Topological Optimization of 3D Structures by Optimality Criteria using ANSYS

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ABSTRACT

This work provides a computational model for the topology optimization of three-dimensional (3D) linearly elastic isotropic structures. Topological optimization is the process of obtaining the best possible results among many possible results under given circumstances. The paper introduces a control-based optimization algorithm to solve topology optimization problems for structures of minimum compliance by constraining the volume. Different types of structures are taken having same material properties, element type and load applied. All the structures are topologically optimized using ANSYS software and the optimized structure with reduced compliance is obtained. Von Mises stresses and final deformed shape for all the structures taken is also obtained in the optimization process. The aim of this research work is to reduce the compliance of the structure under different loading and the boundary conditions along with obtaining the topologically optimized structure.

Keywords - Topological Optimization, ANSYS, Von Mises Stress, Compliance, Optimality Criteria.

1. INTRODUCTION

Topology optimization is a useful tool for designing that generates the optimal conceptual shape of a mechanical structure. The structural shape is generated within a predefined design domain. In addition, the user defines boundary and loading conditions. Without any further decision and guidance of the user, the method will give the structural shape thus provides a first idea of an optimum geometry. A desired property of the structure is maximized by changing the shape of the given material. Usually this maximized property is stiffness. Another usage of topology optimization is minimizing the weight, subjected to a given constraint (such as stress).

Topology optimization is used for many different engineering applications such as fluid mechanics, thermodynamic problems, acoustic problems, electro mechanics problems and solid mechanics. By using topology optimization, designers can easily solve very difficult and complex problems; hence, usage of this method is increasing day by day. The simple idea of the topology optimization is the removal of less efficient materials from a structure. To find accurate solution of topology optimization, the designer must increase the number of iteration and the numbers of elements. When the number of iteration and elements increases, solution time also increases. This is the main drawback of the method that must be overcome. For this reason, in the optimization processes, passive elements (which are found from FE analyses) are eliminated after every iteration loop. In the subsequent iteration loop, unnecessary elements are not used during solution. Hence, at each progressive solution loop, the number of elements decreases.

Topologically structural optimization is regarded as one of the most challenging topics in structural mechanics, in which one needs to change the topology as well as the shape during the process of optimization. More accurate results are obtained by fine meshing the structures but by meshing fine the processing time increases. This significantly increases the complexity of the optimization problems. With the development of highspeed computer, the topology optimization method using numerical approach has been growing quickly.

The present work is to study topology optimization of continuum structures with the help of Optimality criteria method using ANSYS also ANSYS use SIMP method for penalization of intermediate densities. The SIMP method, in which material properties can be expressed in terms of the design variable material density using a simple "power-law" interpolation as an explicit means to suppress intermediate values of the bulk density. This has been generally accepted in topology optimization because of its computational efficiency.

However, like most of the other topology optimization methods, the SIMP method does not directly resolve the problem of non-existence of solution. In this work we will be using commercially available ANSYS 12.0 software for topology optimization.

2. PROCEDURE OF TOPOLOGICAL OPTIMIZATION

Every structure/model that is intended to be optimized in the sense of topology optimization needs a set of imposed boundary conditions (BC) and loads. The optimization then leads to an improved model with respect to the boundary conditions and loads before. The optimization itself is an iterative procedure where the bodies' geometrical structure is changed until a user defined objective is met.

The goal of topological optimization is to find the best use of material for a body such that an objective criterion (i.e. global stiffness, natural frequency etc.) attains a maximum or minimum value subject to given constraints (i.e. volume reduction).

In this work, maximization of static stiffness has been considered. This can also be stated as the problem of minimization of compliance of the structure. Compliance is a form of work done on the structure by the applied load. Lesser compliance means lesser work is done by the load on the structure, which results in lesser energy is stored in the structure which in turn, means that the structure is stiffer.

Mathematically,

Compliance = $\int_v f*u\, dV + \int_s t*u\, dS + \Sigma i^n *F_i*u_i$ ……(1)

Where,

u = Displacement field

f = Distributed body force (gravity load etc.)

F_i = Point load on ith node

u_i = ith displacement degree of freedom

t = Traction force

S = Surface area of the continuum

V = Volume of the continuum

3. STRUCTURES AND BOUNDARY CONDITIONS

Three structures are taken having same material properties but different boundary conditions. Solid 20node 95 element is taken for all the structures which is linear elastic and isotropic material having Young's modulus E = 1.0 and Poisson's ratio of 0.3. The load applied to all the structures is unit loading. Volume reduction for all the structures is 75%.

3.1 Structure 1: Simply supported structure with unit load.

A simply supported solid block of dimensions 50X25X50 is taken. The load is of one unit magnitude is applied at the centre of the lower surface and the four bottom corners are fixed. Figure below shows the structure and the loading condition.

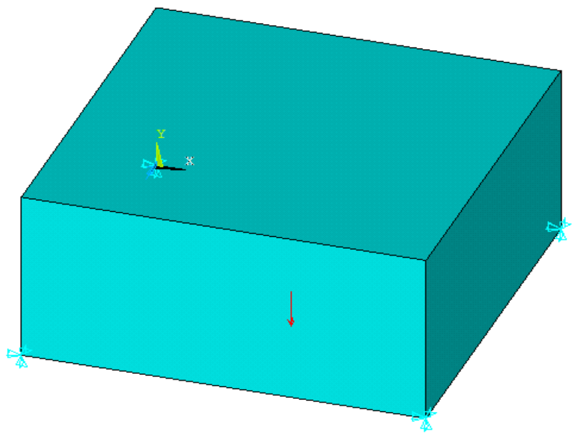

Fig-1: Structure with unit load at the bottom end

After topologically optimizing the structure in 24 iterations the optimized shape that is obtained is shown in the figure below.

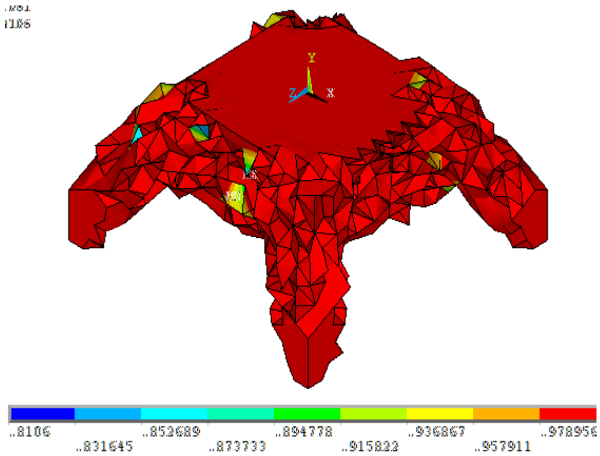

Fig-2: Optimized structure

Compliance as observed in 24 iterations decreases from 9.9179 to 1.547. Graphical representation of variation in compliance with iteration is shown in the figure below.

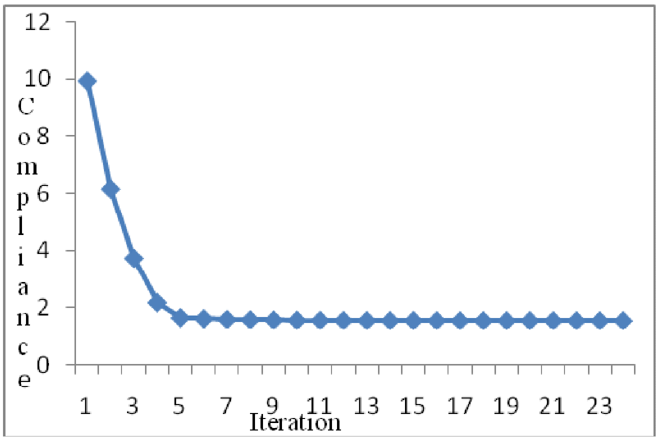

Fig-3: Variation of compliance with iteration

Von Mises stress in the structure is shown in the figure below. Maximum stress is observed at the point of loading. Bottom view of the structure is shown.

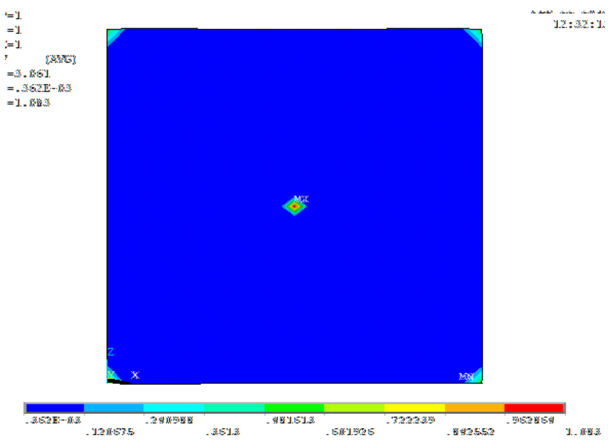

Fig-4: Variation in the von Mises stress.

The deformed and the initial structure as observed after the loading is shown. Blue portion shows the deformed final structure after the loading, while the line above the blue portion shows the initial structure position.

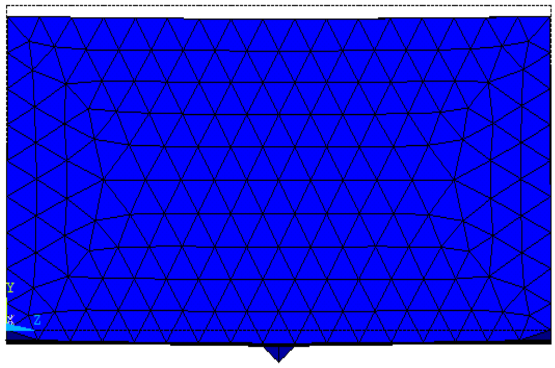

Fig-5: Deformed structure.

3.2. Structure 2: L shape structure

L shape structure is taken with the dimensions of 60X20X20. The upper surface is fixed and the load of unit magnitude is applied at centre of the right face as shown in the figure below.

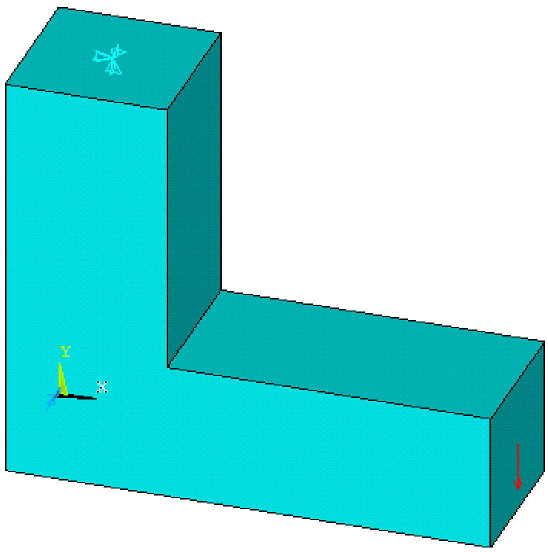

Fig-6: L shape structure with loading

Topologically optimized structure with reduction of 75% in volume after 43 iterations is shown below.

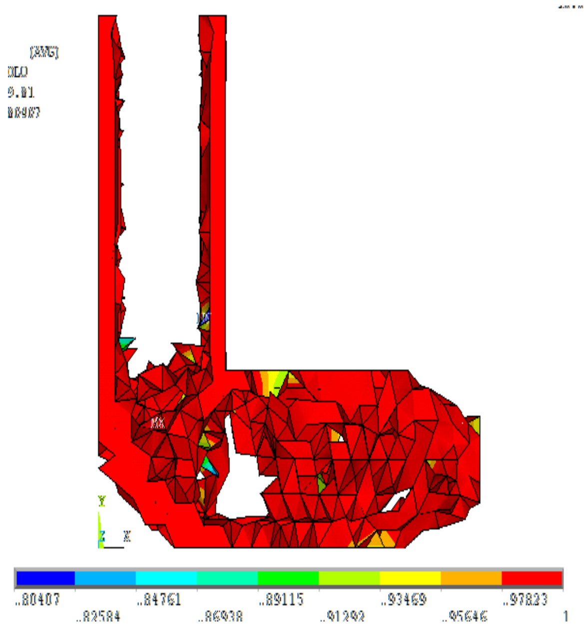

Fig-7: Optimal shape

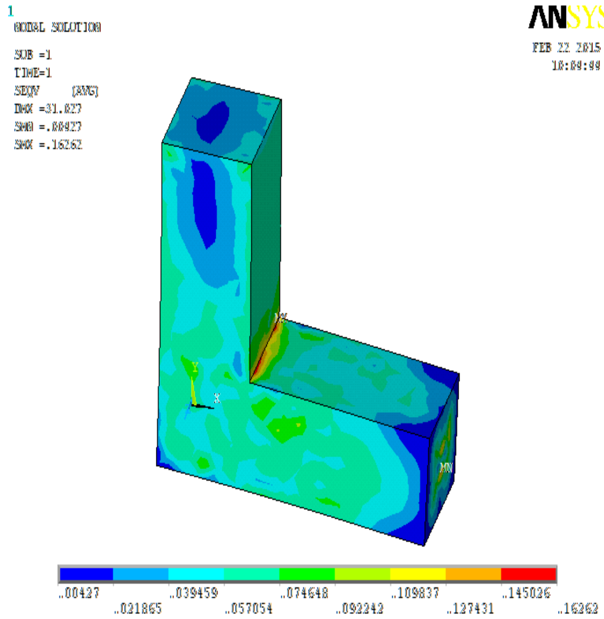

Fig-9: Von Mises stresses

Variation in compliance in 43 iterations from 69.1203 to 26.3475 is represented in the graphical form.

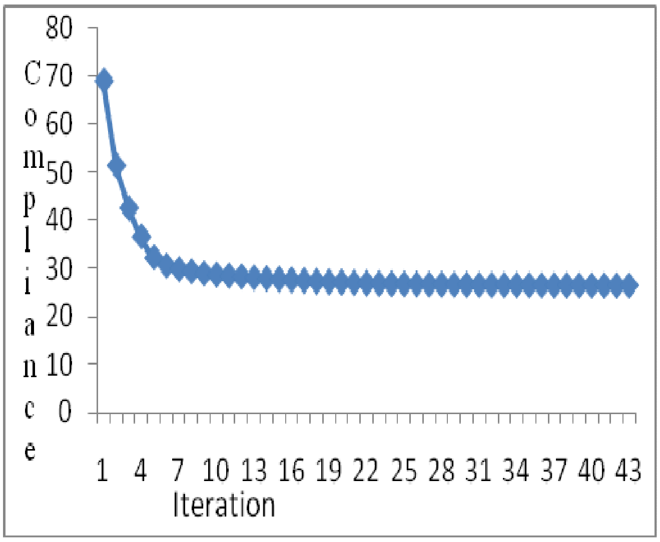

Fig-8: Variation in compliance along with iteration

Von Mises stress variation in the structure with the given boundary and loading condition is shown in the figure. Red portion represents the region of maximum stress.

Deformed observed in the structure with a given conditions is dhown in the figure below. Blue colour represents the deforned structure and dotted black line represents the initial sructure.

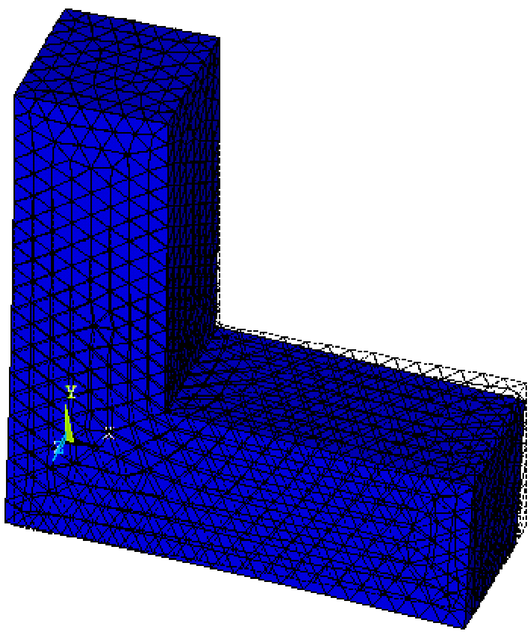

Fig-10: Deformed Structure

3.3. Structure 3: Cantilever beam with shear loading

Cantilever beam with dimensions 100X20X40 is taken. One end is fixed and the shear load is applied at the other end. The figure with applied load is shown in the figure.

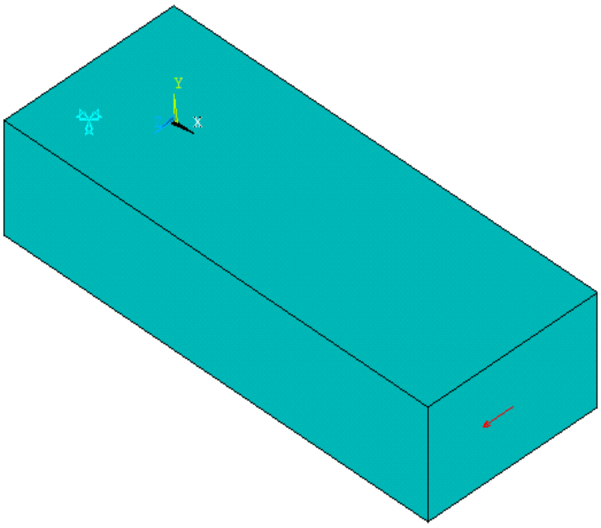

Fig-11: Structure

Topologically optimized structure obtained after 52 iterations with a reduction in compliance value from 22.655 to 8.9318 is shown in the figure.

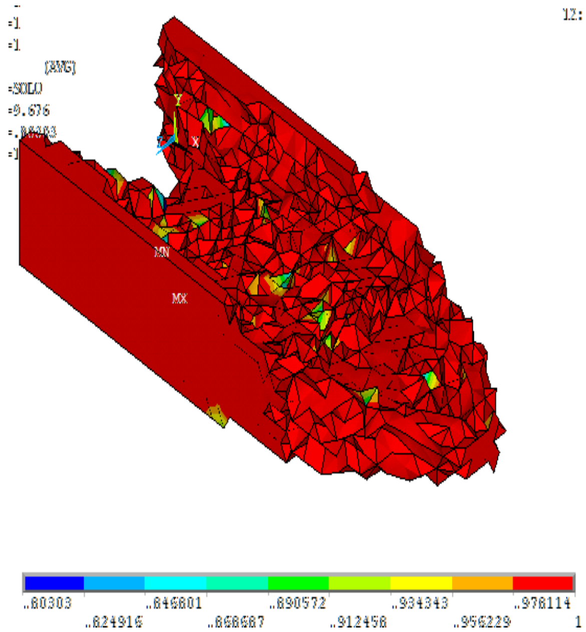

Fig-12: Optimal structure

Variation in compliance as observed in the iteration process is shown in the graph below.

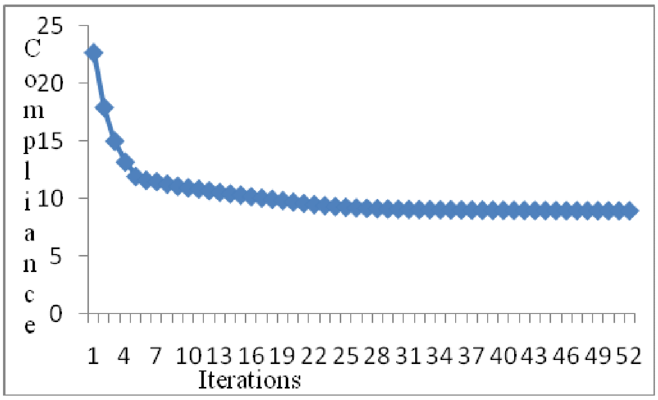

Fig-13: Compliance variation with iteration.

Variation in Von Mises stress distribution in the given loading condition for a cantilever structure is shown in the figure below.

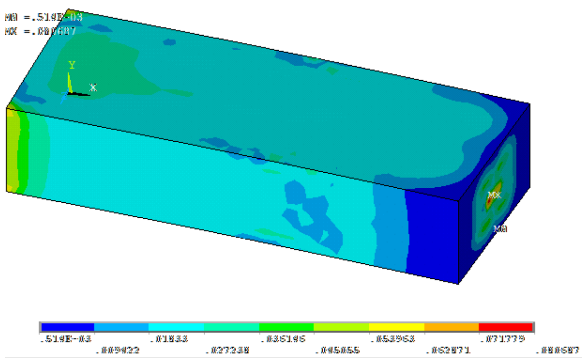

Fig-14: Von Mises distribution

Deformed shape as observed in a given loading condition is shown in the figure below. Blue color represents the deformed shape while the black dotted line represents the initial structure.

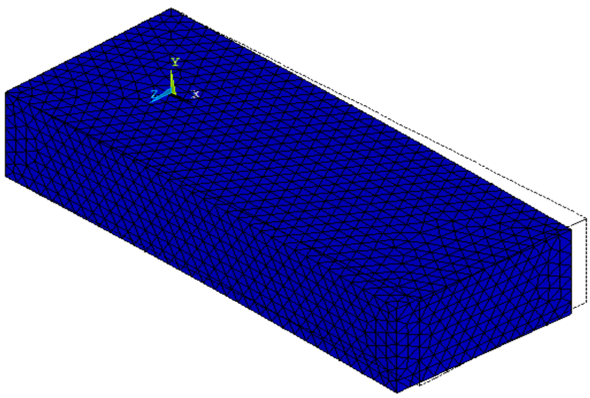

Fig-15: Deformed structure

4. RESULT

In this section the topologically optimized structure and the change in compliance is studied. The optimal structures obtained by iteration are already shown above along with the compliance. Compliance is reduced in all the structures which are our objective and the volume was constrained to the reduction of 75% of the initial value. Thus we have optimized the structures and reduced the value of compliance. In all the structures the compliance is reduced by more than 60%.

1. The first structure which was a simply supported beam the compliance was reduced from 9.918 to 1.547.Thus reducing compliance by 84.40%.
2. In the second structure that was a L Shape structure compliance was reduced from 69.12 to 26.34. A reduction of 61.2%.
3. In the last structure that is a cantilever beam with a shear loading the compliance is reduced from 22.655 to 8.931.Reducing compliance by 60.57%.

Von Mises stress variation in the structures with the given boundary and the loading conditions is shown above. The deformation observed in all the structures was also shown.

5. CONCLUSION

In this paper, a computational model for a topology optimization method for three-dimensional linear elastic isotropic with constraining of volume was presented. The main aim was to perform topology optimization of the 3D structures was to determine optimum size of the structure under various loading conditions. The topologies obtained, satisfying the compliance domain and volume constraints, allow us for a better identification of the final three-dimensional structure. The results are based on Optimality Criterion were obtained using ANSYS. In an attempt to aid the designer with the conceptual design stage, this research work uses a commercially available finite element solver ANSYS 12.0 for the form finding of some commonly used structure in the engineering fields. This paper emphasizes that topology optimization is a very important and the relatively toughest part of the design optimization studies. Therefore, there appears the need of studying topology optimization separately.

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