AALBORG UNIVERSITY

Department of Mechanical and Manufacturing Engineering

Optimal Design of Fatigue-Loaded Jacket Offshore Support Structures

J. Oest, L. C. T. Overgaard and E. Lund

Department of Mechanical and Manufacturing Engineering

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1. Introduction

To further incorporate the operational conditions in the design of support structures for offshore wind turbines, we need rational, trustworthy, and efficient methods to evaluate and optimize for multiaxial, non-proportional fatigue-loading.

The goal of this PhD project is to develop efficient gradient-based fatigue optimization techniques and demonstrate them on a model of a support structure for a large offshore wind turbine in deep waters.

This PhD project is part of the Advancing BeYond Shallow waterS (ABYSS) project that aims at developing a design tool for engineers to design jacket structures for offshore wind turbines. The project is funded by the Danish Council for Strategic Research.

See www.abyss.dk for more information.

2. Optimization Framework

In deeper waters the jacket structure is often chosen as the support structure. Jacket structures are widely used in oil and gas industry, and the design is often based on their knowledge. However, a support structure for a wind turbine experiences completely different loads and consequently very different structural response.

LOADS

The huge time-history loads used in design of support structures give a computational intensive structural analysis which has to be run in each optimization iteration.

The wind and self-weight loads will be determined from multibody simulations by DTU Wind Energy, see figures below.

The wave loads and the soil-structure interaction boundary conditions will be developed by DTU Civil Engineering.

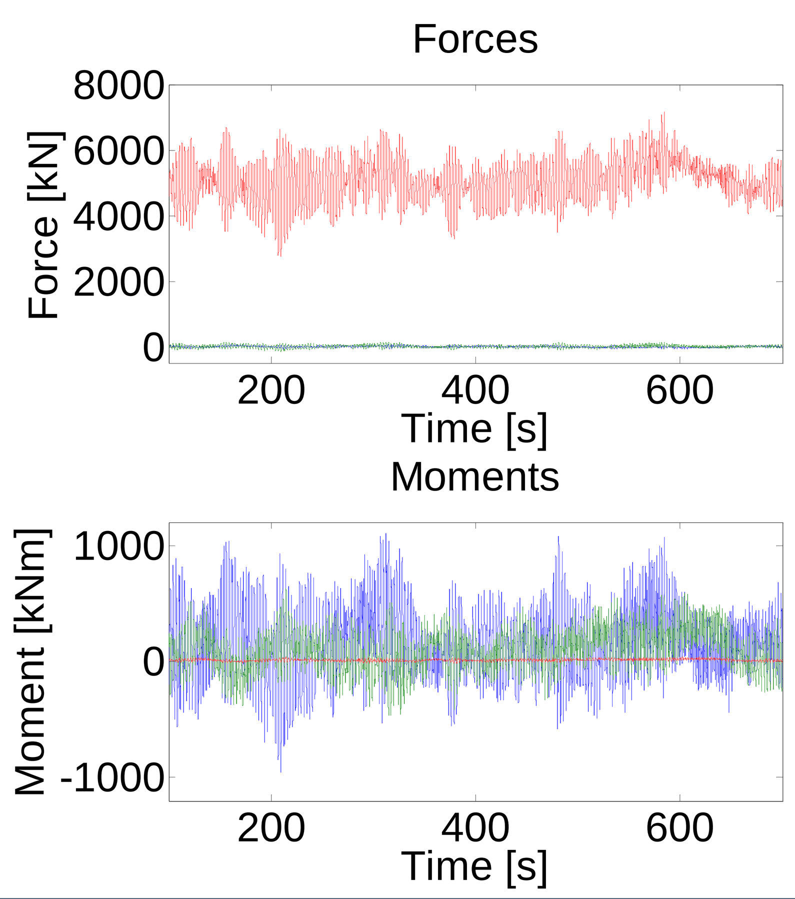
CONSTRAINTS

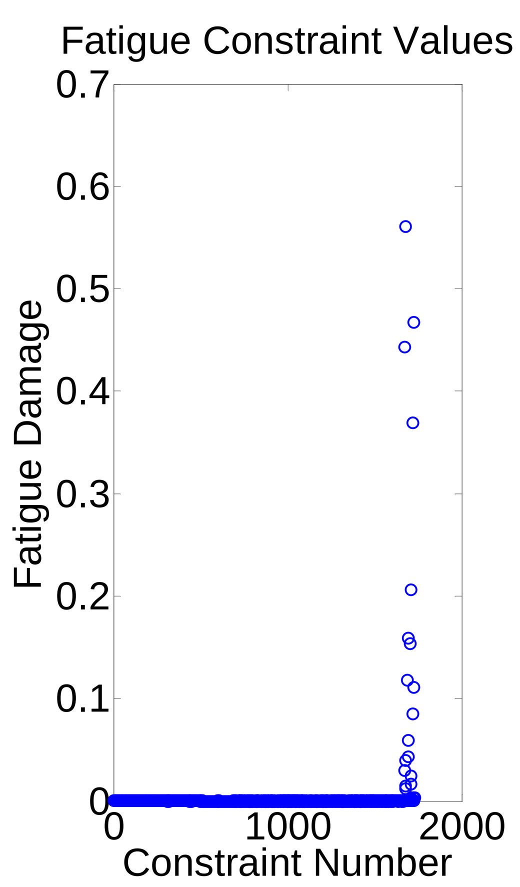
Non-proportional multiaxial loading makes it very difficult to predict where the highest local accumulated damage will occur. Consequently, a large number of constraints must be added, see figure below.

To capture multiaxial effects, non-proportionality effects, and sequential effects in the constraint equations can be very difficult as no generally accepted fatigue criteria exists for this.

OPTIMIZATION

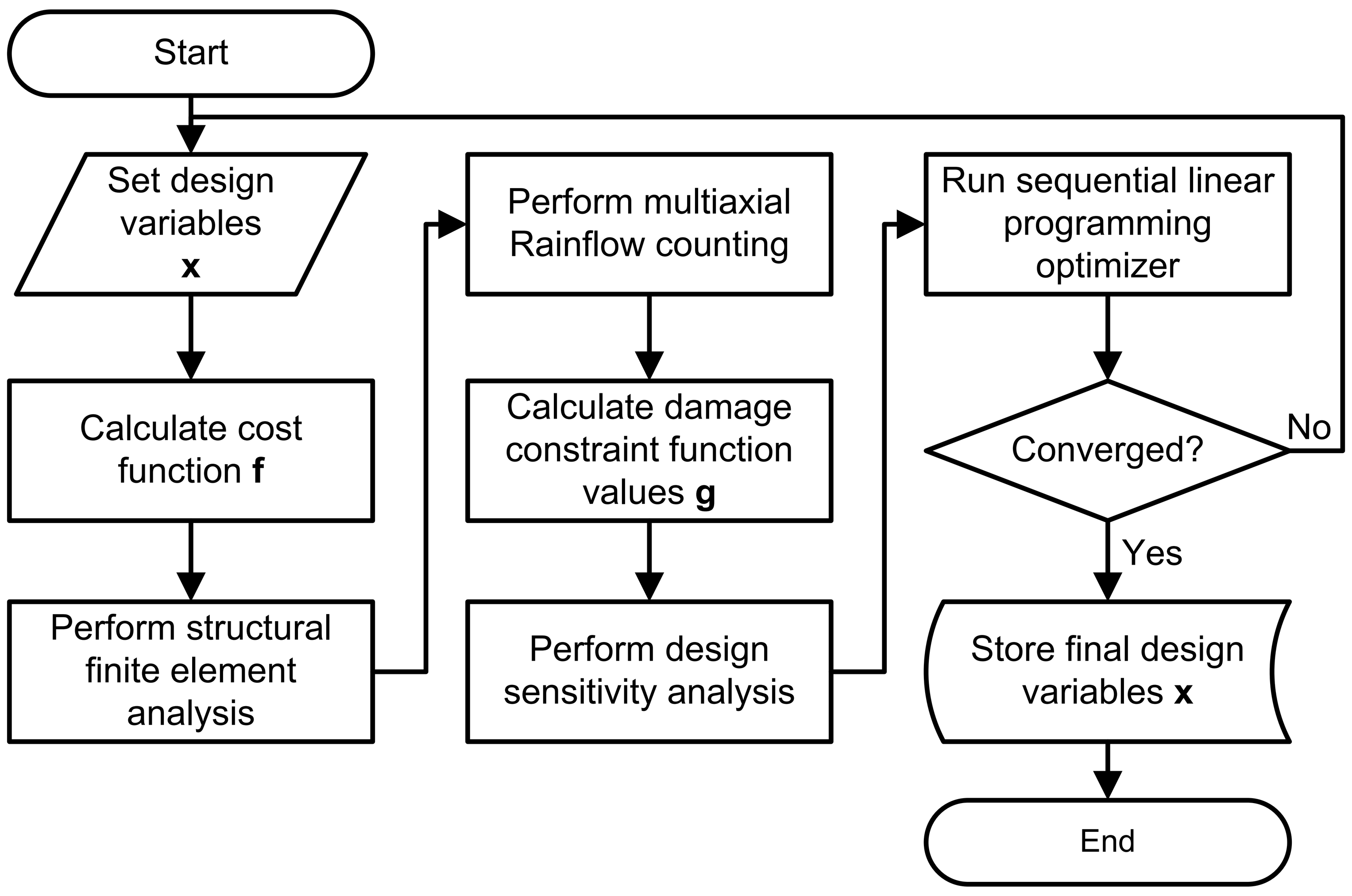
Gradient-based optimization techniques will be utilized to reduce the overall cost of the support structure. The number of design variables will be relatively small, however, there will be a large number of very non-linear inequality constraints.





3. Methods

The fatigue optimization routine can be outlined as:



The majority of the work will consist of the development of the analytical design sensitivity analyses, handling the many constraints and correctly capturing multiaxial and non-proportional effects.

Doing this in a computational efficient manner will be a novel contribution to the field of structural optimization.

Everything is currently being developed in MATLAB, but interfacing with the commercial program FE-SAFE by Dassault Systèmes is planned.

4. Current Work Status

An initial framework has been established. The work so far includes:

Highly idealized fixed-free jacket represented by linear 3D beam finite elements has been implemented and verified. Only wind loads are currently applied to the structure.

Constraints based on Palmgren-Miner's linear damage hypothesis and the Modified Goodman equation for mean stress correction have been implemented and verified.

Design Sensitivity Analysis using the Adjoint method, the Direct Differentiation method, or the Central Finite Difference method has been implemented and verified. Different aggregation functions have also been implemented.

Minimum mass optimization with tube diameter and thickness as design variables has been successfully implemented using IBM CPLEX optimizer. Symmetry conditions for easy manufacturing of the jacket have been used.

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