3D Shear Force and Bending Moment Visualization of Bridge Girders

1. Introduction

Bridge structures are composed of multiple longitudinal girders that carry vertical loads and transfer them to supports. To assess structural safety and performance, it is essential to evaluate:

- Shear Force Diagrams (SFD)
- Bending Moment Diagrams (BMD)

This project extracts internal force results from a finite element model stored in a .nc (NetCDF) file and generates:

1. 2D SFD and BMD for a selected girder
2. 3D MIDAS-style visualization of SFD and BMD for all girders

The implementation uses:

- Xarray for dataset handling
- Plotly for 2D and 3D visualization
- Python for structural post-processing

2. Problem Statement

Given:

- A finite element model stored in `screening_task.nc`

- Internal element force results (Mz, Vy, etc.)
- Member connectivity
- Node coordinates

We must:

1. Extract bending moments (Mz) and shear forces (Vy)
2. Construct physically consistent SFD and BMD
3. Visualize all longitudinal girders in 3D
4. Replicate commercial software-style (MIDAS) post-processing

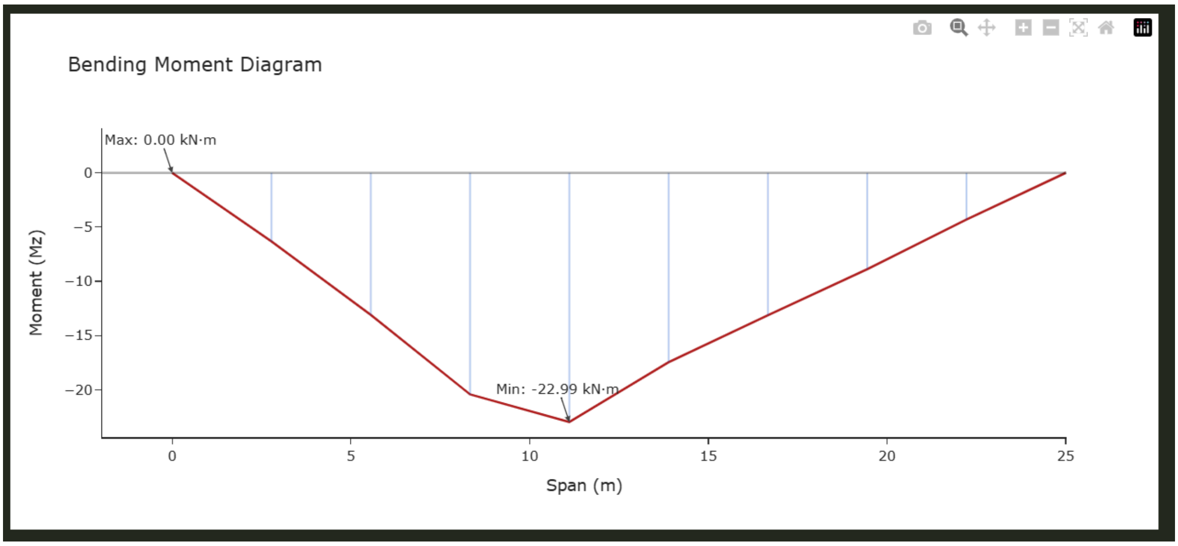
3. Methodology

- Importing the data -
  - The finite element results were imported from a NetCDF (`.nc`) file using the Xarray library, which provides structured access to element-wise internal forces such as bending moment (`Mz`) and shear force (`Vy`) at element start (`_i`) and end (`_j`) nodes.
- Structural Topology Definition -
  - Member connectivity was defined using a dictionary mapping each element to its start and end node IDs, while node coordinates were stored separately to represent the three-dimensional bridge geometry.
- Element ordering along girders -
  - A connectivity-based traversal algorithm was implemented to order the elements. Starting from one element, the next element was identified by matching the end node of the current element with the start node of another, ensuring a continuous girder chain.
- Force Extraction and Continuity Enforcement -

- For each ordered element, internal forces (`Mz_i`, `Mz_j`, `Vy_i`, `Vy_j`) were extracted.
- Continuity checks were performed before proceeding.

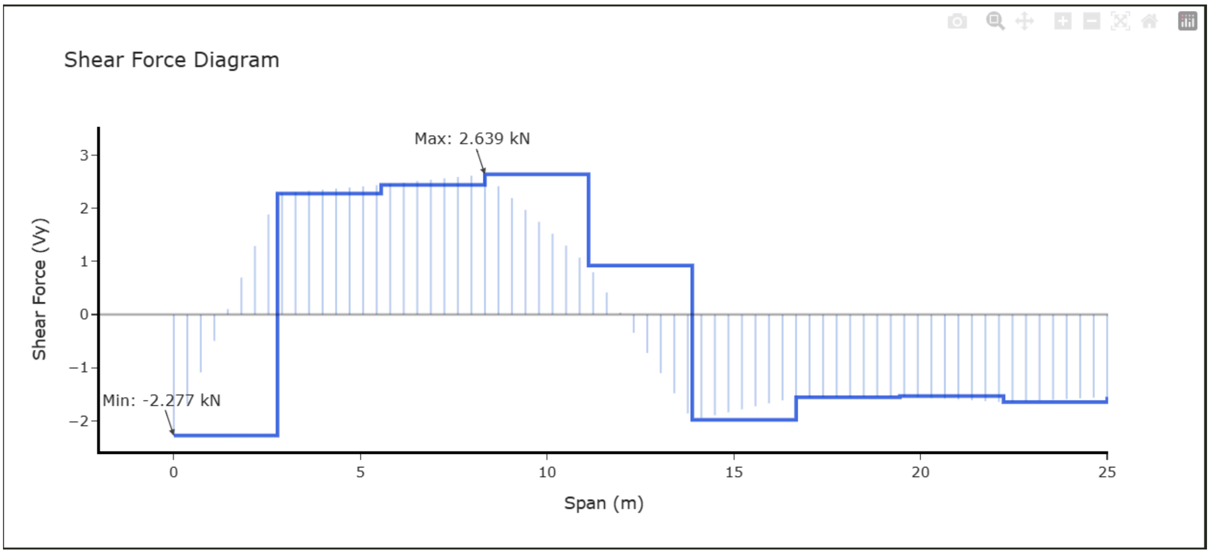
- 2D Shear Force and Bending Moment Diagrams -
    - Using the ordered nodal force values, physically correct 2D SFD and BMD were plotted. Stepwise plots were used for shear forces, while piecewise linear plots were used for bending moments, consistent with beam theory.
- 3D MIDAS-Style Visualization -
    - A modular function was developed to generate 3D force diagrams for all girders. The bridge geometry was plotted in 3D, and shear or moment magnitudes were extruded vertically using scaled offsets, with color mapping applied to represent force intensity.
- Visualization Enhancement and Validation -
    - Dense vertical “curtain” lines and ribbon-style force bands were added to replicate commercial post-processing software (MIDAS) visuals. Global color normalization ensured consistency across girders, and the results were validated against structural equilibrium and theoretical expectations.

4. Plots -



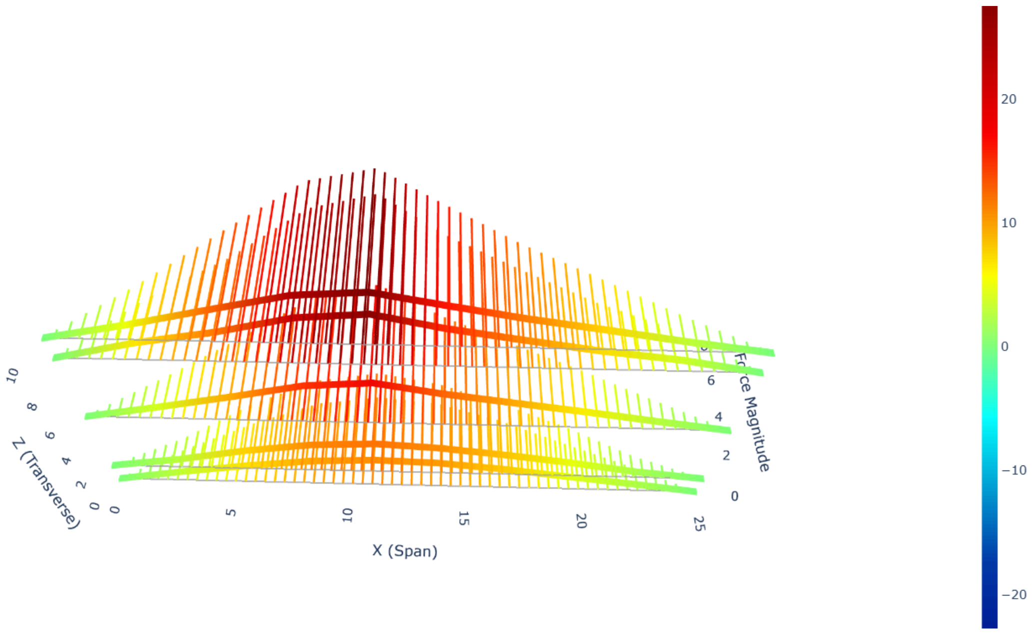
Bending Moment Diagram

The 2D bending moment diagram shows a piecewise linear variation of moment along the span, consistent with beam theory where dM/dx=VdM/dx = VdM/dx=V. The moment is zero at the supports and reaches a maximum negative value near midspan, indicating the critical section for design. The diagram confirms structural continuity and equilibrium along the girder.



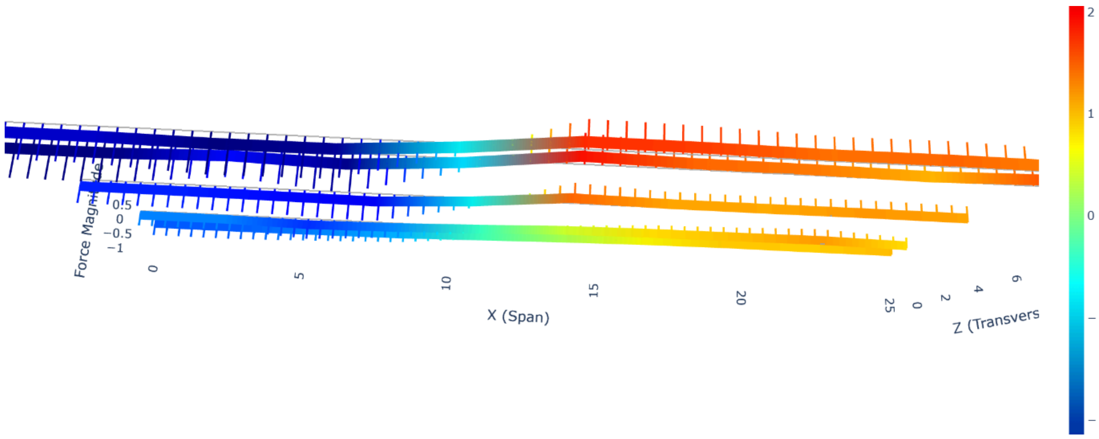
Shear Force Diagram

The shear force diagram exhibits a piecewise constant profile with distinct vertical jumps, which correspond to support reactions and concentrated loads along the span. Regions of constant shear indicate the absence of distributed loading within individual elements, consistent with the relation dVdx=−w(x)\frac{dV}{dx} = -w(x)dxdV=−w(x). The change in sign of shear identifies the location of maximum bending moment, confirming consistency between the SFD and BMD.



3D MIDAS Style BMD

The 3D bending moment diagram presents the variation of internal moments along all longitudinal girders, with force magnitudes extruded vertically and represented using a color scale. The maximum moment occurs near midspan, consistent with the theoretical condition that the peak bending moment develops where the shear force changes sign (V=0V = 0V=0). The symmetric distribution across girders indicates uniform load transfer and structural continuity throughout the bridge system.



3D MIDAS Style SFD

The 3D shear force diagram illustrates the distribution of shear forces along all longitudinal girders, with magnitudes extruded vertically and visualized using a continuous color scale. The abrupt changes in shear represent support reactions and concentrated loads, consistent with the governing relation dVdx=−w(x)\frac{dV}{dx} = -w(x)dxdV=−w(x). Locations where the shear force changes sign correspond to regions of maximum bending moment, confirming consistency between the 3D SFD and BMD representations.