Evolutionary Multiobjective Optimization of Steel Structural Systems in Tall Buildings

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Abstract. This paper presents results of extensive computational experiments in which evolutionary multiobjective algorithms were used to find Pareto-optimal solutions to a complex structural design problem. In particular, Strength-Pareto Evolutionary Algorithm 2 (SPEA2) was combined with a mathematical programming method to find optimal designs of steel structural systems in tall buildings with respect to two objectives (both minimized): the total weight and the maximum horizontal displacement of a tall building. SPEA2 was employed to determine Pareto-optimal topologies of structural members (topology optimization) whose cross-sections were subsequently optimized by the mathematical programming method (sizing optimization). The paper also presents the shape of the Pareto front in this two-dimensional objective space and discusses its dependence on the building's aspect ratio. The results reported provide both qualitative and quantitative knowledge regarding the relationship between the two objectives. They also show the trade-offs involved in the process of conceptual and detailed design of complex structural systems in tall buildings.

Keywords: evolutionary multiobjective optimization, structural design, Pareto front, tall buildings.

1 Introduction

Finding solutions for many structural engineering problems involves multiple and often conflicting objectives. Traditionally, however, due to lack of efficient multiobjective optimization methods, a single 'most important' criterion was selected and treated as the objective with respect to which structural designs were optimized. The remaining objectives were usually converted into constraints which were subsequently used to determine the feasibility of generated structural designs [1]. In the vast majority of structural design applications, the total weight of a structural system was employed as the objective of choice mainly because it can be regarded as a good estimate of structural system's cost [2]. In several other studies, including authors' previous research [3], multiple design objectives were combined into an

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aggregate fitness function using a linear combination of weights [4]. This approach, however, has its obvious limitations. They include the necessity of conducting a large number of design optimization runs for each combination of weights in order to determine the shape of the Pareto front as well as inability to produce proper Pareto optimal solutions when the design spaces are non-convex [5].

Thus, in this paper, we extend the previous aggregate function approach to multiobjective optimization of steel structural systems in tall buildings by using a 'truly' multiobjective optimization algorithm, namely the Strength-Pareto Evolutionary Algorithm 2 (SPEA2) [6]. In our study SPEA2 was used to optimize topologies of steel structures in tall buildings with respect to two objectives (both to be minimized): the total weight and the maximum horizontal displacement of a tall building. SPEA2 was integrated with a mathematical programming method which was utilized to determine optimal cross-sections of structural members. Thus, multiobjective topology and sizing optimization of steel structural systems in tall buildings was achieved.

A large number of computational structural design experiments was conducted in order to determine the shape of the Pareto front in this two-dimensional objective space and its dependence on the building's aspect ratio. In order to achieve this goal, the reported experiments were performed for two classes of steel structural systems in tall buildings: one with 30 stories and 5 bays with a relatively small aspect ratio and the other with 36 stories and 3 bays with a relatively high aspect ratio. The qualitative and quantitative relationships between the two objectives have been investigated and identified for both classes of structural design problems. Also, as in the authors' previous study [3], the qualitative changes among topologies of structural systems located in various regions of Pareto front were analyzed.

The paper is organized as follows. First, a brief review of the history of evolutionary optimization in structural engineering is presented together with a short introduction to the structural design problem investigated in this paper. Next, the problem of topological optimum design of steel structural systems in tall buildings is formalized and its representation introduced. Further, the structure and parameters of conducted multiobjective optimization experiments are described and followed by discussion of obtained results. Finally, initial conclusions are provided.

2 Background

2.1 Evolutionary Computation in Structural Design

The concept of evolutionary-based optimization in structural design is not new. It has a relatively long history dating back to the 1980s and to the initial applications of evolutionary algorithms to sizing and shape optimization of relatively simple structural systems (e.g., trusses [7, 8] and frames [9]). The progress in the fields of evolutionary computation and computing resulted in applications of evolutionary methods to more complex and computationally intensive structural design problems, including the topology optimization of discrete-member trusses [10], topology