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Vancouver, British Columbia, Canada, July 6 to 11, 2008

A NEW IMPACT PANEL TO STUDY BERGY BIT / SHIP COLLISIONS

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Abstract

A new design has been generated for an impact panel that is intended for use in a second bergy bit / ship collision field study. The design incorporates new technology to measure impact loads and pressure distribution at fine spatial resolution. The panel consists of 6 large sensing modules. Each module is a solid acrylic block with dimensions 1m x 1m x 0.46 m, giving the impact panel a total sensing area of 6 m^2. Each module sits on four flat-jack type load cells. All 6 modules are housed in a 3m x 2m rigid steel structure that is welded to the hull of the vessel at the bow center. The top surface of each module is covered with a new pressure-sensing mechano-optical technology capable of measuring pressure with an effective unit sensing area of about 1.3 cm x 1.3 cm. Data from the sensing modules are recorded by cameras operating at a capture rate of 250 images/s that are situated at the back end of each sensing module. A secondary means of measuring pressure at an array of locations on each module surface consists of strain gauges imbedded in the acrylic close to the impacting surface. The panel is intended for use within the next few years in a full-scale study of ship / bergy bit collisions with impact loads in the 0 – 20 MN range.

1. Introduction

In June 2001 the first Bergy Bit Impact Field Study was conducted using the CCGS Terry Fox. This successful program demonstrated that a strong vessel could be instrumented to obtain detailed load and pressure distribution data during intentional impact experiments with bergy bits (Gagnon et al., 2008). Bergy bit impacts are a major hazard for tankers and other vessels operating off the East Coast, and similarly in the Arctic regions where resource development, tourism, mineral transport, etc are on the increase. The recent sinking of the Explorer cruise ship in the Antarctic following a collision with what was likely a bergy bit illustrates this point. Large chunks of multiyear sea ice pose similar hazards in the Arctic regions.

While the first Bergy Bit Impact Field Study was a success, the results showed that the maximum obtainable loads were in the 5 MN range due to the shape of the Terry Fox hull and the position of the impact panels. Both panels, an internal strain-gauge panel and an external panel, were located on the port side of the bow, where only glancing impacts could be achieved. Since that time we have verified this result using extensive numerical simulations. The simulations showed that loads that are of the greatest interest (i.e. 10-20 MN) could not be attained with the impact panels in that location, even when unacceptably risky high-speed impact scenarios were simulated.

Fortunately, the solution that would facilitate a safe and effective field study that would achieve impact loads in the desired range is to mount an impact panel with a vertical orientation at the center of the bow of the Terry Fox. Simulations and calculations show that loads of approximately 20 MN can be achieved with impacts on bergy bits in the 2000 tonne range at moderate speeds, where the maximum acceleration would not exceed the safe range for ship and crew operations, that is, around 0.3 g.

A key element that remains to be resolved in relation to ship and structure collisions with sea ice and glacial ice concerns the distribution of pressure within the contact zone. Several studies, including the first Terry Fox field study, showed the existence of high-pressure zones, regions of relatively intact ice surrounded by low pressure pulverized ice. Do these high-pressure zones increase in size as impact load increases, and just as important, does the pressure in the high-pressure zones increase as their size increases? These are critical questions that must be addressed. The data from the external impact panel used in the first bergy bit impact study suggested the affirmative to both questions (Gagnon, 2008), however, the load range was quite limited and it remains to be seen if the trends continue throughout the full range of interest. The new impact panel described below, used on the Terry Fox for head-on bergy bit collisions, has the capability to resolve these issues.

2. Impact Panel Details

2.1. Attachment to the Bow of the Vessel

The impact panel is modular in design and is 3 m wide and 2 m in height at the front impacting surface. Figure 1 shows its location on the Terry Fox bow. The top of the panel is at the waterline. The panel consists of six 1 m x 1 m modular sensor inserts, each with its own independent array of sensors for measuring load and pressure. The sensor inserts fit into the slots of the box-like structure of the panel, referred to as the backing structure (Figure 2). The backing structure is fabricated using 1” steel plate, welded at all joins. To enable divers to weld the panel to the hull of the Terry Fox it is necessary to do the attachment as a multi-stage process. First a mounting frame must be welded to the hull (Figures 2 and 3). The back end of the frame conforms to the vessel and its shape enables full access for welding all of the conforming metal surfaces to the hull. The front of the mounting frame has several seating pads that mate and bolt to matching seating pads on the back end of the backing structure. Once the backing structure is bolted on then the sensor inserts are individually installed in the six slots. This strategy is similar to that used during the first Terry Fox field study. Removal of the panel from the vessel is accomplished in the reverse order. All electrical cables from the inserts would feed up through a protective conduit welded to the upper hull running from the top of the panel up the side of the ship’s bulwarks from where the cables continue on to the data acquisition hut situated on the vessel’s fore-deck.

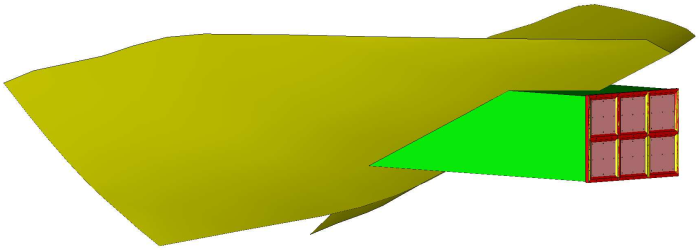

Figure. 1. Impact panel on the CCGS Terry Fox bow.

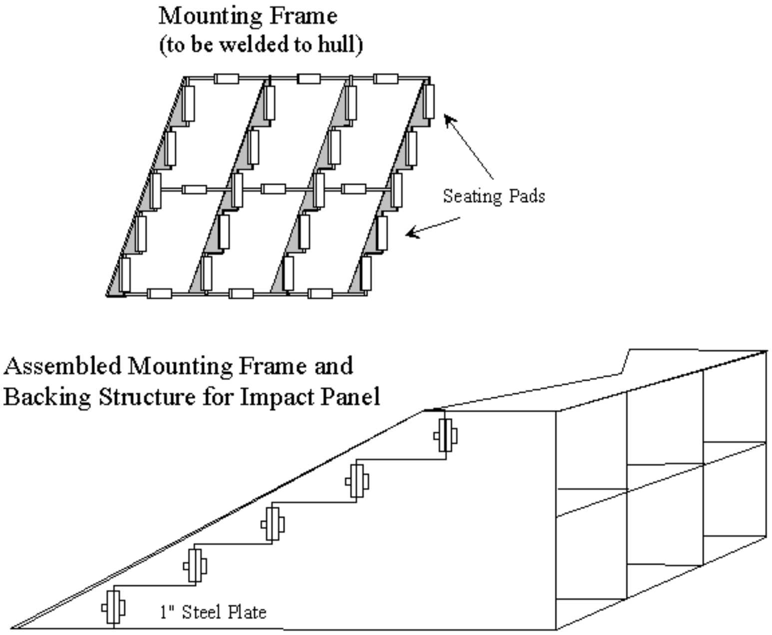

Figure. 2. Mounting frame and backing structure.

2.2. Details of the Impact Panel Sensing Capabilities

A staged strategy will be used for the design and fabrication the impact panel since some of the technology is novel and it is prudent to conduct tests in the lab prior to committing to the final details. A 1/ 6 portion (one sensor insert) of the panel (Figure 4) will be fabricated for extensive testing during the summer of 2008 at IOT and in the Structures Lab of Memorial University. This instrument is referred to as the impact module. Final details of the full impact panel design would be contingent on the results of the lab tests using the impact module. Following the proofing of the impact panel design, the impact module will be used as a research tool for on-going laboratory studies of ice impacts. The details of the impact module construction and functioning are given below. These are essentially the same details that apply to the full impact panel.

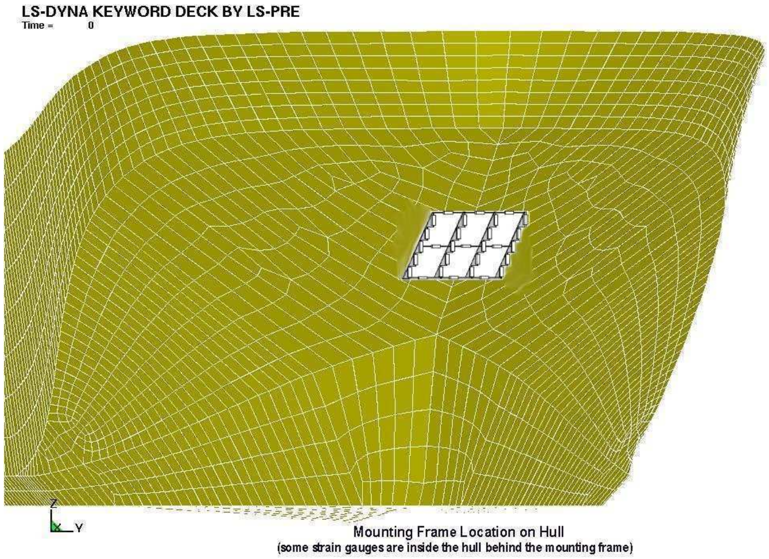

Figure. 3. Mounting frame location on the Terry Fox hull.

The central component of the impact module is a thick transparent block of acrylic measuring 1 m x 1m x 0.46 m (Figure 5). The block rests on four flat-jack type load cells. These cells are metallic envelopes filled with hydraulic fluid. Load applied to the surface of the cell translates into pressure in the fluid, which is monitored by a pressure gauge. The thickness of the acrylic block gives it the flexural strength to withstand high loads while supported at its four corners. The block is held firmly against the load cells by two bolts that pass part-way through opposing corners of the block and that are secured with nuts and thick rubber washers. Also, around the top edge of the block there is a securing plate that bolts to the steel side plating of the impact module with nuts and thick rubber washers (Figure 5). This protects the edges of the block where a thin stainless steel sheet, that covers the

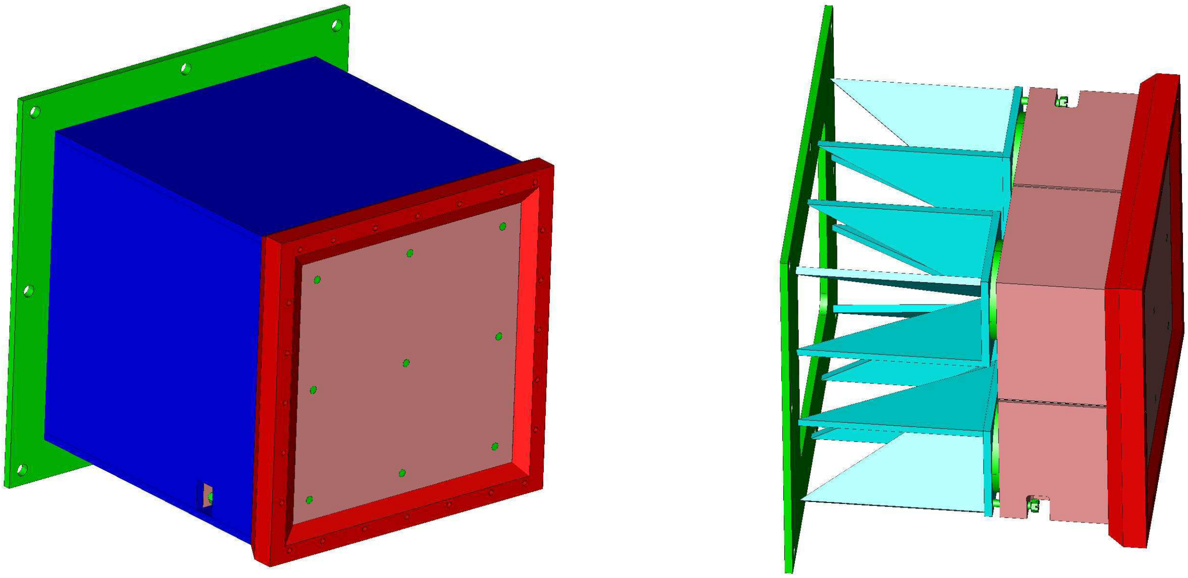

Figure. 4. (Left) Impact module oriented horizontally with the impacting surface in the foreground. (Right) Impact module with side plates removed to show internal structures and components. A protective securing plate is visible around the peripheral edge of the impacting surface.

new pressure sensing technology, is screwed to the block while enabling the load from an ice impact to transfer to the flat load cells.

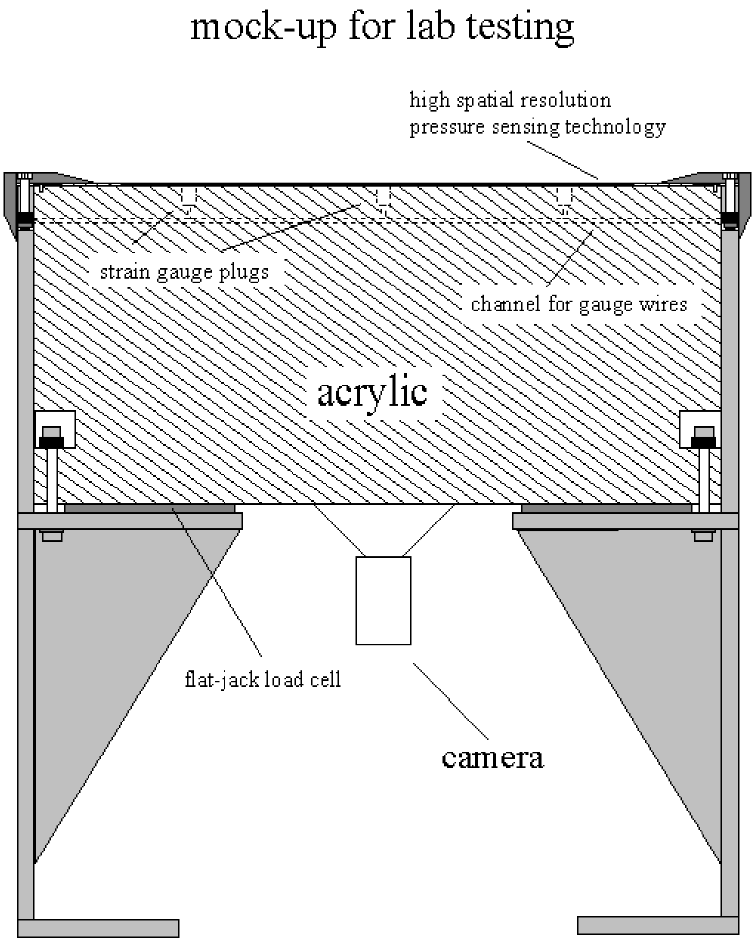

Figure. 5. Sectional view of the impact module.

The top surface of the block is covered by new pressure sensing technology. This new technology consists of many strips of acrylic, 13 mm wide and 4 mm in thickness and ~ 1 m in length, mounted side-by-side on the block's surface. Each strip has a gentle curvature (0.23 m radius) across its width on the face that touches the large acrylic block (Figure 6). Pressure applied to the opposite side of the strips causes them to flatten against the block's surface. The degree of flat contact, i.e. the width of the contact, is a direct measure of the pressure applied and can be calibrated. This type of sensor is very robust and has been used successfully in a number of ice crushing studies (Gagnon and Bugden, 2007; Gagnon and Bugden, 2008; Gagnon and Daley, 2005), in single and multiple strip configurations. Its range of sensitivity is about 0-60 MPa. The pressure sensor strips are covered by a thin sheet of stainless steel that is the contacting surface with the ice during impacts. The unit sensing area for this technology is about 13 mm x 13 mm, hence the top surface of the block is effectively covered by more than 5000 pressure-sensing units. The data acquisition system for the pressure sensing strips is a fast high-resolution video camera (250 images per second) located at the bottom of the block, shown in Figure 5. The acrylic strips are white in color. When not pressed against the acrylic block they make very little contact, and when pressure is applied to them more contact occurs due to elastic flattening of the strips' curved surfaces (Figure 6). The only light source inside the acrylic block is from horizontally oriented LED's around the block perimeter near the top. Light from these LED's normally internally reflects off the top inner block surface. When an acrylic strip is flattened against the block the internal reflection is frustrated, and the light passes through the block's surface to illuminate the white strip where it makes contact. Hence the portion of contact, appearing as white, becomes visible to the camera.

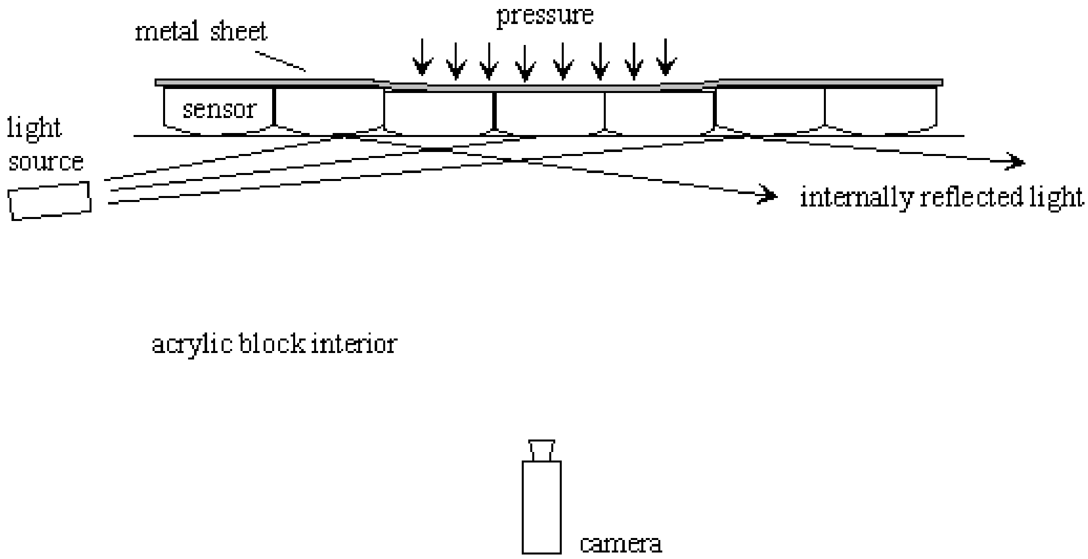

Figure. 6. Schematic showing how the new pressure sensing technology functions. Two of the light rays from the source at the left internally reflect off the block's internal surface where there is no contact with the strips. The center ray illumines the white acrylic strip since the internal reflection is frustrated where the strip is elastically flattened against the block due to the pressure. The curvature of the strips is exaggerated for illustrative purposes.

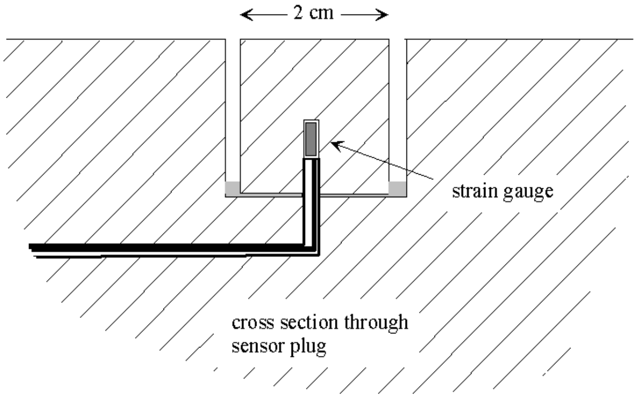

Figure. 7. Sectional view of a strain gauge plug.

In addition to the pressure sensing strips the top surface of the block has an array of 9 pressure sensing plugs recessed in it surface. These are small cylinders of acrylic ~ 2 cm diameter that are located and secured in flat-bottomed holes (with slightly larger diameter) machined in the surface to the exact depth corresponding to the height of the plugs. The end of each cylinder is glued to the acrylic at the bottom of the hole with methyl methacrylate glue that has the same properties as the acrylic. Each plug has a strain gauge imbedded in it with sensitivity along the axis of the plug. Load applied to the top of a plug causes it to contract in length and this registers on the strain gauge. The plugs are essentially pressure transducers that have the same mechanical properties as the block itself. The sensors are useful both for corroborating the output from the pressure sensing strips and as backup sensors in the event there is a problem with the strip sensors.

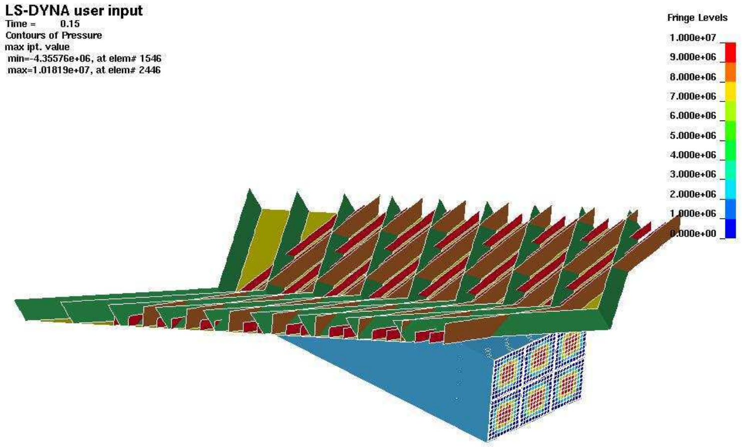

Figure. 8. Finite element stress analysis of the impact panel and Terry Fox hull for a given impact load. The internal structure of the hull, that is, frames and stringers, was included in the simulations.

In addition to the sensors that are incorporated in the impact panel there will also be a separate device, called MOTAN, installed inside the vessel that determines global loads by measuring the full ship motions that result from impacts. This device was used during the first bergy bit impact field study (Johnston et al., 2008). Furthermore, though not part of the impact panel specifically, there will be an array of strain gauges mounted to the inside of the vessel's hull behind the impact panel. The primary purpose of the gauges would be to monitor any plastic deformation of the hull as a safety precaution. Such deformation is not anticipated, however, since numerical simulations of the impact panel on the hull with various loading scenarios applied did not show any plastic deformation of the impact panel or the hull structure (Figure 8).

3. Conclusions

A unique impact panel has been designed for a full-scale ship/bergy bit impact study within the next few years. A device representing a portion of the panel will be fabricated and tested in the lab to proof the technology prior to building the full impact panel. Substantial redundancy is built into the design of the panel to measure loads and pressure distribution. One of the pressure sensing technologies will yield a spatial resolution that effectively amounts to having 30,000 individual pressure sensors on the face of the 3 m x 2 m impact panel.

4. Acknowledgements

The author would like to thank the Program of Energy Research and Development (PERD) and IOT for their financial support of this research. Also, the discussions with Trent Slade regarding the impact panel design details and installation strategies are greatly appreciated.

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