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FIRST RESULTS OF NUMERICAL SIMULATIONS OF BERGY BIT COLLISIONS WITH THE CCGS TERRY FOX ICEBREAKER

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ABSTRACT

Numerical simulations of a collision between the CCGS Terry Fox icebreaker and a bergy bit (1911 t glacial ice mass) have been conducted using LS-Dyna^{TM} software, which incorporates a full Navier-Stokes solver for the fluid component. First results compared favorably with actual data acquired during field tests in June, 2001. The simulations were run on a Beowulf cluster consisting of 15 high-performance CPU's. The modeled volume, including the vessel, water and bergy bit, was meshed using Ansys^{TM} software and contained approximately one million elements. A prior set of non-impact simulations of a model tanker transiting in proximity to model bergy bits showed that at least this number of elements was required. In the results presented here the vessel was traveling at 5 m/s and the impact occurred on the port side of the hull, in the region where the instruments were located during the field tests. A hard crushable foam material model was used for the bergy bit in order to model previously observed ice behavior where the ice contact interface consists of a relatively intact hard zone of ice surrounded by softer pulverized ice. The simulation produced reasonable values for the load, pressure and impact duration values obtained in the field.

KEY WORDS: Numerical simulation; Bergy bit collision; CCGS Terry Fox icebreaker.

INTRODUCTION

Glacial ice masses pose serious hazards for ships operating off the east coast of Canada, where there is particular concern for oil tankers transiting from current and planned offshore facilities, since the environmental impact of an accident would be significant. In rough weather conditions bergy bits (house-sized masses) pose the biggest hazard because they are difficult to detect. The Institute for Ocean Technology has been studying various aspects of the problem for several years, with the intention of creating a validated numerical model of ship/bergy bit collisions. The work has involved extensive physical model testing of a tanker transiting in proximity to bergy bits in IOT's Tow Tank (Gagnon, 2004a), growler impact experiments in IOT's Ice Tank (Gagnon, 2004b) and strength and crushing experiments on iceberg ice and lab-grown ice (e.g. Jones et al., 2003; Gagnon, 2004c). In parallel with the experimental aspects of the project the numerical simulation work has been progressing, and recently the first simulation results were obtained for actual full-scale impacts.

HARDWARE AND SOFTWARE

The simulations were run on a Unix based Scyld™ Beowulf Cluster presently consisting of 45 CPU's (AMD Opteron™ Processor 246). The software used was LS-Dyna™, that incorporates a full 3D Navier-Stokes solver, a number of contact algorithms and a large suite of material types that can be chosen for the interacting structures. Ansys™ was used for the modeling and generation of meshes for the study. It was found that the simulations ran faster as more CPU's were used but that the efficiency decreased so that an optimum number of 12-15 CPU's was the most efficient configuration.

SIMULATION SETUP AND RESULTS

Figure 1 shows the modeled region of the water and air including the vessel and brick-shaped bergy bit. The length-width-depth dimensions of the region were 124m x 69m x 26m, where the top 5m was air. Figure 2 shows the CCGS Terry Fox colliding with a bergy bit during the field experiments. The choices of dimensions for the modeled region and mesh element sizes were determined prior to the collision simulations in a separate set of simulations of a tanker transiting in proximity to a bergy bit, where the results were compared to actual data from physical model tests conducted in IOT's Tow Tank (Gagnon, 2004a). The degree of bergy bit sway due to the hydrodynamic interaction with the tanker was used as the index to compare the results. The shape of the numerically modeled region of the Tow Tank with tanker and spherical bergy bit was similar to that in Figure 1 except that the vessel was a tanker rather than an icebreaker and the bergy bit was spherical rather than brick shaped. The simulations were run at the same scale as the physical model tests

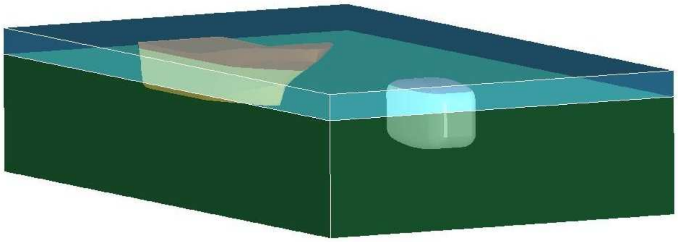

Figure 1. Meshed region for the ship / bergy bit collision simulations.

Figure 2. CCGS Terry Fox colliding with a bergy bit during the field program.

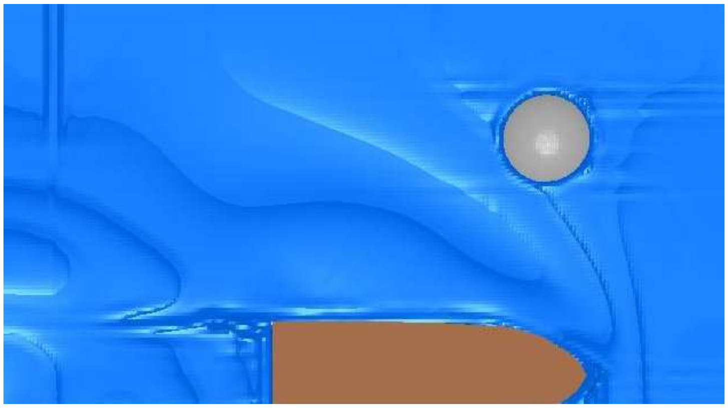

Figure 3. Image from a proximity simulation. The model-sized tanker (brown), moving from left to right was initially at a lateral separation of 2.58m from the bergy bit (gray). The tanker speed was 1.24 m/s. The bergy bit surges and sways in response to the tanker's bow wave.

(1:41), hence the intention was not to simulate full-scale results but rather to test the capability of the software to generate accurate results at the same scale as the physical model tests. The water, bergy bit and air were meshed using brick elements and the vessel using shell elements. The purpose of these prior simulations was two-fold, first to see what size mesh elements and meshed volume would be necessary for convergent results, and secondly to see how accurate the simulations were. To keep the meshed volume within a tractable size only half of the tanker (the front half) was meshed. A similar strategy was employed during the collision simulations, i.e. the front half of the Terry Fox was used (Figure 1). Figure 3 shows an image from a proximity simulation. It was determined after several simulations using three different densities of mesh (250,000, 1,000,000 and 2,000,000 elements) that the results reached convergence when at least 1,000,000 elements were used. Furthermore the agreement between the physical model bergy bit sway results and that of the numerical sway values agreed quite well. Figure 4 shows results for one scenario. The chart show the convergence of the results for 1 and 2 million elements and also the comparison of the sway values from the physical and simulated data sets.

While a full set of validation simulations remains to be performed, the results of the first few were encouraging enough to attempt a simulation of full-scale impacts between a bergy bit and the CCGS Terry Fox icebreaker. Data from the field study conducted in 2001 (Gagnon et al., 2002) were used for comparison. During the field study rough ideas of the underwater shapes were obtained for some bergy bits using sonar, including the bergy bit modeled here. The underwater shape was quite complicated, however, so for simplicity during these first impact simulations a brick-shaped bergy bit with rounded edges was used. The mass of the bergy bit is considered to be accurate. The bergy bit corresponded to bergy bit number 14 in the field study, on which several impacts were conducted. A photo of bergy bit 14 is given in Figure 5.

Figure 1 shows the meshed model for the full-scale collision simulations. Only the front portion of the CCGS Terry Fox vessel was used in the simulation model. This facilitated a suitable distance for the vessel to travel in order to develop a bow wave before the collision while avoiding an overly long volume of water that would necessarily slow down the simulation because of the extra elements. The simulations presently take at least 30 hours to run.

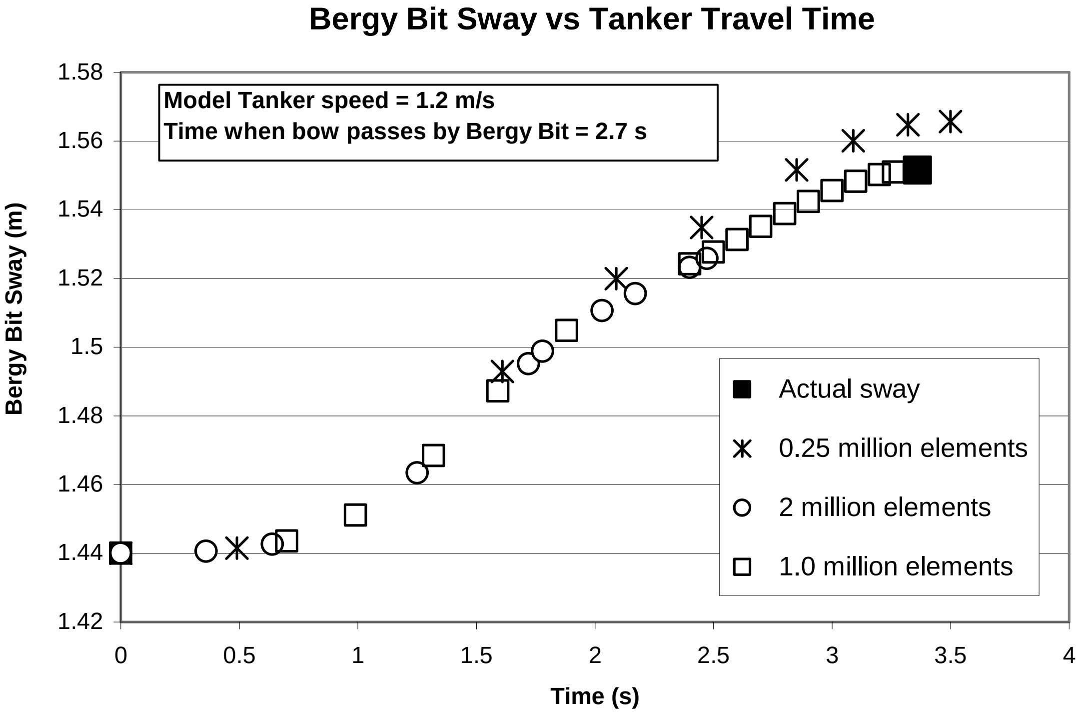

Figure 4. Comparison of actual and simulated data from tanker / bergy bit proximity tests.

To insure that the water and the objects in it behaved correctly during simulations gravity must be applied to the mesh elements. This was done by applying an acceleration equivalent to the acceleration due to gravity to all elements in the meshed model. This results in the proper hydrostatic pressure gradient developing in the water early in the simulation. This creates the proper buoyant forces on the vessel and bergy bit and enables the formation of waves on the free surface of the water.

In LS-Dyna two objects, and materials, can overlap each other within some volume of the mesh and introduce errors in the simulation. Hence it is necessary to ensure that when the bergy bit model and the ship model are inserted in the LS-Dyna k-file that the water is removed from the volume that is to be occupied by the object. This is

Figure 5. Photo of bergy bit number 14 taken from the upper superstructure of the CCGS Terry Fox.

easily done for shell objects within LS-Dyna, whereby the command "initial-volume–fraction" can be used. For non-shell objects only standard shapes such as spheres, cylinders, bricks, etc. can be easily emptied of water before an object is inserted. In the case of the bergy bit mesh model used here the shape is a brick with rounded edges. Hence, a standard brick shape with squared edges of water was removed to accommodate the bergy bit. This initially left gaps in the regions where the bergy bit had rounded edges, but these gaps filled in with water fairly quickly at the beginning of the simulation.

LS-Dyna contains a large suite of material types that can be applied to objects within the simulation. For the present simulation the vessel was treated as a rigid body. Similar results would have been obtained if the vessel shell elements were given elastic properties similar to steel, however the simulation runs faster in the latter case. In the case of the bergy bit, an appropriate material model must be chosen. The appropriateness depends on one having a realistic conception for the actual behavior of ice during crushing and impact. Through several studies it has consistently been shown that during impacts and crushing the region of contact in ice consists of a relatively small intact high-pressure zone that is surrounded by a low-pressure zone of relatively low pressure. During indentation the indentor appears to penetrate the ice by seemingly maintaining contact with the hard zone and soft zone as would be the case if one were to penetrate the ice by melting it. Indeed several studies have shown that melting plays a significant role in removing ice from the high-pressure zones during impact and indentation (Gagnon, 1999). The layer of melt is very thin and therefore impractical to include in a meshed simulation but there is a means of obtaining essentially the same behavior by using a hard "crushable foam" material type from LS-Dyna's suite of material types.

The behavior of the crushable foam material is governed by a material behavior curve that the user has to supply. The curve used here is described by a certain shape on a stress-strain chart (Figure 6). Hence, when the bergy bit is impacted by the ship, all the brick elements behave according to this model. The curve shown in Figure 6 indicates that when the pressure attains 0.1 MPa the impacted elements are capable of exhibiting constant non-recoverable deformation up to a fractional volumetric strain of 0.065, after which pressure will rise at a steep fixed rate with further deformation. The deformation-stress curve in this region is similar to the actual elastic modulus for ice. The deformation is mostly non-recoverable when load is removed, hence the designation

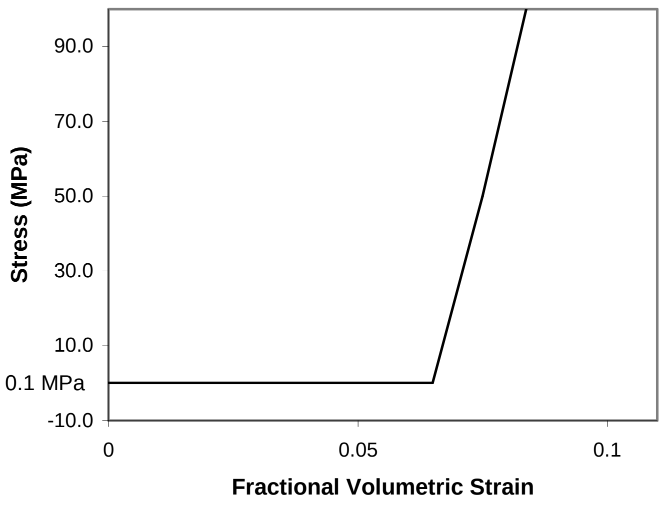

Figure 6. Curve defining the stress and volumetric strain material property behavior assigned to the bergy bit.

‘crushable foam’. The other aspect of the material properties chosen for the ice in the impact zone is a low value of Poisson’s ratio (0.003), to insure a flattening of the ice at the contact zone that is more reminiscent of melting rather than a flattening that induces bulging of surrounding material such as occurs in an elastic deformation scenario with a normal Poisson’s ratio. The curve furthermore ensures that a relatively small region in the center of contact experiences high pressure (a hard zone) and the surrounding contact material exerts a somewhat lower pressure (soft zone). These features of ice have been observed in various studies, some mentioned above.

The particular simulation reported here corresponds to the vessel traveling at 5 m/s with its bow starting at a distance of 35 m back from the bergy bit to allow some time for waves to develop. This also gave sufficient time for the water to fill in completely around the bergy bit, as discussed above. The impact occurs on the port side of the vessel in approximately the same region where the hull was instrumented during the full-scale bergy bit impact tests. Figure 7 shows a sequence of images from the simulation. For this simulation the ship movement was confined to a straight line, however, the ship could roll in response to the impact. The issue of ship movement constraint during the impact is not considered to be so important since the initial impact lasts for less than 1 s during which time the vessel experiences little deflection during the actual tests. In the simulation secondary impacts occurred along the length of the bergy bit as it rotated in response to the initial impact, similar to what was observed in the field study.

We can compare the field results for an impact on bergy bit 14 with the same test parameters as the simulation. Figure 8 (top) shows the load record for the simulated impact. An initial peak is shown that reaches a maximum load of around 6 MN. The initial peak duration is about 0.6s. These results compare reasonably well with the field results, where the two highest peak loads were around 5 and 2.5 MN for respective ship speeds of 3.2 and 6.2 m/s (Gagnon et al., 2002), roughly implying a value of 3.5 MN for a ship speed of 5 m/s and impact duration of about 0.5 s. We may also look at the distribution of load on the hull during the impact, since the field instruments yielded pressure data besides load data. Figure 9 shows the impacted corner of the bergy bit, and the pressure distribution within the region. We can see a small region in the center of the impacted zone where the pressure is high (5-8 MPa, Figure 8 (bottom)) surrounded by a larger region where the pressure is relatively low (~2 MPa). We note that the individual

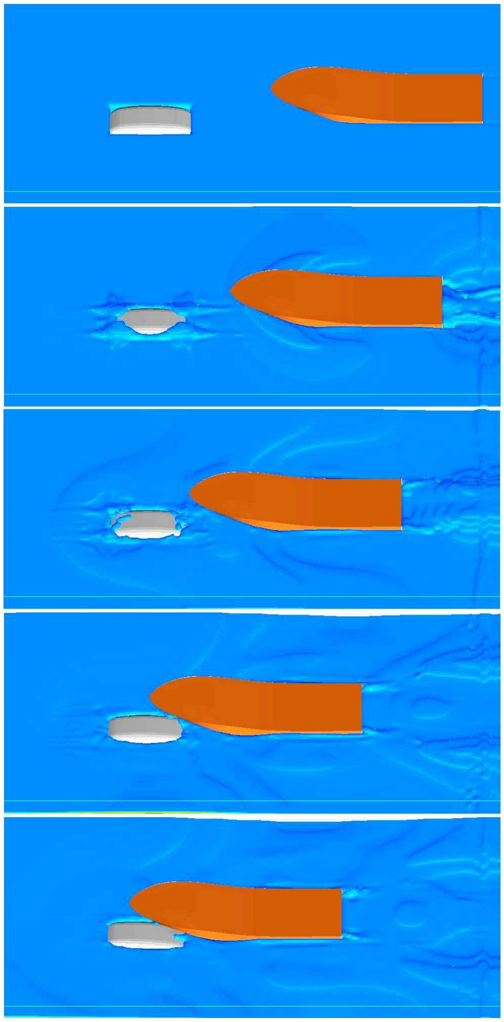

Figure 7. Simulation images from a full-scale bergy bit impact. Respective image times from top to bottom are 0s, 2s, 4s, 6s and 7s, where the peak impact load occurs in the last image. The CCGS Terry Fox was traveling at 5 m/s. The bergy bit mass was 1911 t.

mesh element size in the simulation corresponds to an area larger than the largest sub-panel of the instrumented hull. But we may compare the average pressure on an equivalent sized sub-panel where the data are analyzed after Browne and Ritch in Vol. 4 of the report of Gagnon et al. (2002). If we take the pressure for an area equal in size to the element area we get a pressure of about 7 MPa, in good agreement with the simulation. Similarly the low-pressure material experiences pressure of roughly 2 MPa in both the field data and simulation results. Figure 10 shows a sectional view of the deformation at the impacted corner of the bergy bit that is reminiscent of actual ice behavior during impacts where the flattening appears as if done by melting, leaving hard zones fairly intact.

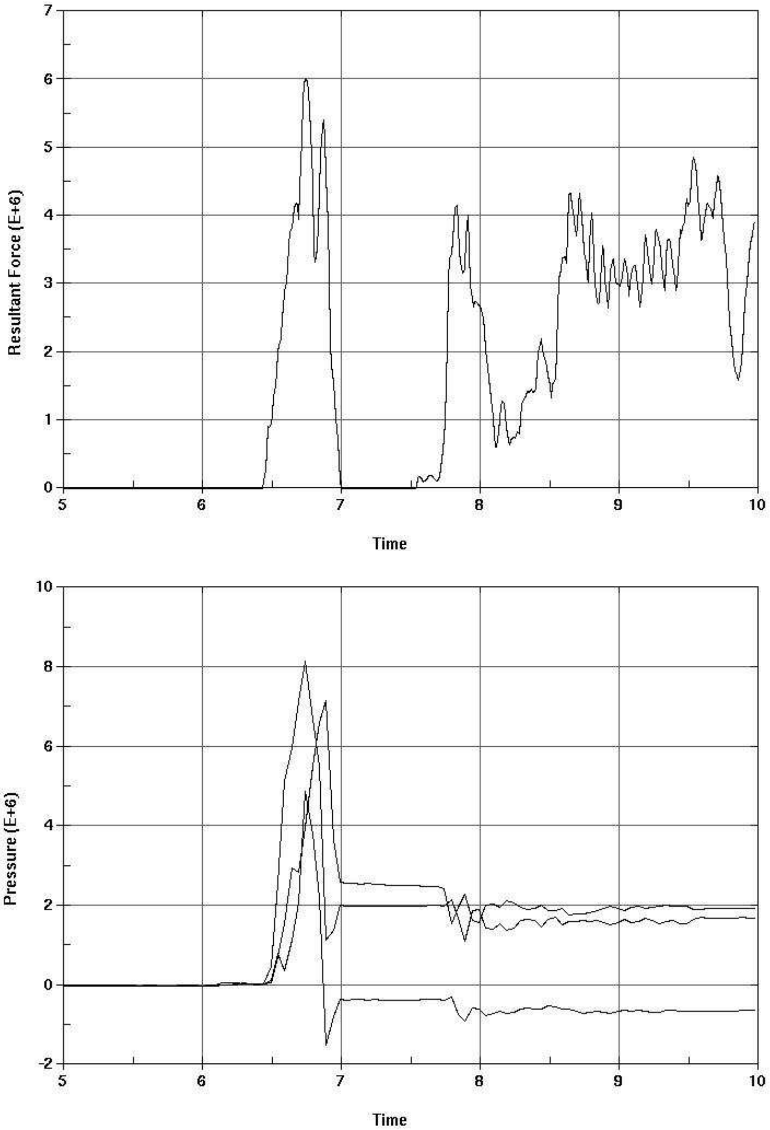

Figure 8. Load (top) and pressure (bottom) data for the simulation shown in Figure 7. The primary impact corresponds to the first load peak centered at 6.8 s, where secondary hits and bumping occur at around 7.6 s and later. The bottom chart shows pressure for three central mesh elements in the impact zone.

CONCLUSIONS

The first numerical simulations of a ship colliding with bergy bits have yielded reasonable results. The ice material behavior incorporated into the simulations provided an analog for observed ice behavior in lab and field experiments. The simulation data roughly approximate the field peak load, impact duration and pressure distribution.

ACKNOWLEDGEMENTS

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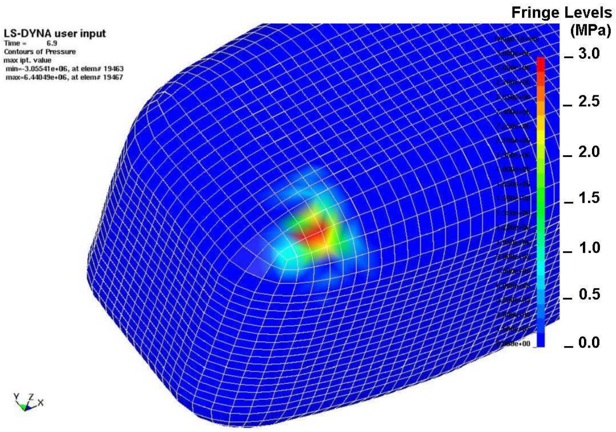

Figure 9. Impacted corner of the bergy bit at time of peak load. Pressure on the few central elements is around 5-8 MPa (Figure 8, bottom).

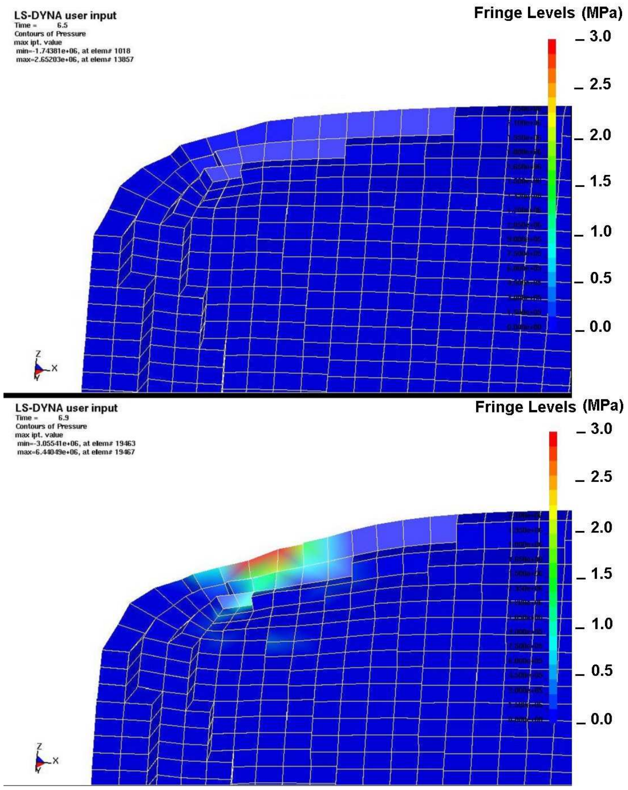

Figure 10. Section showing flattening at the impacted corner of the bergy bit at time of peak load (bottom) and associated pressure. The top image shows the undeformed corner just prior to impact.