ME782 Project

Mechanical Engineering

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Defining the Problem

1.1 The Problem Statement

This project will use topology optimisation to identify and remove redundant material from a 2D rectangular structure, significantly reducing its weight while maintaining structural integrity under various loads. The concept is analogous to designing a bicycle frame; instead of using a solid block of metal, material is placed only where it is needed to effectively distribute loads and enhance strength. Our approach will determine which regions within the rectangle can be eliminated without compromising its ability to withstand applied forces, leading to a highly efficient and lightweight design.

1.2 Background

In modern engineering, the drive to create lightweight yet durable structures is essential, especially in fields such as aerospace, automotive, and cycling. Reducing material usage without sacrificing strength leads to better performance, lower costs, and improved energy efficiency. Traditional design approaches often depend on experience or trial and error, which can leave unnecessary material in the structure. Topology optimisation, however, provides a scientific and computational method to achieve material efficiency. It systematically determines where material should be retained and where it can be removed, based on how loads and stresses flow through the structure.

A practical example of this concept can be seen in bicycle frame design. A solid metal block could easily withstand loads but would be unnecessarily heavy. Instead, engineers design frames with hollow tubes, placing material only along paths where forces travel between the pedals, seat, and wheels. These tubes form an efficient skeleton that provides stiffness and strength while keeping the frame lightweight. Similarly, in this project, topology optimisation will be applied to a 2D rectangular structure to identify regions that do not significantly contribute to load-bearing. By removing redundant material and maintaining essential load paths, the resulting structure will exhibit high strength-to-weight efficiency — much like the optimized form of a modern bicycle frame. To solve this problem, we'll look into Solid Isotropic Material with Penalisation techniques for removal of material.

The Solid Isotropic Material with Penalisation (SIMP) method is a widely used approach in topology optimisation to determine the optimal material distribution within a given design domain. The core idea of SIMP is to represent the material properties of each finite element in the structure using a density variable, which can vary continuously between 0 (void) and 1 (solid material). This allows for a smooth transition between material and void, enabling the optimisation algorithm to explore a wide range of design possibilities.

1.3 Governing Equations

To solve the topology optimisation problem, we will use the Solid Isotropic Material with Penalisation (SIMP) method. The structure will be discretised into N finite elements. Each element will have a density variable x_e that can take values between 0 and 1, where 0 represents void (no material) and 1 represents solid material.