
Project “Computer Experiments”

Fallstudien II / Case Studies II

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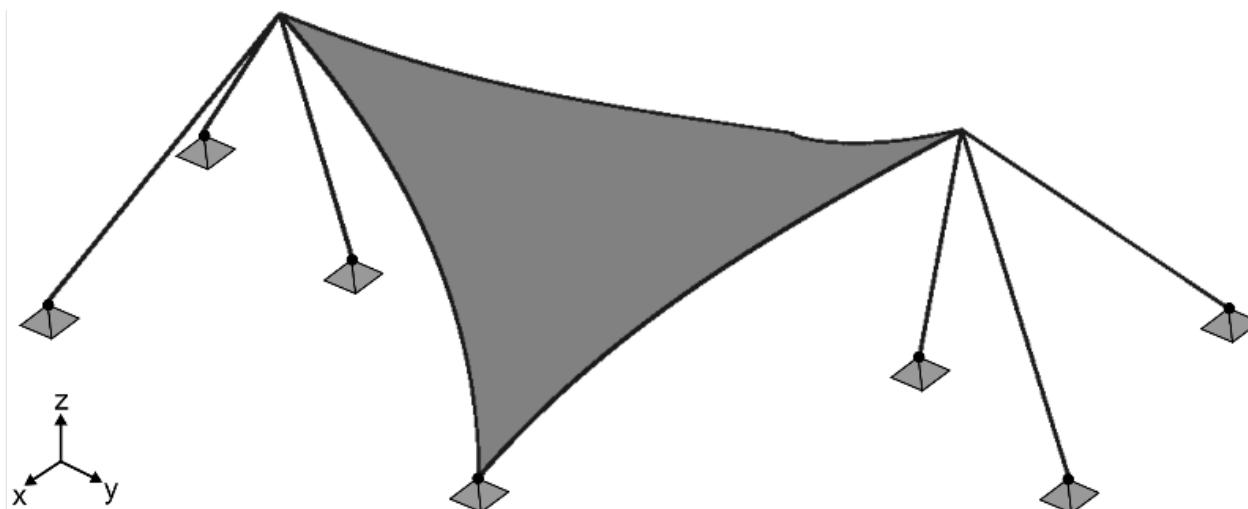
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Computer Model: Sun Sail

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

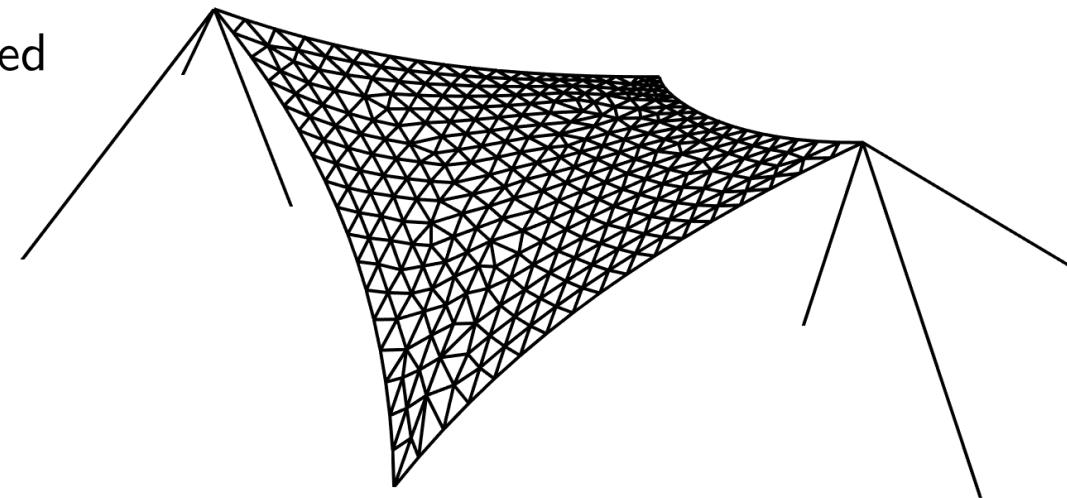


Computer Model: Sun Sail

- 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



¹Dadvand, 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>.

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

Model Input Parameters

$\sigma_{\text{mem, max}}$: Maximal Cauchy stress

| 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 | $\sigma_{\text{mem, y}}$ | [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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How to select “optimal” design points for evaluating the computer model?

- 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?

⇒ $\Delta_{\text{Mem, Max}}$ | parameters