Beam Deflection Calculator

Hero / Landing of project page

Hero image

Class Project

Nov 2025 - Dec 2025

Numerical Beam Deflection Calculator

Numerical structural analysis tool for arbitrary beam loading

(put tags here) Mechanical, Software

Instruction:
Use “**beam-deflection-hero1**” as a faded, full-width hero background image. Treat it as a backdrop (not a foreground image). Increase all hero text to a standard desktop web scale in the final build; small text here is only due to PDF layout constraints.
Ensure sufficient contrast (overlay gradient or blur) so hero text remains readable over the background image.

Project Overview

- Problem: Hand beam calculations are slow, error-prone, and not scalable

- Goal: Build a numerical tool to compute shear, moment, slope, deflection for arbitrary loading

- Outcome: Tool produces physically correct diagrams and max values without closed-form solutions

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Abstract & Motivation

Problem

Hand-calculating shear, bending moment, slope, and deflection for beams is time-consuming and error-prone, especially when evaluating multiple loading configurations. While closed-form solutions exist for simple cases, real design problems often involve mixed loading, varying geometry, and non-trivial boundary conditions.

Solution

This project develops a numerical beam analysis tool capable of computing shear, bending moment, slope, and deflection diagrams for beams subjected to arbitrary point loads and uniform distributed loads. By using numerical methods rather than closed-form equations, the tool scales naturally with problem complexity and provides immediate visual feedback for design iteration.

Outcome

The result is a flexible python based analysis tool that reproduces classical beam theory behavior while remaining extensible to more advanced structural modeling.

System Overview (Inputs → Outputs)

Inputs

- Beam geometry: length, width, height
- Material properties: Young's modulus
- Support conditions: fixed–free or fixed–roller
- Loading conditions:
    - Arbitrary point loads
    - Uniform distributed loads (UDLs)

Outputs

- Shear force diagram, $V(x)$
- Bending moment diagram, $M(x)$
- Slope diagram, $\theta(x)$
- Deflection diagram, $y(x)$
- Maximum values and corresponding locations for each response

This structure allows rapid evaluation of multiple design cases without manual re-derivation.

Temporary Image

Image of excel input sheet

Numerical Methods & Governing Theory (High-Level)

The calculator follows classical Euler–Bernoulli beam theory while relying entirely on **numerical integration** rather than closed-form solutions.

Load Construction

All user-defined loads (point loads and UDLs) are first combined into a **single unified load function** q(x)q(x)q(x).
Loads are stored and processed using structured data representations, enabling arbitrary placement and magnitude without special-case logic.

Reaction Forces

Unknown reaction forces are computed using **static equilibrium**:

- Sum of forces = 0
- Sum of moments = 0

This yields a 2×2 linear system, which is solved using **LU decomposition** for numerical stability and generality.

Integration Chain

Once the load function is defined, the structural response is computed via successive numerical integration:

$$\mathbf{q(x) \rightarrow V(x) \rightarrow M(x) \rightarrow \theta(x) \rightarrow y(x)}$$

- Integration is performed using the trapezoidal rule
- Material stiffness E and second moment of area I are incorporated at the curvature stage
- Boundary conditions are applied based on known fixed-end constraints

This approach mirrors the physical relationships between load, internal forces, and deformation.

Code Flow & Architecture

The software follows a deterministic, modular pipeline:

1. Read and validate user inputs from excel
2. Process and combine applied loads
3. Solve for reaction forces via LU decomposition
4. Construct the unified load function q(x)
5. Perform numerical integration to obtain:
    - Shear
    - Moment
    - Slope
    - Deflection
6. Apply boundary conditions
7. Generate plots
8. Locate maximum values using a discrete 1D grid search

This structure makes the tool easy to extend, debug, and adapt to more complex beam configurations.

Results

The calculator produces smooth, continuous response diagrams that behave exactly as predicted by beam theory:

- Shear force changes discontinuously at point loads
- Bending moment is the integral of shear
- Slope reflects beam curvature and stiffness
- Deflection accumulates smoothly from slope

For tested cases, the numerical results matched analytical solutions in both **shape and magnitude**, confirming correct implementation of the governing relationships.

Temporary Image

Image of excel input example

Caption - Stepper motor control circuit used to position the mechanical distribution hub.
File name “garden-stepper-circuit”

Temporary Image

Image of load distribution graph

Caption - Stepper motor control circuit used to position the mechanical distribution hub.
File name “garden-stepper-circuit”

Image of 4 graphs produced and max values and locations

Temporary Image

Caption - Stepper motor control circuit used to position the mechanical distribution hub.
File name “garden-stepper-circuit”

Section 6

Validation

Validation was performed in multiple stages:

Analytical Comparison

- Shear, slope, and deflection diagrams were verified against hand-calculated solutions
- Numerical results matched expected analytical behavior across all tested cases

Observed Issue

- A minor discontinuity was observed at x=0x = 0x=0 in the bending moment diagram
- The issue is isolated to initial boundary handling and does not affect downstream slope or deflection accuracy

Planned Physical Validation

To further strengthen validation, a physical beam test is planned:

- Fixed-free beam configuration
- Known applied loads
- Measured deflection using physical instrumentation
- Comparison against numerical predictions

This experiment will provide real-world confirmation of model accuracy and quantify prediction error.

Limitations & Assumptions

- Euler–Bernoulli beam assumptions (small deflection, linear elasticity)
- Constant cross-section along beam length
- Discretization resolution affects numerical smoothness
- Limited support types in current implementation

These limitations are known and explicitly addressed in future development plans.

Detailed Numerical Methods & Implementation

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Section 8

Future Implementations

Planned extensions include:

- Additional support types and multiple supports
- Arbitrary distributed load functions
- Variable and non-uniform cross-sections
- Applied moments and torsional loading
- 3D beam behavior
- Stress concentration modeling
- Fatigue and life-cycle prediction
- Failure and safety factor evaluation

The current tool serves as a robust foundation for these expansions.

Section 9

Conclusion

This project demonstrates that **simple numerical methods can accurately reproduce classical beam theory** without relying on closed-form solutions. By combining static equilibrium, LU decomposition, and numerical integration, the calculator provides a scalable and extensible framework for structural analysis.

Beyond academic application, the project reflects a practical engineering workflow: translating theory into a usable tool capable of supporting real design decisions.