacting, splitting, rafting, submerging and buckling. Thus, there is a strong need to measure ice forces on structures to determine their magnitude and thereby build confidence in existing theories and practices. Since the ice conditions vary considerably from one region to another, the ice forces should be measured at as many sites as possible.

Systems for measuring ice forces use either of two basic methodologies (Sodhi and Haynes 1983): 1) placing a load frame (i.e. a beam or a plate) between the ice and the structure and measuring the reaction forces, or 2) measuring the response of the structure in terms of acceleration, displacement or strain at a few points and relating these measurements to the ice forces.

The load frame to be placed between the ice and the structure may be a beam or a plate supported at a few points on the structure. The reaction forces that develop during the ice action are usually measured by load cells, strain gauges or pressure gauges. The installation and instrumentation of the load frame require considerable planning and effort, and its design must take into account the logistics problems associated with the site.

While it is relatively easy to install a strain gauge or an accelerometer on a slender structure to monitor its response, the results are dependent on the development of a reliable mathematical model of the structure through static and dynamic calibration. This difficulty is particularly evident when the response of the structure to ice forces is either so small or so complex as to make the results ambiguous and questionable.

Figure 1. Load panels on the bridge pier in the Ottauquechee River near Quechee, Vermont.

For a review of ice forces and their field measurement, the reader is referred to review papers by Neill (1976) and Sodhi and Haynes (1983).

In this report, we present the procedure adopted for the force measurement at a bridge pier in the Ottauquechee River, Quechee, Vermont. The site is 20 miles from Hanover, New Hampshire, in a steep, shallow river typical of this region. For the measurement of ice forces, we installed four panels, two on each side of the vertical V-shaped pier as shown in Figure 1. Each panel is supported by four pins that are internally instrumented to measure forces in the normal and tangential directions. The ice forces measured on 26 March 1982 during an ice run are presented along with water level variations. We also present some data on the ice thickness and strength.

LOAD PANELS

Some of the important factors considered in the design of the load panels were the range of observed water level variations during the ice runs in previous years, the configuration of the pier, the type of load measurements (e.g. normal and tangential forces), the size and number of panels, the number of load cells, the logistics of panel installations and data acquisition, and other factors.

The size of each panel is 0.56 by 1.22 m (22 by 48 in.). We established these dimensions to cover both the entire width of the bridge pier and the expected range of water level variations. A schematic sketch of the panel is shown in Figure 2, and Figure 3 shows a photograph of the panels from the top of the bridge pier. A small gap in the panels—shown in Figures 2 and 3—ensures negligible interaction between the panels on each side of the V-shaped pier.

We designed the panels (see Fig. 4) to be rigid and strong not only to endure the ice action but also to keep their natural frequency of vibration as high as possible in order to prevent any modification in the measurement of ice forces. Each panel was supported by four 50.8-mm (2-in.) diameter pins that were internally instrumented to measure forces in two perpendicular directions. The arrangement for the support system is shown in Figures 2 and 5. A compromise had to be made between the high stiffness of the support system and the resolution of the measured forces. The load capacity of each pin is 222.5 kN (25,000 lb).

We devoted special attention to the protection of cables as it is very difficult to rectify any problem related to water leakage after installation. We connected the cables to the biaxial force measuring pins and

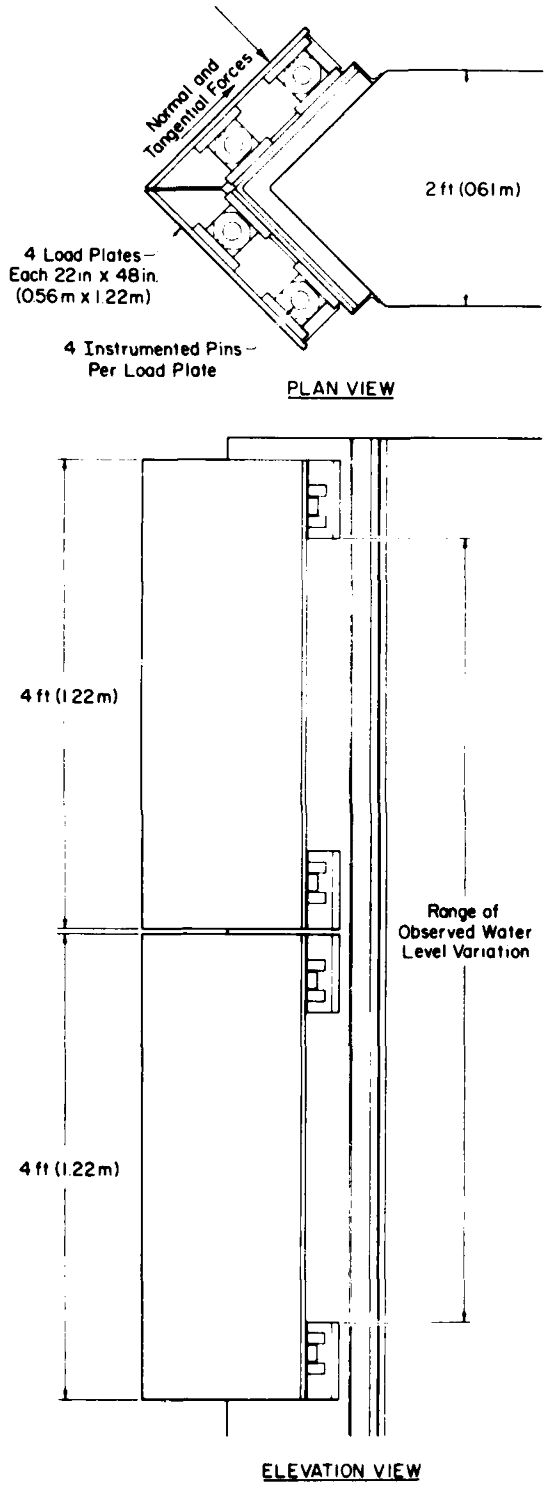


Figure 2. Schematic of the panels.

Figure 3. Panels as viewed from the bridge deck.

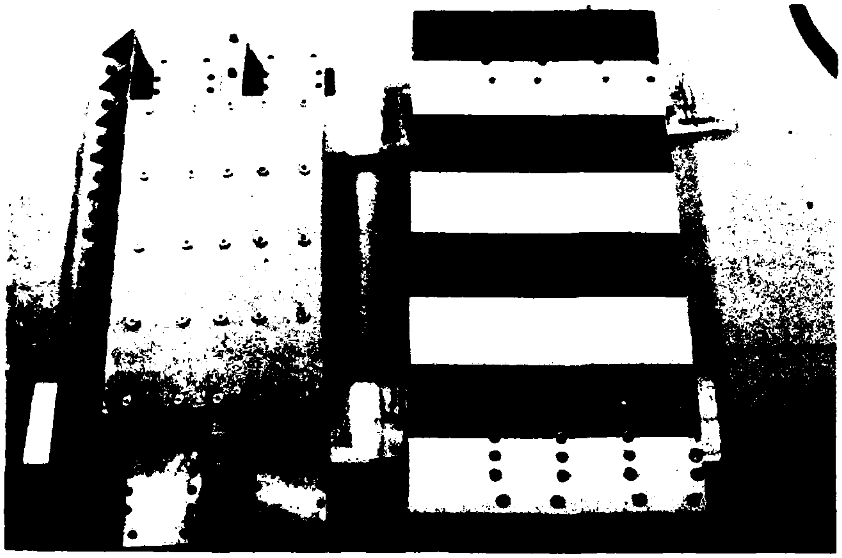


Figure 4. Load panels.

Figure 5. Instrumented pins and the cables running behind steel plates.

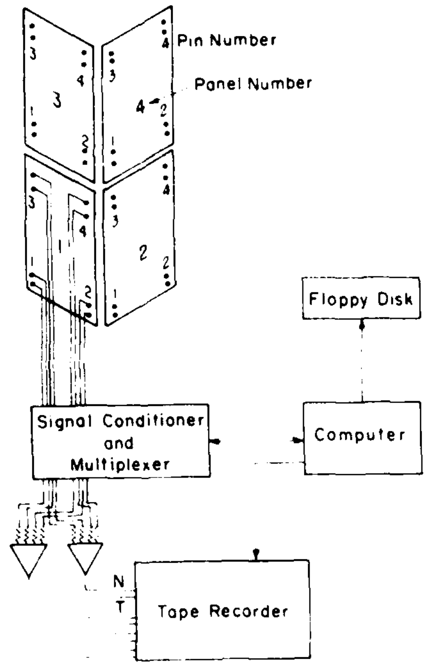


Figure 6. Data acquisition system for each panel. The letters N and T stand for the sum of normal and tangential force signals from a panel.

checked for any leakage. They were further protected from ice by running them behind the steel plates as shown in Figure 5.

The arrangement for data acquisition is shown in Figure 6. The data from 32 channels were amplified and filtered before recording them in analog and digital forms. The digital recording was done on floppy disks with the help of a small computer that continuously monitored the data and also controlled the operation of a magnetic tape recorder. Whenever the data in any one channel exceeded a preset value, the data on all channels were recorded along with time and date. If the root-mean-square value of the measured force on any channel exceeded a preset value, the tape recorder was switched on for continuous analog recording.

RESULTS

Ice movement in the Ottauquechee River is caused mainly by the sudden rise in water level caused by the failure of ice jams. It rained continuously about 24 hours before the ice moved on 26 March 1982. A 6-hour record of the stage at different locations along the river prior to the ice movement and including the time of the ice movement is shown in Figure 7. Sudden changes in water level at different points along the river are caused by small- or large-scale movement of ice that also sets water waves propagating upstream and downstream. The ice movement at the site started at about 1413 hours and lasted for about 6 to 8 minutes. Since we were waiting for this event, we had switched on all the recording equipment manually.

The water level reached only up to the middle of the lower two panels and so the ice did not hit the upper two panels at all. A partial record of the normal and tangential forces is presented in Figure 8.

We made the following observations while standing on the bridge during the ice run. The ice hitting the bridge pier was broken up. The average size of floes ranged from 1 m (3 ft) to a maximum of 10 m (30 ft). The ice thickness was in the range of 0.15 m (0.5 ft) to 0.6 m (2 ft). A photograph of the broken-up ice deposited along the river banks is shown in Figure 9. Soon after the start of the ice run, the broken

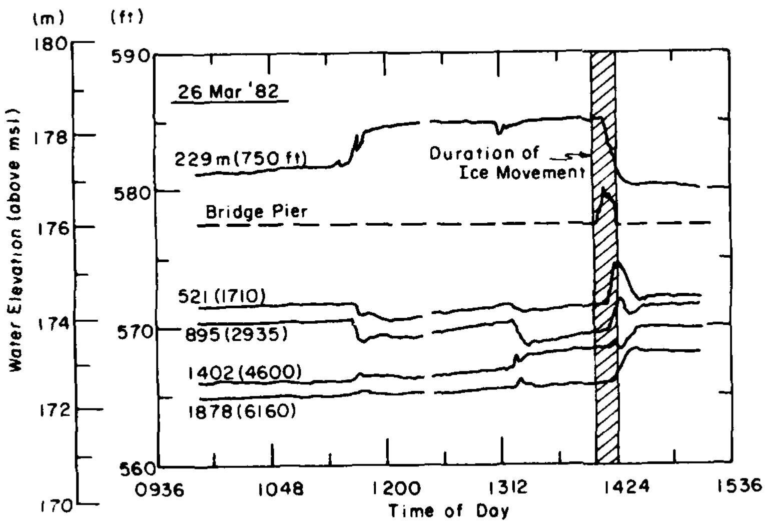
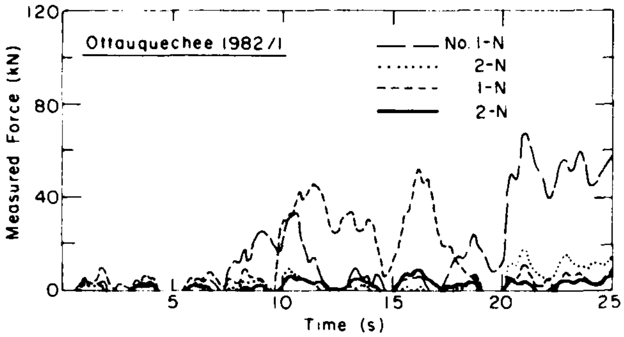
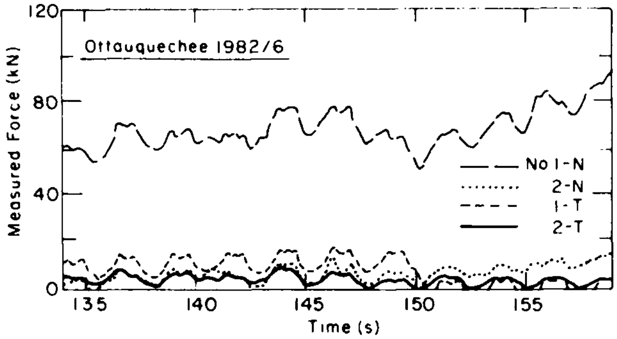


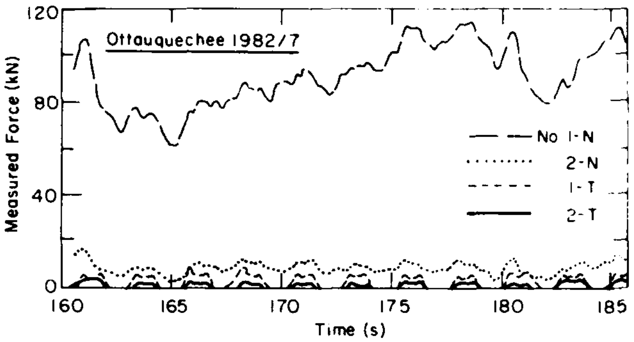
Figure 7. Record of stage vs time at different points along the river. The number on the records refers to the position of gauges upstream (above the dashed bridge pier line) or downstream (below the dashed bridge pier line) of the bridge pier. The gauge installed on the bridge pier measured the water level only during the ice movement—the dashed line indicates the time it was out of water.



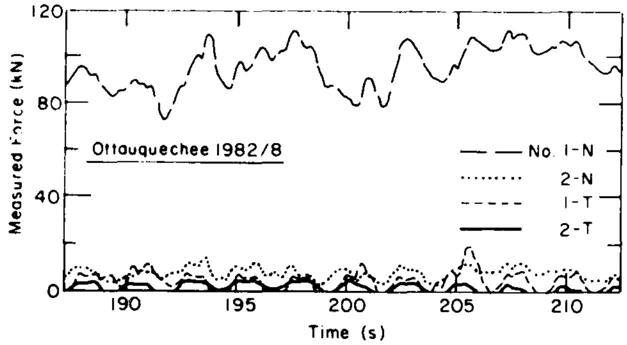
a. 0–25 seconds.



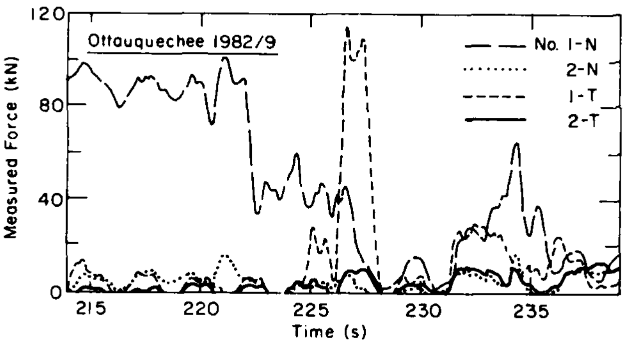
b. 135–160 seconds.



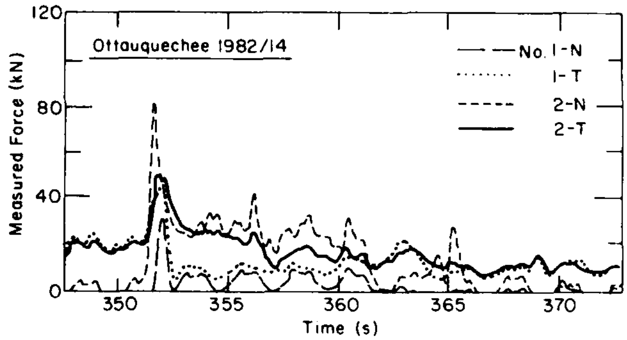
c. 161–185 seconds.



d. 187–212 seconds.



e. 214–239 seconds.



f. 348–372 seconds.

Figure 8. Ice force records. The time indicated in seconds is from the start of the ice run. (T and N are normal and tangential force records: 1 is the left panel, looking downstream, and 2 is the right panel, also looking downstream.)

Figure 9. Ice blocks deposited along the banks after the ice run. The scale in the photograph is in feet.

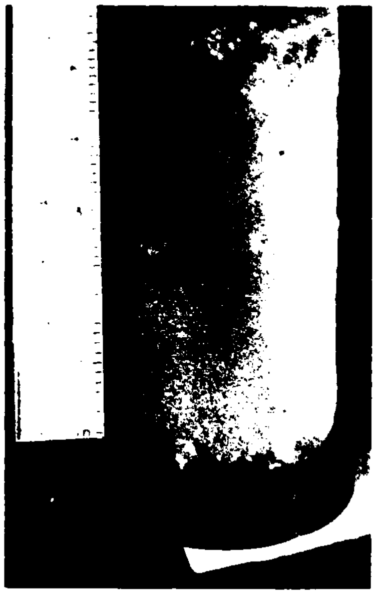


Figure 10. Specimen for the compressive strength test.

Table 1. Results of compressive strength tests at -1°C (30°F).

Sample	Crosshead speed (m/s)	Crosshead speed (in./s)	Compressive strength (MPa)	Compressive strength (lb/in.^{2})
1	8.33×10^{-6}	3.3×10^{-4}	2.457	356
2	8.33×10^{-6}	3.3×10^{-4}	2.673	388
3	8.33×10^{-6}	3.3×10^{-4}	2.428	352
4	8.33×10^{-6}	3.3×10^{-4}	1.8[illegible]	2[illegible]3
5	8.33×10^{-6}	3.3×10^{-4}	2.4	360
6	8.33×10^{-6}	3.3×10^{-4}	1.5	228
7	8.33×10^{-4}	3.3×10^{-2}	2.[illegible]	297
8	8.33×10^{-4}	3.3×10^{-2}	2.[illegible]	[illegible]5
9	8.33×10^{-4}	3.3×10^{-2}	2.4[illegible]	[illegible]4

ice on the left bank stopped moving because of ice arching between the piers and the bank. The ice on the right bank continued to pass under the bridge. A constant force level in the normal direction of panel 1 (the left panel, looking downstream) may be seen in the ice force record shown in Figure 8. Four minutes from the start of the ice run, the ice on the left bank started to move again. The broken ice passing under the bridge was loose and it did not cause any severe loading on the panel. Then a triangular shaped floe (7 m by 5 m by 5 m) hit the panel directly, registering a response on all force measuring systems of panels 1 and 2. After that event, the ice cleared and there was open water in the river.

Some ice was brought to the laboratory and stored in a freezer for later measurement of compressive strength. Specimens (Fig. 10) were prepared from those ice blocks. The results of compressive strength tests conducted at -1°C (30°F) are given in Table 1. Although the number of tests conducted is limited, the compressive strength of ice was in the range of 1.57 to 2.67 MPa (228 to 388 lb/in.^{2}).

DISCUSSION

During the ice movement, we did not observe any splitting, crushing or bending failures. The floes would hit the bridge pier, and be either deflected or stopped by the impact. For the major portion of the ice run, the ice had arched on one side of the bridge. The static force recorded was 110 kN (24,730 lb). Although it was difficult to estimate the area of contact between the ice and the pier, an estimate of the contact area may be made by assuming it to be average ice thickness (0.46 m) times the length of the panel (0.56 m). Thus, we estimate the maximum static ice pressure to be 435 kPa (63 lb/in.^{2}). The maximum force recorded during an ice impact was 120 kN (27,000 lb). Since we could not estimate the contact area between the impacting floe and the panels, we have not estimated the ice pressure resulting during an ice impact. The force records in Figure 8 indicate that the ice force in the tangential direction is small compared to that in the normal direction except during an impact of a floe on the pointed nose.

Although the ice action on the bridge pier was not particularly severe, it is still important to keep on gathering field data on ice forces. This will generate a large quantity of data from which statistical information on the level of ice forces may be derived.

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