Discrete design optimization under buildability constraints

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Abstract

The optimal design of structures has been an important research topic over the past half century. Numerous scientific papers have been published in this field. Nevertheless, practicing structural engineers seem to hesitate to adopt optimization as a daily design tool, even for relatively simple and tedious tasks such as the sizing of the members of a steel structure. One of the reasons for this apparent reluctance is the fact that it is very difficult to ensure the buildability of the optimized design by taking into account the appropriate technological constraints.

In this paper we present a method to account for technological constraints in design optimization. The method is applicable to any design optimization problem, but in order to demonstrate the idea we apply it here to a simple (but realistic) example problem: the size and shape optimization of a Warren truss under static loading. The truss is composed of steel Circular Hollow Section (CHS) members. The objective is to minimize the weight of the truss. The usual displacement, member force, and buckling constraints as formulated in Eurocode 3 are imposed. In addition, the joints must satisfy the rules specified in the CIDECT design guide for CHS joints, the member sections must be chosen from a given section catalog, all top chord members must have the same external size, and all bottom chord members must have the same external size.

In practice, this optimization problem is often solved by means of a fully stressed design approach. In this way, a design is found that satisfies all member checks, but the joints remain to be designed manually. Dependent on the sections chosen for the braces and the chords, some of the joints will need to be strengthened by means of stiffening plates or by locally using a heavier section. Such interventions require additional welding (and testing of the welds), and this has a serious impact on the fabrication cost.

We present a new optimization scheme for discrete design optimization based on the optimality criteria method. In order to obtain a buildable design, all technological constraints are enforced throughout the optimization procedure, thereby avoiding the need for manual postprocessing. The optimization scheme proceeds as follows: if the design is infeasible, the investment in the most cost-efficient optimization parameter is increased. If the design is feasible, the investment in the least cost-efficient optimization parameter is reduced. Eventually all optimization parameters are equally efficient; at this point we can no longer improve the design by saving on parameter A in order to invest in parameter B; the optimum is reached.

The optimization scheme developed is successfully applied to the example problem. In addition, a simpler problem is considered to make a comparison with a genetic algorithm (the constraints on the external chord member sizes are dropped as the genetic algorithm is unable to handle them): the final value of the objective function is practically identical for both optimization methods, but the computation time is 10 to 100 times lower for the new method.