

## Preview of LS-OPT<sup>®</sup>/Topology Version 2

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### Summary:

This paper gives a preview of of LS-OPT/Topology version 2, a topology optimization tool. The focus is on its capabilities, current development directions, and integration into an industrial design environment. Examples of using the new developments such as global constraints, prescribed geometric properties, and shells are given.

### Keywords:

Topology optimization.

## 1 Overview

The goal of topology optimization is to find the shape of a structure with the maximum utility of the material. For dynamic problems like crashworthiness simulations, this is achieved by designing for a uniform internal energy density in the structure while keeping the mass constrained.

The overall LS-OPT/Topology [1] process consists of (i) the design problem definition, (ii) performing the design optimization iteratively using LS-DYNA® [2], and (iii) post-processing the results.

The topology design problem is defined by (i) the allowable geometric domain, (ii) how the part will be used, and (iii) properties of the part such as manufacturing constraints. Additionally, you have to specify methodology requirements such as termination criteria and management of the LS-DYNA® evaluations. The information is grouped using the following three headings:

- *Cases* These store the load case data such as, the LS-DYNA® input deck and executable to use. The *Cases* data therefore contain the information on how to simulate the use of part.
- *Part* The rest of the problem definition data such as the part ID and extrusion definition is given here.
- *Method* These are methodology data such as the convergence criterions.

The initial parts specify the design domain – the optimum parts computed will be inside the boundaries delimited by the initial parts. The parts must be modeled using \*MAT\_PIECEWISE\_LINEAR\_PLASTICITY using solid or shell elements.

The part may contain holes; a structured mesh is accordingly not required and there is no node or element numbering convention as in other approaches. Geometry constraints such as being an extrusion or a casting direction may be specified.

The use of the part is described by LS-DYNA input deck. The design process aims for a uniform internal energy density in the structure as computed by LS-DYNA using this input deck.

The final shape of the part is described by the subset of the initial elements used. The use of an element is controlled by changing the amount of material in the element. This is achieved by assigning a design variable to the density of each element. The material is parameterized using a so-called *density approach*. In this approach, a design variable is directly linked to the individual material element such that each cell has its own material model. The design variable  $x$ , also known as relative density, varies from 0 to 1 where 0 indicates void and 1 represents the full material. The material properties corresponding to the values of design variables are obtained using an appropriate interpolation model as described in the manual [1].

## 2 Control Parameters

### 2.1 Mass Fraction

The optimal design is created by deleting a fraction of the original part. The *Mass Fraction* parameter controls the amount of mass preserved. The effect of different values of this parameter is shown in Figure 1 using the default value of the other parameters.

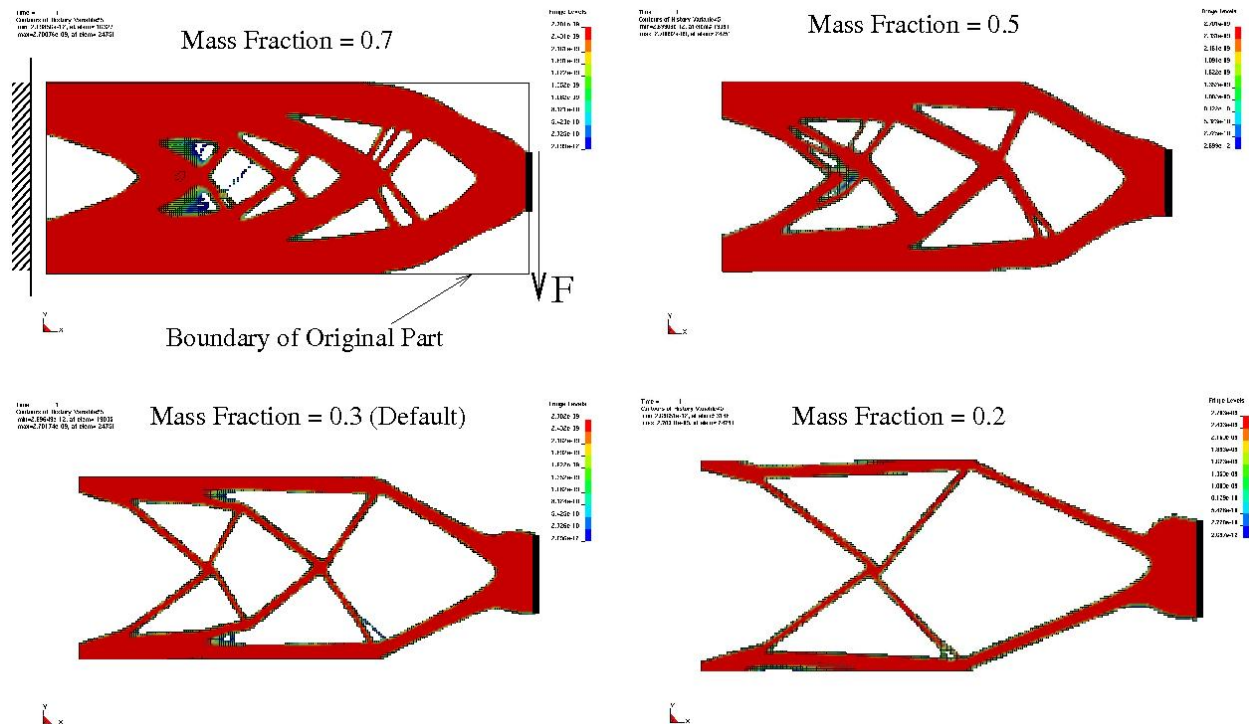


Figure 1 : The effect of the mass fraction bound. Different designs created using different mass fractions are shown. The mass fraction is the fraction of original mass that must be kept. So for a mass fraction of 0.3, the software will remove 70% of the original structure.

### 2.2 Convergence Tolerance Parameter

The analysis is terminated when the change in the *Density Redistribution* (view this history in the viewer panel) for the iteration is less than the *Convergence Tolerance*. The *Density Redistribution* can be interpreted as the portion of material move in an iteration; if the *Density Redistribution* is 1.0 (not actually possible), then all possible mass have been redistributed.

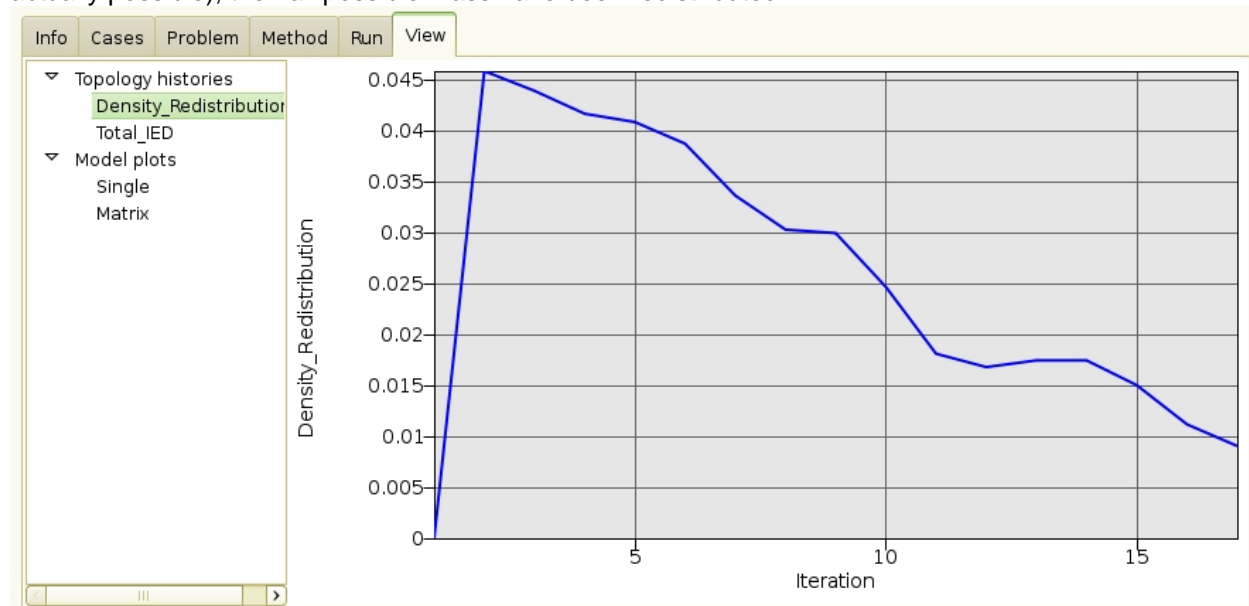


Figure 2 The *Density Redistribution* at every iteration. The optimization is terminated when this value is less than the convergence tolerance. The parameter indicates which percentage of the geometry have altered during a design iteration.

### 2.3 Proximity Tolerance Parameter

This parameter describes a distance controlling the neighborhood size of the elements. The design variable at an element is updated using the result at the element averaged together with that of its neighbors. Smaller values of this parameter yield finer-grained structures as show in Figure 3.

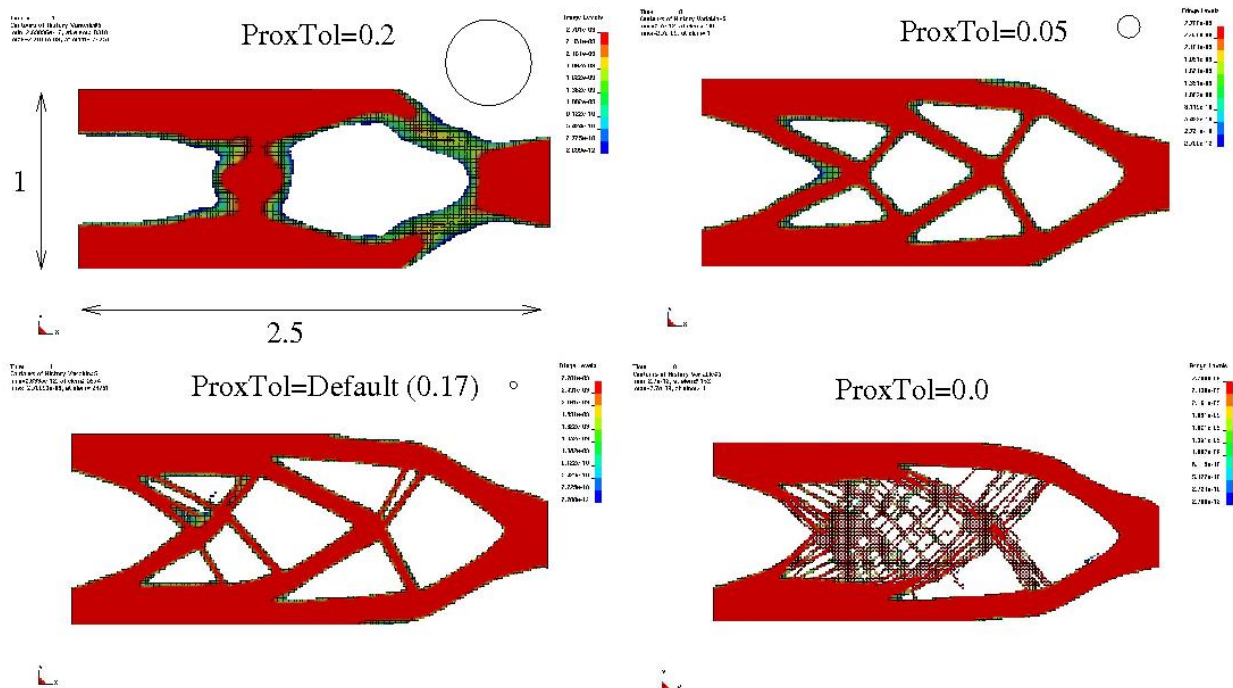


Figure 3 Effect of the proximity tolerance parameter. The mesh is 100 x 250. The small circles show the neighborhood size. A parameter value of zero results in a checkerboard pattern.

### 3 Collaboration with other CAE Companies

Beta CAE Systems S.A., the author of the ANSA preprocessor, is looking into CAE work flow procedures incorporating LS-OPT/Topology. In addition, Detroit Engineered Products, author of MeshWorks Morphier, is investigating methods of using their mesh refinement technologies. Contact these parties for more information.

### 4 New capabilities in version 2

The following new capabilities are being added to create version 2.

#### 4.1 Global constraints

The global constraints are used to constraint responses caused by the whole part, such as a displacement or reaction force. This is actually a method of computing the mass fraction, because the mass of the structure is increased or decreased until the constraints are satisfied.

#### 4.2 Shells

The thickness of shells can be redesigned to have a uniform distribution of the internal energy density. Unlike for the solids a 0/1 behavior is not enforced, and the goal is therefore not to create a new geometry, but to find a thickness distribution.

#### 4.3 Geometric constraints and multiple parts

These are constraints on the final geometry allowing practical parts, which can be manufactured, to be designed. The different types of geometry constraints are shown in Figure 4, while the GUI interface showing the definition of multiple parts and geometric constraints is shown in Figure 5.

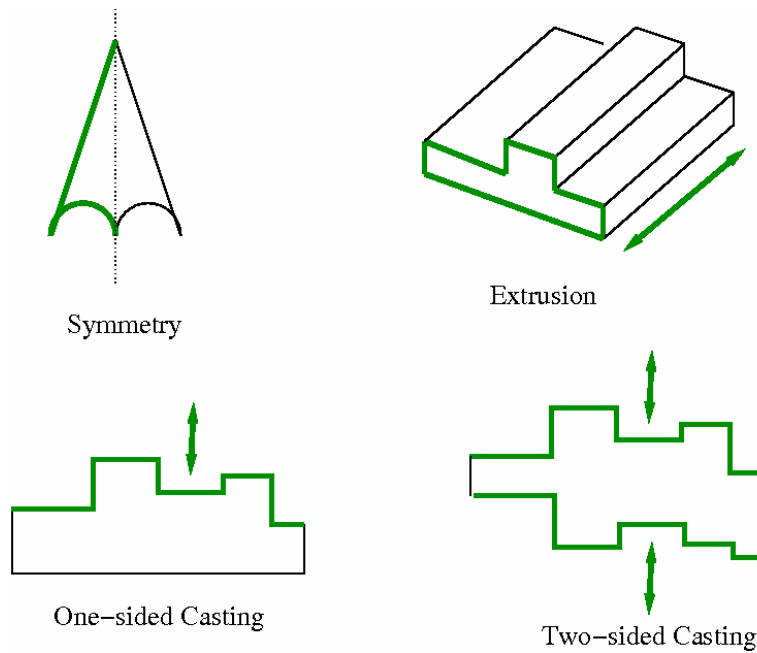


Figure 4 Geometry and manufacturing constraints

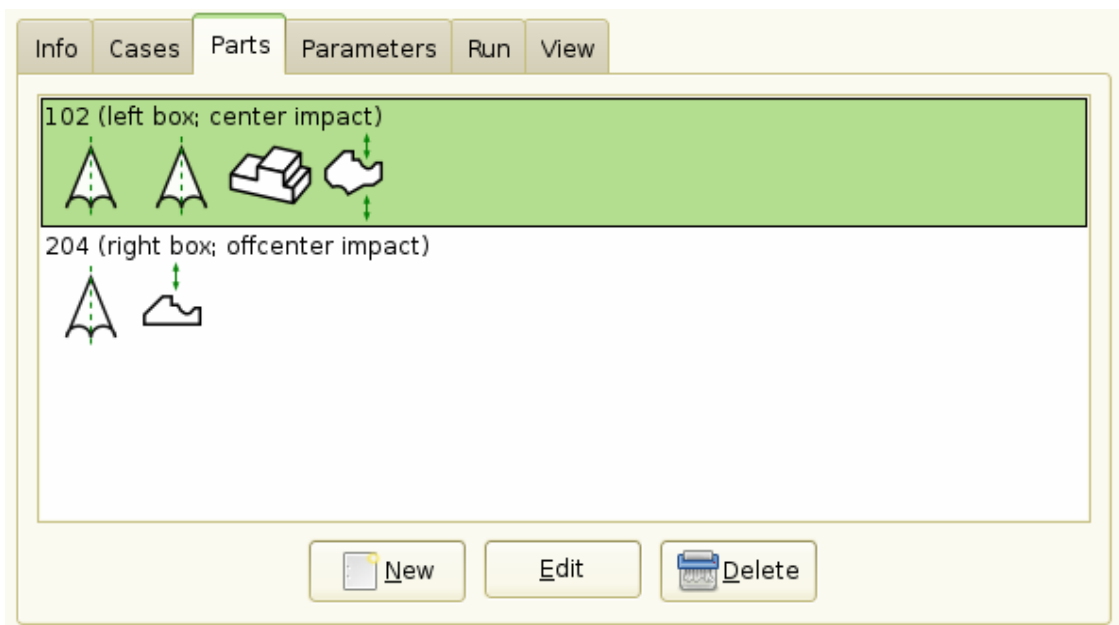


Figure 5 Different parts, each with multiple geometry constraints can be specified.

## 5 Example with new capabilities

### 5.1 Global, symmetry, and extrusion constraints

The problem as shown Figure 6 consists of a beam being subjected to two impact load cases as shown.

The problem has two symmetry constraints and an extrusion constraint. It is required to be an extrusion in the z-direction and to be symmetric about both the YZ and ZX plane as shown in the figure.

The problem also has two global constraints: for each load case it is required that the displacement is less than 100 units.

The resulting optimal design is shown in Figure 7 with the histories of the constraint values for the iterations as shown in Figure 8.

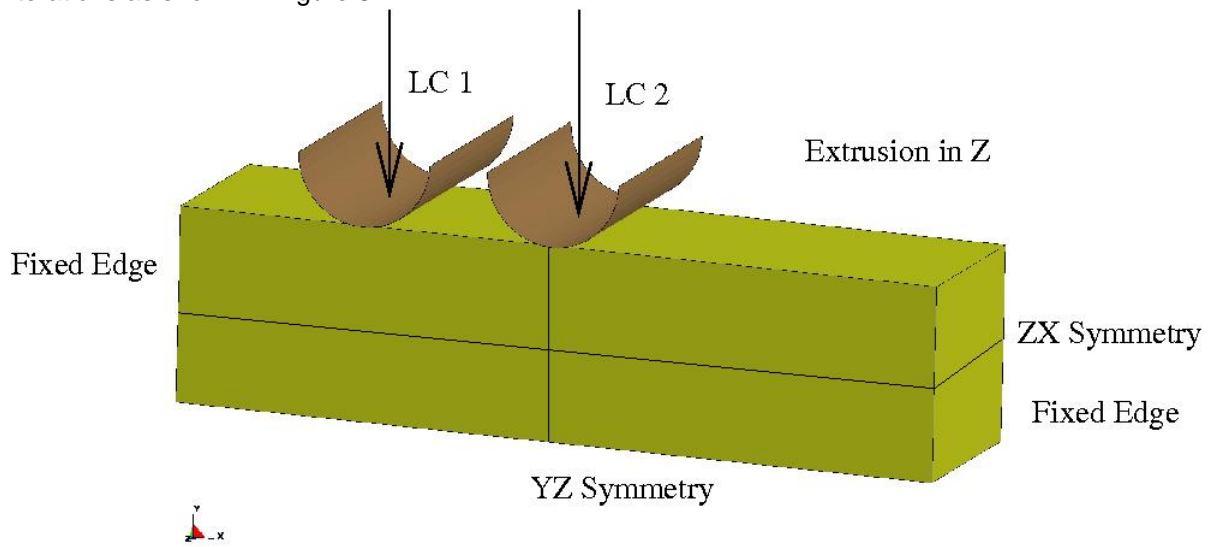


Figure 6 Design problem with two load cases and three geometric constraints

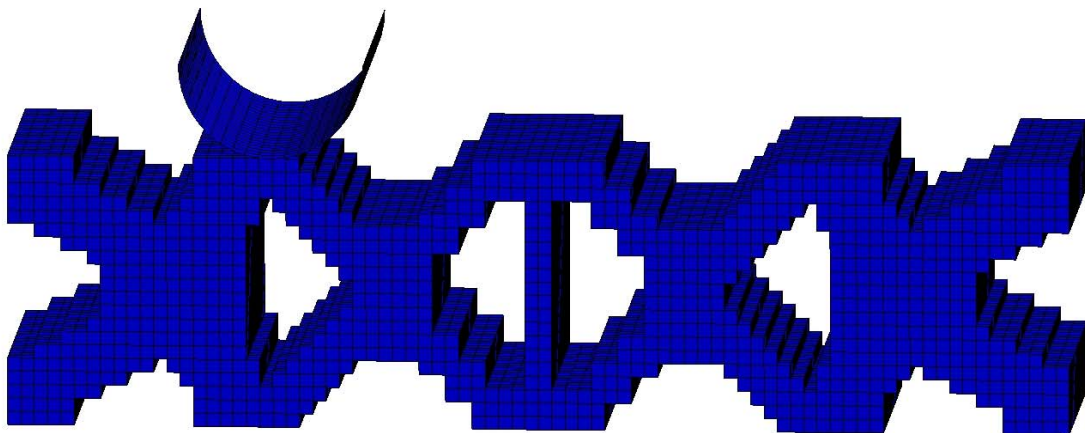


Figure 7 Optimal design

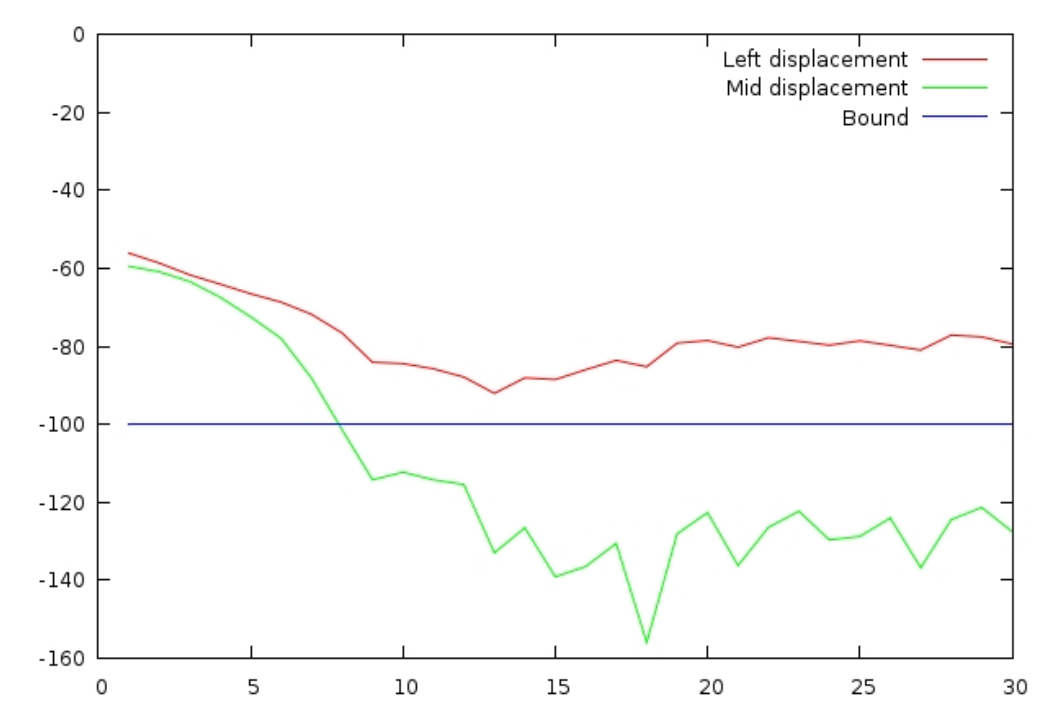


Figure 8 Constraint histories

## 5.2 Casting constraints

The problem as shown in Figure 9 has been analyzed without any geometric constraints, with a casting constraint in the negative x-direction, with a casting constraint in the positive y-direction, and with a casting constraint in the positive z-direction. It can be seen that the designs with casting constraints are easier to manufacture.

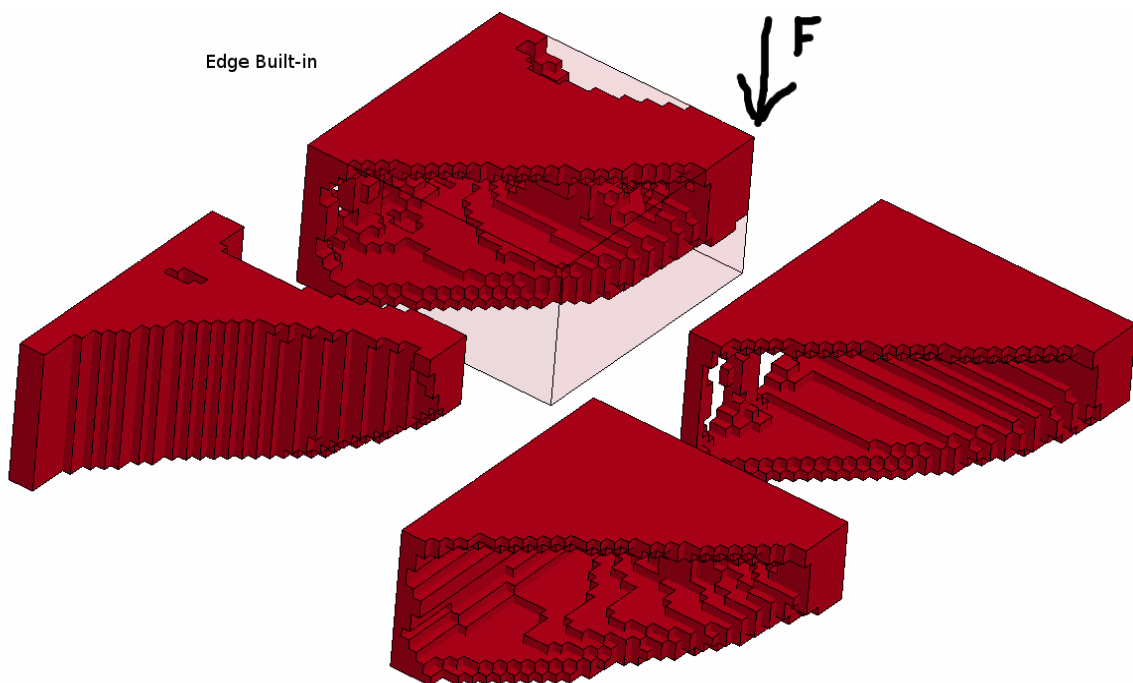


Figure 9 Problem with casting constraints

## 6 Summary

LS-OPT/Topology computes the shape of a structure with the maximum utility of the material. It has been developed for non-linear structures analyzed in an industrial environment. This tool has been extended to shells, global constraints, multiple parts, symmetry, and extrusion constraints.

## 7 References

- [1] Livermore Software Technology Corporation, LS-OPT/Topology: A Topology Optimization Tool for LS-DYNA, User's Manual, Version 1.0, Livermore Software Technology Corporation, Livermore, CA, 2009.
- [2] Hallquist JO. LS-DYNA theoretical manual, Livermore Software Technology Corporation, Livermore, CA, 1998.
- [3] Goel T, Roux WJ, and Stander N. A Topology Optimization Tool for LS-DYNA users: LS-OPT/Topology. 7th European LS-DYNA Users Conference, Salzburg Austria, 14-15 May 2009.