THE DETERMINATION OF ICE FORCES ON SMALL STRUCTURES

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(1) - SUMMARY

The development of apparatus to measure the total force exerted by ice on a small structure designed to house navigation aids marking the centreline of a shipping channel is described. The apparatus consists of a number of self-contained load-sensing panels set into the face of the lightpier. These panels are connected electrically to an integrating circuit which automatically determines the resultant moment of the forces on the structure.

The resultant moment data is collected by means of five digital clocks which, using a maximum expected moment as a datum, will record the total elapsed time the moments are in various percentage ranges of the reference value.

Provision is made for the attachment of a multichannel oscillograph to provide continuous recording of output data during calibration, instrument checking, during periods of vigorous ice activity, and for any future expanded program of detailed data collection.

Remote collection of digital data will be possible by means of semi-automatic Telex-based equipment. Additional alarm circuits will be provided to indicate malfunctions of the equipment or the need to change oscillograph paper rolls.

It is expected that the apparatus will be put into operation during the winter season 1971-72.

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(2) - BACKGROUND

Ice is an important factor in the design of engineering structures and in the planning of water resource development in northern climates, and particularly throughout Canada. It must be taken into account in the design of dams, bridges, water intakes, wharves and any structure which is exposed to water which might develop an ice cover during the winter season.

The economic effect of ice on structures is felt not only in the damage which occurs annually to various installations, but also in the extra costs which result from allowing for ice forces in their design. Most design codes take ice into account by recommending the forces which the structures must be designed to withstand. However, most of these design codes are based not on scientific experiment, but on limited observation, and upon the fact that structures designed to some arbitrary criterion have not yet failed.

Laboratory research on ice properties has, in the past, been largely concerned with the relationship between the physical strength of small samples and temperature, rate of loading, brine content, previous history and crystal structure. Field research has tended to be limited in scope and specific in application.

The designer of new structures, however, must contend with different problems. He is interested in forces against a specific structure, e.g. static and dynamic loads, sheet buckling of the ice, thermal effects, wind effects on floating ice pans and, in general, any physical attack of ice against the structure.

The behaviour of ice on arctic shores, or inland rivers and lakes, is complex and extremely variable. Present knowledge of the process of ice breakup and the forces produced by large ice sheets is limited. The application of arbitrary design codes in the design of ice-exposed structures is unsatisfactory, since it provides no indication of the margin of safety being provided. The best way to gain a better understanding of the factors involved is a program of field investigation in which measurements of ice forces against existing structures are related to the physical circumstances of the ice attack.

In this way, design criteria derived from experimentally determined ice forces can be developed to provide the designer with an adequate knowledge of safety margins and risk of failure.

(3) - PREVIOUS FIELD RESEARCH

A number of field investigations have been carried out in recent years to investigate the magnitude and variation of ice forces against test structures.

In the early 1950's, Ontario Hydro instrumented a number of its dams by installing freely suspended concrete blocks in the upstream face. The lateral ice thrust against these blocks was measured by load cells which were placed between the back of the block and the dam. The ice forces so measured were recorded as voltages proportional to the force exerted on the cells. These installations measured mainly static ice forces due to the thermal effects on the ice sheets which covered the headponds upstream from the dams. Typical measured values of thrust, reported by Willmot (1952), are of the order of 50 pounds per square inch (psi). It was noted that under severe conditions it could be expected that higher pressures, possibly four times those recorded, might be observed. However, it is obvious that even these severe forces would be considerably less than the 400 psi often assumed in design analysis.

In connection with the design of the Northumberland Strait Crossing, prototype ice forces were measured in 1965 and 1966 on a pier at Port Borden in Prince Edward Island. Northumberland Consultants Limited installed a pair of hollow steel panels containing a number of flat hydraulic jacks equipped with pressure measuring devices. Unfortunately, due to the small amount of ice activity during the tests, little useful data was obtained.

In 1966, a pier in a new bridge over the Athabaska River at Hondo, Alberta was instrumented by the Alberta Research Council and Department of Highways to measure ice pressures during spring breakup. The device consisted of a hinged steel pier nose acting upon a calibrated load cell. Successful measurements have been made and published for the first year's operation. However, a strong ice push that occurred during the winter of 1968-69 brought about unexpectedly large impact loads which caused the load cell to fail, and a load cell of larger capacity was installed in the following winter. A four-year record of observations is now available at this pier.

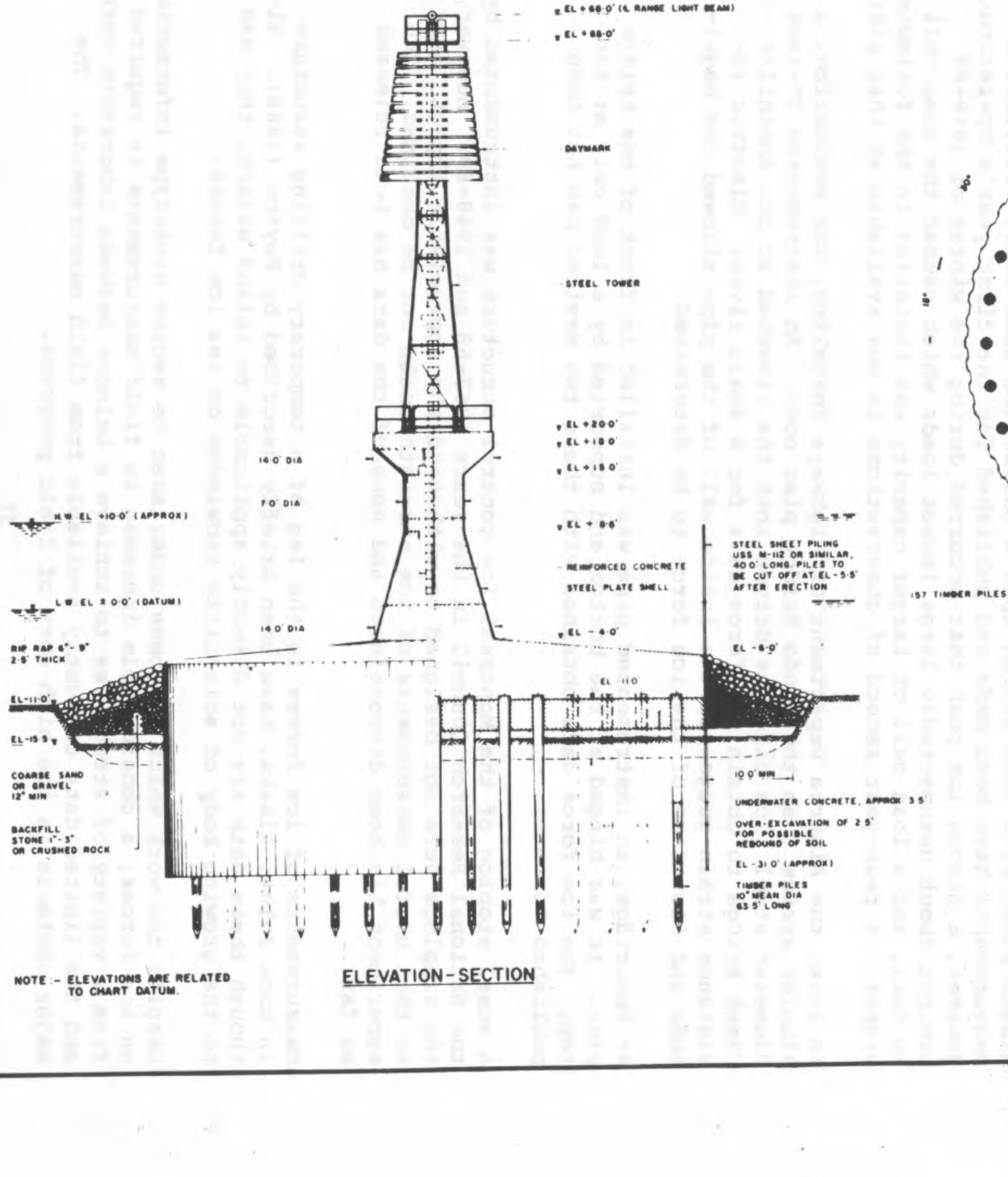
In 1968, the Alberta Department of Highways installed, for evaluation, a simpler system than the Hondo Bridge pier nose. An instrumented 20-inch diameter steel pipe pile was driven into the riverbed at the Kneehills Creek Bridge to obtain ice force data for a small river. Electric resistance strain gauges on the inside wall of the pipe allowed the magnitude and elevation of the ice force to be determined.

At Pembridge, an instrumented pipe was installed in front of one bridge pier. It was hinged at the bottom and supported by a load cell at the top. The ice force data obtained with these two devices has not been published to date.

A steel stoplog of the Montreal ice control structure was instrumented by the National Research Council in the years 1967-68 and 1968-69. However, the stoplogs were not designed to withstand the appreciable impact loads so that useful measurements of ice strength could not be obtained. The experiment has been discontinued and none of the data has been released so far.

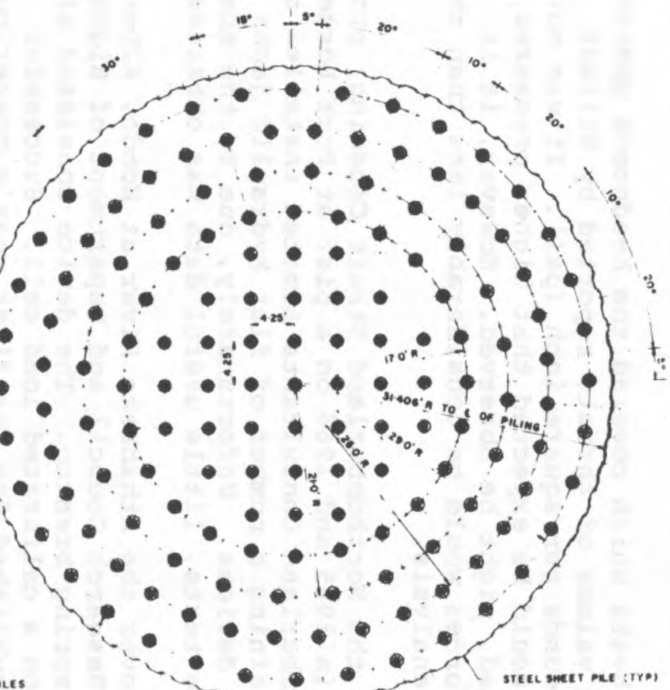
Measurements of ice forces in the leg of a temporary drilling structure in Cook Inlet, Alaska, have been briefly described by Peyton (1968). Although these data are not directly applicable to inland waters, they add to the growing body of scientific knowledge on sea ice forces.

Despite the work which has been undertaken to secure prototype information on ice forces, a considerable increase in field measurements is required from a variety of structures to achieve a balance between laboratory work and the limited data currently available from field measurements. The major obstacle is the high cost of field programs.



ELEVATION-SECTION

NOTE :- ELEVATIONS ARE RELATED TO CHART DATUM.



PLAN OF PILING

LAKE ST. PETER, P.Q.
CURVE NO 2 - UPSTREAM RANGE
REAR PIER

SCALE
5 0 5 10 15 20 30 FEET

FIGURE 1

(4) - LIGHTPIER INSTRUMENTATION

The use of lightpiers as channel markers in Lake St. Peter, as reported by Danys (1970), was started in 1907 and, despite early failures due to poor soil conditions and ice attack, has been continuous to date. Evolution of the lightpier configuration, adjusted to changing needs and design practices, has resulted in the development of a relatively compact, strong structure easily adaptable to varying site requirements.

Present navigation requirements demand reliable and accurate markers of the channel and, especially, of its centreline. Economics dictate that construction and maintenance costs be minimized, and that a relatively simple design should be adopted. The present design, a steel clad reinforced concrete tower on a timber pile foundation, combines the required features and has provided satisfactory service. A typical lightpier structure is shown on Figure 1.

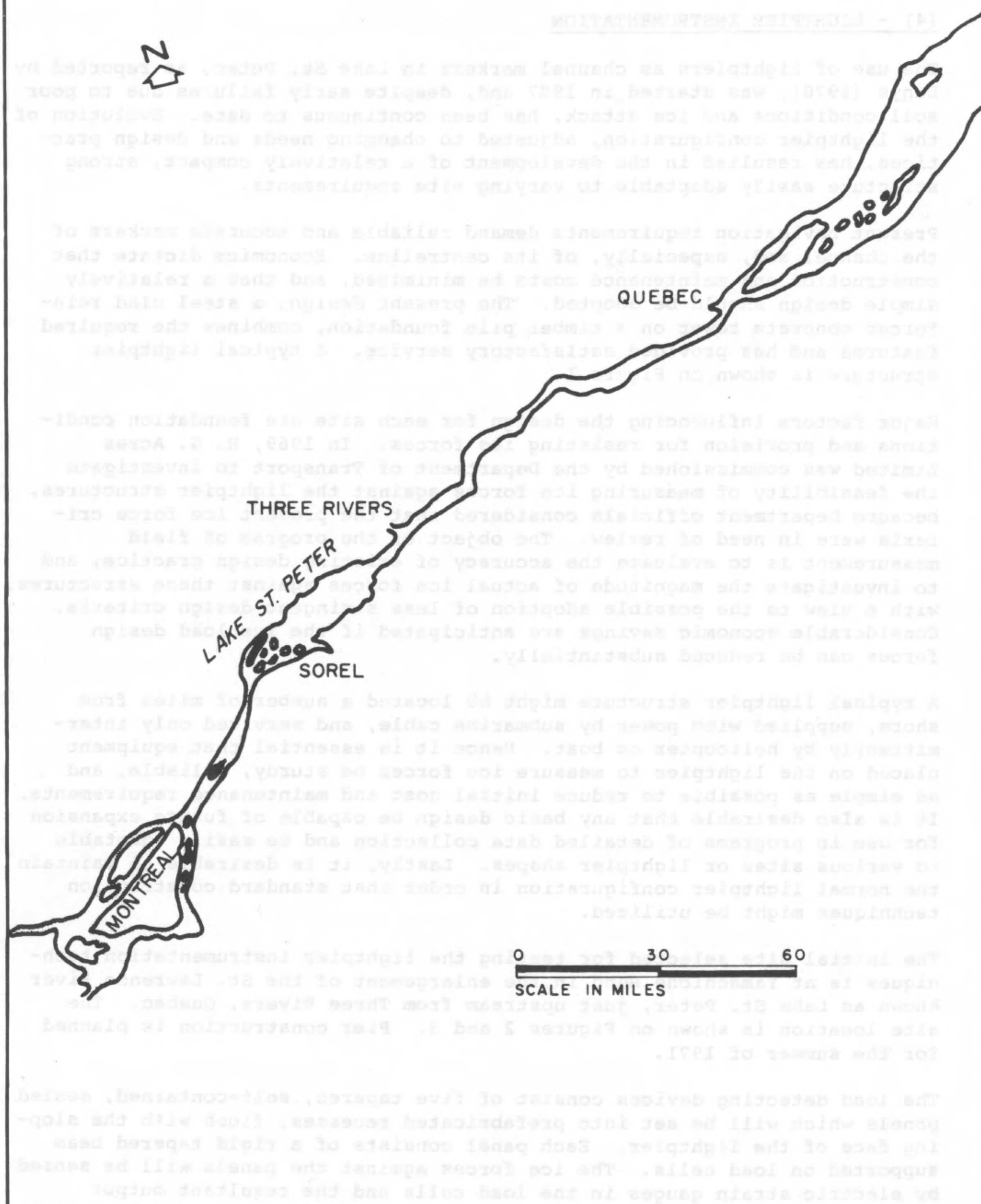
Major factors influencing the design for each site are foundation conditions and provision for resisting ice forces. In 1969, H. G. Acres Limited was commissioned by the Department of Transport to investigate the feasibility of measuring ice forces against the lightpier structures, because Department officials considered that the present ice force criteria were in need of review. The object of the program of field measurement is to evaluate the accuracy of existing design practice, and to investigate the magnitude of actual ice forces against these structures, with a view to the possible adoption of less stringent design criteria. Considerable economic savings are anticipated if the ice load design forces can be reduced substantially.

A typical lightpier structure might be located a number of miles from shore, supplied with power by submarine cable, and serviced only intermittently by helicopter or boat. Hence it is essential that equipment placed on the lightpier to measure ice forces be sturdy, reliable, and as simple as possible to reduce initial cost and maintenance requirements. It is also desirable that any basic design be capable of future expansion for use in programs of detailed data collection and be easily adaptable to various sites or lightpier shapes. Lastly, it is desirable to maintain the normal lightpier configuration in order that standard construction techniques might be utilized.

The initial site selected for testing the lightpier instrumentation techniques is at Yamachiche Bend in the enlargement of the St. Lawrence River known as Lake St. Peter, just upstream from Three Rivers, Quebec. The site location is shown on Figures 2 and 3. Pier construction is planned for the summer of 1971.

The load detecting devices consist of five tapered, self-contained, sealed panels which will be set into prefabricated recesses, flush with the sloping face of the lightpier. Each panel consists of a rigid tapered beam supported on load cells. The ice forces against the panels will be sensed by electric strain gauges in the load cells and the resultant output signals will be transmitted along interior cables to automatic electrical processing and recording devices housed within the lightpier superstructure. A schematic diagram of the apparatus is shown on Figure 4.

The data recording devices consist of time-accumulating clocks which will



ST. LAWRENCE RIVER-MONTREAL TO QUEBEC FIGURE 2

PROJECT LOCATION

FIGURE 3

collect information on a statistical basis and will require only simple observation at two-week intervals. Analysis of the accumulated data can be done simply and manually in the office. Provision is made for continuous collection of more detailed output which will initially be used on a short-term basis during commissioning and calibration, and may be employed later during periods of severe ice activity, or alternatively, in connection with a more detailed program of ice force and meteorological observations.

The apparatus consists of three main parts:

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

(b) - The electrical integrating circuit which combines the voltage outputs from each of the load cells; and

(c) - The recording devices in which the data are stored.

<u>(a) - Load-sensing Panel</u>

The load panel assembly, as shown on Figure 5, consists of a rigid beam, simply supported on electrical resistance load cells, and sealed within an oil-filled box.

Measurement of the normal reactions at each end of the beam allows calculation of the total applied normal force. The rigidity of the beam ensured that ice contacting the pier cannot distinguish between the beam and the normal pier surface.

The flexible seal between the rigid beam and the box excludes water, thus assuring a minimum of corrosion of the device and preventing the formation of ice behind the beam.

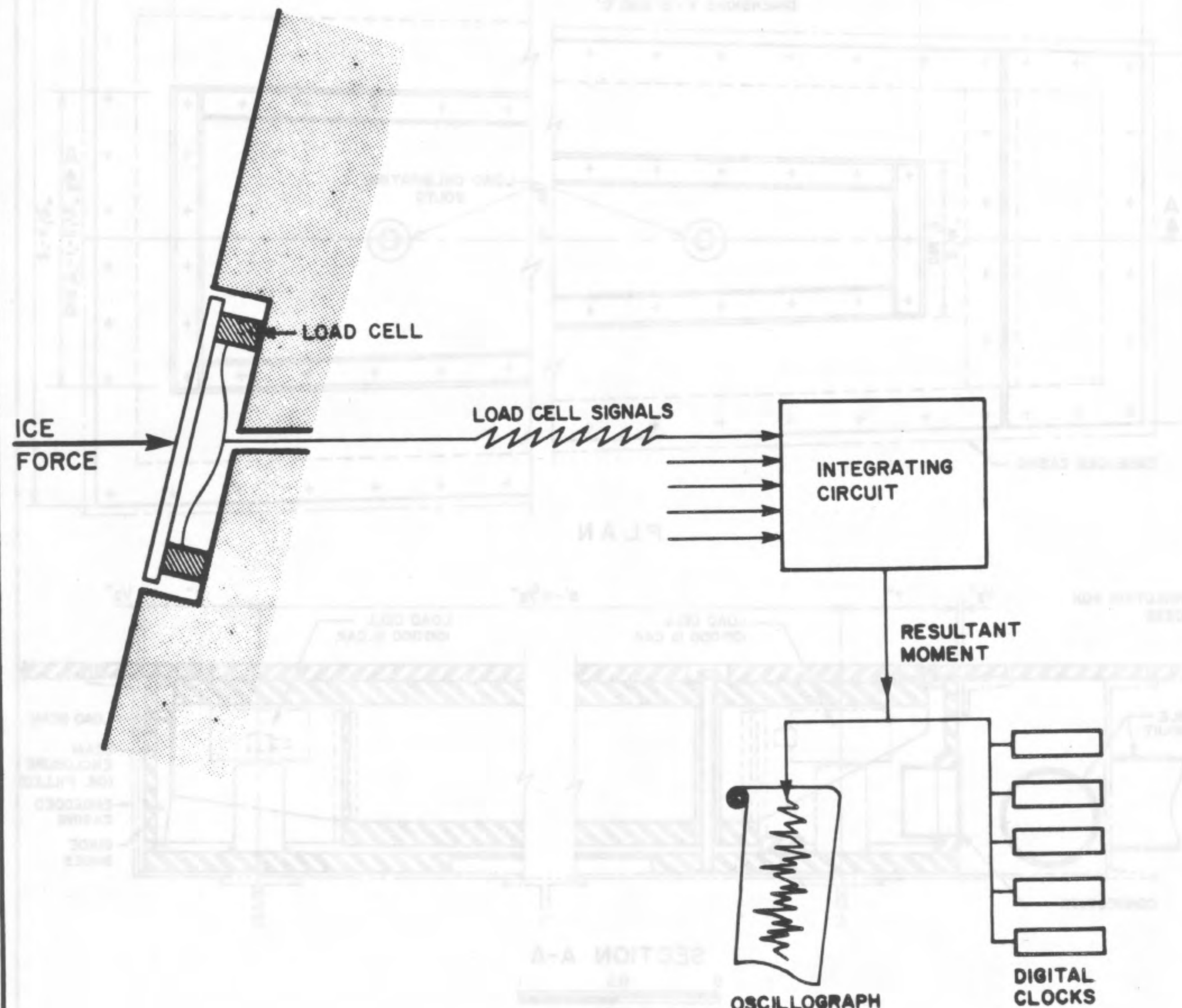
The proportion of the ice load absorbed in deforming the seals, and the frictional forces parallel to the conical lightpier surface, are expected to be small relative to the normal forces measured.

It was initially envisioned that approximately 12 of these load-sensing panels would be required, uniformly spaced around the periphery of the lightpier. However, since in this location the ice attack is characteristically unidirectional, only five of the panels are required, placed on the side of the pier from which the ice forces are expected.

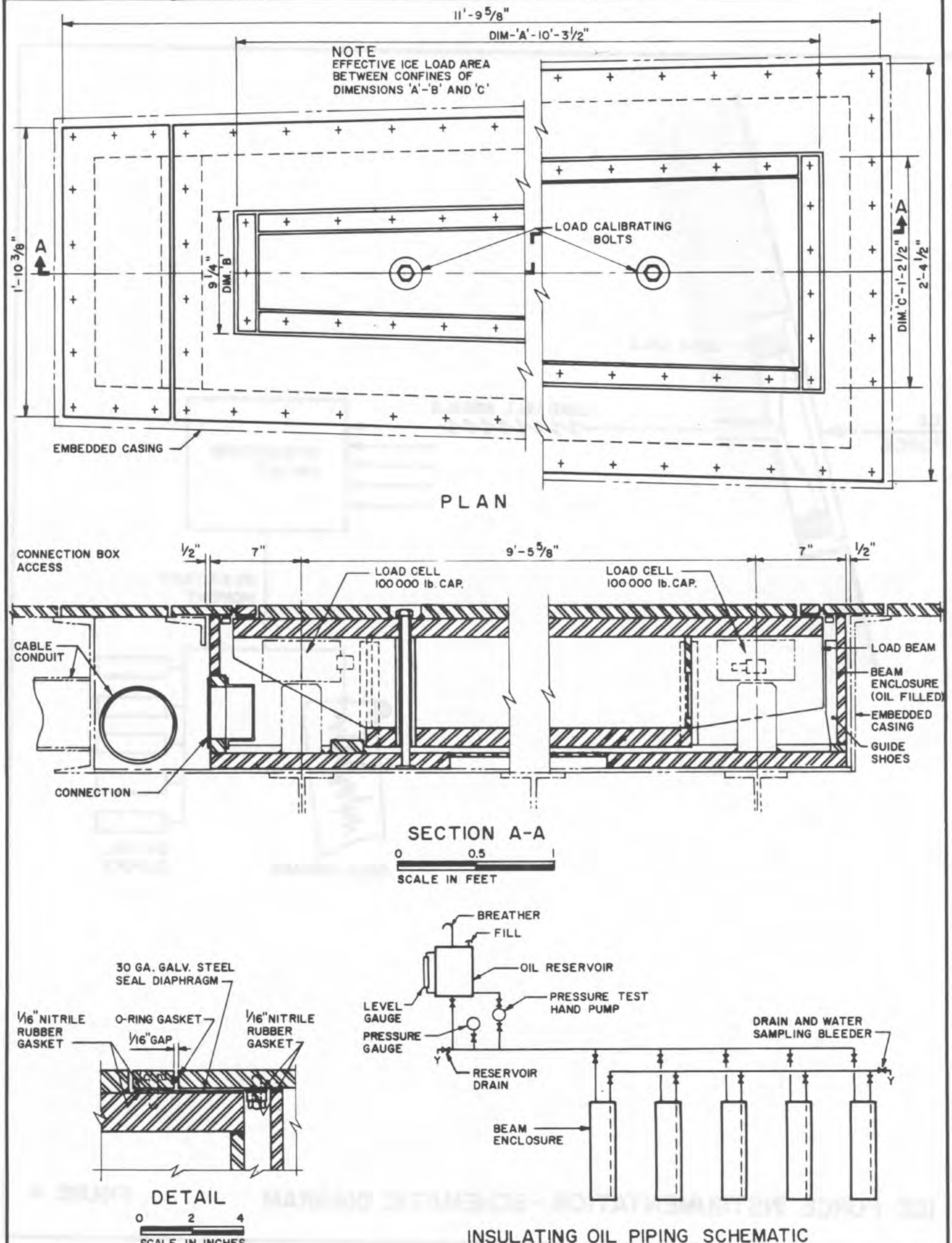
<u>(b) - Electrical Integrating Circuit</u>

The continuous recording of data from each load cell in each load-sensing panel would result in the accumulation of an enormous amount of data requiring considerable time for processing and analysis. While such information might prove useful in a program of detailed data collection, for the purposes of the initial stages of the investigation, a statistical recording of the resultant force against the structure is sufficient.

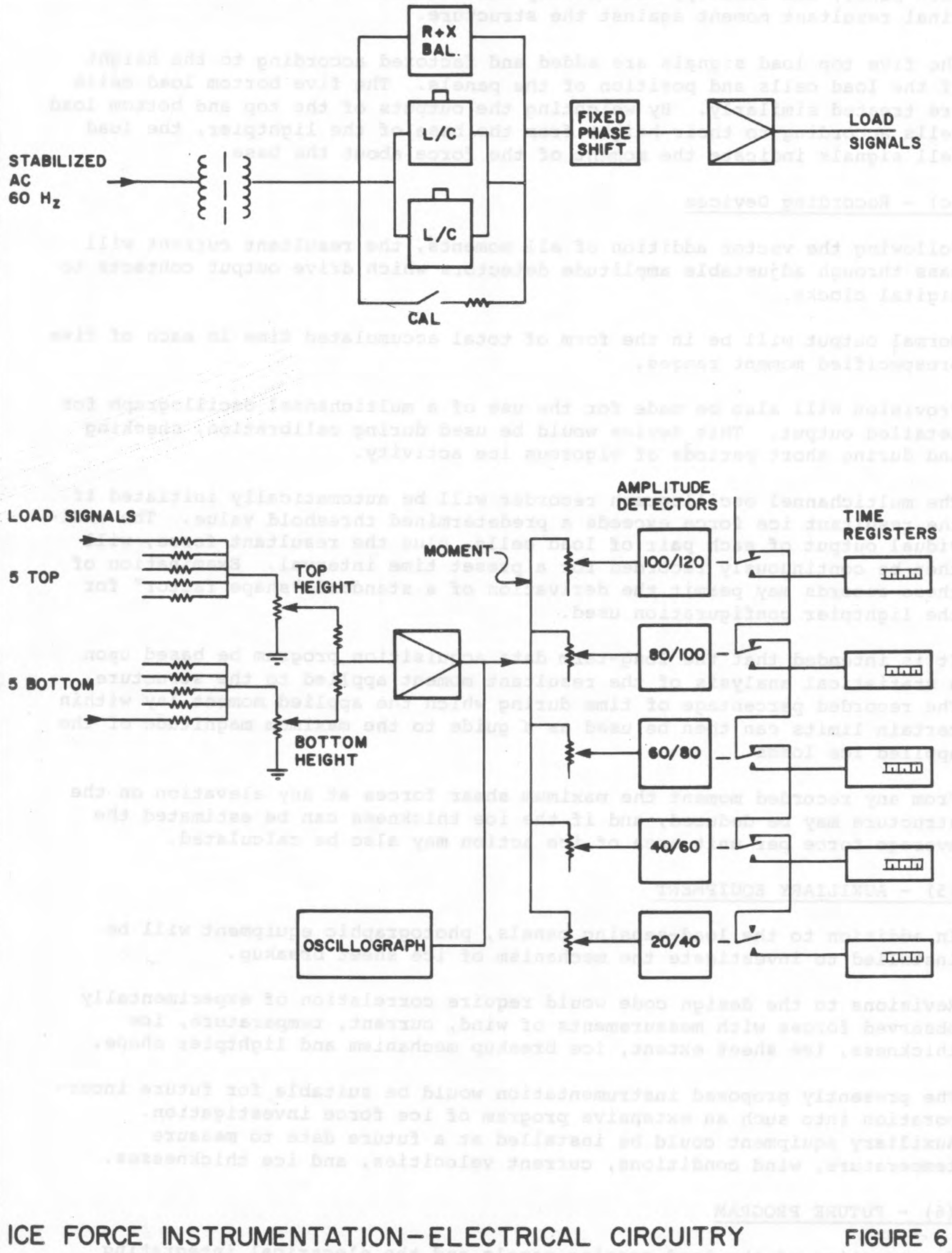
A block diagram of electrical integrating circuits used to combine the output from each load-sensing panel is shown on Figure 6. The purpose of this circuit is to input the voltages from each individual load cell, compute the moment against the structure using the forces at the top and bottom of



ICE FORCE INSTRUMENTATION - SCHEMATIC DIAGRAM FIGURE 4



ICE FORCE INSTRUMENTATION - PANEL ASSEMBLY FIGURE 5



ICE FORCE INSTRUMENTATION—ELECTRICAL CIRCUITRY FIGURE 6 each panel, and finally, vectorially add all moments to calculate the final resultant moment against the structure.

The five top load signals are added and factored according to the height of the load cells and position of the panels. The five bottom load cells are treated similarly. By weighting the outputs of the top and bottom load cells according to their height from the base of the lightpier, the load cell signals indicate the moment of the force about the base.

(c) - Recording Devices

Following the vector addition of all moments, the resultant current will pass through adjustable amplitude detectors which drive output contacts to digital clocks.

Normal output will be in the form of total accumulated time in each of five prespecified moment ranges.

Provision will also be made for the use of a multichannel oscillograph for detailed output. This device would be used during calibration, checking and during short periods of vigorous ice activity.

The multichannel oscillograph recorder will be automatically initiated if the resultant ice force exceeds a predetermined threshold value. The individual output of each pair of load cells, plus the resultant force, will then be continuously recorded for a preset time interval. Examination of these records may permit the derivation of a standard "shape factor" for the lightpier configuration used.

It is intended that the long-term data acquisition program be based upon a statistical analysis of the resultant moment applied to the structure. The recorded percentage of time during which the applied moment lay within certain limits can then be used as a guide to the maximum magnitude of the applied ice loads.

From any recorded moment the maximum shear forces at any elevation on the structure may be deduced, and if the ice thickness can be estimated the average force per unit area of ice action may also be calculated.

(5) - AUXILIARY EQUIPMENT

In addition to the load-sensing panels, photographic equipment will be installed to investigate the mechanism of ice sheet breakup.

Revisions to the design code would require correlation of experimentally observed forces with measurements of wind, current, temperature, ice thickness, ice sheet extent, ice breakup mechanism and lightpier shape.

The presently proposed instrumentation would be suitable for future incorporation into such an extensive program of ice force investigation. Auxiliary equipment could be installed at a future date to measure temperature, wind conditions, current velocities, and ice thicknesses.

(6) - FUTURE PROGRAM

Construction of the load-sensing panels and the electrical integrating equipment is now underway. The construction of the lightpier will be completed during the summer of 1971, and recesses will be left in the sloping face of the lightpier into which the panels will be inserted. Installation of the load-sensing panels and electrical equipment will be accomplished during the fall so that data recording may begin during the winter season 1971-72.

Approximately three or four periods of significant ice activity may be expected during each winter season; during initial formation of the ice cover, during the breakup of the ice cover, and immediately following the periodic passage of ice breakers serving the adjacent shipping channel. It is anticipated that sufficient experience will have been obtained in the operation of the device and in the interpretation of the data by the end of the first winter season to allow a first estimate of the range of prototype ice forces.

The development of satisfactory design criteria can be attempted only after a thorough investigation of the phenomena involved. In the case of ice phenomena, this normally requires several seasons to ensure that a representative range of conditions are experienced. Consequently, it is expected that the collection and analysis of ice force measurements and related physical parameters over several seasons will be necessary before the data and knowledge gained from the Yamachiche Bend lightpier can result in the formulation of an appropriate design code.

Acknowledgment

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