International Journal of Scientific Research and Engineering Development-– Volume 6 Issue 2,Mar-Apr 2023

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

A General Review of Structural Optimization Methods

Aman Kumar[1], Sheela Malik[2], Shivender[3]
1.MTech, student Ganga institute of technology and management haryana, India.
2. Assistant Professor, civil engineering Ganga institute of technology and management haryana, India.
3. Junior Engineer CADA Irrigation Deptt Haryana, India

****

Abstract

Every manufacturing company strives to focus on lowering production costs and reducing component weight while maintaining the needed performance characteristics in the current era of technological advancement. By picking a more effective structural arrangement and improving the structure's shape and topology, material and energy savings can be accomplished. Design engineers are searching for scientific approaches to optimize models. Efficiency and economy are essential criteria for choosing novel approaches to enhance the performance of the current systems. The theory underlying shape and topology optimization and how it might be applied to enhance the design process will be clarified by the current review. Over the past few decades, structural optimization has established itself as a crucial element in the design process. The techniques fall under the categories of topology, size, and form optimization. Minimizing stresses, weights, or compliance for a specific amount of material and boundary conditions can be the optimization's goal. The technique can be applied to the design of engineering structures as well as the customization of microstructures.

Keywords: Optimization, Topology, Material Saving, Design, Efficiency, Innovative Methods.

****

Introduction

The potential for modelling intricate mechanical structures has made optimization approaches more crucial. Topology optimization, which finds an optimal material distribution [6] within a chosen geometrical design space to best meet loading requirements and limitations, is a typical strategy in the layout design of structural elements. Shape optimization, which maximizes weight (mass) within predetermined parametric geometric restrictions, is another crucial strategy for optimizing the structure. The Solid Isotropic Material with Penalization (SIMP) method, where the density is roughly approximated as constant throughout each element, is the most used numerical technique for topology optimization. In the current effort, the optimization's goal is to identify a design that maximizes stiffness for a specific amount of material. Being a global measure that can be expressed by a scalar value, stiffness—or rather, its complement, compliance—is advantageous as the target. Also, the constraint on the volume is very straightforward because it is linear and monotone, which in most instances results in a reliable numerical approach. The SIMP process is simple to use and quantitatively effective at the same time. It is built on a series of convex approximations. By penalizing gray designs with a scaling of the elastic constitutive relation, a clear black/white solution is produced. Due to the length scale being absent, it has been demonstrated that this formulation is improperly posed. The solution to this issue is to normalize it using something like a filter. Shape optimization is still challenging for complicated shaped items, such as the body structures of automobiles, primarily because it is challenging to convert form design parameters into useful analytic models. Aspects of structural design difficulties are addressed differently through sizing, shape, and topology optimization.

Structural Optimization

Easily traceable since 1904, when Michell [1] established equations for structures with lowest weight given stress constraints on various design domains, structural optimization is a subset of optimization problems. Save and Prager's research from 1985 [2] demonstrated that the resulting structures—popularly known as Michell structures—had the lowest compliance for equivalent volume structures and so represented the worldwide ideal for minimizing compliance when volume issues are present.

In engineering, the maximization or minimization of a problem while taking into account certain limitations is known as the optimization of an objective function. The goal of structural optimization is to determine the best material distribution for a structure given certain requirements. Mass, displacement, and compliance are examples of typical functions to decrease (strain energy). Most frequently, this issue is constrained by the component's mass or size.

Traditionally, this optimization is carried out manually utilizing an intuitive iterative procedure that basically consists of the stages below.

1. An idea for a design.
2. Evaluating design specifications, perhaps using a finite element analysis (FEA)
3. Verify whether or not requirements have been met. if anything is lacking, repeat the process. 2 & 3.

The outcome is highly influenced by the designer's background, skill set, and opinion of how well they comprehended the issue. Trial and error can be used to change the design. This procedure may take a long time and produce a less-than-ideal design. The three main categories of structural optimization problems are Size (mass), Shape, and Topology (layout). See Fig. 1.

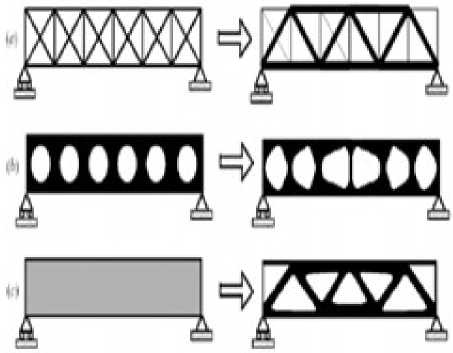

Fig. 1. a. Sizing b. Shape c. Topology Optimization (**Courtesy:** Ref. 6.)

Statement of Optimization Problem

Constrained minimization is a common strategy used to solve most engineering problems. Finding the least weight design of a structure that is subject to limits on stress and deflection is an illustration of such a constrained minimization problem. Constrained issues can be represented using the general nonlinear programming form shown below:

minimize $f(x)$

subject to

$gi(x) \leq 0 \quad i = 1, \ldots, m$

and ,

$hj(x) = 0 \; j = 1, \ldots, l$

where $x = (x, x, \ldots, xn);$

$f(x)$ = objective or cost function,

$g's$ are inequality constraints, and $h's$ are equality constraints.

To formulate Eq. (1.2) in the form: minimize f, the inequality constraints in Eq. (1.1) include explicit lower and upper limitations on the design variables (x). By concentrating on optimization, weight reduction can be achieved. In the current work, size and shape.

Methods of Structural Optimization

The creation of mechanical products and the design phase of any structure or component that is subject to loads are the current focus of structural optimization. The rigorous task of designing a structure requires the design engineer to concentrate on a number of objectives, including minimizing total weight (mass) [17] or volume[13], minimizing stress (fluctuating or static), maximizing stiffness, homogenizing stress distribution, reducing production costs, etc. Finding the ideal geometry for a chosen design space that targets several parameters is the goal of structural optimization. It can be separated into three separate branches. Optimization of topology, size, and shape are the strategies often focus on size, form, or topology; occasionally, an integrated approach is used. Shape and size of a structure can be easily controlled because the design variables are the boundary coordinates (shape optimization) or the structure's physical dimensions (size optimization), but topology management requires more effort. Several techniques for structural optimization are studied and described as:

Sizing optimization

The most basic type of structural optimization is sizing optimization. The structure's geometry is known, and the goal is to make it as efficient as possible by changing the component sizes. The dimensions of the structural components, such as a rod's diameter, a beam's thickness, or a sheet of metal, are the design variables in this case. Similar to size optimization, where the design variables are the diameter of the rods The design variables in a sizing optimization problem are often geometrical dimensions like the part's length, width, or thickness.

Shape optimization

Similar techniques are used for shape optimization and topology optimization. The definition of the design variables is where the key distinction lies. The boundary's coordinates are design variables. The three modules of geometrical representation, structural analysis, and optimization algorithms make up the shape optimization process [19]. The initial stage in the shape optimization procedure is to choose a geometrical representation, The nodal coordinates are selected as the design variable because ANSYS makes it very straightforward. The basic design model is created while taking the architectural or structural requirements into account. An analysis model is created from the design model. Hence, previous studies have concentrated on the goal function, such as lowest cost or least weight. As established analysis tools, ANSYS [13] & [15] have been applied in numerous real-world engineering projects and can analyze practically all structures.

A numerical model for the examination of form optimization of diverse structures is developed by Yunliang Ding [3]. outlined the various phases involved in the form optimization procedure. He states that the model description, choice of the objective function and shape variables, representation of boundary shape, production and refining of the finite element mesh, sensitivity analysis, and solution methods are the processes of shape optimization. In their work, these steps are examined in detail. Finite Element (FE) analytical interface was used to discuss the process of form optimization on a V-shaped anvil by X. Duan et al. This particular form of parametric optimization process utilizes the FEA software MARC.

Topology optimization

The most often used structural optimization method is topology optimization, which is typically taken into account at the conceptual design phase. The term "topology optimization" derives from the Greek word "topos," which means "landscape or place." The hardest of the three structural optimization types is probably topology optimization. By figuring out the structure's ideal topology, the optimization is carried out. Thus, optimization happens by choosing design variable values that match the component topology resulting in the best structural behavior [4] and [5].

One design variable is coupled to each element in topology optimization, which makes use of a fixed finite element mesh. Depending on the design variable, the associated element may or may not represent structural material or a hole. By linking the applied loads to the established boundary conditions, the structure's connectivity is altered in such a way that the goal function is minimized while being subject to the specified limitation. When topology optimization is used to structural design, factors including weight, stresses, stiffness, displacements, buckling loads, and resonance frequencies are often taken into account, with some of these factors defining the objective function and others imposing constraints on the system.

Topology optimization is a new research area that is rapidly growing. It has interesting theoretical ramifications in the fields of mathematics, mechanics, multiphysics, and computer science. It also has significant practical applications in the product development (particularly automotive and aerospace) industries and is probably going to play a big part in micro- and nanotechnologies. The Australian inventor Michell (1904)[1], who devised optimality criteria for the least weight truss layout, presented the first work on topology optimization a century ago. Authors and his research team extended Michell's theory to grillages (beam systems) after seven decades; these authors are cited in several works (starting with Rozvany 1972). Based on these applications, Prager and Rozvany (1977) developed the initial general theory of topology optimization, known as the "optimal layout theory" (for a review, see Rozvany 1993 or Rozvany et al. 1995). Yet, it also has significant ramifications for numerical techniques and continuum-type structures. They applied this principally to exact analytical optimization of grid-type structures. Several works examine this theory's extensions and the precise answers to well-known benchmark problems (Lewinski and Rozvany 2007-08) [12]. Bendsoe and Kikuchi (1988) [5] and [6] are responsible for the creation of topological optimization. They presented a topology optimization method based on homogenization. They made the assumption that the structure is made up of a number of non-homogenous pieces that are divided into solid and void regions, and then used an optimization technique to create the best design possible given the volume constraints. According to their methodology, areas with dense cell composition are areas of structural shape, whereas those with empty cell composition are places of extra material. Several papers on the applications and methods of topology optimization were discussed at the World Congress in Seoul in 2007. Varun Ahuja et al. (2012) presented a paper and explored optimization techniques in reducing the weight of engine mounting brackets at the Hyper Works Technology Conference (HTC) and came to the conclusion that employing the Opti-Struct Software tool might reduce the bracket's weight by 15%. Several studies on topology optimization are discussed at this conference. M.V. Aditya Nag (2012) demonstrated at the HTC Conference how to reduce the weight of an engine mounting bracket by up to 60% without sacrificing the bracket's structural integrity[16]. Misra (2012) and Dheeraj Gunwant compared The outcomes of the ANSYS-based Optimality Criteria [18]which was a gradient based method, were compared with those obtained by Element Exchange Method which was a non-gradient based method.

Conclusion

To get the best values for the various dimensions, size optimization is necessary. Shape optimization is an extension of size optimization that offers more flexibility in the layout of the structure, including where connections between parts should be placed. Modified designs can only be developed using a small set of optimization variables since they are constrained to a fixed topology. The size and shape optimization is advanced by topology optimization, which places no constraints on the optimal structure. It merely looks for the governing equations' ideal domain inside a given design field. It offers a minimal distribution of materials inside a chosen design area. Topology optimization offers more latitude than size and shape optimization because it doesn't call for an initial structure. Finding an optimum structure that complies with the specified restriction just requires the design space, the loads, and the boundary conditions.

References

1. A.G.M. Michell. LVIII. The limits of economy of material in frame structures. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, , 1904.
2. Save, M. and Prager, W., editors Structural Optimization, Volume 1: Optimality Criteria. Plenum Press, New York, NY 1985.
3. Yunliang Ding ,Shape optimization of structures: a literature survey, Department of Aeronautical, Structures and Materials, computers & Structures Vol. 24. No. 6. pp. 985-1004. 1986.
4. M.P. Bendsøe and N. Kikuchi. Generating optimal topologies in structural design using a homogenization method. Computer methods in applied mechanics and engineering, 71(2):197–224, 1988.
5. M.P. Bendsoe, and N. Kikuchi.Generating optimal topologies in structural design using a homogenization method by Comput. Meth. Appl. Mech. Eng. Vol: 71: 197-224.,1988.
6. M.P. Bendsøe. Optimal shape design as a material distribution problem. Structural optimization, 1(4):193–202, 1989.
7. M.P. Bendsøe, A. Ben-Tal, and J. Zowe. Optimization methods for truss geometry and topology design. Structural and Multidisciplinary Optimization, 7(3):141–159, 1994.
8. X-duan, T Sheppard, Shape optimization using FEA software-A v-shaped anvil as an example, Journals of material processing technology vol no 120 pp 426-431, 2002.

9. Martin Philip Bendsøe and Ole Sigmund. Topology Optimization - Theory, Methods, and Applications. Springer Verlag, Berlin, second edition edition, 2003.
10. Gong Shuguang , "ANSYS engineering application and its analysis"(Book style) Beijing China Machine Press,.4 pp. 35–85,2003.
11. M. Zhou, N. Pagaldipti, H.L. Thomas, Y.K. Shyy, "An integrated approach to topology, sizing, and shape optimization", Structural and Multidisciplinary Optimization, vol. 26, no. 5, pp. 308-317, 2004

12. G. I. N. Rozvany.A critical review of established methods of structural topology optimization" by , Springer-Verlag ,2008.
13. Prashant Kumar Srivastava "Volume Reduction of A Mechanical Component using ANSYS" in M.Tech Dissertation ,HBTI ,Kanpur,INDIA(2011).
14. Varun Ahuja Sandip Hazra Application of Optimization Techniques in Reducing the Weight of Engine Mounting Bracket" by, HTC (Hyper Works Technology Conference) Conference, India 2012.
15. Dheeraj Gunwant & Anadi Misra Topology Optimization Of Continuum Structures Using Optimality Criterion Approach In ANSYS" by , International Journal of Advances in Engineering & Technology, Nov. 2012

16. M.V.Aditya Nag .Topology optimization of a Engine Mounting Bracket", , HTC (Hyper Works Technology Conference) Conference, India 2012
17. Prashant Kumar Srivastava, Rajive Gupta & Simant. Structural Weight optimization of A Bracket using ANSYS, International Journal of Research Engg & Technology, Vol 3, Spl Issue 10, 2014
18. Kishan Anand , Anadi Misra. Topology Optimization and Structural Analysis of Continuous Linear Elastic Structures using Optimality Criterion Approach in ANSYS.International Journal of Innovative Research in Science, Engineering and Technology Vol. 4, Issue 6, June 2015.
19. Guoyong Cuia, Changyu Cuia,b,Shape Optimization Based on ANSYS, Journal of Information & Computational Science–4297 July 20, 2015.
20. S S Rao, Optimization Theory & Applications, ,Wiley Eastern limited, INDIA
21. Kalyanmoy Deb, Optimization For Engineering Design (Algorithms and Examples), Prentice-Hall of India Private Limited, New Delhi, INDIA
22. Dukkipati,Rao,Baht, Computer Aided analysis and design of Machine Elements , New Age Int Publication,INDIA