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Computational framework for topology optimization under stress and stability constraints

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1. Introduction

The goal of this study is to develop a MATLAB-based computational framework for structural topology optimization under stress and stability constraints. This framework can be applied in various fields of engineering, such as the design of lightweight structures and machine parts, control of mechanical properties during topology optimization, and ensuring structural safety by controlling the probability of failure, to name a few [1].

Contrary to recently used by many researchers a compliance-based topology optimization in this study a stress based fomulation is utilized. However, including in topology optimization local material failure criteria, such as stress constraints, has two major challenges:

1) topology optimization with many local (stress) constraints becomes computationally very expensive using gradient-based optimization,

2) so-called 'singular optima' arise in topology optimization with stress constraints.

To tackle the above mentioned problems in this study stress-constrained approach is proposed based on a fully stressed design methodology [2].

2. Methodology

For effective solution of the stress constrained topology optimization the design problem is formulated in the following way: we are looking for minimum-weight design of structure made of elastic or elastoplastic material with constraints imposed on allowable stresses and buckling load multiplier.

Additionally beside of purely deterministic cases the proposed methodology comined with first order reliablity analysis is able to find optimal topology of the stucture subjected to probabilitic loads.

For that purpose a newly developed program called MorphoGen system is used [3]. The system is written in MATLAB using an object-oriented programming (OOP) paradigm and a layered architecture, both of which allow efficient development of the system. The system also includes two main layers:

• the first one is responsible for finite element analysis (FEA) [4] and
• the second one for reliability assessment.

3. Results

Effectivenss of the proposed methodology has been demonstraed on a example of a single module of Arm-Z manipulator. Arm-Z is a concept of a robotic manipulator comprised of linearly joined congruent modules with possibility of relative twist (1 DOF). The advantages of Arm-Z are: economization (massproduction) and robustness (modules which failed can be replaced, also if some fail the system can perform certain tasks).

Non-intuitive and difficult control are the disadvantages of Arm-Z.

In other words, the combination of non-trivial module shape with forming of practical modular structures and their control (from state A to B) is computationally expensive.

During the numerical simulation it has been shown that the optimal topology of the Arm-Z module obtained without taking into account buckling constraints can lead to unsafe designs.

4. Conclusions

In this study a unified computational framework that integrates reliability-based topology optimization with various type of constraints, including displacements, elastoplastic stresses, low-cycle fatigue and buckling, has been proposed.

For that purpose the MorphoGen - an integrated software package has been used, development of which has been inspired by topological optimization of Extremely Modular Systems.

The effectiveness and constraints and importance of buckling of the proposed methodology was demonstrated on the example of elephant trunk manipulators built from Arm-Z tubular modules.

4. References

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