Structural Analysis Visualization using Xarray

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1 Introduction

This report is prepared as part of the FOSSEE Osdag Winter Internship 2025 screening task. The objective of the task is to use Python and Xarray to read internal force data from a NetCDF file for a steel bridge grillage model, and to generate shear force and bending moment diagrams using Matplotlib (PyPlot).

The task is divided into two parts:

- **Task-1:** Generate 2D Shear Force Diagram (SFD) and Bending Moment Diagram (BMD) for the central longitudinal girder.
- **Task-2:** Generate 3D SFD and BMD for all longitudinal girders, similar to post-processing in commercial software.

2 Data and Tools Used

The following input files were provided for this screening task:

- `screening_task.nc` – a NetCDF file containing internal forces for all elements and components in the grillage model.
- `node.py` – a Python file defining a dictionary of node coordinates:

$$\text{nodes}[id] = [x, y, z]$$

- `element.py` – a Python file defining a dictionary of element connectivity:

$$\text{members}[id] = [\text{start\_node}, \text{end\_node}]$$

The main Python libraries used are:

- **Xarray**: to open and work with the NetCDF dataset.
- **NumPy**: for numerical operations and array manipulation.
- **Matplotlib (PyPlot)**: to create the 2D and 3D diagrams.

The internal force data is stored in an Xarray `DataArray` called `forces` with dimensions:

$$\text{forces(Element, Component)}$$

where the `Component` coordinate includes entries such as `Mz_i`, `Mz_j`, `Vy_i`, `Vy_j`, etc. For this task, the following components are used:

- Bending moment about the z-axis: `Mz_i`, `Mz_j`
- Shear force in the vertical direction: `Vy_i`, `Vy_j`

3 Task-1: 2D SFD and BMD of Central Longitudinal Girder

Objective

The objective of Task-1 is to generate the shear force and bending moment diagrams for the central longitudinal girder of the bridge model, using the values stored in the Xarray dataset for a single load case.

The central longitudinal girder is defined by the following element IDs:

$$[15, 24, 33, 42, 51, 60, 69, 78, 83].$$

Method

The steps followed in the Python script for Task-1 are:

1. Load the dataset using Xarray:

```
ds = xr.open_dataset("screening_task.nc", engine="netcdf4")
forces = ds["forces"]
```

2. Import the node and element dictionaries from `node.py` and `element.py`:

```
from node import nodes
from element import members
```

3. For each element in the central girder:
   - Obtain the start and end node IDs from `members[elem]`.
   - Read the corresponding node coordinates from `nodes`.
   - Extract bending moment and shear force values at the i and j ends:

     ```
     Mz_i = forces.sel(Element=elem, Component="Mz_i")
     Mz_j = forces.sel(Element=elem, Component="Mz_j")
     Vy_i = forces.sel(Element=elem, Component="Vy_i")
     Vy_j = forces.sel(Element=elem, Component="Vy_j")
     ```

4. Use the node z-coordinate as the longitudinal axis of the bridge, and build continuous arrays of (z, M_z) and (z, V_y) by appending values in the element order.
5. Plot the BMD and SFD using Matplotlib, add axis labels and grids, and save the figures as PNG files:
   - `central_BMD.png`
   - `central_SFD.png`

4 Task-1: 2D Visualization

Central longitudinal girder elements:

$$[15, 24, 33, 42, 51, 60, 69, 78, 83]$$

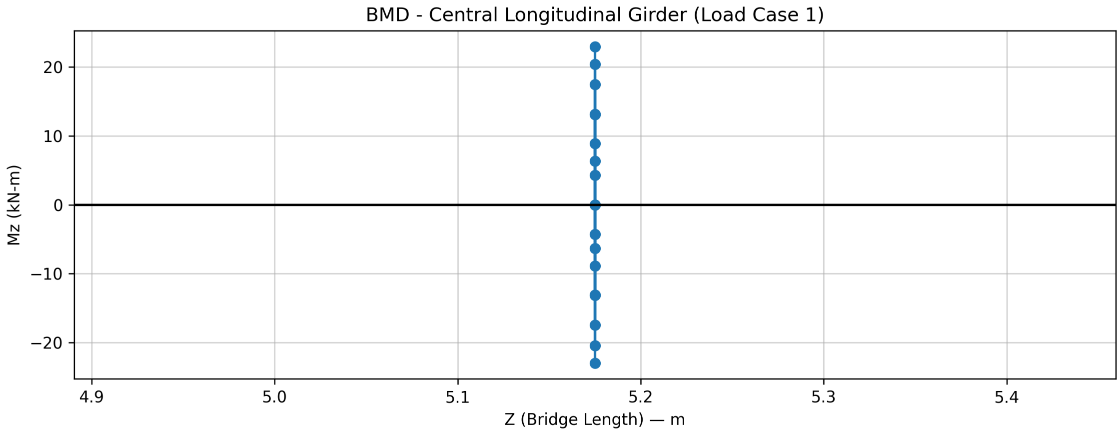

Figure 1: Bending Moment Diagram (Central Longitudinal Girder)

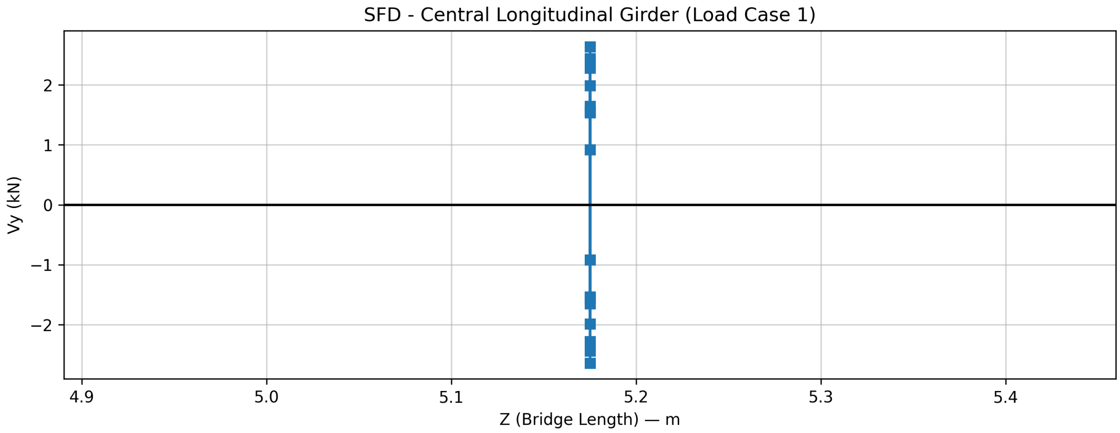

Figure 2: Shear Force Diagram (Central Longitudinal Girder)

5 Task-2: 3D SFD and BMD for All Longitudinal Girders

Objective

The objective of Task-2 is to generate 3D visualizations of shear force and bending moment diagrams for all the longitudinal girders in the bridge. The goal is to produce a MIDAS-like view where internal forces are extruded vertically over the bridge framing.

Method

The main steps in the Task-2 script are:

1. Use the same `nodes`, `members`, and `forces` data as in Task-1.
2. Define lists of element IDs corresponding to the five longitudinal girders, using the pattern specified in the problem statement.
3. Plot the base bridge framing in 3D using the node coordinates and element connectivity.
4. For each girder and each element in that girder:
   - Read the node coordinates (x, y, z) for the start and end nodes.
   - Extract the internal forces as in Task-1, but now for all girders.
   - Apply a vertical scaling factor to the bending moment or shear force values so that the diagrams are visible without distorting the geometry too much.
5. Plot the extruded lines in 3D using Matplotlib's `Axes3D`, with different colours for different girders.
6. Save the 3D BMD and 3D SFD plots as:
   - `3D_BMD.png`
   - `3D_SFD.png`

Results for Task-2

The 3D Bending Moment Diagram for all longitudinal girders is shown in Figure 3. The 3D Shear Force Diagram is shown in Figure 4. These figures help to visualize how internal forces vary along each girder and across the width of the bridge.

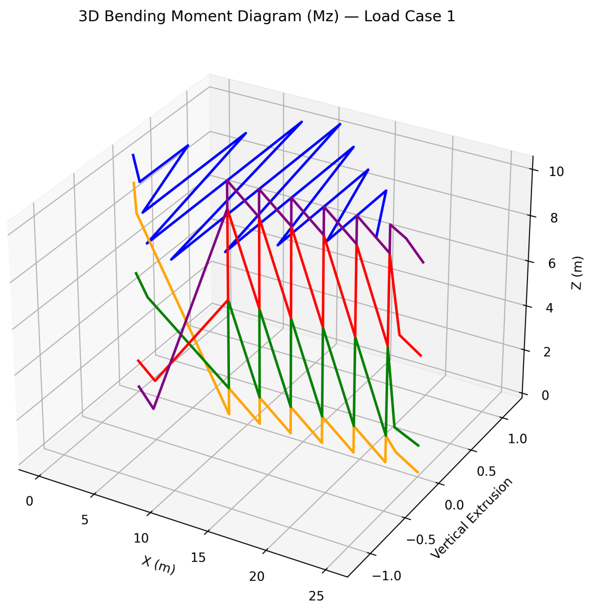

Figure 3: 3D Bending Moment Diagram for all longitudinal girders.

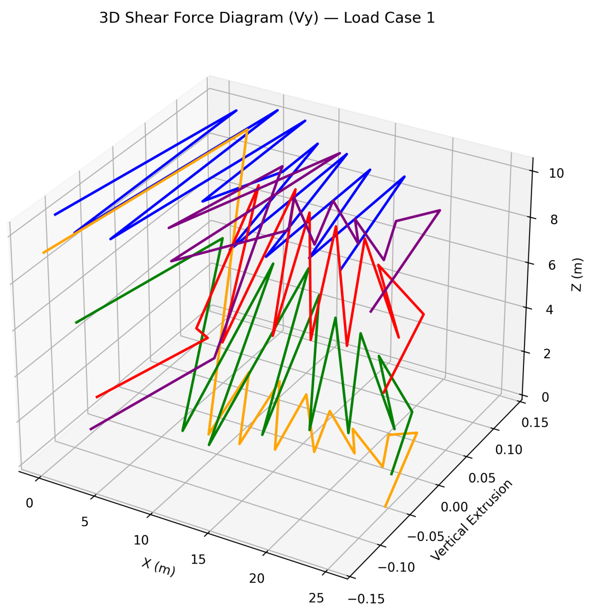

Figure 4: 3D Shear Force Diagram for all longitudinal girders.

6 Conclusion

In this screening task, I have:

- Used Xarray to read internal force results from a NetCDF file of a bridge grillage model.
- Extracted bending moment (M_z) and shear force (V_y) values for specific elements.
- Plotted 2D SFD and BMD for the central longitudinal girder using Matplotlib.
- Generated 3D visualizations of SFD and BMD for all longitudinal girders using node coordinates, element connectivity, and internal forces.

The Python scripts are structured so that they can be extended to other load cases or additional result components in the future. The GitHub repository for this work contains all the source files, plots, and instructions to reproduce the results.

Acknowledgement

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References

- Osdag: Steel Design and Detailing Software, FOSSEE, IIT Bombay.
- Xarray Documentation: `https://docs.xarray.dev`
- Matplotlib Documentation: `https://matplotlib.org`