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Topology Optimisation of A Two Point Load case Continuum Structure using Firefly Algorithm - IV

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Abstract

Topology optimization is a relatively new and emerging area of research in the field of structural engineering. The idea is to determine the optimum distribution of material in the given design domain and not to focus on shape or correcting the dimensions of initial designs. Metaheuristics are widely used in the field of optimization of continuum structures. Firefly algorithm proposed by Xin-She Yang is considered as one of the best performing algorithms which require fewer iterations to converge. This paper is a series of ongoing research work in structural optimization using firefly algorithm. The focus of this paper is to optimize a two point load case problem one of the complex in the field of optimization involving several degrees of freedom. An attempt has been made to verify the distribution of material and the convergence of the firefly algorithm. The analysis shows that the algorithm is very effective to determine the distribution of material and the final distribution is a near approximation of the theoretical distribution.

Keywords: *Two point load, Firefly, Structural Optimization, Metaheuristics, Topology, Civil,*

INTRODUCTION

The study on optimization has been of intense area of interest to both Mathematicians and Engineers. This field of applied mathematics and mechanics has gained enough attention with the ease of availability of computational power. Civil Engineering, which is believed to be the oldest of all, Optimisation has large number of applications in Structural Engineering. In olden days, when forts, and temples were constructed with large sections of columns and beams, the structures were very heavy. With the availability of computational power, the researchers began to work in this field and during the past 50-60 years Optimisation has gained considerable attention from across the fields for example science, medicine, agriculture, physics, biomechanics and so on.

In 1870, James Clark Maxwell [5] is one of the forefather's in the field of optimization. His collection of research work, a massive two volumes book is a benchmark reference in this field of study. In 1904, Anthony Graham Michell [6] an Australian engineer published his famous paper on "LVIII The Limits of Economy of material in frame-structures" applying the principles of Maxwell has revolutionized optimisation. His paper is published in Philosophical Magazine [S.6. Vol. 8. No.47 Nov 1904]. Michell structures are dealt even today in every textbook on structural optimization. The research went cold for a few decades until the computers were used in this field. With the ease and availability of computational power the research took new heights during the last 60 years. Several researchers from around the world have contributed substantially and the subject of optimization began to evolve.

Objectives

To determine the distribution of material in the given domain carrying two point loads

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Scope of the study

The analysis is limited to linear static elastic limits only and the material obeys Hooke's Law.

The analysis does not include buckling.

LITERATURE REVIEW

Sokol [9] in his paper on truss optimization presents an approach in using a fixed ground structure approach and linear programming formulation of the problem. He presents a new solver which is based on fast interior point method. Lewinski et. al. [4] presents a two-point problem with different values of d, d = 0.5l, 0.75l. He penalized the domains in the problems using Generalised Rational Approximation of Material Properties (GRAMP) and Solid Isotropic Material with Penalisation (SIMP) [3]. The approximate "0-1" topologies obtained using these two different models were presented. Sokol and Rozvany [9] present new numerical solutions for domains which carry multiple loads. The method is based on adaptive ground structure approach and the minimum weight is calculated using stress based formulation. The two-load case problem is solved in this paper as a special case of three forces problem. The solutions were performed using the ground structure with over a 75 million design variables, which is 2.5 times more than the one-point load case problem. The numerical solutions were then compared with the analytical solution.

STRUCTURAL OPTIMISATION [11]

There are three major components for any structural optimisation problem. They are

1. Formulation of a mathematical model
2. Representation
3. Optimisation method

In addition to the above, one can also consider economy, aesthetics, functionality and following is a brief discussion of these:

(a) Functionality – The main intended purpose of the structure. Say, a bridge – one needs to know how long, how many lanes, loading expected.

(b) Conceptual design – In addition to the functionality, one also needs to know what type of bridge – a truss bridge, a suspension bridge, an arch bridge.

(c) Optimisation – The next step would be the optimisation step wherein within the chosen type one has to design the bridge within the constraints for low cost and least material.

(d) Further details – can include aesthetics, social factors.

Repeat the process iteratively until a design satisfying the constraints is converged. Using a computer based finite element methods can help to develop an optimum design in an effective way. The optimum design of a structure has to satisfy these and also at the minimum cost as well. Simply said, the mathematical formulation of all the measurable factors in an optimisation problem for designing an optimum structure whose main task is to carry loads by satisfying all the constraints can be termed as structural optimisation.

Mathematically, an optimisation problem consists of:

(a) Objective function (f) – A function useful to classify a design for every possible value of f indicates the level of acceptability of design. 'f' can be a measure of the weight. [11]

(b) Design variable (x) – A vector/function to represent a choice of material or geometry which can be altered during an optimisation process.

(c) State variable (y) – for a given x, y is a function that represents the response of the structure.

A general form can be minimise f(x, y) subject to design constraints f(x), behavioural constraints y (such as displacements), equilibrium constraints.

For example, the objective can be to minimize weight

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s.t.
Stress in each element (f_e) < Maximum permissible stress (f_{max})
Displacement at any point (u_i)< Maximum permissible displacement (u_{max})
Volume of the final structure (V_s) > minimum volume of the structure (V_{min})
Given, the Maximum permissible stress and Maximum allowable displacement, Minimum Volume, Young's Modulus of Elasticity, Poisson's Ratio, and Weight Density.

METHODOLOGY

Few papers were published on solving a two point load case. In this paper, a two point load case problem is optimized using firefly algorithm [10]. Only one of the possible distribution of material is presented in this paper for the sake of simplicity.

The representation of the given domain is performed using 1's and 0's. The element carrying the material is denoted as '1' and the element carrying no material is denoted as '0'. The entire domain is denoted using a string of 1's and 0's [1]. The relative density is calculated using Firefly Algorithm. The Young's Modulus 'E' of the element is calculated using the SIMP law [2]. The stiffness of the element is calculated using the modified 'E'. The shape functions of the traditional elements first order four node quadrilateral elements Quad4 is used. The analysis is performed. The last step is the decoding process wherein the distribution of the material is determined. This process is repeated until convergence and the relative densities are recalculated using the basic ESO approach.

Simply said, these three steps viz., formulating a mathematical model, representation and optimisation process are core for any optimisation problem. Several researchers have focused more on the optimisation process and the mathematical model, but a good representation can make a better design solution.

ANALYSIS

Assumptions

1. The applied load is distributed over three nodes to avoid any stress concentration
2. The support is distributed over three nodes to avoid stress concentration
3. The structure is assumed to be symmetrical about the vertical axis at the centre. Only one half of the structure on the left side of the axis is analysed
4. The nodes at the axis of symmetry will have only vertical deflection and the horizontal displacement is taken as zero
5. The elements connected at the corners cannot carry any moment
6. The elements are assumed to be connected with each other having at least one edge in common

Two Point Load Problem [9] [4]

The design domain is a plate of dimensions 8 m x 4m. The domain is meshed using first order quadrilateral elements having four nodes each. As shown in the Fig. , due to symmetry only half of the structure is analysed. Two point concentrated loads are applied at a distance of 4m from left end support. The number of elements in one half of the structure are 512 and the number of nodes are 561. The modulus of elasticity is taken as 1e9 N/m^2 and Poisson ratio as 0.3. The weight density of the material is taken as 10000. The thickness is taken as 0.01m. The load is distributed over three nodes to avoid the stress concentration problems. The supports are distributed at the left end over three nodes to avoid stress concentration [7]. The final distribution as shown in the Fig has a similar distribution of material as that of the distribution from the theoretical analysis. Fig showing the topology of the structure using exact

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solution, Gramp and Simp methods for d = 0.5l. Lewinski [4] in his paper used a large number of elements to discretize the material domain. The distribution of material is similar to the one obtained using firefly algorithm. The elements are aligned in a straight line showing that the stresses in each element are equal. The stresses are evaluated at the centroid of each element and might have a lower estimate than the stresses when calculated at the gauss points.

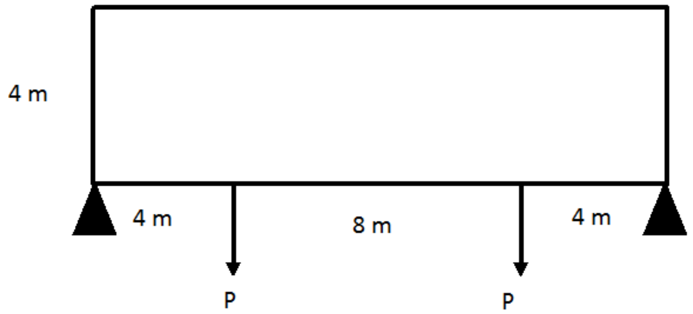
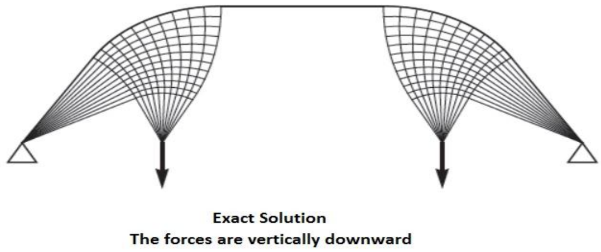


Fig.1 *showing the domain with two forces and two fixed supports [4] [8]*



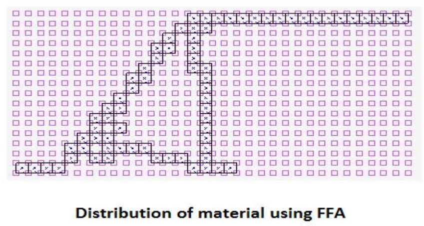


Fig.2 (a) *showing the exact solution [4]* ***(b)*** *Distribution of material using FFA*

Fig. showing topology of the optimized structure using (a) Exact (b) SIMP and (c) GRAMP for d = 0.5L [4] In the present study the value of d = 4 and L = 8

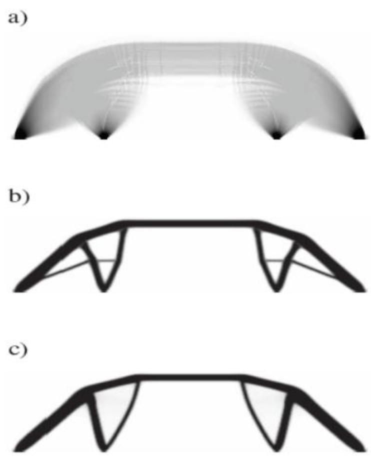


Fig.3 *showing topology of the optimized structure using (a) Exact (b) SIMP and (c) GRAMP for d = 0.5L [4]. In the present study the value of d = 4 and L = 8*

Limitations

1. The stress is evaluated only at the centroid of each element.
2. The elements having material are aligned in a single horizontal line and have a chance of shear locking, high shear stress between each element. The problem can be addressed by using higher order elements such as eight node quadrilateral elements, or nine node quadrilateral elements.

CONCLUSIONS

In this paper, the two point load case problem is studied. Several authors have addressed this problem to determine the optimum distribution of material in the design domain for this Michelle problem. In this paper, an attempt has been made to check whether firefly algorithm can be effectively used to optimize such a complex problem involving millions of degrees of freedom. In this study only one

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half of the structure is analysed due to symmetry. Fewer number of elements were used to find one of the possible layout of the distribution of material. The analysis shows that firefly algorithm can be used effectively to determine the distribution of material in the given design domain.

Future Study

The study can be extended to solve a three point load case problem.

The study can address an inclined load case problem as well.

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