

GRADIENT BASED OPTIMIZATION OF DISCRETE STRUCTURAL MEMBERS USING CONTINUOUS SELECTION VARIABLES

Felipe Fernández

Universidad San Francisco de Quito

Keywords: discrete structural optimization, continuous relaxation methods, selection variable formulation, SIMP and RAMP penalization, gradient based optimization

Abstract

The optimal design of truss and frame structures commonly requires selecting cross sections and materials from predefined catalogs, leading to discrete and highly nonconvex optimization problems. Traditional approaches model these decisions using integer or mixed integer formulations, which are typically solved with gradient free or combinatorial methods. While these techniques can represent the discrete nature of the problem accurately, they suffer from poor scalability due to the exponential growth of the design space and the large number of structural analyses required. To address these limitations, continuous relaxation strategies have been proposed, where discrete choices are approximated using interpolation and penalization schemes. However, existing approaches often require multiple design variables per member, additional assignment constraints, or post processing steps such as rounding, which can compromise feasibility or computational efficiency. Moreover, ensuring consistent treatment of stiffness, stress, and mass within a unified framework remains a challenge, particularly for large scale structures with many members and competing design objectives.

In this work, a continuous selection variable formulation is introduced to enable gradient based optimization of structures with discrete design alternatives using a single variable per member. Material and geometric properties are interpolated through piecewise weight functions, allowing smooth transitions between catalog candidates while promoting discrete solutions through penalization. Distinct interpolation strategies are employed for stiffness, stress, and mass, and the formulation is implemented within a finite element framework based on three dimensional Timoshenko beam elements with consistent sensitivity analysis. The design problem is posed as a trade off between mass and compliance subject to explicit stress constraints evaluated at multiple locations, avoiding the need for aggregation. The resulting nonlinear optimization problem is solved using an interior point method, and a global optimization strategy is incorporated to improve exploration of the nonconvex design space. Numerical results demonstrate that the

proposed framework can recover high quality discrete designs efficiently, while providing improved robustness and scalability compared to existing approaches.