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RECENT TESTS OF PROJECTILE IMPACT ON FRESHWATER ICE

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ABSTRACT

This paper presents a description of an instrumented projectile which can be used to measure the impact properties of freshwater ice. The projectile is instrumented with 5 pressure cells, an accelerometer, a load cell and 2 displacement gauges. When dropped onto the surface of freshwater ice, it provides information on the local crushing pressures, pressure distributions, crushing energy and damage processes in the ice. Some preliminary test results are presented.

1.0 INTRODUCTION

The high speed impact of ice on ships and structures plays an important role in their design. For example, the peak or local pressures on the hull of an icebreaking ship are dictated by the impact crushing pressures of ice. Similarly, a moving ice floe hitting a bridge pier can result in local ice crushing at impact speeds. Although long recognized as very important, there still remain many unanswered questions related to the impact pressures of ice.

Because of the importance of this problem and the lack of quality information on the ice crushing process, a test program was undertaken between the National Research Council of Canada and the Canadian Coast Guard. This joint program was formatted to include several tasks. One of the most important tasks was to measure, in a laboratory environment, the pressures associated with the ice crushing process at impact speeds.

In order to understand the ice crushing process, it is important to have a well-designed and fully instrumented test system, and to use it in a controlled laboratory environment. By doing this, a great deal of useful information can be obtained. This was accomplished by designing and building an instrumented projectile that could be dropped onto the surface of an ice sheet. With this approach, local pressures, loads and accelerations could be measured for impact speeds ranging from 2 to 6 m-s^{-1}.

This paper presents a detailed description of the test apparatus and presents some preliminary information on the drop tests on freshwater ice.

2.0 THE IMPACT PROJECTILE

2.1 GENERAL CONSIDERATIONS

There were several aspects to the design of the experimental arrangement. First, it was necessary to develop a scheme that would enable the measurement of pressures at impact speeds in a controlled laboratory setting. Next, it was necessary to choose instrumentation that would compliment the test apparatus and give significant information. Third, since the impact event occurs in a very short time duration, a very high speed data acquisition system was required.

In developing the test apparatus, various schemes were considered. It was decided to use an instrumented projectile that would impact an ice sheet by simply falling due to gravity. This system has several advantages. It gives high impact speeds that can be varied for each test. Also, by adjusting the drop height and the mass of the projectile, it is possible to change the energy of the impact over a wide range. By careful design and selection of the instrumentation, local impact pressures and pressure distributions can be measured.

The detailed design of the projectile was carried out by GEOTECHnical Resources of Calgary. Figure 1 shows a schematic of the projectile. The projectile consists of an instrumented head connected to a hollow tube. Three different interchangeable heads were designed and built: spherical, cylindrical and wedge-shaped. Each head is instrumented with

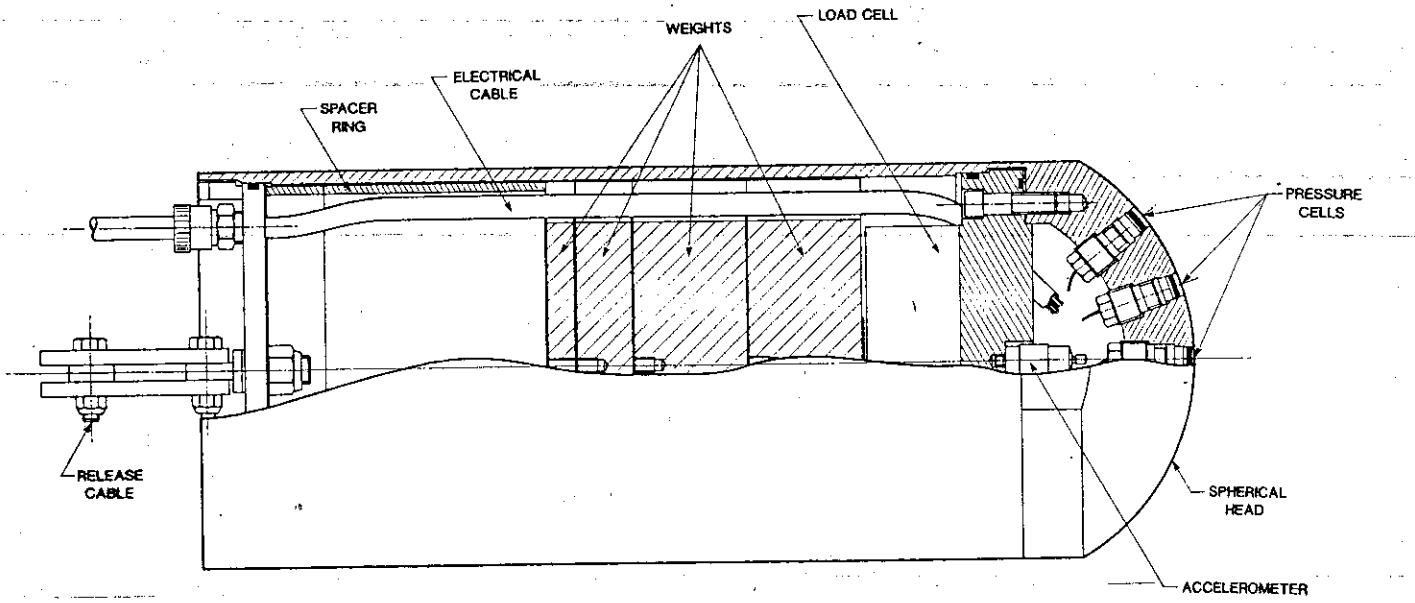

Figure 1 : Schematic illustration of the projectile showing the location of the five pressure cells, the load cell and the accelerometer.

five (5) pressure cells of 100 mm² sensing area. Weights could be added to the projectile in the tube portion in order to vary the total mass of the projectile. In addition to the pressure cells, the projectile contains an accelerometer and a load cell. External displacement gauges were used to measure the position of the projectile at impact, and from this, the velocity at impact. Each of these features will be discussed in turn.

2.2 PROJECTILE SIZE, SHAPE AND MASS

The details of the size, shape and mass of the projectile were dictated by the constraints imposed by the laboratory test set-up, the physical requirements necessary for ice crushing at impact, and the funds available for the projectile. The projectile was designed to be used in the ice tank in Ottawa at the National Research Council of Canada. This ice tank is 21 m long by 7 m wide and 1.2 m deep. The tank is spanned by a carriage which can travel the length of the tank. The carriage supports a 1 ton capacity jib crane. This crane is 3 m above the surface of the ice and is at the ceiling of the ice tank chamber. The use of this facility placed two restrictions on the design of the test projectile. First, the jib crane, which was used to support the projectile above the ice surface provided a maximum drop space of approximately 2.5 m. With this height restriction, it was necessary to design the projectile to be relatively short in order to get a reasonable drop height. Second, the maximum ice thickness which could be grown in the ice tank in a reasonable time was approximately 40 cm. With this condition it was necessary to limit the total mass of the projectile so that it did not penetrate through the ice sheet.

It was decided at the outset that a realistic maximum input energy for the tests should be 1 kJ. Thus, with this criterion and the height restriction it was decided that the projectile should have a changeable mass with a range of 30 to 65 kg. A projectile with this mass should give good ice crushing when dropped onto an ice surface, without through penetration. The width of the projectile was chosen to be on the order of 17 cm. These conditions place restrictions on the overall length of the projectile.

Since it was necessary to have different impact head shapes, it was decided to build the projectile with a basic cylindrical shape to which the different heads could be mounted. The body of the projectile was a hollow tube to which either weights or spacer rings could be placed, depending upon the desired mass of the projectile. A multi-strand electrical cable was used to connect the instrumentation to the data acquisition hardware. The actual connection to the individual transducers was made by electrical soldering. This positive type of connection was required to withstand the high decelerations placed on them at impact.

2.3 PROJECTILE HEADS

Three different projectile head shapes were chosen for study: spherical, flat circular (i.e. cylindrical) and wedge-shaped. Each head has locations for five pressure cells. The sensing face diameter and area for the pressure cells are 11.26 mm and 100 mm² respectively. The pressure cells were arranged on the impact faces so that at least three cells were in-line in the expected direction of crushed ice flow. One cell was always placed in the centre of the loading face. The other cells gave estimates of the uniformity of the impact pressures. Each of the pressure cells were machined to be flush with the surrounding face. The heads which were made from stainless steel were machined to a smooth finish. The details for each of the three heads is shown in Figure 2.

2.4 PRESSURE CELLS

Each pressure cell consists of a piston, a load transducer and a retaining screw which holds the piston in contact with the transducer. An O-ring seal and a back-up ring prevent crushed ice or fluid from entering the projectile head. The combination of load transducer and piston of fixed known area gave a very

effective pressure cell. This type of pressure cell differs from the usual type in that its sensing face is relatively immune to damage caused by hard spots in the contact medium.

In choosing the load transducer for the pressure cell, both the size of the sensing face and the maximum expected pressure influence the choice. Sensotec LFH-61 load transducers with a 9 kN capacity were used. This transducers loaded over a 100 mm² sensing area gives a pressure cell rating of 89 MPa and an overload rating of 133 MPa. This was felt to be sufficient for these tests.

2.5 ACCELEROMETER

A single accelerometer was mounted inside the projectile at the interface between the projectile body and the head. Because of the high deceleration of the projectile at impact, the accelerometer was chosen to have a high range. Moreover, because of the short time duration of the impact, an accelerometer with a high transient response was required. With these requirements, a PCB Model 302A02 accelerometer was chosen. It had a range of ± 500 g and a resonant frequency of 40 kHz.

2.6 LOAD CELL

Although the test configuration did not provide a means of unambiguously measuring the total force at impact, it was decided to include a load cell into the assembly. A 220 kN capacity Interface Model 1221-EX-50k load cell was mounted inside the main body of the projectile. The location of the load cell, which was above the accelerometer, made its output sensitive to both the impact load and the mass of the weights mounted above it in the projectiles body. For this reason, the load cell output requires additional analysis to determine the impact load.

2.7 DISPLACEMENT MEASUREMENTS

Displacement measuring devices were used to try to obtain information on the time of initial impact, the speed of the projectile at impact and the amount of rebound. A number of different schemes were considered including mechanical displacement transducers, string potentiometers, mechanical grids, velocity transducers and optical techniques. For the first phase of testing, two displacement gauges were used in two different configurations. For some tests, the gauges were mounted on a collar on both sides of the projectile. This proved unsatisfactory, however, because the ends of the gauges produced small spall craters in the ice, leading to inconclusive measurements of displacement. In a second configuration, the transducers were mounted onto a base plate which was placed on the surface of the ice. A small collar mounted onto the projectile contacted the displacement gauge as the projectile struck the ice. The results from these technique, however, also proved to be unsatisfactory. Examining the displacement records indicated that the displacement transducers did not appear to have the necessary high frequency characteristics to provide accurate results. Because of this, the output from the displacement gauges were not considered to be reliable. A new scheme for measuring displacement is being developed, but no details on its performance is available to date.

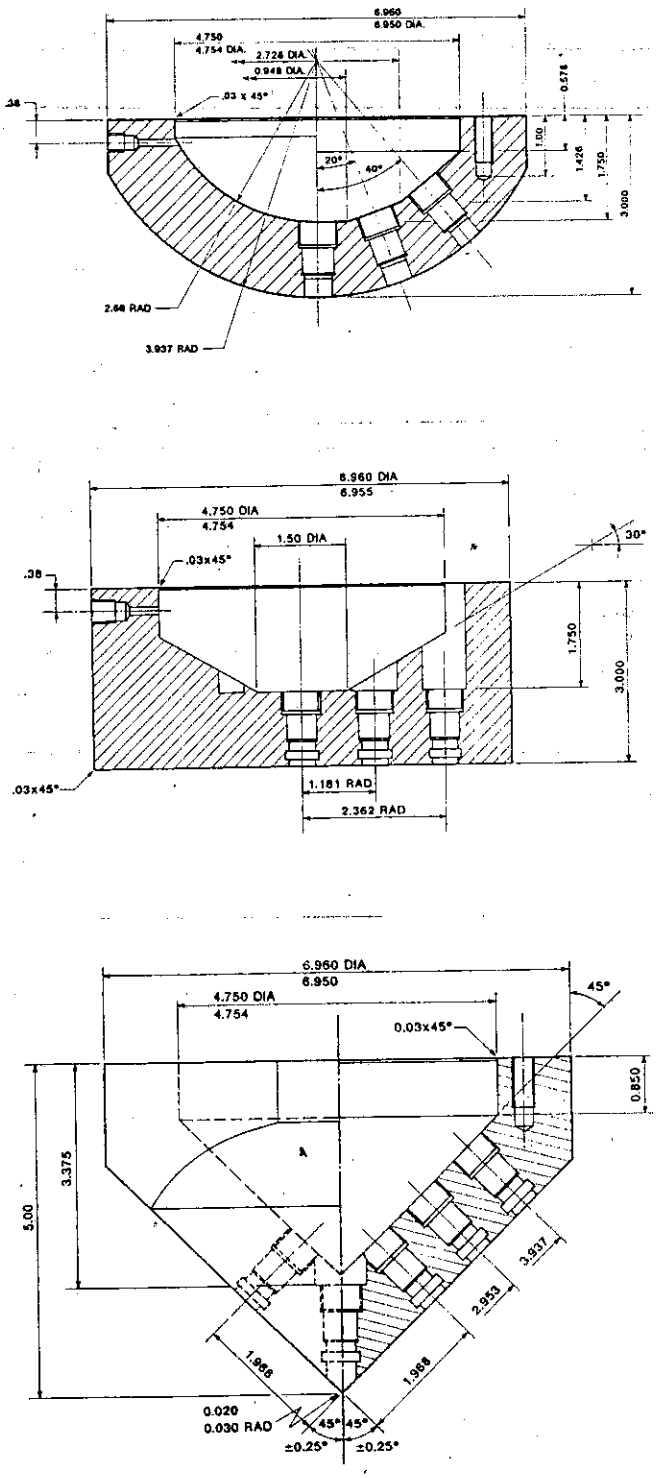

Figure 2 : Schematic illustration showing the details of the three projectile heads.

2.8 RELEASE MECHANISMS

A chain hoist connected to the jib crane was used to position the projectile at any desired height above the ice surface. A helicopter release hook provided an instantaneous release of the projectile. Three different schemes were used to provide guidance for the projectile during the fall: a hollow tube, an open-frame support system and free-fall. Of these, the second technique proved to be the most reliable for a number of reasons. First, it allowed the projectile to free-fall with little interference from the guidance assembly. Second, it provided a base for mounting displacement transducers, and third, it allowed multiple impact drops in the exact same location. A photograph of the test assembly is shown in Figure 3.

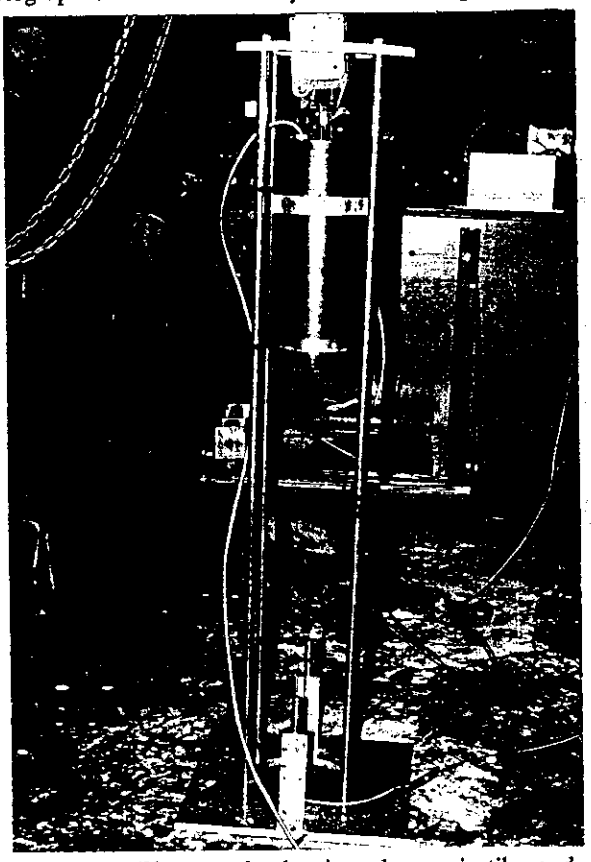

Figure 3 : Photograph showing the projectile and the guidance assembly before a test.

3.0 INSTRUMENTATION ON THE ICE

Two accelerometers were frozen onto the ice to measure the ice acceleration at impact for both the vertical and horizontal directions.

4.0 HIGH SPEED DATA ACQUISITION

Because of the short duration of the impact event it was imperative to have a data acquisition system that could sample at extremely high rates. For this, a NEFF System 480 Data Acquisition and Recording System was used with a VAX 3200 Workstation. This data acquisition system allowed high speed data acquisition at rates up to 50,000 Hz per channel. The system was configured to use a "trigger" system in which the data was collected but not stored until a critical voltage level was measured in one channel. When the level was reached, the data was collected and saved for a time period designated by the user, for a time period both before and after the trigger level voltage. This made it convenient to obtain a "snapshot" of the event without having to collect a lot of extraneous data. It was found that the impact event lasted for approximately 6 to 8 msec so the data acquisition system was configured to measure for a total of 14 msec. This extra time guaranteed that the full event would be measured.

5.0 PRELIMINARY DROP TEST RESULTS

A number of impact tests have been performed using this system with the spherical-shaped head. The details of the test results are too lengthy to present here. They will be published at the Tenth International Association for Hydraulic Research Symposium on Ice, to be held in Espoo Finland this year. However, some preliminary results of the impact tests will be presented here.

Figure 4 shows a typical result for the pressures, projectile deceleration and force, and the ice acceleration in the vertical direction. For this test (DRJUNE28_003), the drop height of the projectile was 0.5 m and its mass was 63.6 kg. The ice was 33 cm thick. The velocity of the projectile at impact was 3.1 m-s^{-1}. The whole loading event lasted less than 8 ms. The rise in the pressure in the centre pressure cell is extremely rapid, rising to a value of 30.6 MPa. The three outer pressure cells record much lower pressures. The fifth pressure cell shows no pressure since it did not penetrate into the ice. The impact caused considerable damage to the ice in various forms. At impact a crater formed in the ice. For this test the depth of the crater was 0.65 cm in the centre. In general the depth of the crater was a direct function of the input energy of the projectile at impact. Several small fragments of ice were expelled from the crushed ice region directly below the projectile. In addition, there were usually a few large radial cracks emanating from the impact region. Directly below the impact crater there were cone-shaped cracks. The damage processes were quite varied and clearly complex. Considerable work is required in this area to try to understand these phenomena.

6.0 SUMMARY

This paper presented a description of new system developed to measure the impact crushing pressure of ice. The apparatus consists of an instrumented projectile which impacts an ice sheet through a gravity free-fall. The projectile is instrumented with five pressure cells, an accelerometer and a load cell. Three different shapes of the impact face are available: spherical, cylindrical and wedge. Some preliminary test results of a typical test were presented for an impact test with a spherical-shaped projectile.

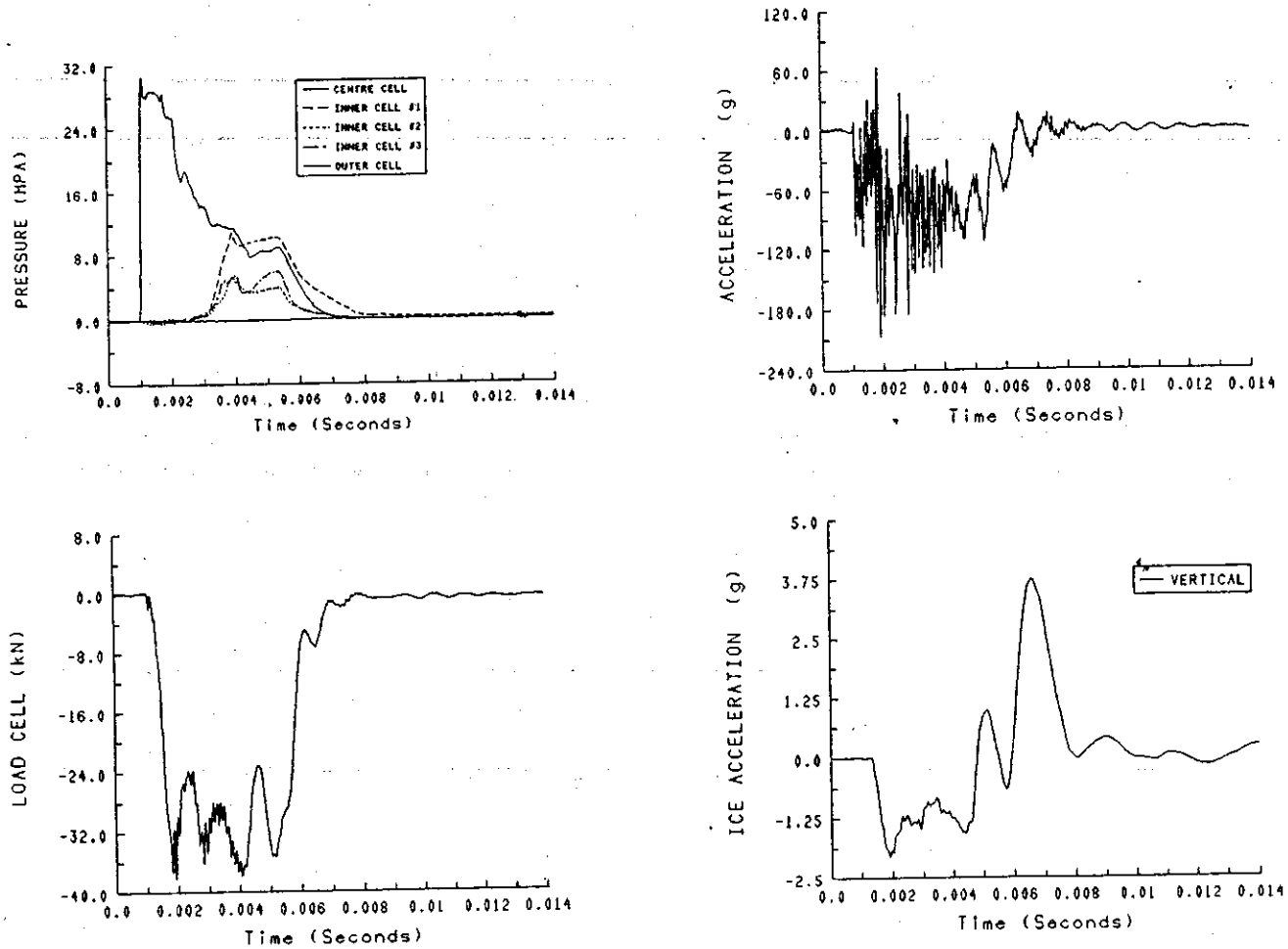

Figure 4 : Time-series plots of an impact test on freshwater ice showing the pressures, decelerations and loads on the projectile, and the ice accelerations during an impact event.

7.0 ACKNOWLEDGEMENTS

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