Structural Optimization 2025 - Project #1

Description: A tripod is supported at Nodes 1, 2 and 3, according to the figure below. The force F at Node 4 is applied in the negative z-direction. Find the values of x_1 and x_2 such that the following objective function is minimized:

$$f = \sqrt{\|R_1\|^2 + \|R_2\|^2 + \|R_3\|^2}$$

where $\|R_1\|$, $\|R_2\|$ and $\|R_3\|$ are Euclidean norms of the reaction forces from the supports. The values x_1 and x_2 are xy-plane nodal movements of Node 4.

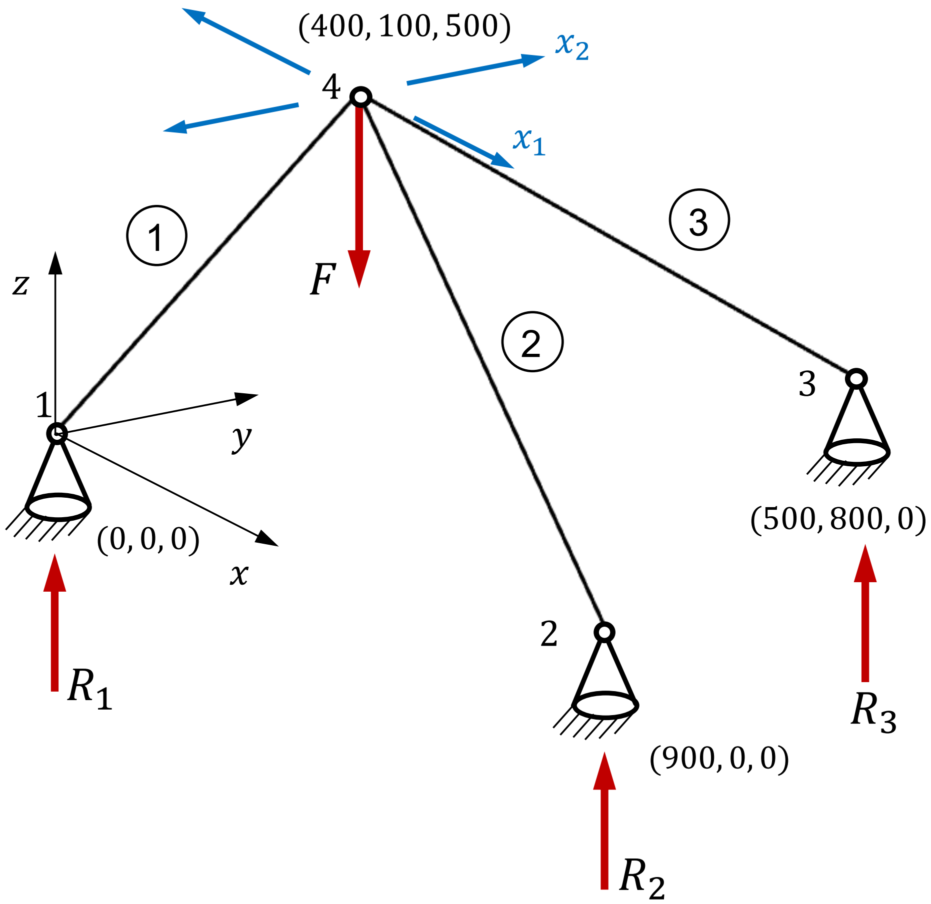

Figure 1. Tripod with cross-section sizes $A_1 = A_2 = A_3 = 15\ \mathrm{mm}^2$, load $F = 1000\ \mathrm{N}$, and Young' modulus $E = 210\ \mathrm{GPa}$

Required libraries and templates: Download EDACFEM: A linear truss and beam FE simulation environment implemented in MATLAB from Moodle. The environment supports a linear truss formulation and both Euler-Bernoulli and Timoshenko beam models. The environment requires MATLAB Parallel Computing Toolbox and MATLAB Optimization Toolbox. The project hand in template is available on Moodle for download.

Tasks:

1. Calculate the structural response of the tripod using EDACFEM. Model the tripod based on the Euler-Bernoulli beam model. Calculate and report the value of the objective function f for $\mathbf{x}^{(1)} = (-200,\ -200)^{\mathrm{T}}$.

2. Use the quasi-Newton method in MATLAB to minimize the objective function f in terms of nodal movements x_1 and x_2. Calculate the structural response of the tripod using EDACFEM. Set $\mathbf{x}^{(1)} = (0,\ 0)^{\mathrm{T}}$ as the optimization starting point and report $\mathbf{x}^*$ and $f(\mathbf{x}^*)$. Visualize the displacement field and von Mises stress of the optimized structure using EDACFEM interfaces.

3. Calculate the sensitivities of the objective function using the first-order finite differences approximations. Calculate the step size for the first-order finite differences approximations of the sensitivities of the objective function based on the following five points: $\mathbf{x}_1 = (-500,\ -500)^{\mathrm{T}}$, $\mathbf{x}_2 = (500,\ 500)^{\mathrm{T}}$, $\mathbf{x}_3 = (-500,\ 500)^{\mathrm{T}}$, $\mathbf{x}_4 = (500,\ -500)^{\mathrm{T}}$, $\mathbf{x}_5 = (0,\ 0)^{\mathrm{T}}$. Report the gradient of the objective function for $\mathbf{x} = (200,\ 100)^{\mathrm{T}}$.

4. Implement the steepest descent method and inexact line search with bracketing and backtracking based on the Armijo's rule to optimize the tripod structure. Use solutions of Tasks 1 and 3 to set up the structural optimization workflow. Calculate the step size for the first-order finite differences approximations of the objective function sensitivities based on the points from Task 3. Set $\mathbf{x}^{(1)} = (0,\ 0)^{\mathrm{T}}$ as the optimization starting point and report $\mathbf{x}^*$ and $f(\mathbf{x}^*)$ such that the objective function f is minimized. Use $\eta = 2$, $\rho = 0.2$, $\mu = 0.5$, and the stopping conditions $\|\nabla f\|_2 \leq$ 1e-6 and $i \geq 30$ (number of iterations).

Bonus Task: Implement the BFGS method and inexact line search based on the implementation from Davidon. Use solutions of Tasks 1 and 3 to set up the structural optimization workflow. Calculate the step size for the first-order finite differences approximations of the objective function sensitivities using the points from Task 3. Set $\mathbf{x}^{(1)} = (0,\ 0)^{\mathrm{T}}$ as the starting point and report $\mathbf{x}^*$ and $f(\mathbf{x}^*)$ such that the objective function f is minimized. For the line search use $\gamma = 0.9$. Implement the stopping conditions using $\|\nabla f\|_2 \leq$ 1e-6 and $i \geq 30$ (number of iterations).

Deliverables and how to submit: Write a one-page report comprising the reported values as required in Tasks 1-4, and Bonus Task if applicable. Group the one-page report and all MATLAB files relevant for each task in corresponding folders Report, Task_1, Task_2, Task_3, Task_4 and Bonus_Task folder if applicable. <u>Do not submit the EDACFEM framework files</u>. Compress all folders in one file and submit using the Project#1 task submission on Moodle.

Submission deadline: 11:59PM, 26.03.2025

Important information: To receive the ECTS credits for the course, it is required that an overall passing grade is obtained after submitting each of the three projects, which are to be completed individually. Each project consists of four tasks, Tasks 1-4, worth 25 Points each. The total number of points per project is 100. Each project has one additional Bonus Task worth 100 points and graded separately to the Tasks 1-4. If a passing grade is obtained over all three Bonus Tasks, a final grade bonus of 0.5 is awarded.