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Review Article

Critical Reviews on Topology Optimisation of Reinforced Concrete

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Abstract

Current demand on resources have forced engineering sector to look at more efficient design and construction methods. Methods that will yield better designs that are cost effective and put less demand on decreasing resources. This study introduces applications of structural topology optimization to reinforced concrete structures. Structural topology optimization is a technique for finding the optimum material layout. Aerospace and automotive engineers routinely employ topology optimization and have reported significant structural performance gains as a result. Recently designers of buildings and structures have also started investigating the use of topology optimization, for the design of efficient and aesthetically pleasing developments. The main objective is to achieve a reduction in the weight of concrete structures. This is motivated by the need to reduce cement production which is a major source of CO_2 emissions. Using this engineer can find the best concept design that meets the design requirements. In this paper a critical review on topology optimization of reinforced concrete structures are investigated based on different topology optimization techniques.

Keywords: Topology optimization; Critical Review

Introduction

Structural optimization is concerned with maximizing the utility of a fixed quantity of resources to fulfill a given objective. Three categories of structural optimization exist; shape, size and topology. Structural topology optimization is the most general of the three categories yielding information on the number, location, size and shape of openings within a continuum. The first solutions to a topology optimization problem were presented by Michell [1]. Modern topology optimization techniques can be applied to generalized problems through the use of the Finite Element (FE) method, as a relatively recent innovation. Aerospace, automotive and mechanical engineers have successfully utilized topology optimization in order to achieve weight savings in structures. Enthusiasm for topology optimization in the field of civil/structural engineering, where weight savings are seen as less critical due to the one off nature of building structures, is generally accepted as being more muted. Topology optimization has found several novel applications in the field of civil engineering, most notably; a novel technique for geotechnical analysis and reinforcement layout optimization in concrete structures. The main focus of this review study is applications of topology optimization to reinforced concrete structures.

Topology Optimization Techniques

Topology optimization involves the determination of features such as the number, location and shape of holes and the connectivity of the domain [2].

Homogenization method

In their ground breaking paper, Bendsoe et al. [3] presented the homogenization method. Subsequent research on the field of structural topology optimization has been on the basis of their work. The homogenization method works on the basis of replacing materials in a composite domain with a kind of equivalent material model. This is done because “even with the help of high-speed modern computers, the analysis of the boundary value problems consisting of composite media with a large number of heterogeneities is extremely difficult” [4]. Such a procedure is called homogenization. It is assumed that the design domain is made of periodic microstructures, hence this type of materials are called composites with periodic microstructures.

Simp method

The SIMP (Solid Isotropic Microstructures with Penalization) was proposed by Bendsoe (1989) which he called the direct approach method. The basic concept of SIMP method is that "grey" elements are penalized and removed from the domain to obtain a black ($\rho = 1$) and white ($\rho = 0$) topology. That is any element that has density within $0 < \rho < 1$ is removed from the design domain. It is assumed that the domain is made of an artificial material and its density can be related to structures stiffness by the following power law [3].

Evolutionary structural optimization (ESO)

The Evolutionary Structural Optimization (ESO) method was proposed by Xie & Steven [5]. The basic idea of the method is that inefficient elements are removed from the design domain based on a material removal criterion. Such a criterion function or parameter value is calculated for each element and in each iteration some elements with the lowest criterion value that do not meet the minimum criterion set are eliminated [6]. By progressively removing such elements the structure will evolve towards an optimum.

Bi-directional evolutionary structural optimization (BESO)

Two major deficiencies present in early versions of ESO method was solution time and uniqueness [5]. Since elements were only removed in the ESO method, it was questioned if the method ensured that it was not a local optimum solution that was obtained and could the elements removed, be returned. The "Bidirectional Evolutionary Structural Optimization" method presented by Querin et al. [5] provided an improved version of the ESO algorithm. The improved method was able to remove inefficient material to eliminate low stress as well as add materials to efficient areas to alleviate high stress.

The element efficiency in BESO is measured the same way as in ESO but the adding and removing uses a different procedure. A control parameter named "Inclusion Ratio" is used to control the amount of material that is added. When no more elements is removed or added that is at steady state, the inclusion ratio is decreased and the rejection ratio is increased.

Performance-based optimization (PBO)

The PBO method combines the topology and sizing optimization into a single scheme to achieve the optimal topology and thickness design of continuum structures. The performance of the structure is the objective criteria for the method that is it uses realistic performance criteria. These performance criteria include structures stiffness, strain, shear, etc.

Smooth evolutionary structural optimization (SESO)

It is a variant of ESO. Here the elements are removed smoothly [7-12]. Here the element with lowest Von Mises stress is calculated for element removal. He demonstrated that SESO can be used for problems containing nonlinearities, dynamic analysis etc.

Topology Optimization of Reinforced Concrete Structures

There are many researchers who have concentrated on topology optimization of reinforced concrete structures. After going through a critical review of this literature, the following findings are made and are given in Table 1. The volume reduction of deep beam using different topology optimization techniques are compared shown in Figure 1.

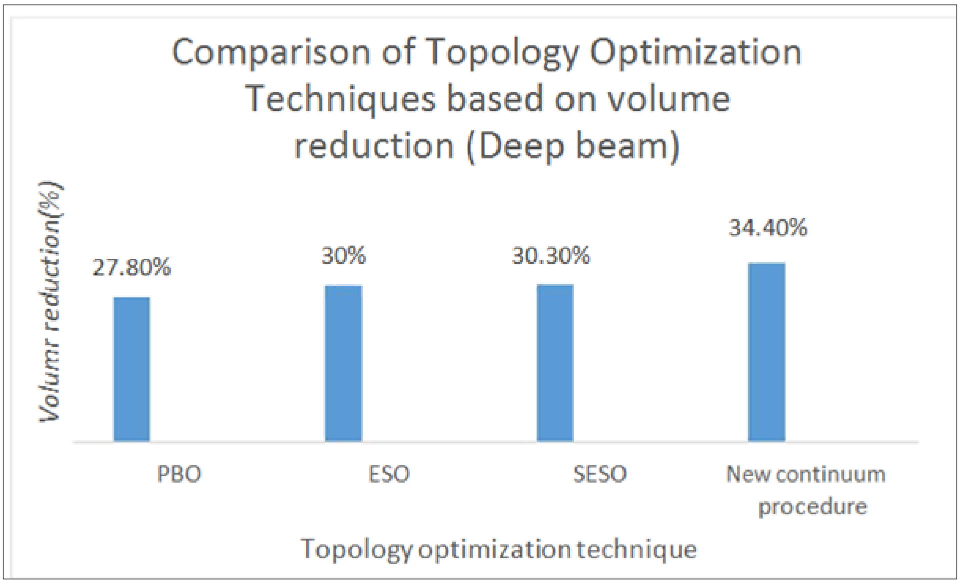

Figure 1: Comparison of techniques.

Table 1.

Sl no.	Topology optimization techniques	Author (year)	Structural	Findings
1	A new continuum topology optimization	Oded Amir [8]	Deep beams	Weight of optimized beam is 65.6% and 80% load carrying capacity of full beam, per unit weight 22% more load carrying capacity. Final volume is 34.4%
2	A new continuum topology optimization	Oded Amir [8]	Corbels	Weight of optimized beam is 60.8% and 80% load carrying capacity of full beam, per unit weight 32% more load carrying per unit weight 32% more load carrying capacity.
3	A new continuum topology optimization	Oded Amir [8]	Wall with opening	Weight of optimized beam is 72.1% and more load carrying capacity of full beam.
4	Evolutionary structural optimization	Y M Xie [9]	Short cantilever	56.87% volume reduction
5	Evolutionary structural optimization	Y M Xie, 2006 [9]	Deep beam with hole	33% volume reduction
6	Bi-directional Evolutionary structural optimization	Harianto Hardjasaputra [10]	Cantilever beam	35% volume reduction
7	Bi-directional Evolutionary structural optimization	Harianto Hardjasaputra [10]	Beam with large opening	50% volume reduction
8	Performance based optimization	Quin Quan Liang [11]	Interior beam column connection	27.7% volume reduction
9	Performance based optimization	Quin Quan Liang [11]	Deep beam	27.9% volume reduction
10	Smooth evolutionary structural optimization	Valerio S, Almeida [7]	Simply supported beam	43.9% volume reduction
11	Smooth evolutionary structural optimization	Mariano Victoria [12]	Deep beam with web openings	41.65% volume reduction
12	Smooth evolutionary structural optimization	Valerio S, Almeida [7]	Deep beam with hole	30.3% volume reduction

Conclusion

The main goal of topology optimization is to achieve a reduction in the weight of concrete structures. This is motivated by the need to reduce cement production which is a major source of CO2 emissions.

a. The volume reduction is more in SESO technique as compared to ESO technique (10.9%) in the case of deep beam with hole.

b. The new procedure developed by Oded Amir the volume reduction is more as compared to all other techniques.

c. In case of wall with opening the load carrying capacity is more in optimized wall than whole wall.

d. In performance based optimization the volume reduction is small compared to other techniques (27.7% in interior beam column connection and 27.8% in bridge pier)

e. The new procedure developed by Oded Amir, suggests bigger potential to topology optimization.

f. Another motivating factor of topology optimization is the growing interest within the architectural community in topology optimization as means of generating aesthetic and efficient structural forms.

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