PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

MEASUREMENT OF ICE FORCES AGAINST A LIGHTPIER

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BACKGROUND

Ice is an important factor which has to be taken into account in the design of all engineering structures in northern climates. Many design codes giving allowances for ice forces are based upon limited observations and upon the fact that structures designed to meet arbitrary criteria have not yet failed. This approach is unsatisfactory in that it provides no indication of the margin of safety against failure.

Lightpiers have been used as channel markers in Lake St. Peter, an enlargement of the St. Lawrence River, since 1907. The observed ice resistance of these and other structures in the St. Lawrence River demonstrates a wide variability which has not been thoroughly assessed. Nevertheless, the empirical code now in use for the design of these channel marking lightpiers has been developed from experience and gives a durable structure.

Since 1959, lightpiers in Lake St. Peter have been designed to resist an impact force from floating ice calculated from the following equation:

$$P = m.n.b.h.q.$$

where P = total horizontal force on the structure at the design water level;

m = 0.67 for circular pier, shape and contact coefficient;

n = slope coefficient, calculated as cos A for force P acting perpendicular to the slope and $\cos^2 A$ for the resultant horizontal force; A is the slope angle with the vertical;

b = width of the structure, equivalent to the diameter;

h = 30 inches, thickness of solid ice sheet, maximum measured during 10-year period;

q = 250 pounds per square inch, assumed effective crushing strength of the ice.

However, a better understanding of the factors which control the magnitude of ice forces is required to provide the designer with an adequate knowledge of safety margins.

Because of the soft lake bed, provision for resisting ice forces becomes a major factor influencing the design of the pier base. A program of field measurements has therefore been initiated to measure the actual forces against typical piers to evaluate present design practices and to indicate the scope for reducing the severity of present design criteria, and hence the cost of the structure.

The initial site for testing the lightpier instrumentation techniques is at Yamachiche Bend, adjacent to the St. Lawrence River Ship Channel in Lake St. Peter (Figure 1). A typical lightpier is shown in Figure 2. Total calculated horizontal force for this pier is 540 kips (270 tons) at high water level, and 830 kips (415 tons) at low water level.

LIGHTPIER INSTRUMENTATION

Fundamental requirements for ice load-measuring devices are that they be sturdy, reliable, devoid of non-essential complexity, inexpensive and relatively maintenance free. Additionally, for the lightpier application, it was desirable that any basic design be capable of expansion to meet the needs of future programs of detailed data collection and also be easily adaptable to various sites and lightpier shapes. Lastly, it was desirable to maintain the normal lightpier configuration in order to utilize standard construction techniques.

Initial attention was given to an evaluation of various concepts for ice load-measuring devices including:

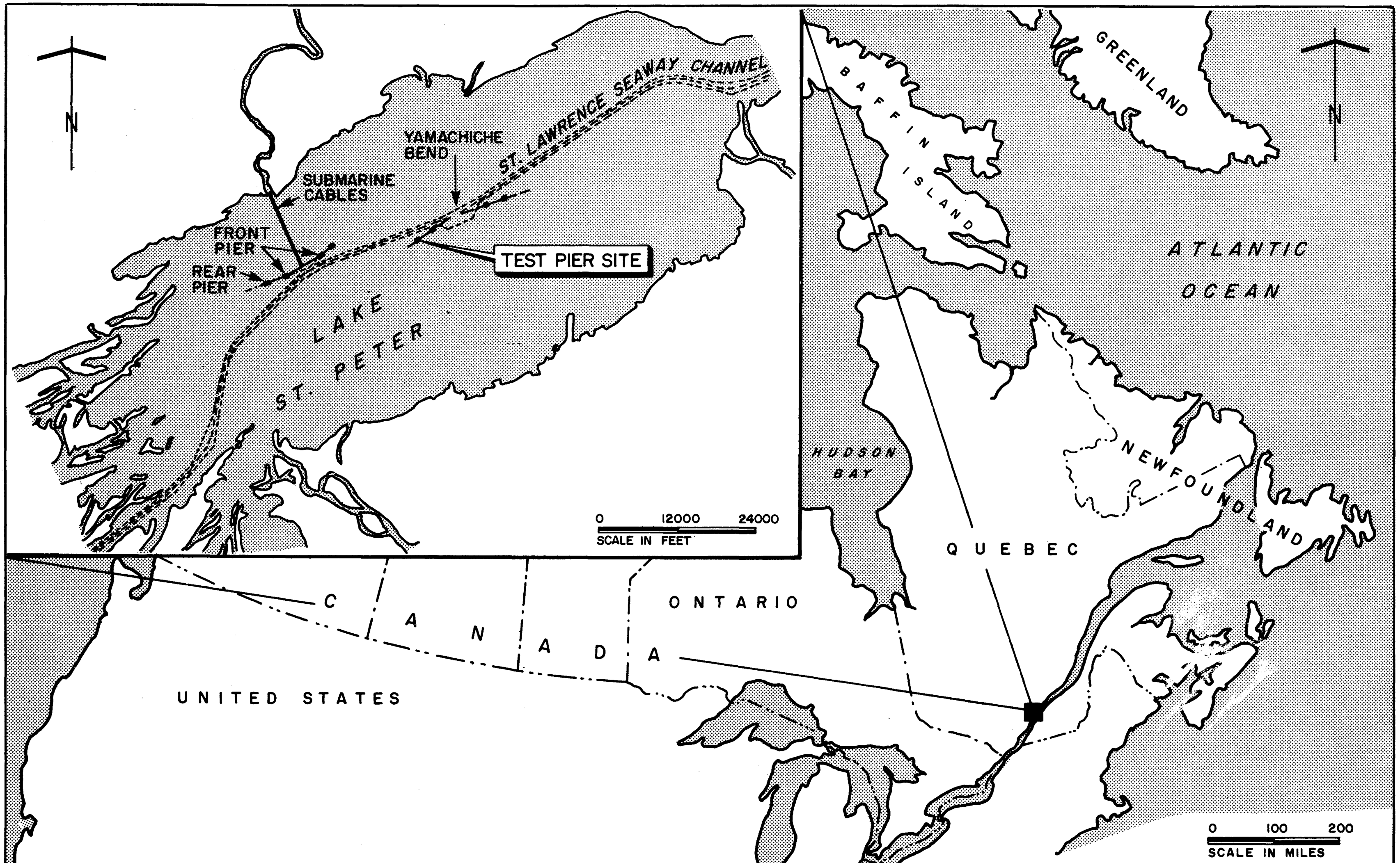
(a) - Devices requiring the test pier to be mounted upon a dynamometer designed to measure total ice force;

(b) - Pressure-sensing devices attached to the exterior surface of the pier; and

(c) - Pressure-sensing devices supported in recesses in the surface of the pier.

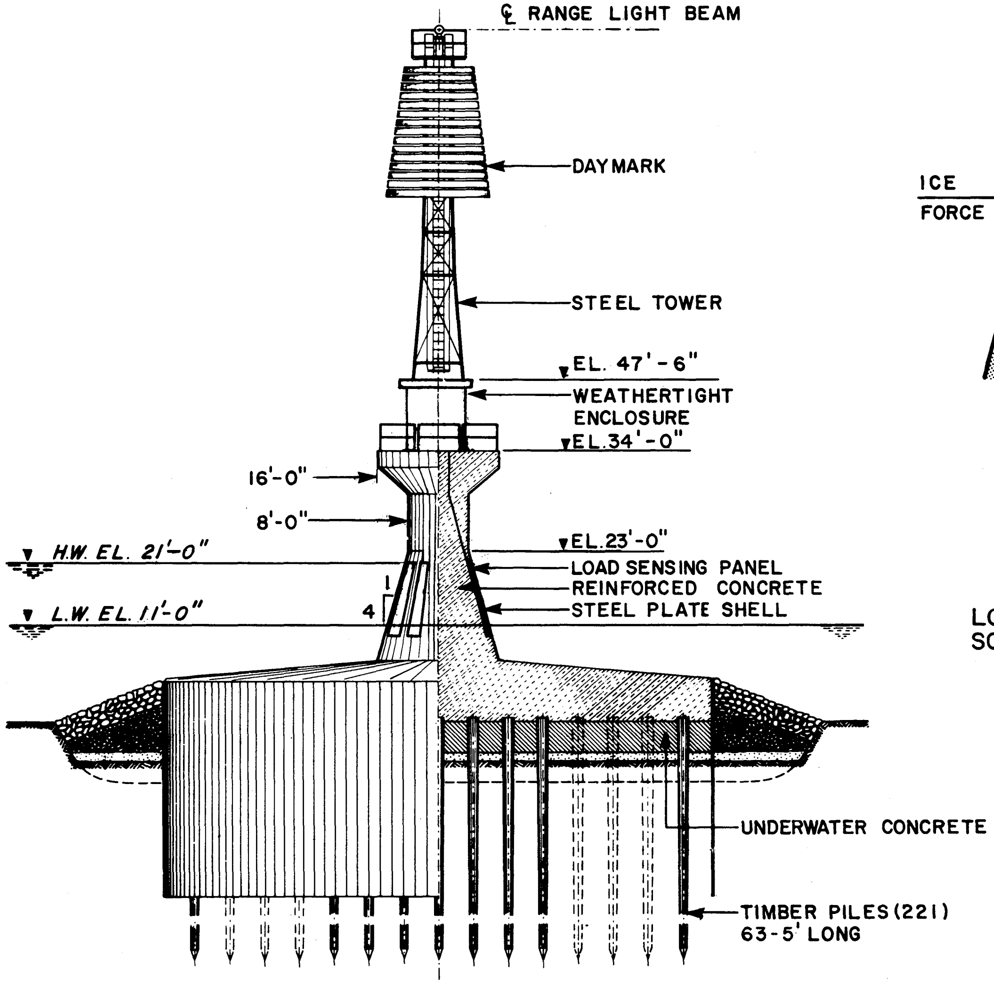
Devices in category (a) were unsuitable since they required major changes in pier design and construction techniques, and because later modifications and refinements of the system would be difficult and costly.

Devices in category (b) were rejected because experience has shown that ice movements can shear off projections and ancillary

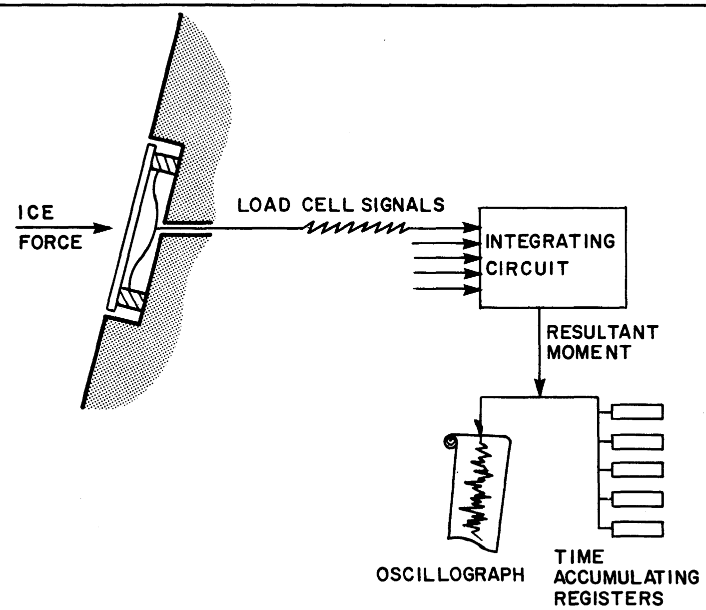


PROJECT LOCATION

FIGURE I



ELEVATION - SECTION



LOAD PANEL INSTRUMENTATION
SCHEMATIC DIAGRAM

LAKE ST. PETER LIGHTPIER

FIGURE 2

equipment such as bolts and ladder rungs. Also, projecting instrumentation may modify ice behavior and so yield misleading information.

Several devices in category (c) were studied. An exterior steel shell supported on many load cells, or numerous load cells in the pier surface, were rejected due to the complicated data recording and analysis required. Panels set in the pier surface were finally selected because of their simplicity, economy and potential reliability.

The load-measuring apparatus consists of four main parts:

(i) - The load-sensing panels set into the face of the pier;

(ii) - The electrical integrating circuit which combines the voltage output from each of the load cells;

(iii) - The recording devices in which the data are stored;

(iv) - The remote control and sensing system.

Load-Sensing Panel

The load panel assembly, Figure 3, consists of a rigid beam simply supported on four electrical load cells and sealed within an oil-filled box. The sealed units are placed in recesses provided in the conical base of the lightpier. Embedded conduits permit the connection of the load-detecting devices to electrical apparatus which processes the load cell signals, and provide a path for oil conduits which connect each panel to an oil reservoir and pumping system in the superstructure of the lightpier.

Measurement of the reaction at each end of the beam allows calculation of the total applied normal force, and the elevation at which the load is applied. The rigidity of the beam ensures that impacting ice cannot bridge across the beam to the surrounding pier surface.

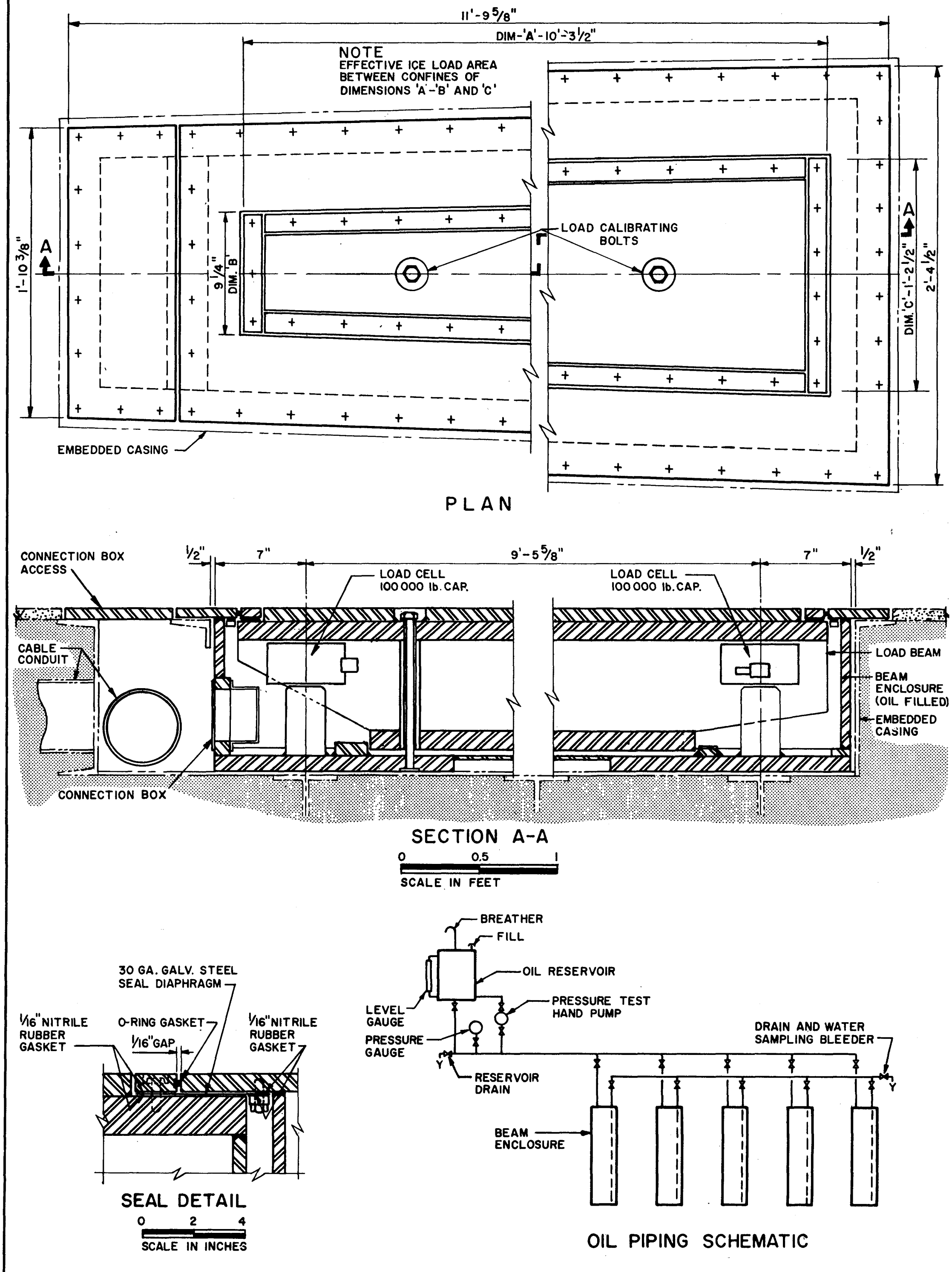
The flexible seal between the rigid beam and the box excludes water to prevent the formation of ice behind the beam. The box is slightly pressurized with oil to prevent the inflow of water in the event that a small leak develops.

Each load-sensing panel will be prefabricated and calibrated before installation in the recesses in the lightpier surface, where it will be attached to the electrical and oil conduits.

Since the direction of ice attack is characteristically unidirectional at this particular pier site, only one side of the pier is to be instrumented. Five panels will be used, covering a total angle of 141 degrees.

Electrical Integrating Circuit

The continuous recording of data from every load cell would result in the accumulation of a large amount of data requiring considerable time for processing and analysis. While such information might prove useful in a program of detailed data collection,



ICE FORCE INSTRUMENTATION - PANEL ASSEMBLY

FIGURE 3

for the purposes of the initial stages of the investigation, a statistical recording of the resultant moment against the structure is sufficient.

A block diagram of the electrical integrating circuit needed to combine the output from each load-sensing panel is shown in Figure 4. The circuit receives voltages from each load cell, adds the output from the pairs of load cells at the top and bottom of each panel, computes the moment exerted against the structure using the forces at the top and bottom of each panel and, finally, vectorially adds all moments to calculate the final resultant moment against the structure.

Individual leads run from each load cell to the lightpier enclosure housing the electrical integrating circuit. Provision is made for doubling the output from one load cell if the second cell of a pair ever becomes defective.

The load cells operate on alternating current. A phase shift is given to the signal from each panel, corresponding to the physical position of that panel on the lightpier, with respect to a reference direction. That is, using as references the phase of the alternating current supply and the expected ice flow direction, the phase of the output signal from each panel is lagged or advanced with regard to the reference alternating current, an amount equivalent to the physical angular displacement of the respective panels from the reference direction. Addition of the alternating current output from the load cells therefore gives a vector addition of the forces registered on all panels.

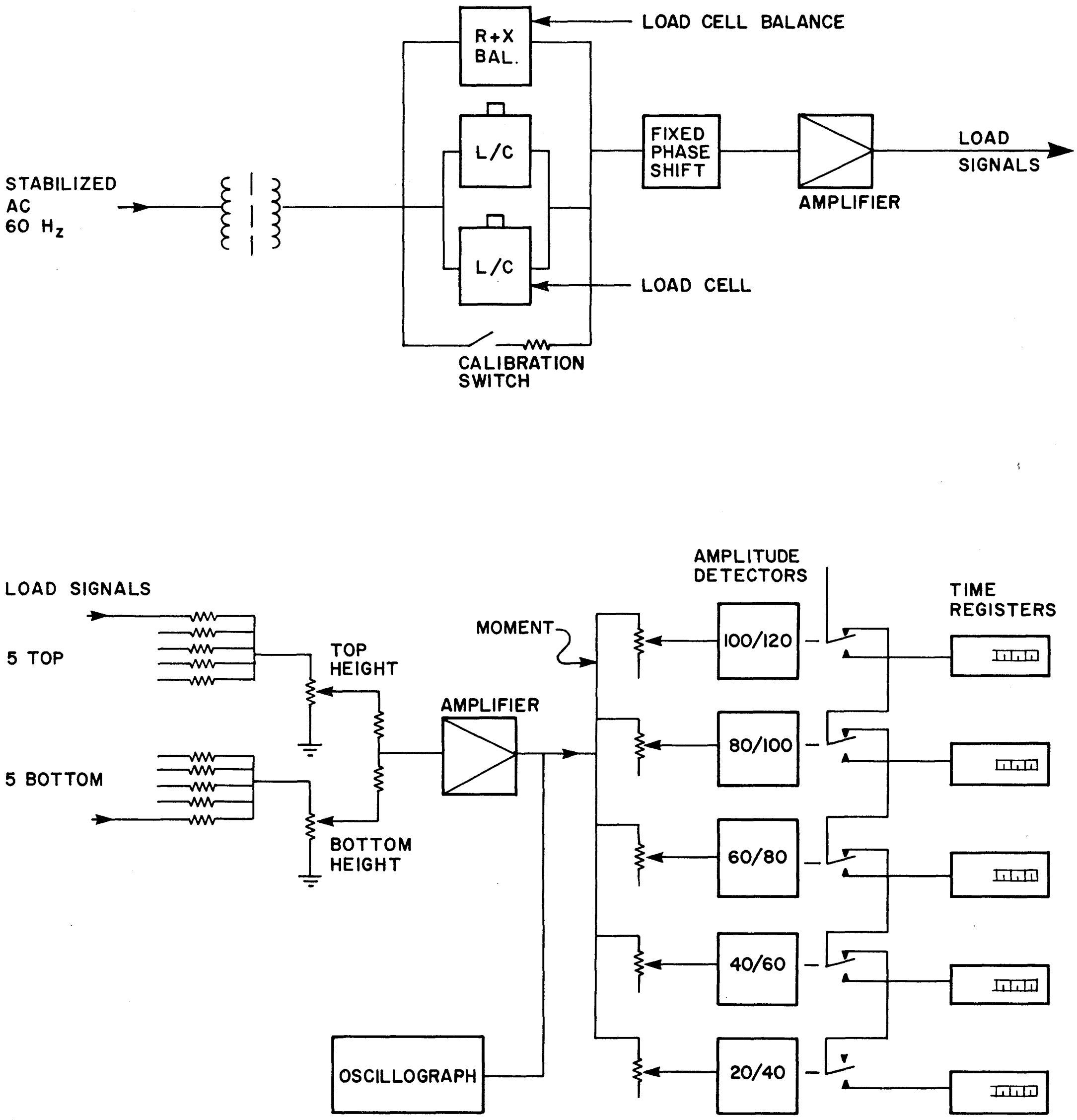
Weighting the outputs of the top and bottom load cells, according to their height above the base of the lightpier, allows the load cell signals to represent the overturning moment of the force above the base.

Recording Devices

Long-term statistical data are obtained from five time-accumulating registers. Detailed continuous output on an oscillograph may also be used intermittently.

Time-Accumulating Registers - Following the vector addition of all moments, the resultant current passes through adjustable amplitude detectors which drive output contacts to digital clocks. Normal output is in the form of total accumulated time during which the applied moment on the structure is within each specified range.

Oscillograph - The multichannel oscillograph recorder is provided for calibration checks and detailed data collection. The output of each pair of load cells plus the resultant moment is continuously recorded for a preset time interval. Examination



ICE FORCE INSTRUMENTATION–INTEGRATING CIRCUIT FIGURE 4 of these records may permit the derivation of a standard "shape" factor for the lightpier.

A date/time recording device has been attached to the oscillograph to permit quick identification of each section of the record. The device comprises a battery-powered calendar watch, the face of which will be imprinted on the oscillograph paper roll during each recording. The device has the advantage of being independent of the land cable power supply, and will thus record the correct date and time even following a power outage.

Remote Operation and Sensing

Operation of the force measuring and recording equipment is designed to be fully automatic, with continuous data recording by the digital clocks. A timer is used to initiate the oscillograph for a 1-minute period of detailed data collection each hour. In addition, operation of the oscillograph is initiated automatically whenever the resultant moment on the pier exceeds a predetermined threshold value. However, in order to reduce the number of visits to the lightpier to the minimum required for oscillograph paper change while maintaining availability of the data collected, a telemetry system is provided to permit:

(a) - Remote initiation of multichannel oscillograph operation;
(b) - Interrogation of the apparatus from shore to retrieve readings from the time clocks;
(c) - Checking the amount of paper remaining on the oscillograph roll;
(d) - Monitoring the alarms indicating a circuit malfunction.

The telemetry system comprises a remote control station, a land station and a pier radio station, with a telex communication between the remote control station and the land radio station. Working from a control box at the remote control station, an operator initiates the semiautomatic telemetry system by establishing a telex connection from the base station to the land radio station in the vicinity of the pier. This radio then sends a signal to a radio receiver at the pier which energizes the pier transmitter. The time clock data is then transmitted automatically in binary coded decimal form to the land radio station, and relayed by the telex line to the base station where it is displayed in binary form on a lighted panel. The transmitted information comprises data from each time-accumulating clock, an indication of the amount of oscillograph paper remaining, and various other indicators or alarm signals. Following data transmission, the circuit remains open for a short interval during which a pulse may be sent to the pier equipment to start or stop the oscillograph or camera. This control facility will be used to monitor the effects on ice loads of such events as the passage of an ice breaker through the adjacent shipping channel.

Use of the control facility for data monitoring and collection from the remote base station provides a safety factor in that data may be obtained daily to mitigate the effects of any malfunction of the apparatus, which otherwise could result in the loss of 2 to 3 weeks of record. The alarm circuits are intended to give an early indication of malfunctions in critical items—an especially desirable feature in a test installation such as this.

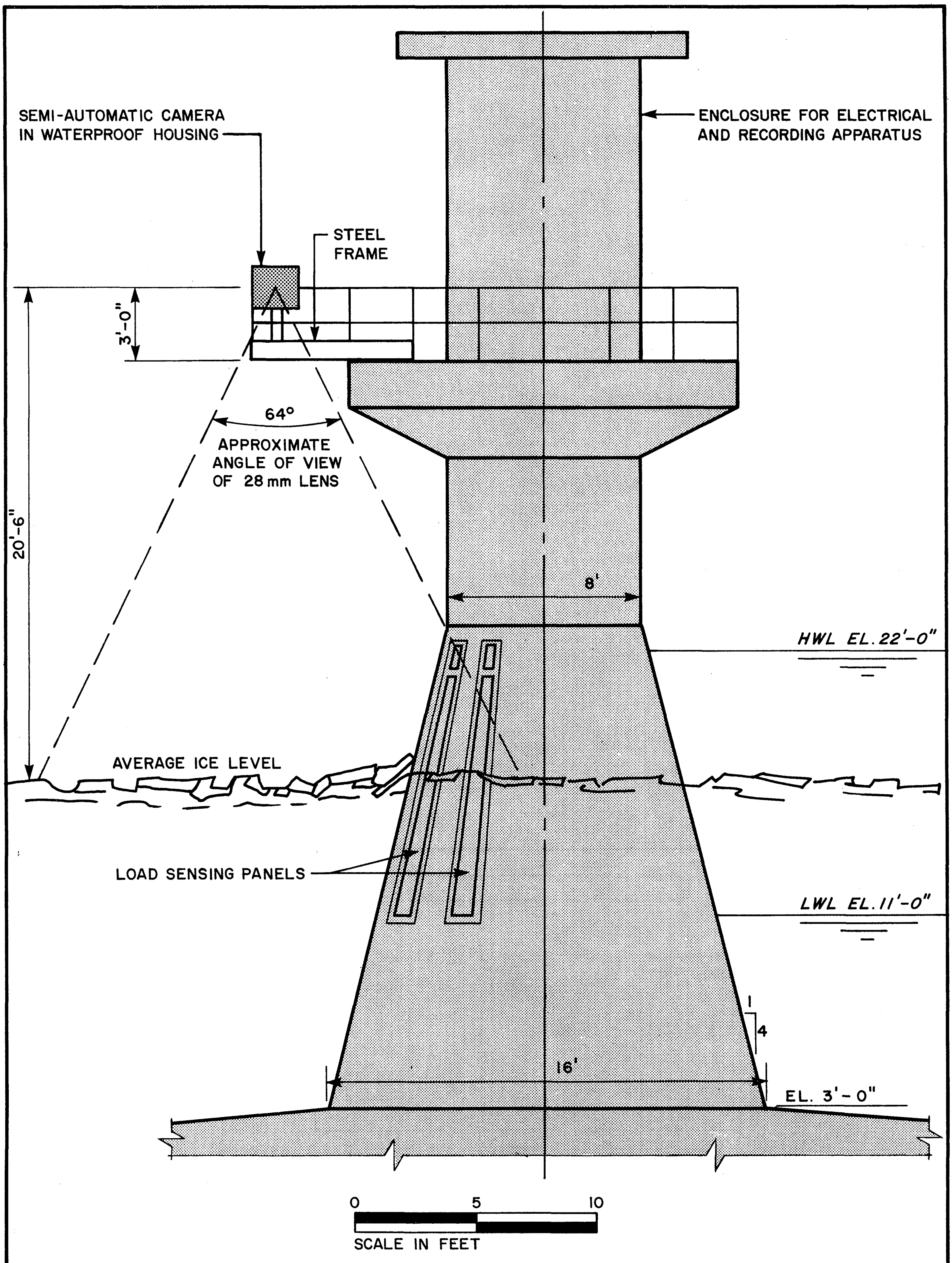
AUXILIARY EQUIPMENT AND OTHER OBSERVATIONS

Lake St. Peter is one of the critical sections for navigation in the St. Lawrence River, especially during the winter season. In winter, the icebreakers keep the navigation channel across the lake open in order to prevent ice jams and the resulting flooding of the low areas of Montreal. For several years, observations of ice formation have been made from an airplane. Measurements of wind, current, air and water temperatures, ice thickness, ice sheet extent and other ice observations including laboratory tests on the ice samples have been carried out. To supplement these observations, an automatic water-level gauge station will be installed in one of the lightpiers in Lake St. Peter. It will be possible to correlate all these observations with the experimentally observed ice forces on the lightpier to evaluate the present design assumptions. Also, photographic equipment will be installed on the pier to investigate the mechanism of ice sheet break-up against the pier

Photographic Equipment

An automatic still camera will be mounted on the pier (Figure 5) to photograph ice movements and break-up on and around the structure. The 35-mm camera, in a heated weathertight housing, will be provided with motor-driven rewind and a strobe flash unit powered from the 120-volt land cable supply. The camera will be triggered by an electrical contact on the oscillograph recorder control, and will take a picture each time the recorder is initiated.

Under the presently envisioned operation, a photograph will be taken each hour during the automatic initiation of the oscillograph. This will show the general pattern of ice formation against the structure which produces the recorded forces. A photograph will also be taken each time the oscillograph is initiated by large ice loads against the panels. In addition, an automatic sequence timer will be provided to allow remote initiation of time-lapse photography. In



CAMERA INSTALLATION

FIGURE 5

this mode of operation, the camera will initially be set to take a picture every 15 minutes until it runs out of film. A 250-exposure film magazine will be used.

Following break-up of the ice cover during the spring, the camera will be remotely initiated to photograph the continuous ice break-up against the pier.

Each photograph will contain the picture of the face of a battery-powered calendar watch. This will allow easy identification of each photo for comparison with the oscillograph records.

Present plans call for the installation this year (1971) of a similar camera assembly on an existing, manned lighthouse at Prince Shoal, some 100 miles downstream from Quebec City, to confirm the reliability of the various components and to permit evaluation of various exposure settings and time intervals between photographs.

INVESTIGATION PROGRAM

The construction of the lightpier which is to be instrumented was originally scheduled for completion during 1971, but, due to budget constraints, construction has been delayed until 1972. Recesses will be left in the sloping face of the lightpier for insertion of the load-sensing panels, and it is expected that the instrumentation, which is now (August 1971) being assembled, will be installed by October 1972. Data recording is scheduled to begin during the winter season 1972-1973.

Three or four periods of major ice activity may be expected during each winter season because of the icebreaker's operations:

- For 2 to 3 weeks at the beginning of the winter, because the formation of an ice cover near the pier occurs much later than in the river upstream or in the adjacent areas in the lake;
- During the spring break-up of the ice cover;
- At least once or twice during the winter because winds and natural ice erosion open this area for floating ice.

It is anticipated that sufficient information will be obtained from this installation during the first winter to indicate the course of future investigations. The instrumentation has been designed to facilitate future incorporation into a more extensive program of ice force investigation. The data available from this current installation, however, will indicate the course of future investigations and provide a first estimate of the suitability of current design procedures.

The cost of the instrumentation described herein is of the order of $120,000. This represents some 20 per cent of the cost of a non-instrumented lightpier, but it is hoped that this cost can be recouped by savings on future construction, due to a more precise knowledge of ice forces and the consequent adoption of less conservative design ice loads.

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