**Mechanics of Flexible Structures & Soft Robots**
MAE-263F
Fall 2025

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# Homework 2

**Due Date: 11:59 PM, 10/27/2025**

You should create a single GitHub repository for this class and share it with the instructor (`khalidjm@seas.ucla.edu`). All the homeworks, reports, presentations, and proposal should be uploaded to this repository. Do not create a separate repository for each assignment. Within your repository, create a separate folder for each assignment (e.g., `homework_1`, `homework_2`, `homework_3`, `homework_4`, `homework_5`, `proposal`, `midterm_report`, and `final_report`).

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**Submission Instructions:** Your submission on BruinLearn should only contain the URL to your GitHub repository. Your GitHub repository should include the following items:

1. **Report in PDF format:** Submit a report in `.pdf` format (file name should be `Homework1_LASTNAME.pdf`, replacing `LASTNAME` with your last name) addressing the questions asked in the deliverables. Include all the plots and figures requested in the assignment and discuss them in the report. See the syllabus for formatting requirements. As stated in the syllabus, you must use one of the provided templates.

2. **Source code:** The submission should include one main file named exactly as `HomeworkX.[ext]` (where `X` is the homework number) along with any additional files (e.g., functions or text files) as necessary. The main file should require no more than a single command to run or one click for execution.

3. **README file:** Add a `README.md` file on GitHub to provide clear instructions on how to run your code and describe the purpose of each file included in your repository.

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Recall Euler-Bernoulli beam theory from elementary mechanics class. You can look up the solution for a simply-supported aluminum beam subjected to a single point load. The beam has length $l = 1$ m and a constant, circular-tube cross section with outer radius $R = 0.013$ m and inner radius $r = 0.011$ m. A force, $P = 2000$ N, is applied 0.75 m away from the left-hand edge.The modulus of elasticity is $E = 70$ GPa for aluminum and $I$ is the moment of inertia of the cross section, $I = \frac{\pi}{4}(R^4 - r^4)$.

We can represent the beam as a mass-spring system with a mass $m$ located at each node where

$$m = \pi(R^2 - r^2)l\rho/(N - 1) \tag{1}$$

and density of aluminum is $\rho = 2700$ kg/m$^3$. The formulation of the elastic energy remains the same. Instead of gravity and viscous drag as external forces, the only external force is the force $P$ applied at a node that is located 0.75m away from the first node. If no node is exactly 0.75 m away, take the node that is closest to the desired distance.

Also note that the first node is constrained along both $x$ and $y$-axes and the last node is constrained

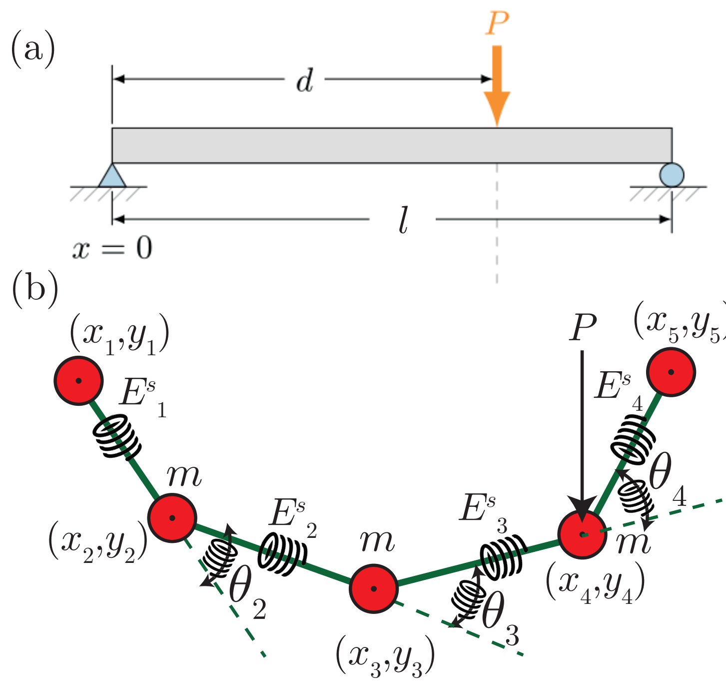


Figure 1: (a) Elastic beam and (b) its discrete representation.

along $y$-axis. For these three constrained degrees of freedom, the governing equations are simply

$$x_1(t_{k+1}) = 0, \tag{2}$$

$$y_1(t_{k+1}) = 0, \tag{3}$$

$$y_N(t_{k+1}) = 0. \tag{4}$$

**Task:** Write a solver that simulates the beam as a function of time (between $0 \le t \le 1$ seconds) implicitly. Use $\Delta t = 10^{-2}$ s for the implicit simulation and $N = 50$.

1. Plot the maximum vertical displacement, $y_{\max}$, of the beam as a function of time. Depending on your coordinate system, $y_{\max}$ may be negative. Does $y_{\max}$ eventually reach a steady value? Examine the accuracy of your simulation against the theoretical prediction from Euler beam theory:

$$y_{\max} = \frac{Pc\left(l^2 - c^2\right)^{1.5}}{9\sqrt{3}EI\,l} \qquad \text{where} \qquad c = \min(d, l-d) \tag{5}$$

2. What is the benefit of your simulation over the predictions from beam theory? To address this, consider a higher load $P = 20,000$N such that the beam undergoes large deformation. Compare the simulated result against the prediction from beam theory in Eq. 5. Euler beam theory is only valid for small deformation whereas your simulation, if done correctly, should be able to handle large deformation. You should create a plot of $P$ ($20 \text{ N} \le P \le 20,000 \text{ N}$) vs. $y_{\max}$ using data from both simulation and beam theory and quantify the value of $P$ where the two solutions begin to diverge.