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TOPOLOGY OPTIMIZATION OF TRUSS

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ABSTRACT

The cost of steel structure depends upon the weight of the structure corresponding to material distribution in the members of the structure. The main aim of the study is to provide structural stability of the structure with cost consideration taken into account. The optimised design of a structure is always becomes a challenging topic for the structural designers. In this Study, the aim is on obtaining topological optimised steel truss structure without deviating from engineering specifications & restrictions. An efficient computer tool or software is preferred for linear static analysis of the structure such as HyperWorks. This increases the optimization speed & decreases the solution time needed for analysis & optimization It is well known for dealing the global optimization problems.The work is carried out by making nodal displacement, stress as constrains. The study is done with purpose of minimization of mass of the structure. The present study concerns over linear static analysis & topology optimisation of a skeletal structure (truss) having non linear problems or two noded line elements

1. INTRODUCTION

Structural optimization has become a valuable tool of research for designers and engineers in past years. Although the process of optimization has been applied for years, optimization in field of engineering has not been a commonly used design tool, until high performance computing systems were made generally available. As industry adopts higher forms of optimization, structures are becoming lighter, stronger, and cheaper. In today’s engineering industry, this type of problem solving and product improvement is now a vital part of the design process.

Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenances of any engineering system, engineers have to take many technological and managerial decisions at several stages. Optimization can be defined as the process of finding the conditions that gives the maximum or minimum value of a function. In other words optimization is the selection of a best element from set of available alternatives which satisfied certain criteria.

Optimal design of truss-structures has always been an active area of research in the field of Search and optimization. Various techniques based on classical optimization methods have been Developed to find optimal truss-structures. Structures are becoming lighter, stronger, and cheaper as industry adopts higher forms of optimization. Optimization of truss structures can be classified into three main categories: sizing, shaping, and topology optimization.

- Topology optimization involves defining the optimal distribution of material, often from a given initial distribution, called ‘ground structure ‘in truss problems, or a bulk of material in continuum structures. Topology optimization is concerned with connectivity or the problem of to be or not to be of the elements between the nodes.
- Sizing optimization considers the cross sectional dimensions as design variables. An area of members has to be variable assuming that the connectivity and nodal coordinates of the truss are fixed. However, in truss design problems, cross sections are considered discrete variables such that member cross-sectional areas are specific predefined values.

- Shape optimization considers the geometrical variables related to the shape of the structure. The topology remains constant. Nodal coordinates mainly has to be variable.

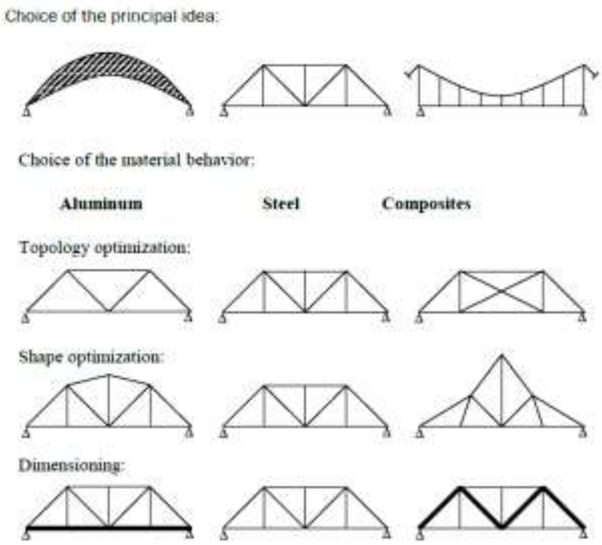


Fig 1 Classification of the Structural Optimization Process on Basis of Design Variable

Under topology optimization, the material density of each element should take a value of either 0 or 1, defining the element as being either void or solid, respectively. Optimization of a large number of discrete variables is computationally restricted. Therefore, representation of the material distribution problem in terms of continuous variables has to be used. With the density method, the material density of each element is directly used as the design variable, and varies continuously between 0 and 1; these represent the state of void and solid, respectively. Intermediate values of density represent fictitious material. The stiffness of the material is assumed to be linearly dependent on the density. Most of the work has been dedicated to the so-called maximum stiffness (or minimum compliance) formulations. However, since a few years different approaches have been proposed in terms of minimum weight with stress (and/or displacement) constraints. Hyper Works v.14 is a comprehensive simulation platform for rapid design exploration and decision-making. It consist modelling, analysis, optimization, visualization, reporting and collaborative simulation management.

2. FORMULATION

In Hyper Work CROD element of element library is used; this is 1D line element having only one degree of freedom which is displacement in axial direction. Therefore after analysis, only axial displacement and axial stresses result are shown. The Stiffness matrix of truss element comprised of material property and geometric under analysis process is given by eq (1) is. Generally geometrical property, force vector and material are comprised into stiffness matrix to search displacement vector. If displacements do not satisfy the feasible design, recursion process continues until optimization is achieved. The objective function for minimization of weight is given by Equation (2). Constrains of displacement in x-axis and y-axis are given by Equation (3) and (4) respectively .Stress constrains are displayed by (5). Stiffness matrix for static analysis of truss is

$$\begin{Bmatrix} fi \\ fj \end{Bmatrix} = \frac{AE}{L}\begin{vmatrix} 1 & -1 \\ -1 & 1 \end{vmatrix} \begin{Bmatrix} ui \\ uj \end{Bmatrix} \qquad (1)$$

Where,
f = axial force, KN;
A =Area of member, mm^2;
E =Modulus of elasticity, N/mm^2;
L =Length of member, M;

u =Nodal displacement, mm; and
i, *j* =1, 2, 3.........n, (n= no of members).
Formulation of topology optimization is base on stress and displacement approach,
Minimize weight,

$$\min (W) = \sum_{n=0}^{n} A_e L_e \rho_e \tag{2}$$

Subjected to,

$$u_k^{min} \leq u_k \leq u_k^{max} \tag{3}$$

$$v_k^{min} \leq v_k \leq v_k^{max} \tag{4}$$

$$\sigma_n^{min} \leq \sigma_n \leq \sigma_n^{max} \tag{5}$$

Where,
A_e =Area of member, mm^2;
Le =Length of member, m;
ρ_e =Material density, kg/m3;
σ = Axial stress, N/mm^2;
u =Displacement in x-axis, mm;
v =Displacement in y-axis, mm;
k =1, 2, 3......m, (m= no of nodes); and
n =0, 1, 2, 3......n, (n= no of element).
Formulation of topology optimization is based on minimize compliance and maximum volume,

$$\min_x f^T u(x) \tag{6}$$

Subjected to,

$$K(x)\, u(x) = f \tag{7}$$

$$0 \leq x \leq 1$$

Given that,

$$K(x) = \sum_i x_i K_i \tag{8}$$

Compliance minimization is given by Eq. (6), *f* is vector of applied load given by Eq. (7) and K is the element stiffness matrix associated with variable given in Eq. (8), *u*(*x*) is displacement vector.

3. NUMERICAL EXAMPLE

A 2D truss made up of 11 members is, as shown in Fig 2. Areas of all members are taken as 0.01935m2. Truss support two downward force of same magnitude given as 444.82 kN acting at node 3 and node 5. The allowable nodal displacement is 0.0502m. All members are subjected to an allowable axial stress of σ=±172.368 MPa, modulus of elasticity of material is taken as E=68.95 GPa and material density is ρ=2768 kg/m3. HyperWorks v.13 tool is use to topology optimization.

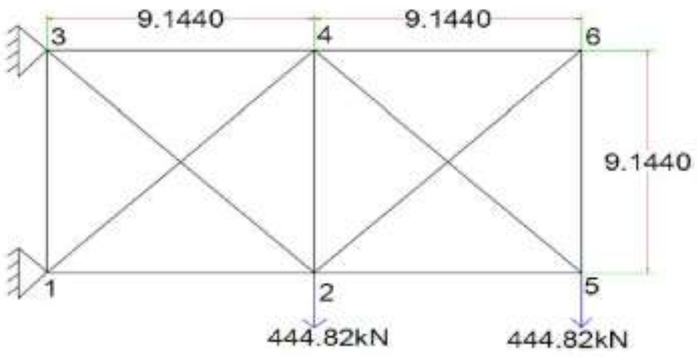


Fig-2 Benchmark Problem

Static analysis of truss gives the displacements and elongations corresponding to nodes and members respectively are shown in Fig 3. In this figure red coloured members are subjected to maximum elongation and minimum or zero elongation with dark blue coloured members. Maximum deflection of 34.23mm is figure out at end node 5.

Table 1: Displacements in Nodes of 11 Member 6 Node Benchmark Truss

Node ID	Displacement (mm)
1	00
2	16.49
3	15.38
4	00
5	34.32
6	32.93

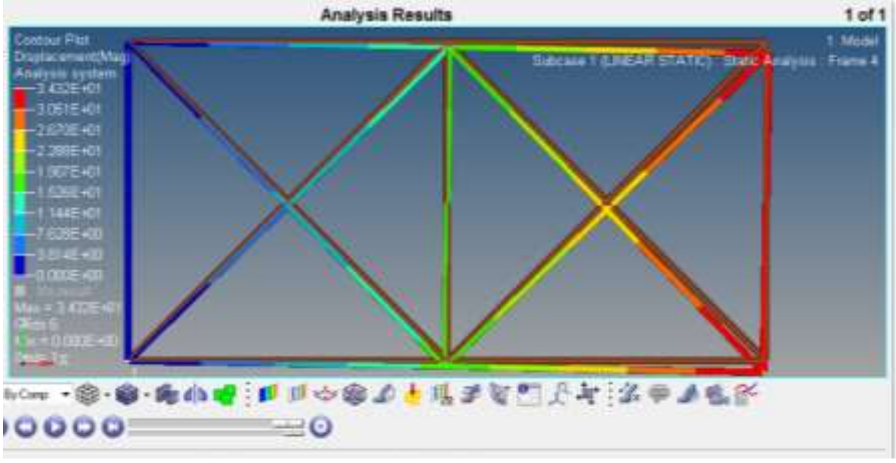


Fig- 3 Displacement after Static Analysis

Nodal ID and longitudinal stresses are shown in Table-2. The maximum compressive stress is observed in Node 4 with 26.31 MPa value. Figure 4 shows contour plot of stresses of the truss.

Table 2: Stresses in Member of 11 Member 6 Noded Benchmark Truss

Node ID	Stress (MPa)
1	-26.02
2	-6.33
3	10.15
4	26.31
5	4.975
6	1.801

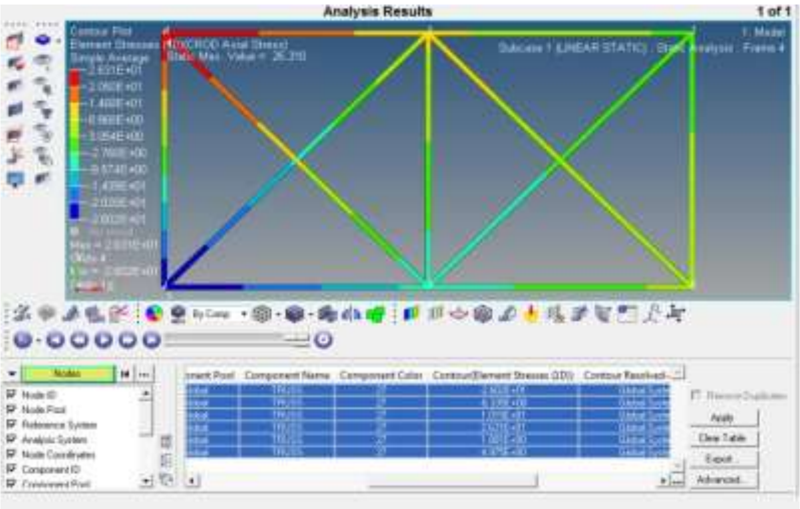


Fig-4 Contour Plot of Stresses of the Truss

New topology of truss is represented by presence or absence of any element in truss and colour changes in iteration process. If there is absence of any element in truss, constraint gives minimum weight and satisfies stable topology, it leads to new topology. The figure shows topology obtained in final iteration. Initially truss has all members in blue colour. After Iteration starts the truss starts changing its colour of the member. All member of truss are not in same colour, some elements are red and some are orange as well as yellow. This means colour represents the density of element of truss which decides its topology.

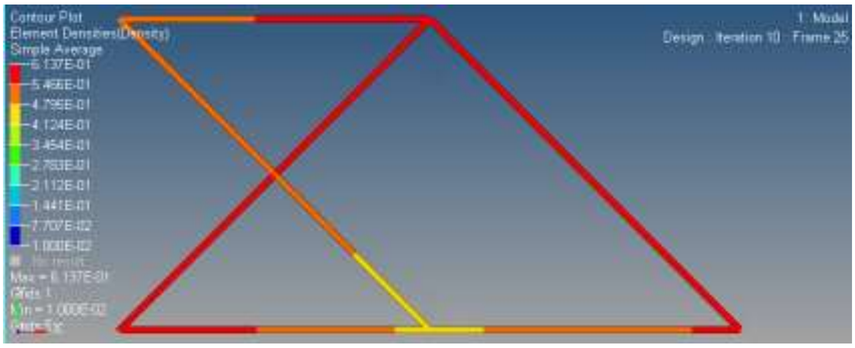
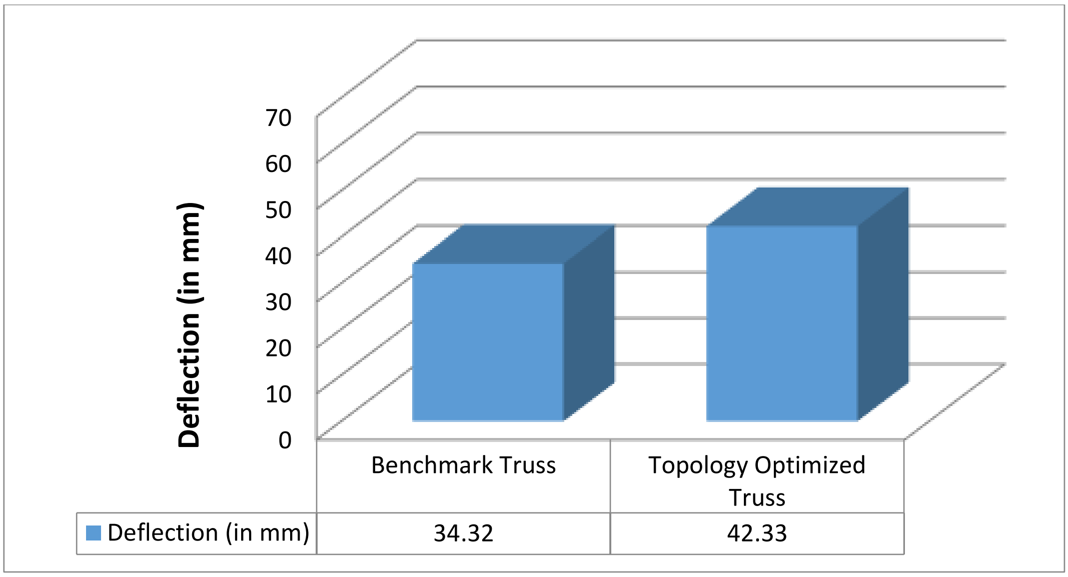
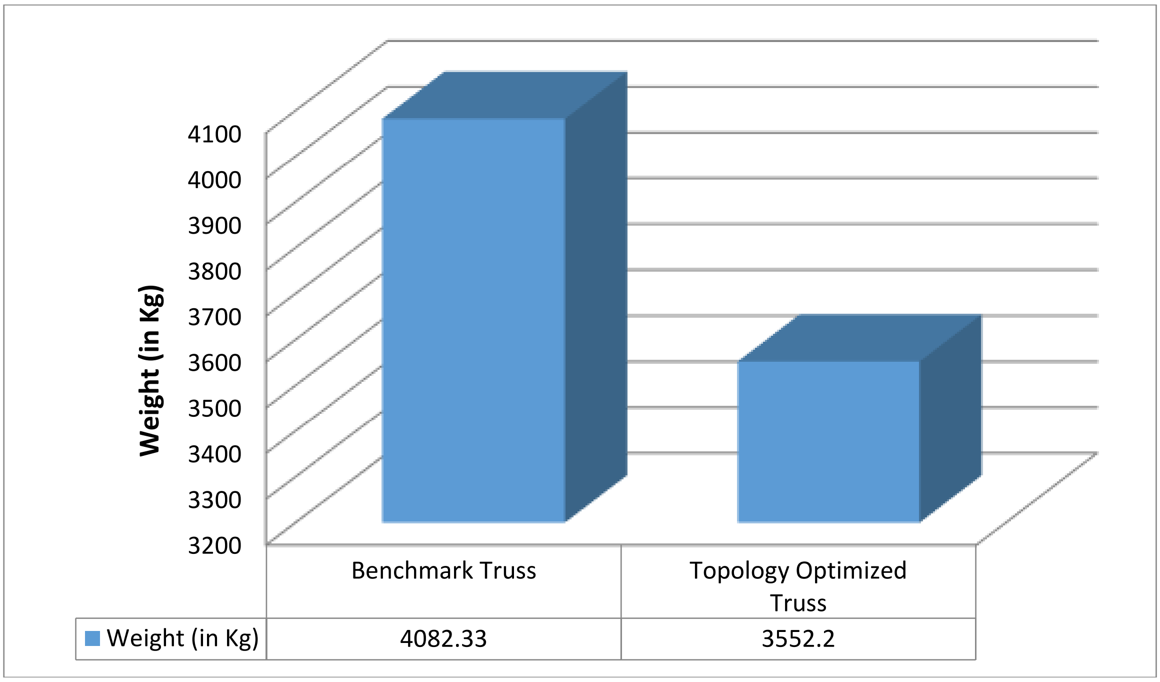


Figure 5- Result of Topology Optimization Obtained after Completion of 10th Iteration

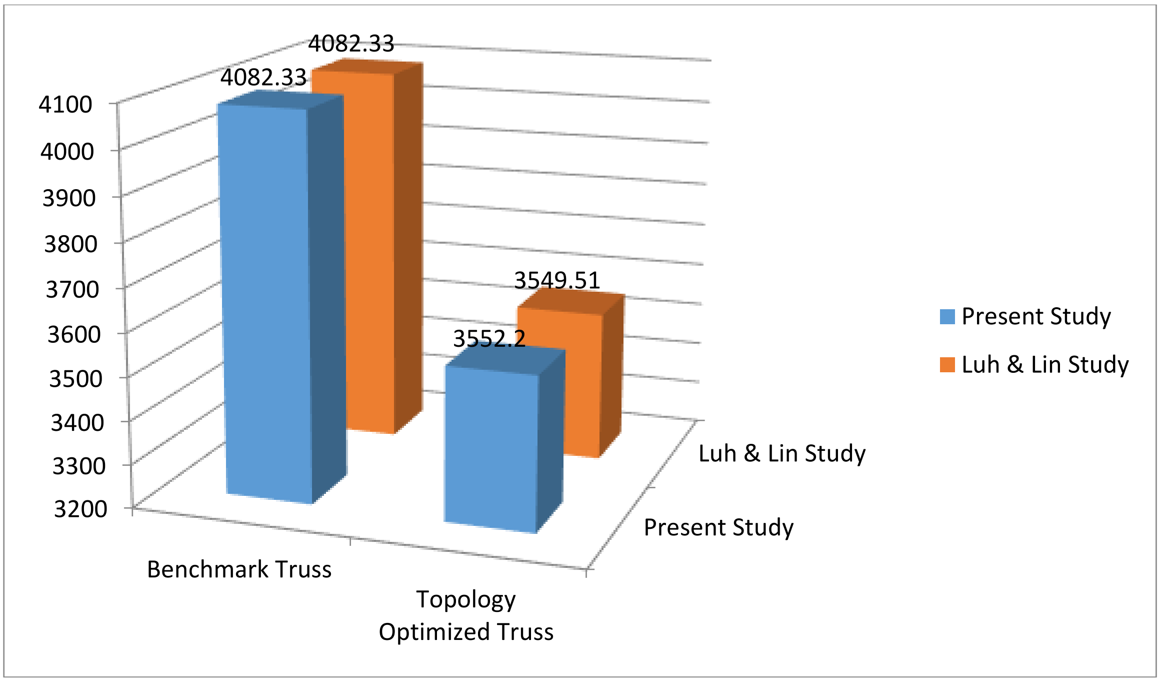


Graph 1: Comparison of Downward Deflection of Truss



Graph 2: Comparison of Weight of Truss (Kg)

Optimized weight obtained by this study and obtained by Luh and Lin is compared in Graph 3. After optimization the weight of truss get reduced by 87.02 % of its initial weight of structure.



Graph 3: Comparison of Weights (Kg)

4. CONCLUSIONS

The present study, an optimization technique for indeterminate truss has been studied using Hyper Work software. An approach is proposed based on using element densities of the member as design variable and nodal displacements and stresses are constraints. The following conclusions are made. Objective function for minimizing the weight depends upon various parameters such as element density, area, node coordinate as design variable. Number of iterations to obtain the results is less it means convergence of result is achieved in less computational time. Linear static result produce by tool is similar to the results obtained by analytical method. The present work is a good contribution to use the structures to its maximum capacity and to enhance nation economy by reduced material consumptions.

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