A Comparison of Evolutionary Algorithms on Stress-constrained Multi-objective Topology Optimization of Truss Structures

Hao Hu, Gang Li
Department of Engineering Mechanics,
State Key Laboratory of Structural Analyses for Industrial Equipment,
Dalian University of Technology, Dalian, 116024, China

Abstract

Many industrial problems involve stress constraints, multiple performance requirements and only allow for commercially available discrete member sizes. As a conceptual design methodology, topology optimization is naturally extended to multi-objective cases with discrete element sizes. Evidently, this multi-objective combinatorial optimization problem is posed with integer sizing variables and Boolean topology variables. In contrast to the compliance minimization problems, single-objective stress-constrained topology optimization of truss suffers from the singularity problem, then the global optimal condition cannot be guaranteed, and this situation is very likely to propagate into multi-objective cases. On the other side, the gradient-based algorithms might be low efficient when assisted with some discrete variable handling techniques in stress-constrained cases. These difficulties make conventional gradient-based methods not so reliable and efficient as in other cases and call for new techniques.

Multi-objective evolutionary algorithms (MOEA) are categorized as stochastic search methods and particularly suitable for discrete multi-objective topology optimization (DMOTO) owing to their good robustness, inherent parallelism, and ability to approximate all the trade-off pairs within a single run. They can also mend the above mentioned possible defects of gradient-based optimization, such as non-smooth utility function, disconnected design space and local minima. Some researchers applied MOEA to this field recent years, but the studies all concentrated on avoiding infeasible solutions and increasing efficiency from the perspective of topology optimization itself. However, the performance discrepancies among different MOEAs on topology optimization have been completely overlooked. And the true Pareto fronts of the test problems have not been rigorously derived, which make it difficult to exhibit the strengths and weaknesses of the algorithms, let alone to compare gradient-based and non gradient methods MOTO.

This work is the first step before the comparative study between gradient-based methods and MOEAs. Unlike the former, the performance discrepancy among the latter is significant, hence the state-of-the-art of MOEAs' performance on DMOTO must be revealed. We analyze a set of stress-constrained problems with different dimensionality and their counterparts with adjustable shapes to test the limit of existing algorithms. Their optimal Pareto fronts with different shape and configuration are derived using parallel numerating method. A recently proposed performance assessment procedure is employed to perform the comparative study with emphases on convergence and efficiency. The results not only reveal competent MOEAs and several difficulties for DMOTO of truss structures but also provide a reference to test the efficiency of gradient-based methods and MOEAs.

Key words—Multi-objective evolutionary algorithm, topology optimization, combinatorial optimization, Pareto front, Stress constraint