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RÉSUMÉ

Des capteurs de mesure des charges de glace ont été installés sur le pilier de la courbe Yamachiche, sur le Saint-Laurent, en aval de Montréal. Des panneaux constitués de plaques d'acier appuyées sur des cellules extensométriques sont utilisés pour mesurer les charges statiques, et des accéléromètres servent à mesurer les charges dynamiques. On montre ici comment ce système a fonctionné au cours des années 1983-1984 à 1985-1986 et on fournit quelques estimations préliminaires concernant les forces globales que la glace exerce sur le pilier.

STATIC AND DYNAMIC ICE LOADS ON THE YAMACHICHE BEND LIGHTPIER, 1984-86

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ABSTRACT

Ice load measuring sensors were installed on the Yamachiche Bend lightpier in the St. Lawrence River downstream from Montreal. Panels consisting of steel plates supported on load cells are used to measure static loads while accelerometers are used to monitor dynamic loads. Operation of the system over the winters of 1983-84 to 1985-86 is described and some preliminary estimates of the total ice forces on the pier are presented.

INTRODUCTION

Predictions of ice loads on structures can be made from analytical and physical models, but the models must be based on full-scale observations for calibration and verification. Owing to the difficulties of carrying out such measurements successfully, relatively few projects have as yet been carried out at full-scale.

Traditionally, a pressure of 2.8 MPa (400 psi) has been adopted in calculating ice loads on bridge piers. The Canadian Standards Association (1978) and the Ministry of Transportation and Communications (1983), Ontario, have proposed that under certain circumstances lower design ice pressures could be used. Considerable judgement is required, however, in selecting the appropriate level for design purposes. Such decisions are usually based on qualitative information and argument. Field measurements of actual ice loads are needed to establish maximum loads and the probability of exceeding given load levels.

Field measurements of river and lake ice on structures include those reported by Neill (1976), Lipsett and Gerard (1980), Huiskamp (1983), Danys (1981), and Haynes and Sodhi (1983), who also gave a comprehensive review of available literature. Empirical formulas for ice loads were also given by Korzhavin (1971), Afanas'yev et al. (1979) and Neill (1981).

A program of ice force measurements is being carried out at the Yamachiche Bend lightpier in the St. Lawrence River downstream from Montreal. Each ice load measuring panel comprises a steel plate supported on three load cells. This has been supplemented with accelerometers in order to provide a better indication of dynamic ice loads.

Over the period 1983-1986 measurements were made with both load panels for static loads and accelerometers for dynamic loads. At the same time general ice conditions were catalogued. This paper will briefly describe the measuring systems used, present the results, describe the analysis technique, and compare the ice loads predicted from direct static and accelerometer measurements.

STATIC ICE FORCE MEASUREMENTS

The pier at Yamachiche Bend is conical at water level, with a slope of 4 vertical to 1 horizontal. The diameter at ice level is approximately 4 m. Detailed drawings of the pier are available (Danys, 1975). Five panels are installed on the west (upstream) side of the pier. It and ice conditions around it are shown in Fig. 1. The original load panels and electronics were reconditioned and upgraded in 1983 (Frederking et al., 1985). Extensive field calibration tests were carried out when the panels were re-installed and again in the summers of 1984 and 1985 to verify the operation of the system. These repeated calibration tests indicated that the calibration factors (ratio of load to signal voltage) varied on average ±10%, and ±25% in an extreme instance. One of the main problems in converting the voltage signal to load was that of selecting the appropriate "zero load" signal. The method varied from season to season and will be discussed later. Since access to the pier is very restricted in the winter, a telemetry system is used to transfer data to a shore station where it is recorded. Because the data are potentially overwhelming, a strategy for sampling and condensing had to be adopted. Again details will be discussed on a season by season basis.

Figure 1. Yamachiche pier, 19 January 1984

DYNAMIC ICE FORCE MEASUREMENTS

The Yamachiche lightpier is subjected to dynamic as well as static ice forces. The dynamic ice forces occur as a result of ice failure in crushing and bending, and as a result also of ice impact and rotation round the pier. Dynamic forces are of short duration, e.g., 0.01 to 2 s, but can be of high magnitude; in fact, they can be several times higher than the static loads. High local pressures can be caused by dynamic loads. Such local pressures can cause damage to structures, as has been observed at the Yukon River bridge (Buska, 1986) where the steel nose armour was torn from one of the concrete bridge piers and spalling of the concrete was caused during the ice run of 1985.

The present approach for measuring dynamic ice forces uses a transfer function derived from results of "plucking" tests on the lightpier. ("Plucking" was done by step unloading, i.e. by applying a load to the pier then abruptly removing it by rupture of a notched tension member.) The tests were carried out in September 1984 (Haynes, 1986) and yielded a transfer function matrix, viz.,

$$[H(\omega)] = \frac{\{\ddot{x}(\omega)\}}{\{f(\omega)\}} \qquad (1)$$

where $\{\ddot{x}(\omega)\}$ is the measured accelerometer response signal and $\{f(\omega)\}$ is the applied force vector, both of which are in the frequency domain via a Fourier transform. The unknown force vector due to an ice loading event can be found from

$$\{f(\omega)\} = [H(\omega)]^{-1} \{\ddot{x}(\omega)\} \qquad (2)$$

where $\{\ddot{x}(\omega)\}$ is now the measured response vector during ice loading. This force can be found in the time domain by the inverse Fourier transform

$$\{F(t)\} = \int_{-\infty}^{\infty} [H(\omega)]^{-1} \{\ddot{x}(\omega)\} e^{i\omega t} \, d\omega \qquad (3)$$

where the desired ice force is $\{F(t)\}$.

Six accelerometers at three different levels (same locations as for the plucking tests) were mounted on the pier. A triggering system activated a magnetic tape recorder whenever a threshold acceleration was exceeded. A time signal was also put on the record so that loads measured by dynamic and static methods could be compared.

RESULTS

1983-84 Season

Operation of the system started in mid-November 1983. The equipment and recording procedures were tested and open water signals were determined for an initial period of five weeks when there was no ice around the pier. During a visit to the site on 19 December 1983 the water was still open, with only scattered slush. Measurements continued until 18 April 1984, although ice disappeared several weeks earlier. There were some shut-downs between 19 December and 18 April owing to power failures at the pier.

Three visits were made during the measurement period to observe ice conditions and to check the operation of the equipment. By 19 January a solid ice cover had formed and a rubble accumulation surrounded the pier. The rubble had an oval shape, extending from 4 to 5 m in front of most panels. Ice blocks constituting the rubble varied in thickness from 0.2 to approximately 0.6 m. Holes drilled in the rubble showed that the rubble keel was grounded at a depth of 2.5 m, i.e., it reached the foundation of the pier. Ice thickness outside the rubble was approximately 0.6 m. Another visit was made on 1 February when ice conditions were very similar to those of 19 January. By the next visit on 30 March, open water surrounded the pier, with only a few isolated ice blocks drifting about.

The following strategy was adopted to provide a reasonably accurate description of the load history and details of any significant events. Outputs were recorded for 1 min at 10-min intervals. During each of these sampling periods the signals were recorded once every 2 s. In addition, recording of all signals was triggered if any one signal exceeded a critical value, taken as 0.1 V, which corresponds to approximately 13.4 kN on an individual load cell. For calculation of loads the minimum "zero load" voltage over the season was selected since it would produce conservative (high) load values. A typical record of force versus time for each panel is presented in Fig. 2. These are hourly mean force values, but maximum values of forces were not significantly higher.

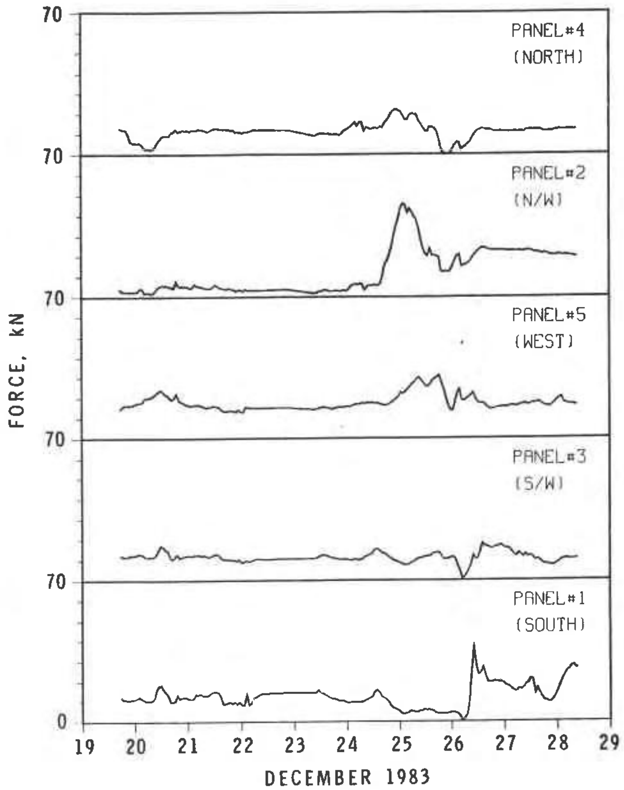

Figure 2. Hourly mean ice force vs time, 19-29 December 1983

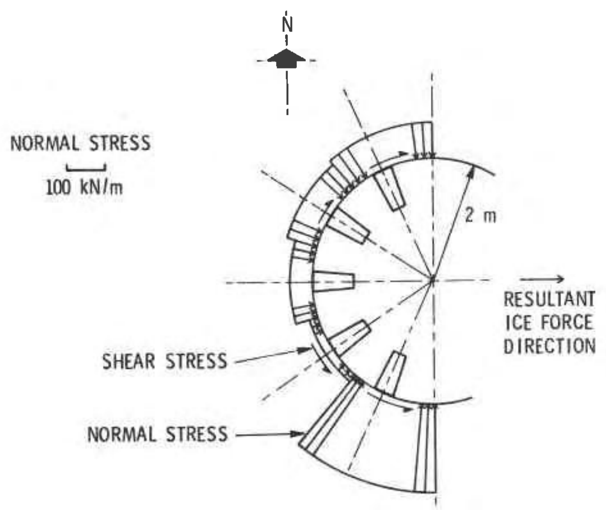

Figure 3. Assumed ice stress distribution on pier

The five load panels cover the west side of the pier, facing upstream, the direction of predominant ice movement (Fig. 3). At the observed elevation of ice contact with the panels the forces would be acting on a horizontal length of approximately 0.27 m of each panel. Measured loads were converted to load per unit length by dividing the given values by 0.27 m. The average ice thickness was approximately 0.6 m for most of the season. Thus, nominal stresses were calculated by dividing the loads by the area (0.162 m^2).

Estimating the total ice force on the pier would require knowledge of the normal and shear stresses along its perimeter. The present arrangement gives only normal stresses on part of the perimeter. Measurements were extrapolated to calculate the total ice force using four methods. The first assumes that stresses act on the west half of the pier perimeter. Normal stresses are extrapolated over sectors assigned to the panels. Tangential stress equal to 0.2 of the normal stress is added on each sector. The resultant force component in the easterly direction was considered to be the total load. A typical stress distribution at one instant is shown in Fig. 3. The second method considers a similar, normal stress distribution, but no tangential stresses are added. The southernmost panel, however, often measured the highest stresses. Consequently, a third method was adopted where stresses are assumed to act on the half of the perimeter centred around this panel. Normal and tangential stresses are assumed to be symmetrical about it. The fourth method is similar to the third, but excludes tangential stresses. Examples of the total load calculated are shown in Fig. 4. It may be seen that methods one and three produce larger total load values than methods two and four.

1984-85 Season

For this season a different recording strategy was used, in this case recording continuously with a 20-s scan interval. A time lapse film was also made using a Super 8 movie camera taking one frame every half hour. The film was used to characterize ice conditions at the pier and to establish zero-load voltages. This allowed the zero-load voltage to be re-set several times during the season, based on observed open water periods. There were again problems with the power supply to the pier, so that a record was obtained for only parts of February and March 1985.

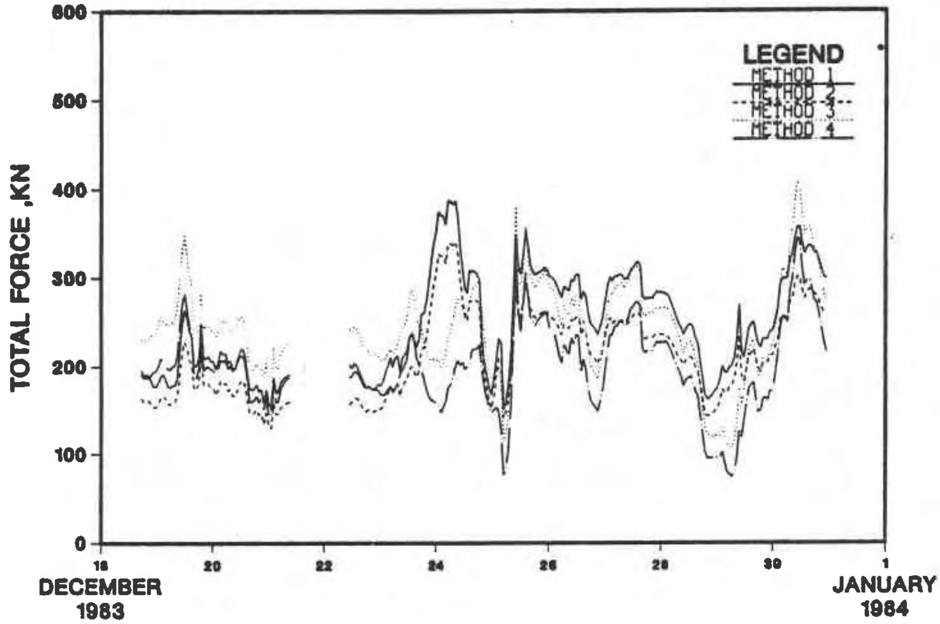

Figure 4. Hourly mean of total ice force acting on pier, four methods of calculation, December 1983

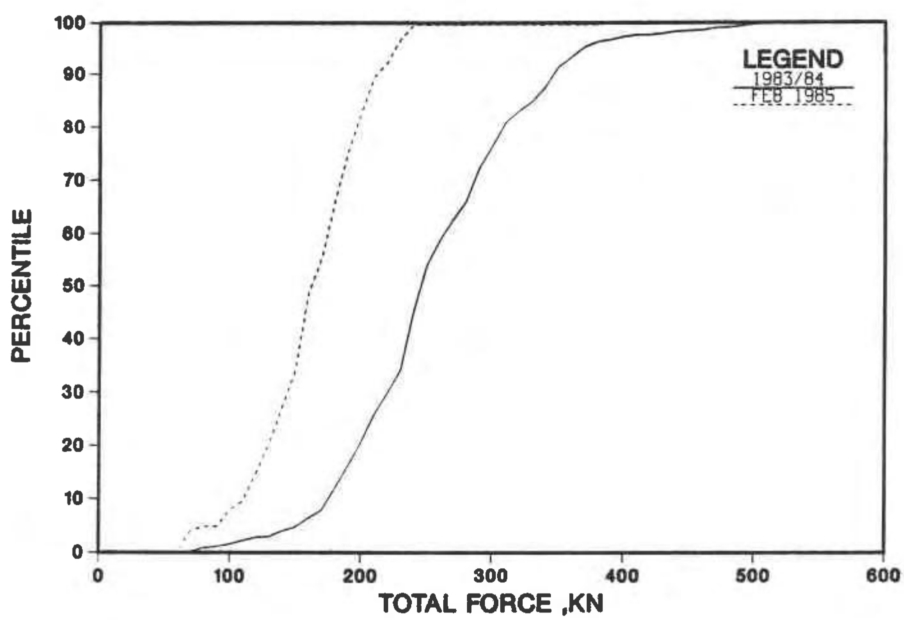

Figure 5. Comparison of cumulative distribution of total force, calculated by method 1, 1983/84 and February 1985

Ice conditions were similar to those of the 1983-84 season. In general, the nature of the records was similar to that of the previous season, but on average the total force on the pier was less (Fig. 5).

1985-86 Season

During the 1984-85 season several load cells had failed, with the consequence that no results could be obtained from the westernmost panel. This was unfortunate, but it did provide an opportunity to install for the 1985-86 season an add-on panel type of transducer normally used for making in situ pressure measurements in ice covers. It was an "IDEAL" panel transducer supplied by Terrascience and configured to fit directly over the old unserviceable panel. Rated capacity was 3 MPa. The panel transducer was 2.5 m high by approximately 0.5 m wide and was divided into five horizontal sectors so that a vertical distribution of ice load could be obtained. A small meteorological station with data logger was placed on the pier and the time-lapse movie camera was again used.

The sampling strategy for the telemetry system was the same as that for the 1984-85 season. The data logger at the meteorological station had extra channels available and the IDEAL panel signals were recorded on it as well. The logger was programmed to record the mean and maximum values over each half-hour interval. The analogue tape recorder on which the accelerations were recorded had one free channel and the middle section of the IDEAL panel was also fed into it. With this overlapping of records it was possible to compare results obtained by different recording strategies and different measurement approaches.

The results of the 1985-86 season are still being analysed, but a sample record will be presented. A dynamic ice loading event from the middle sector of the IDEAL panel is shown in Fig. 6a; the concurrent accelerometer versus time signal is shown in Fig. 6b. The accelerometer signal transformed to the frequency domain was used in Equation (3) to obtain the dynamic ice force. A maximum dynamic force of 37 kN on the pier was found for this event. This is lower than the total ice force of 200 kN on the middle section of the IDEAL panel determined from the static force measurements. The dynamic load is based on accelerations of the lightpier and therefore does not include static loads, which may also be present. An ice pile-up at the base of the lightpier would be an added mass and attenuate the accelerometer signals. Figure 6 indicates significant peak loads, however, and the dynamic ice loads correspond to these peaks. The analogue tape recorder, which can record high-frequency signals, showed that panel transducers can detect dynamic ice loads.

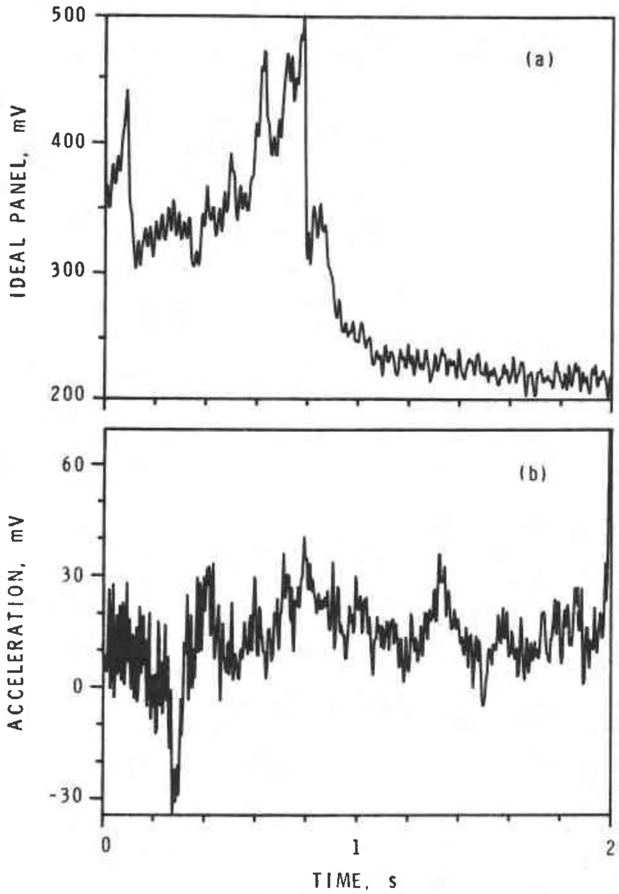

Figure 6. Comparison of accelerometer record and IDEAL panel record for an ice loading event

SUMMARY

(1) For the 1983-84 season the maximum static ice force was 600 kN, generated by a 0.6-m thick ice cover acting on a pier width of 4 m at the waterline. Loading events were static, lasting several hours to a few days. A static ice cover surrounded the pier for most of the ice season.

(2) For the 1984-85 season the maximum static ice force was about 300 kN. Ice conditions were generally similar to those of the previous season.

(3) These ice forces are substantially lower than the value calculated from CSA(1978): 2200 kN for an effective crushing pressure of

700 kPa, ice thickness 0.6 m and pier width of 4 m.

(4) For the 1985-86 season a direct comparison of static and dynamic ice forces was made. The measured dynamic forces were substantially less than the static forces.

(5) Further analysis is required to relate ice forces on the pier to the ice conditions.

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