technische universität dortmund

fakultät statistik

Project “Computer Experiments”

Fallstudien II / Case Studies II

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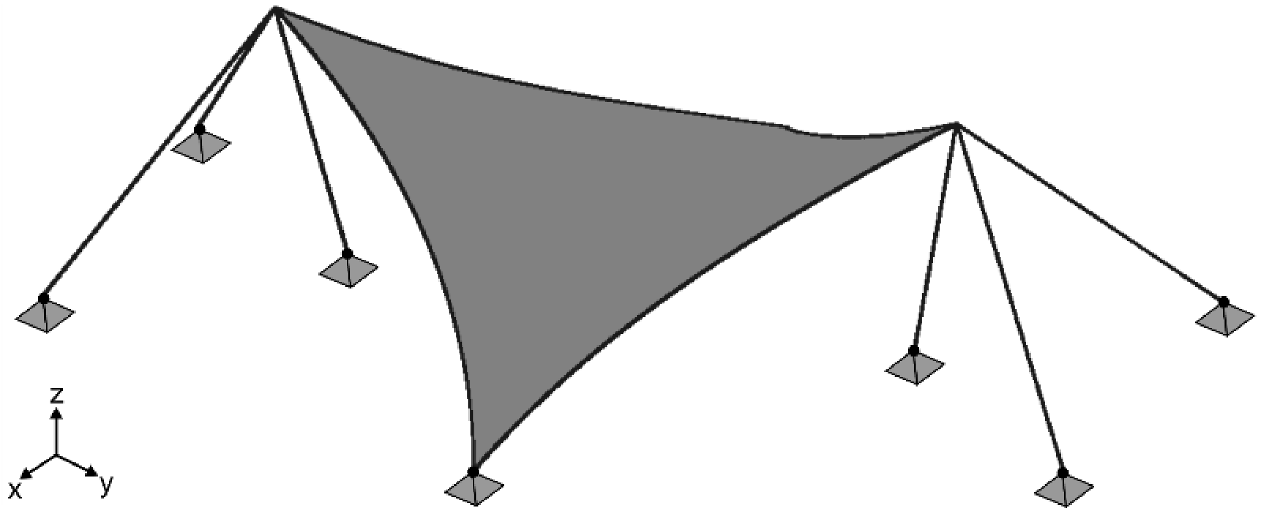
Computer Model: Sun Sail

- Structure parts of the sun sail: membrane, truss, edge and support cables
- Membrane structure with hyperbolic paraboild shape
- Base area of membrane is 6 m $\times$ 6 m and a height of 3 m
- Structure is supported by elastic trusses, which are braced by pre-stressed cables

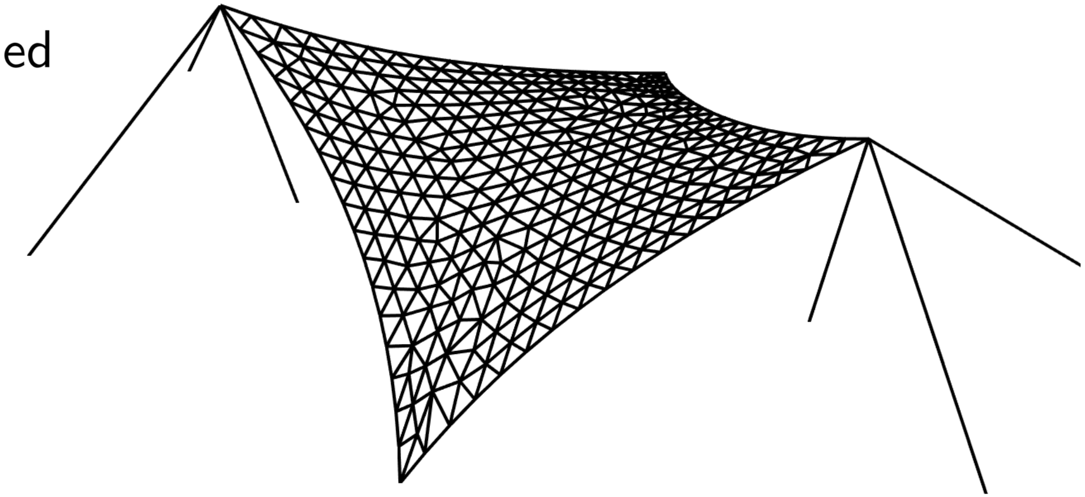


Computer Model: Sun Sail

- Assume an isotropic pre-stress σ_{mem} for the membrane
- Edge and support cables are pre-tensioned by σ_{edg} and σ_{sup}
- Membrane is modeled with a linear elastic, isotropic material law defined by Youngs's modulus E_{mem} and Poisson's ratio ν_{mem}
- Winkling deformation due to tension loss is taken into account
- Sun sail is subjected to a snow load f_{mem}
- Model response: Maximal Cauchy stress in the membrane $\sigma_{\text{mem, max}}$
- Structure fails when the maximum stress in the membrane $\sigma_{\text{mem, max}}$ exceeds the rupture stress $\sigma_{\text{mem, y}}$

Computer Model: Sun Sail

- Pre-stressed membrane structure is represented by a finite element model
- Finite element mesh with 690 elements
- Structural analysis is performed with the open-source multi-physics software `Kratos`[1,2]
- Computer model depends on a set of (uncertain) material parameters



[1] Dadvand, P., Rossi, R., Oñate, E. (2010). An Object-oriented Environment for Developing Finite Element Codes for Multi-disciplinary Applications. *Archives of Computational Methods in Engineering*, **17**(3):253–297. https://doi.org/10.1007/s11831-010-9045-2.

[2] Ferrándiz, V. M., Bucher, P., Zorrilla, R., et al. (2023). *KratosMultiphysics/Kratos: Release 9.3*. https://doi.org/10.5281/zenodo.7681287.

Model Input Parameters

Part	Quantity	Symbol	Unit	Distrib.	Mean	Std.
Membrane	Young's modulus	E_{mem}	[GPa]	Lognormal	0.6	0.09
	Poisson's ratio	ν_{mem}		Uniform	0.4	0.0115
	thickness	t_{mem}	[mm]	Deterministic	1	
	pre-stress	σ_{mem}	[MPa]	Lognormal	4	0.8
	surface loading	f_{mem}	[kPa]	Gumbel	0.4	0.12
	rupture stress[1]	$\sigma_{\mathrm{mem,\,y}}$	[MPa]	Lognormal	11	1.650
Truss	Young's modulus	E_{tru}	[GPa]	Deterministic	205	
	cross sectional area	A_{tru}	[cm^2]	Deterministic	25	
Edge cable	Young's modulus	E_{edg}	[GPa]	Deterministic	205	
	diameter	d_{edg}	[mm]	Deterministic	12	
	pre-stress	σ_{edg}	[MPa]	Lognormal	353.678	70.735
Support cable	Young's modulus	E_{sup}	[GPa]	Deterministic	205	
	diameter	d_{sup}	[mm]	Deterministic	12	
	pre-stress	σ_{sup}	[MPa]	Lognormal	400.834	80.166

[1] No parameter of the structural analysis model.

Finite Element Methode

1. Definition of continuous governing equations (usually partial differential equations) and boundary conditions
2. Discretisation of the entire domain into a finite number of small elements connected by nodes
3. Reformulating the original differential equations in a "weak form" for each element
4. Assemble equations from all elements into a global system of equations that represents the entire domain and apply boundary conditions
5. Solve the large global system of linear equations

Surrogate Model

- Computationally expensive deterministic model not sustainable
- Surrogate model: Approximate time-consuming computer model by a computationally cheaper model

What is a suitable choice for a surrogate model?

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- Computer model runs are required to train a surrogate model

Design of Computer Experiments

How to select "optimal" design points for evaluating the computer model?

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- Simplifying assumptions:
  - Homogeneously distributed material parameters across the membrane
  - Stochastically independenten material parameters
- Limited budget for computer model runs $n_{\max} \leq 200$

Analysis of Computer Experiments

What could be possible research questions?