Layout optimization of roof structures: from benchmark to practical solutions

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Abstract

Digital design tools provide designers wishing to create bespoke building designs with significant design freedom. Given this, optimization tools are increasingly being used to identify optimal structural forms, often using metaheuristic optimization methods. However, there is 'no free lunch' [1] - since these methods are computationally inefficient designers normally limit design freedom by employing only a few design variables. Alternatively, larger scale optimization problems can be solved using gradient-based methods. However, these methods also become computationally expensive when practical design requirements are incorporated. It should also be borne in mind that, when solving complex (e.g., nonconvex) optimization problems, only local optima are likely to be found; the optimality status (i.e., the gap to the global optimum) of the reported structural forms remains unknown in both approaches. Therefore, it is of interest to develop optimization methods that can provide benchmark solutions, against which the optimality of alternative designs can be evaluated.

To achieve this, the long established numerical layout optimization method [2] is here employed. Since the underlying optimization problem is convex, a global optimum is guaranteed. In addition, the computational process is extremely efficient; e.g., problems with 1,000,000 design variables can be tackled in less than one minute on a modern PC. This means that layout optimization is capable of identifying benchmark solutions that are globally optimal for a given numerical discretization. Also, considering truss structures supporting roof loads, transmissible loads [3] can be included in the formulation. This allows loads to migrate to their most optimal point of application in the optimization process, also defining the envelope of the structure.

The traditional numerical layout optimization procedure [2] incorporates only linear constraints; thus practical constraints, which are often non-linear and non-smooth in character, cannot be included, leading to potentially impractical structural forms (e.g., including long members that are prone to buckling failure). To address this, linearly relaxed constraints can be included, so that the relaxed problem produces a solution that bounds the true globally optimal solution from below. This solution can then be used as a benchmark as part of a global-local optimization framework as follows: firstly, a linearly relaxed problem is solved to provide a benchmark; then the relaxations are removed, and the original more complex optimization problem solved, with e.g., the structural volume prescribed to be within a specified % of the benchmark if desired.

Using this global-local optimization framework, a range of roof-like structures are optimized with a number of common practical constraints incorporated, including local (Euler buckling) and global stability constraints, joint complexity, and deflection limits under pattern loads. Several examples are shown to demonstrate the efficacy of the proposed method.

References

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