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Size optimization of truss structures for sequential loading scenario using evolutionary algorithms

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Abstract. Evolutionary algorithm-based size optimization of plane and space truss structures is studied for sequential loading scenarios. Size optimization of a truss is a search for the most suitable cross-sectional areas of the truss members from the available design spaces. The novelty of the present work lies in developing an evolution-based algorithm that can consider the sequential loading scenario while designing the planner and space trusses. Fortran-based computer programming has been developed for the proposed optimization method considered here. A standard displacement-based finite element method is implemented to obtain the trusses' nodal displacement and elemental stresses. To assess the performance of the proposed algorithm three plane trusses (3-bar, 18-bar, and 200-bar) and three space trusses (22-bar, 25-bar, and 72-bar) with various displacement and stress constraints under sequential loading have been considered. The optimum weights obtained from all the problems considered here have been analyzed and compared with the same, as obtained from other methods mentioned in the existing literature. It is important to note here that the results are in close agreement and in some cases optimum weights obtained from the present study are even better than the earlier results. Finally, a real-life design problem of an industrial roof truss has been considered to assess the applicability of the proposed algorithm. The convergence study and optimum cross-section of the truss have been reported as a case study.

Keywords: evolutionary algorithms; finite element analysis; FORTRAN programming; sequential loading; size optimization; truss structures

1. Introduction

In modern human civilization, trusses are an inevitable part of civil engineering structures. The universal use of trusses in the construction of industrial and high-rise structures, bridges, transmission towers, etc. in contemporary society has put forward the engineering optimization technique as a primary research area among structural designers. With the advancement of optimization techniques, the designers aim to figure out a design solution for a particular truss structure that will be cost-effective besides being safe and aesthetic (Pham 2016). As described by Bouzouiki *et al.* (2021), the optimization of truss structures can be categorized into three basic formats, (1) size optimization (considering the cross-section area of the truss members as the design variables), (2) shape optimization (considering the nodal location of the truss as the design variables), and (3) topology optimization (considering the nodal connectivity of the truss as the design variables and elimination the unutilized nodes and elements from the optimized truss). Besides the research in the individual categories (such as, for size optimization: Rajeev and Krishnamoorthy (1992), Makris and Provatidis (2002) etc; for shape optimization: Wang *et al.* (2002), and for topology optimization: Deb and Gulati (2001), studies considering the combination of each category are also found in the literature (such as Oshaki 1998, Gil and Antoni 2001, Rahami *et al.* 2008, Bouzouiki *et al.* 2021, Grzywiński 2022, etc.). It is important to note that, as the cost of the material is the major concern for a designer, the primary objective of the optimum design of the truss is to keep the structure safe while decreasing the cross-section area of the truss elements to reduce the overall cost of the structure. For this purpose, size optimization of the truss has been carried out by several researchers in the past few decades and present (Rajeev and Krishnamoorthy 1992, Makris and Provatidis 2002, Li *et al.* 2007, Awad 2021, Altay *et al.* 2023, Aydogdu *et al.* 2023, etc.) to minimize the overall weight of the truss.

Alongside the classical differential equation-based or gradient-based optimization techniques, Evolutionary Algorithm and Metaheuristic Optimization Algorithm (MOA) gained much popularity among researchers due to their gradient-free nature and global optimization approach in the size optimization of trusses (Boussaid *et al.* 2013). Among these two techniques, an evolutionary algorithm-based approach is formulated on the biological evolution process (Alhijawi and Awajan 2023). It considers reproduction, crossover, and mutation-like operators to expand the search pace in an optimization problem (Deb 2012). Its parallel nature boosts its efficiency. There is a vast literature on size, shape, and topology-based optimization of trusses through evolutionary and Metaheuristic Optimization Algorithms (MOA), though based on authors' knowledge majority of them are limited to

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RESEARCH PAPER

Weight Minimization of Truss Using Strain Energy Density and Genetic Algorithm for Single and Multiple Load Cases

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Abstract
Minimization of structural weight greatly affects the overall cost of a truss structure. This study focuses on the weight minimization of truss structures using the Strain energy (SE) criterion and the Genetic Algorithm (GA) based optimization approaches. Single and multiple load cases are considered to obtain the optimum weight of the truss. While designing roof trusses, wind loads need to be considered alongside the existing dead and live loads. The novelty of this study lies in the fact that two of the proposed algorithms consider the multiple load cases to be applied on the roof truss successively. The complete algorithm and flowcharts proposed for both the cases using strain energy and GA-based method are presented in detail. Fortran-based computer programs are developed to verify the efficiency of the proposed algorithms. Initially, the optimum weights are validated with the existing literature and then some new case studies have been suggested based on the proposed algorithm. In the case of a 10 bar truss under a single load case, the proposed GA-based weight minimization process provides the most optimum weight in comparison to the proposed SE-based method or other recent methods. It has also been observed that the proposed GA-based method provides the lowest possible structural weight for all the trusses considered in the study. An application problem has also been considered to assess the design effectiveness of the proposed algorithm.

Keywords Size optimization of truss · Finite element method · Strain energy density criteria · Genetic algorithm · Multiple load cases · FORTRAN programming

1 Introduction

In the modern era of Engineering, trusses are widely used in most structures such as buildings, bridges, power transmission towers, cooling towers, military structures, storehouses, etc. While designing the components of a truss, designers need to consider its safety, cost-effectiveness, and aesthetics. Various design outcomes are possible while satisfying these design criteria. It is a challenging task to find the most suitable design outcome out of the nearly infinite numbers of solution spaces as it demands lots of iterations and time. A suitable optimization technique provides an effective means in this aspect by making these calculations faster [1]. Hence, since the last few decades, the determination of the optimum weight in a truss structure has been a preferable area for researchers in the optimization domain. Optimum truss design can be achieved through three possible ways [2]. Firstly, though, changing the cross-section area of the truss members (size optimization) [3–5], secondly, through changing of nodal coordinates of the joints of the truss (shape optimization) [6], and lastly through changing the nodal connectivity of the truss (topology optimization) [7]. In all three cases, the remaining two parameters are kept constant. It is important to note here that various studies are also present in the recent past where combinations of these methods were taken into consideration [8, 9]. The primary goal of the

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