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Topology Optimization of Deep Beam Using Ansys

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ABSTRACT

Current demand on resources have forced engineering sector to look at more efficient design and construction methods. Every manufacturing organization is striving to focus to lower production costs and to reduce weight of component while meeting the required performance characteristics. Saving of material and energy can be achieved through optimizing the shape and topology of the structure by choosing a more efficient structural configuration. The purpose of optimization is to achieve the best design relative to a set of prioritized criteria or constraints. Beams of large depth known as deep beams are used in structures like buildings, bunkers and tanks. This paper gives the results of studies on structural optimization of deep beams. Structural optimization is implemented using ANSYS software. ANSYS is a general-purpose software that uses Finite Element Analysis (FEA) to simulate engineering problems. The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow and other attributes.

KEYWORDS: Deep beams, Structural optimization, Finite Element Analysis, ANSYS

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INTRODUCTION

Optimization of an objective function is fundamentally the maximization and minimization of a problem subjected to given constraints. Various optimization methods are sizing optimization, topology optimization and shape optimization. Structural optimization has over the past decades qualified as an important tool in the design process and is one of the most discussed topics of engineering. Structural designing methods usually depend on the formulae and result in a feasible design which may not be necessarily an optimum one. This leads to choose an optimal layout of a certain structure or a structural component from the available domain of solutions which represent a physical model of the actual problem. Therefore, optimized designs produce highly efficient and reliable results. Finite element method along with optimization algorithm is used to analyze the effective cross-sectional geometrical parameters and state variables such as total equivalent stress on the beam weight.

Shutian Liu, et al, 2007,[7] studied a section topology optimization technique based on an anisotropic beam theory considering warping of sections and coupling among deformations. Several kinds of topologies of the cross-section under different load conditions were given, and the effect of load condition on the optimum topology was analyzed. Kishan Anand et. al, 2015,[3] provided data on structural optimization of orthotropic structures using ANSYS. The optimality criterion was taken as the maximization of static stiffness. The comparison between the results of optimal topologies obtained for isotropic material and orthotropic material in ANSYS was studied and it was found that the optimized shape for the orthotropic material properties are nearly same as that of structures for isotropic material properties for same boundary and loading conditions. James et al, 2015[10], focused on the application of structural topology optimization technique to design steel perforated I-sections as an initial effort to replace the conventional cellular beams and the mechanisms involved when subjected to bending and shear actions were also comprehended.

Jackson e.al,2016,[9] a density-based approach for topology-optimized design of plain concrete beams was used and subsequent construction and experimental evaluation was performed. ‘Contrast based Fruit Fly Optimization’, was presented by Kanarachos et al, 2017,[4] mimicking the fruit fly behavior and more efficient multi-parameter optimization problems were further addressed. The results indicated that the algorithm attained the same or better performance than other optimization algorithms. Davin Jankovic et al, 2018,[6] dealt with the topology optimization of two structures, a cantilever beam with a load at the center of the free end and an MBB-beam (Messerschmitt – Bolkow – Blohm). The topology optimization was carried out using ANSYS Parametric Design Language (APDL).

MODELLING OF DEEP BEAMS

The construction industry has great importance in the sustainable development context, not only by its contribution to the economy, but also for its great social and environmental impacts. A sustainable build approach consists in minimizing the consumption of natural resources and maximize their reuse. In this sense, a competitive advantage for companies in this sector is the reduction of material used in construction.

Design of concrete structure can be done referring standard codes. Many papers were published for different design approach. Here, design of deep beam is done based on ACI 318:2008 and IS 456:2000. Strut and Tie method of design is adopted in ACI 318:2008 while IS 456:2000 uses method of shear wall design.

Design of Deep Beams

Three deep beams of varying l/d ratios 1.92, 1.76, 1.64 (depth 600mm, 650mm and 700 mmm respectively) having same span were designed as per IS456:2000. The reinforcement details of the beams are given in Table 1 For beam of l/d ratio 1.64, 6 numbers of main reinforcement bars of 12mm ϕ are arranged in 2 layers with 3 bars in each layer at a depth of 115mm from the bottom face. 10mm ϕ horizontal rebars are provided at 300mm c/c and 8mm ϕ vertical rebars are provided at 300mm c/c as shown in Figure 1.

Table 1: Reinforcement Details of Beams

Depth of Beam (mm)	Main Reinforcement	Horizontal Rebars	Vertical Rebars
600	#8, 12mm Ø	10mm Ø bars @ 300mm c/c	8mm Ø bars @ 300mm c/c
650	#6, 12mm Ø	10mm Ø bars @ 300mm c/c	8mm Ø bars @ 300mm c/c
700	#6, 12mm Ø	10mm Ø bars @ 300mm c/c	8mm Ø bars @ 300mm c/c

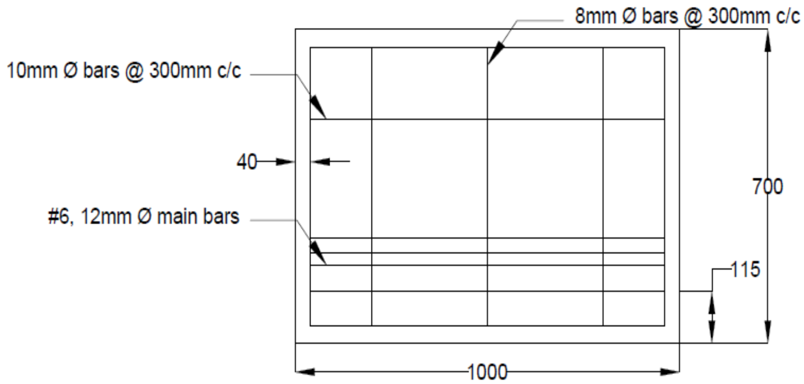


Figure 1: Detailing of 700mm deep beam

Geometric Modelling of Deep Beam

The deep beams of varying l/d ratios (1.92, 1.76,1.64) are modelled in ANSYS workbench (2019), which offers a very user-friendly platform for finite element modelling. All beams are of same span, 1000mm. Concrete is modelled using SOLID186 element and reinforcement is modelled using BEAM188 element available in ANSYS 19. The meshing is done such that the elements are of 25mm size. The elements generated for deep beam of depths 600mm, 650mm and 700mm are 74474, 76441 and 85964 respectively and the number of nodes are 122404, 129592 and 138903 respectively. Proper bonding is provided between concrete and reinforcement bars. The material properties assigned to steel and concrete are given in Table 2.

Table 2: Material Properties of Steel and Concrete

	Concrete	Steel
Modulus of Elasticity (GPa)	30	200
Poisson's ratio	0.15	0.3
Ultimate Tensile strength (MPa)	5	500
Ultimate Compressive strength	41	-

The support conditions are provided such that the deep beams are simply supported beams. A superimposed load of 500kN is applied on the top surface of the beams. Finite element model of deep beam of depth 700mm is given in Figure 2 and the reinforcement details are shown in Figure 3.

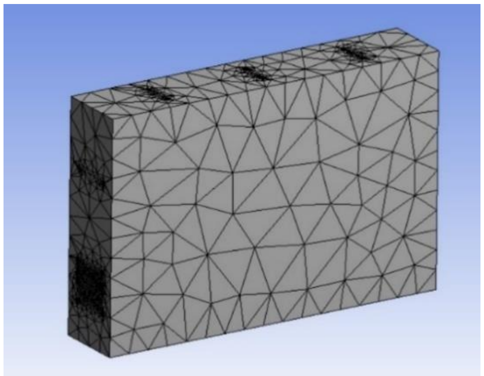


Figure 2: Finite element model of deep beam

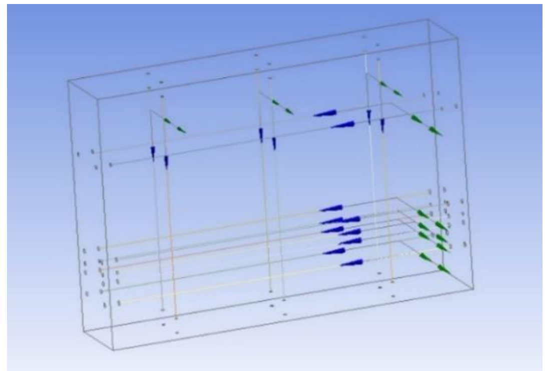


Figure 3: Finite element modelling of reinforcement bars

STATIC STRUCTURAL ANALYSIS OF DEEP BEAMS

Prior to optimisation, static structural analysis is performed on beams of varying l/d ratios. While performing the static analysis, superimposed load of 500kN is applied on the top surface of the beam. The response to loading such as deformation, normal stress and equivalent stress due to the superimposed loads are noted.

Deformation of Deep Beam

The maximum deformation for beams of depth 600mm, 650mm and 700mm are 0.2699mm, 0.2719mm and 0.2722mm. Deformation in the direction of loading vs depth of beam is plotted and is given in Figure 4.

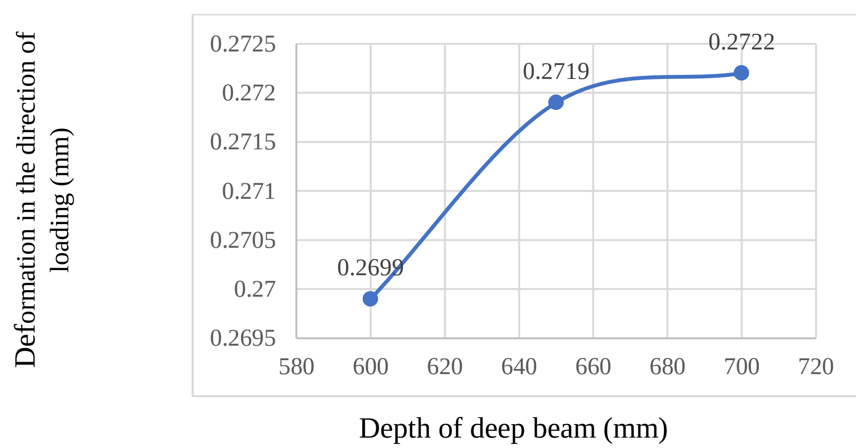
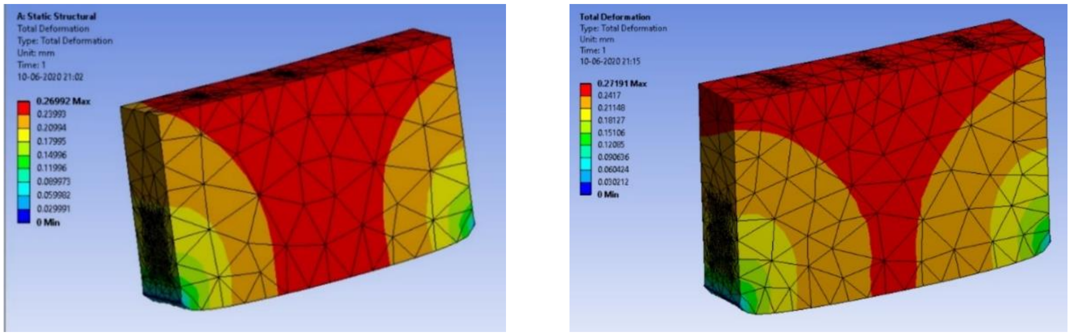


Figure 4: Maximum Deformation v/s Depth of deep beams



The variation of deformation along the depth of deep beams are given in Figure 5.

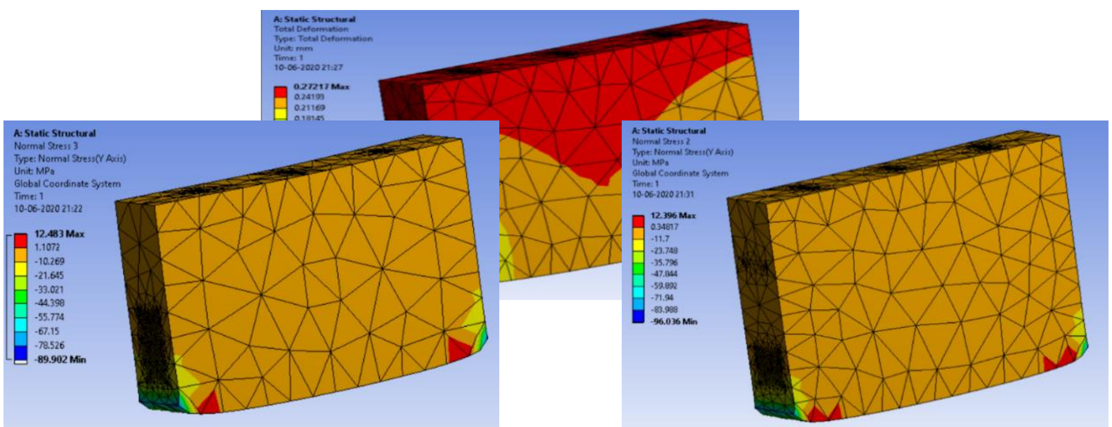
(a) Depth of beam = 600mm **(b) Depth of beam = 650mm**

(c) Depth of beam = 700mm

Figure 5: Variation of deformation along the depth of deep beam

Normal Stress in Deep beam

The normal stress in the deep beam under the loading of 500kN was noted for deep beams of varying l/d ratios. The maximum value of normal stress for deep beams of depth 600mm, 650mm and 700mm are 89.9MPa, 105.2MPa and 96.03MPa respectively. The variation of normal stress along the depth of



the beam is depicted in Figure 6. It was noticed that for all cases, the maximum stress occurs at the base face of beam near the supports.

(a) Depth of beam = 600mm **(b) Depth of beam = 700mm**

Figure 6: Variation of normal stress along the depth of deep beam

The study of response parameters of deep beams helps to identify the feasibility of optimization of deep beams.

TOPOLOGY OPTIMIZATION OF DEEP BEAM

ANSYS Workbench provides options for topology optimization of beams in the analysis system tab. The topology optimization tab is coupled with the solution of the static structural analysis tab. Minimization of compliance is set as the objective of optimization[7]. The designed region and the exclusion region are defined. The percentage of material to be retained is also set.

The beams are then solved to get the optimized layout using minimization of compliance as the objective. The topology optimized beams with material removed are generated. Results such as the reduction in volume and mass are also generated. Figure 7 shows the output of topology optimization of beam of depth 700mm. The variations in mass and volume of beams before and after topology optimization are formulated in Table 3.

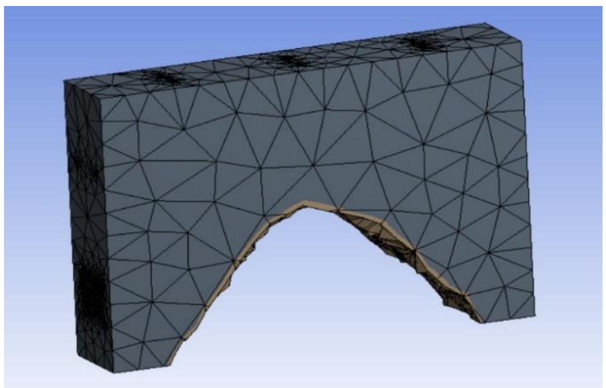


Figure 7: Topology Optimized Beam of depth 700mm

Table 3: Comparison of Variations in Mass and Volume of Beams Before and After Topology Optimization

Depth of deep beam	600mm	650mm	700mm
Original Volume	1.1872×10^8 mm³	1.2897×10^8 mm³	1.388×10^8 mm³
Final Volume	9.3335×10^7 mm³	1.0001×10^8 mm³	1.0746×10^8 mm³
Percentage Volume of Original	78.618 %	77.540 %	77.417 %
Original Mass	273.06 kg	296.64 kg	319.25 kg
Final Mass	214.67 kg	230.02 kg	247.15 kg
Percentage Mass of Original	78.618 %	77.540 %	77.417 %

Static Analysis of Topology Optimized Beam

The dimensions of the topology optimized beam of l/d ratio 1.64 are studied and they are used to model the optimized beam. The properties of concrete and steel remain same as that of the non-optimized beam. Then the beam subjected to loading conditions similar to that of the non-optimized beam. Then the static structural analysis of optimised beam is performed and deformation and normal stress are noted

Results of Structural Analysis of Optimized Deep Beam of Depth 700mm

By performing the static analysis of optimised beam, the maximum deformation and maximum stresses are noted. It is observed that maximum deformation is 0.2681 mm and maximum stress in concrete is 21.668 MPa. The variation in deformation and stress along the depth of the beam (depth = 700mm) are given in Figure 8 and Figure 9 respectively.

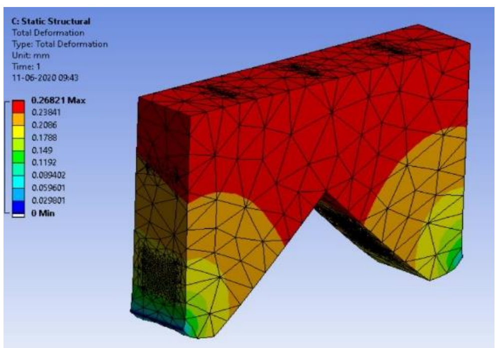


Figure 8: Deformation contour of optimized beam

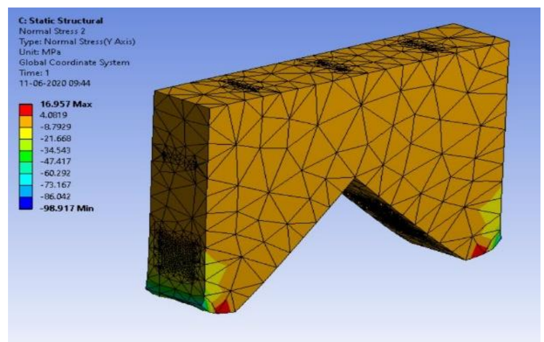


Figure 9: Stress contour of optimized deep beam

Comparison of static analysis results of deep beam before and after topology optimization

Table 4 shows a comparison between results of static analysis of deep beam of depth 700mm before and after topology optimization.

Table 4: Comparison Between Static Analysis Results

Parameters	Non optimized beam	Topology optimized beam
Maximum Deformation (mm)	0.2722	0.2682
Maximum Normal Stress (MPa)	12.396	16.957

From the results obtained after performing static structural analysis on topology optimized beam of depth 700mm, it is clear that the values of normal stress and deformation are found to be safe. Hence, material removal from beams is performed without compromising its strength characteristics.

CONCLUSIONS

Deep beams of varying l/d ratios were deigned as per IS456:2000 and modelled using Finite Element Method in ANSYS Software. These beams were subjected to static structural analysis and their results were compared. By performing this analysis, the feasibility of optimization was studied, and Topology optimization of deep beams were performed. Further, static structural analysis of topology optimized deep beam of l/d ratio 1.64 was performed and the corresponding results were found to be safe. The results of static analysis before and after performing topology optimization were also compared.

The major conclusions are:

(i) by topology optimisation, 21.382%, 22.460% and 22.583% of materials can be removed from original beams of l/d ratios 1.92, 1.76 and 1.64 respectively.

(ii) for beam with l/d ratio 1.64, the maximum deformation before optimization was found to be 0.2722mm and that after optimization was 0.2682mm

(iii) for beam with l/d ratio 1.64, the maximum normal stress before optimization was found to be 12.396 MPa and that after optimization was 16.957 MPa

Hence the current demand of construction industry for an efficient design and construction methods are satisfied through this project as the optimized beams satisfy the required performance characteristics as that of the original beams. By optimizing the beam, material can be removed, thus, the weight of the structure is reduced and the construction cost is minimized. It also ensures saving of resources thereby making construction practices more economical and sustainable.

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