Models and numerical methods for optimal design of fail-safe structures

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Abstract

Fail-safe structural optimization problems ensure that the found design is safe even after a certain number of predefined types of damage conditions apply in the worst-case locations or scenarios. Loss of structural properties due to these damages can as a result be mitigated which is important to ensure safety. The economic consequences of the damage can also be reduced since the structure can continue carrying loads until the damage can be repaired or the damaged part replaced. One considered engineering application is conceptual and preliminary fail-safe optimal design of offshore wind turbine support structures which are often welded steel frame structures (jackets). In this application, the design requirements are based on mass, strength, fatigue, and dynamic properties. Local damages are modelled as either complete loss or thickness degradation of some predefined number of members.

Fail-safe sizing optimization of truss structures dates back to [1]. The problems in [1] are minimum weight problems with strength, displacement, and dynamic constraints. The number and the locations of the damaged members are considered to be known a priori resulting in small-scale problems by today's standards. More recently, fail-safe design based on topology optimization of continuum structures was proposed in [2]. Local failures are in [2] modelled by removing material in patches of predefined location, shape, and size. The objective function is the worst-case compliance.

A major computational obstacle in fail-safe structural optimization is the large number of constraints required if the damage locations are considered to be unknown. This is particularly the case for the considered application. The considered problems are modelled as nonlinear constrained optimization problems by enumerating all damage scenarios. Rather than resorting to constraint aggregation techniques we pursue a theoretically and computationally appealing possibility based on constraint generation. It is similar to the working-set approach proposed in [3] for sizing optimization of frame structures under transient analysis and strength constraints. In the working-set algorithm a sequence of nonlinear optimization problems are solved. These are relaxations of the original problem and obtained by removing most of the complicating constraints. Some violated constraints are re-introduced, the relaxation is resolved, and the process is repeated. For some problem classes this ensures global optimality and we outline the theoretical properties of the algorithm and the favorable situations.

Numerical experiments of both topology optimization and sizing optimization are presented. The results indicate that optimal topologies and structural dimensions in fail-safe design can change drastically compared to the nominal design even for moderate damage. They also suggest that the working-set approach is an efficient and robust way of solving the problems.

References

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