FOSSEE Summer Internship Report

On

OSDAG Module Development

Submitted by

Aditya Donde

B.Tech Graduate Student, Department of Civil Engineering

Vishwakarma Institute of Information Technology

Mumbai

Under the Guidance of

Prof. Siddhartha Ghosh

Department of Civil Engineering

Indian Institute of Technology Bombay

Mentors:

Ajmal Babu M S

Parth Karia

Ajinkya Dahale

July 27, 2025

Acknowledgments

- Start with a general statement of thanks. Express your overall gratitude to everyone who supported you during your project or research.
- Project staff at the Osdag team, Ajmal Babu M. S., Ajinkya Dahale, and Parth Karia,
- Osdag Principal Investigator (PI) Prof. Siddhartha Ghosh, Department of Civil Engineering at IIT Bombay
- FOSSEE PI Prof. Kannan M. Moudgalya, FOSSEE Project Investigator, Department of Chemical Engineering, IIT Bombay
- FOSSEE Managers Usha Viswanathan and Vineeta Parmar and their entire team
- Acknowledge the support from the National Mission on Education through Information and Communication Technology (ICT), Ministry of Education (MoE), Government of India, for their role in facilitating this project
- Acknowledge your colleagues who worked with you during your internship or project.
- If appropriate, thank your college, department, head, and principal for their support during your studies.

Contents

1 Introduction **5**

1.1 National Mission in Education through ICT 5

1.1.1 ICT Initiatives of MoE 6

1.2 FOSSEE Project 7

1.2.1 Projects and Activities 7

1.2.2 Fellowships 7

1.3 Osdag Software 8

1.3.1 Osdag GUI 9

1.3.2 Features 9

2 Screening Task **10**

2.1 Problem Statement 10

2.2 Tasks Done 10

2.3 Static and Dynamic Analysis 10

2.4 Structural Metric Calculations 11

2.5 Algorithm and Python Implementation 11

2.6 Graphical User Interface (GUI) 11

2.7 Animated Visualization 11

3 Internship Task 2: Local Environment Setup for Osdag Development **24**

3.1 Task 1: Problem Statement 24

3.2 Task 1: Tasks Done 24

3.2.1 1. Forked and Cloned the Repository 24

3.2.2 2. Configured Upstream Remote 25

3.2.3 3. Checked Out the Main Branch from Upstream 25

3.2.4 4. Created and Activated Conda Environment 25

3.2.5 5. Installed Osdag in Editable Mode 26

3.2.6 6. Launched Osdag 26

3.2.7 Summary of Commands 26

4 Internship Task 3: Reimagining the Osdag UI **28**

4.1 Problem Statement 28
4.2 Tasks Done 29
4.2.1 1. Studied Osdag Structure and Modules 29
4.2.2 2. Designed New Home Page Layout 29
4.2.3 3. Designed a Module Design Page 29
4.2.4 4. Tools Used 30
4.3 Documentation 30
4.3.1 Reimagined Home Page UI 30
4.3.2 Reimagined Module Design Page UI 31
4.3.3 Design Philosophy 31

5 Internship Task 3: Design and Detailing Checklist (DDCL) Report for Base Plate Connection 32
5.1 Problem Statement 32
5.2 Tasks Done 33
5.3 Documentation 33

6 Internship Task 4: Design and Detailing Checklist (DDCL) Report for Pinned Base Plate under Small Eccentric Load 48
6.1 Problem Statement 48
6.2 Tasks Done 49
6.3 Documentation 49

7 Internship Task 5: Bug Report: Base Plate Module in Osdag 70
7.1 Problem Statement 70
7.2 Tasks Done 70
7.3 Documentation 71

8 Internship Task 6: Design and Detailing Checklist (DDCL) of Fixed Base Plate Report for Osdag 75
8.1 Problem Statement 75
8.2 Tasks Done 76
8.3 Documentation 76

9 Internship Task 7: Design and Detailing Checklist (DDCL) Report for Base Plate with Hollow/Tubular Column **98**

9.1 Problem Statement . . . 98

9.2 Tasks Done . . . 99

9.3 Documentation . . . 99

10 Internship Task 8 Development of Laced Column Compression Member **115**

10.1 Problem Statement . . . 115

10.1.1 Background . . . 115

10.1.2 Design Requirements . . . 115

10.1.3 Project Objective . . . 116

10.2 Tasks Accomplished . . . 116

10.2.1 Module Architecture . . . 116

10.2.2 Core Calculation Functions . . . 116

10.2.3 Code Integration . . . 117

10.3 Python Code Implementation . . . 117

10.3.1 Module Imports and Initialization . . . 117

10.3.2 Spacing Calculation Function . . . 120

10.3.3 Tie Plate Design Function . . . 122

10.3.4 Lacing Design Function . . . 124

10.3.5 Full code . . . 132

10.4 Documentation . . . 132

10.4.1 Directory Structure . . . 132

11 Conclusions **134**

11.1 Tasks Accomplished . . . 134

11.1.1 Module Architecture . . . 135

11.1.2 Core Calculation Functions . . . 135

11.2 Skills Developed . . . 136

A Appendix **138**

A.1 Work Reports . . . 138

Bibliography **142**

Chapter 1

Introduction

1.1 National Mission in Education through ICT

The National Mission on Education through ICT (NMEICT) is a scheme under the Department of Higher Education, Ministry of Education, Government of India. It aims to leverage the potential of ICT to enhance teaching and learning in Higher Education Institutions in an anytime-anywhere mode.

The mission aligns with the three cardinal principles of the Education Policy—**access, equity, and quality**—by:

- Providing connectivity and affordable access devices for learners and institutions.
- Generating high-quality e-content free of cost.

NMEICT seeks to bridge the digital divide by empowering learners and teachers in urban and rural areas, fostering inclusivity in the knowledge economy. Key focus areas include:

- Development of e-learning pedagogies and virtual laboratories.
- Online testing, certification, and mentorship through accessible platforms like EduSAT and DTH.
- Training and empowering teachers to adopt ICT-based teaching methods.

For further details, visit the official website: www.nmeict.ac.in.

1.1.1 ICT Initiatives of MoE

The Ministry of Education (MoE) has launched several ICT initiatives aimed at students, researchers, and institutions. The table below summarizes the key details:

No.	Resource	For Students/Researchers	For Institutions
Audio-Video e-content			
1	SWAYAM	Earn credit via online courses	Develop and host courses; accept credits
2	SWAYAMPRABHA	Access 24x7 TV programs	Enable SWAYAMPRABHA viewing facilities
Digital Content Access			
3	National Digital Library	Access e-content in multiple disciplines	List e-content; form NDL Clubs
4	e-PG Pathshala	Access free books and e-content	Host e-books
5	Shodhganga	Access Indian research theses	List institutional theses
6	e-ShodhSindhu	Access full-text e-resources	Access e-resources for institutions
Hands-on Learning			
7	e-Yantra	Hands-on embedded systems training	Create e-Yantra labs with IIT Bombay
8	FOSSEE	Volunteer for open-source software	Run labs with open-source software
9	Spoken Tutorial	Learn IT skills via tutorials	Provide self-learning IT content
10	Virtual Labs	Perform online experiments	Develop curriculum-based experiments
E-Governance			
11	SAMARTH ERP	Manage student lifecycle digitally	Enable institutional e-governance
Tracking and Research Tools			
12	VIDWAN	Register and access experts	Monitor faculty research outcomes
13	Shodh Shuddhi	Ensure plagiarism-free work	Improve research quality and reputation
14	Academic Bank of Credits	Store and transfer credits	Facilitate credit redemption

Table 1.1: Summary of ICT Initiatives by the Ministry of Education

1.2 FOSSEE Project

The FOSSEE (Free/Libre and Open Source Software for Education) project promotes the use of FLOSS tools in academia and research. It is part of the National Mission on Education through Information and Communication Technology (NMEICT), Ministry of Education (MoE), Government of India.

1.2.1 Projects and Activities

The FOSSEE Project supports the use of various FLOSS tools to enhance education and research. Key activities include:

- **Textbook Companion**: Porting solved examples from textbooks using FLOSS.
- **Lab Migration**: Facilitating the migration of proprietary labs to FLOSS alternatives.
- **Niche Software Activities**: Specialized activities to promote niche software tools.
- **Forums**: Providing a collaborative space for users.
- **Workshops and Conferences**: Organizing events to train and inform users.

1.2.2 Fellowships

FOSSEE offers various internship and fellowship opportunities for students:

- Winter Internship
- Summer Fellowship
- Semester-Long Internship

Students from any degree and academic stage can apply for these internships. Selection is based on the completion of screening tasks involving programming, scientific computing, or data collection that benefit the FLOSS community. These tasks are designed to be completed within a week.

For more details, visit the official FOSSEE website.

Figure 1.1: FOSSEE Projects and Activities

1.3 Osdag Software

Osdag (Open steel design and graphics) is a cross-platform, free/libre and open-source software designed for the detailing and design of steel structures based on the Indian Standard IS 800:2007. It allows users to design steel connections, members, and systems through an interactive graphical user interface (GUI) and provides 3D visualizations of designed components. The software enables easy export of CAD models to drafting tools for construction/fabrication drawings, with optimized designs following industry best practices [1, 2, 3]. Built on Python and several Python-based FLOSS tools (e.g., PyQt and PythonOCC), Osdag is licensed under the GNU Lesser General Public License (LGPL) Version 3.

1.3.1 Osdag GUI

The Osdag GUI is designed to be user-friendly and interactive. It consists of

- **Input Dock**: Collects and validates user inputs.
- **Output Dock**: Displays design results after validation.
- **CAD Window**: Displays the 3D CAD model, where users can pan, zoom, and rotate the design.
- **Message Log**: Shows errors, warnings, and suggestions based on design checks.

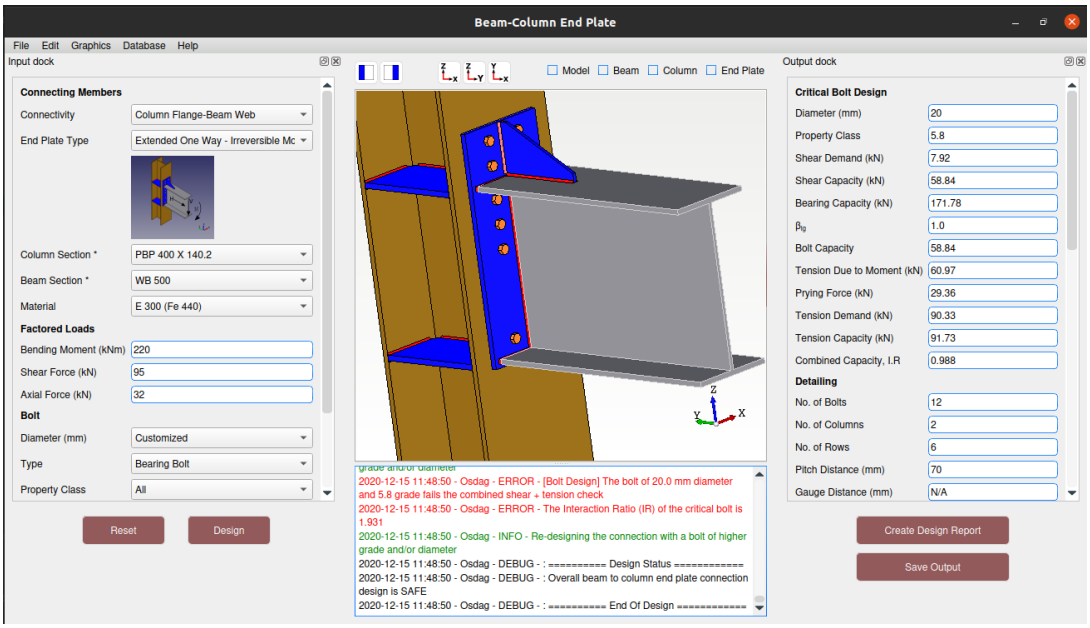

Figure 1.2: Osdag GUI

1.3.2 Features

- **CAD Model**: The 3D CAD model is color-coded and can be saved in multiple formats such as IGS, STL, and STEP.
- **Design Preferences**: Customizes the design process, with advanced users able to set preferences for bolts, welds, and detailing.
- **Design Report**: Creates a detailed report in PDF format, summarizing all checks, calculations, and design details, including any discrepancies.

For more details, visit the official Osdag website.

Chapter 2

Screening Task

2.1 Problem Statement

Develop a program to calculate shear force and bending moment for a beam experiencing a moving load. Applicants using the concept of influence line diagram will be given preference

2.2 Tasks Done

I developed a Python application that performs a comprehensive analysis of a simply supported beam subjected to two moving loads. This project combines several advanced structural engineering and software development concepts to create an intuitive and powerful analysis tool.

2.3 Static and Dynamic Analysis

The application includes both static analysis for fixed load positions and dynamic analysis for moving loads. The dynamic analysis is inspired by the principles of **Influence Line Diagrams**, allowing simulation of realistic loading conditions and evaluation of their effects throughout the beam's span.

2.4 Structural Metric Calculations

The program computes essential structural parameters:

- **Support Reactions** at the left and right supports (R_A and R_B).
- **Shear Force** at the mid-span.
- **Bending Moment** at the left support (zero for a simply supported beam).
- **Absolute Maximum Shear Force** and **Bending Moment** across the entire beam, including their precise locations.

2.5 Algorithm and Python Implementation

I designed a robust algorithm and implemented it using **Python**, employing key libraries:

- **NumPy** for efficient numerical operations.
- **Matplotlib** for static and animated plotting.

2.6 Graphical User Interface (GUI)

To enhance accessibility and usability, I developed an interactive GUI using **PyQt5**. Through this interface, users can:

- Input the beam's span.
- Specify the magnitude of the two loads.
- Define the spacing between the two moving loads.

2.7 Animated Visualization

A standout feature of the application is its **real-time animated visualization** of bending moment and shear force diagrams. As the loads traverse the beam, the internal force diagrams dynamically update, providing a clear and intuitive visual understanding of how the internal forces change.

Beam Analysis with Moving Loads using Influence Line Diagrams

[Aditya Donde]

July 25, 2025

1 Introduction

This report details the development of a Python-based application for analyzing a simply supported beam under moving loads. The program calculates shear forces and bending moments using both static analysis and a dynamic moving load simulation inspired by Influence Line Diagrams. It also provides an interactive graphical user interface (GUI) built with PyQt5, allowing users to input beam parameters and visualize the resulting internal force distributions through animated plots.

2 Problem Statement

The primary challenge addressed by this project is the analysis of a simply supported beam subjected to a moving load. The analysis includes:

- Calculating maximum support reactions.
- Determining bending moment and shear force at specific points on the beam.
- Finding the maximum shear force and bending moment along with their locations as the load moves.

2.1 Objective

The objective is to develop an algorithm that:

- Computes the maximum reaction forces at the beam supports.

- Determines bending moment at the position where load W1 is applied (x = 0).
- Calculates shear force at the mid-span of the beam.
- Uses a moving load analysis (with Influence Line Diagrams) to evaluate the entire beam for maximum shear force and bending moment.
- Provides a user-friendly GUI with animation to visualize how these quantities change as the load moves.

3 Methodology

The solution involves two key parts:

Static Analysis:

- The beam is analyzed with W1 applied at x = 0 and W2 applied at a distance x from the left support.
- Reactions at supports A and B are determined using equilibrium equations.
- Bending moment at the left support is zero, and shear force at mid-span is computed based on load positions.

Dynamic Analysis (Influence Line Method):

- The moving load is simulated by shifting the position of W1 from 0 to L - x while keeping a constant separation between W1 and W2.
- For each load position, shear force and bending moment distributions along the beam are computed.
- The maximum shear force and bending moment along with their corresponding positions are determined by iterating over the beam length.

A PyQt5-based GUI is integrated to allow user input for beam parameters and to display animated plots of the shear force and bending moment distributions as the loads move along the beam.

4 Design Calculations

The calculations are based on fundamental principles of static equilibrium and the influence line method:

4.1 Reactions:

For a simply supported beam with loads W1 at 0 m and W2 at x m:

$$R_B = \frac{W_2 \cdot x}{L}$$
$$R_A = W_1 + W_2 - R_B$$

4.2 Bending Moment:

At the left support (x = 0), the bending moment is zero. For any section y along the beam:

$$M(y) = R_A \cdot y - (\text{load contributions})$$

4.3 Shear Force:

The shear force at any section is computed by summing the forces to the left of that section and subtracting the applied loads accordingly.

4.4 Dynamic Analysis:

By moving the load positions along the beam and recalculating the internal forces at discrete intervals, the maximum shear force and bending moment along with their locations are found.

5 Expected Outcomes

Static Outputs:

- Reactions at supports A and B.
- Bending moment at the left support (BM-01 = 0).
- Shear force at mid-span (SF-01).

Dynamic Outputs:

- Maximum shear force (SF-max) and its location.
- Maximum bending moment (BM-max) and its location.

GUI and Animation:

- A user-friendly interface for inputting beam length, load values, and distance between loads.
- Real-time animated plots that update as the moving load changes position.
- Output display for static analysis results.

6 Flowchart

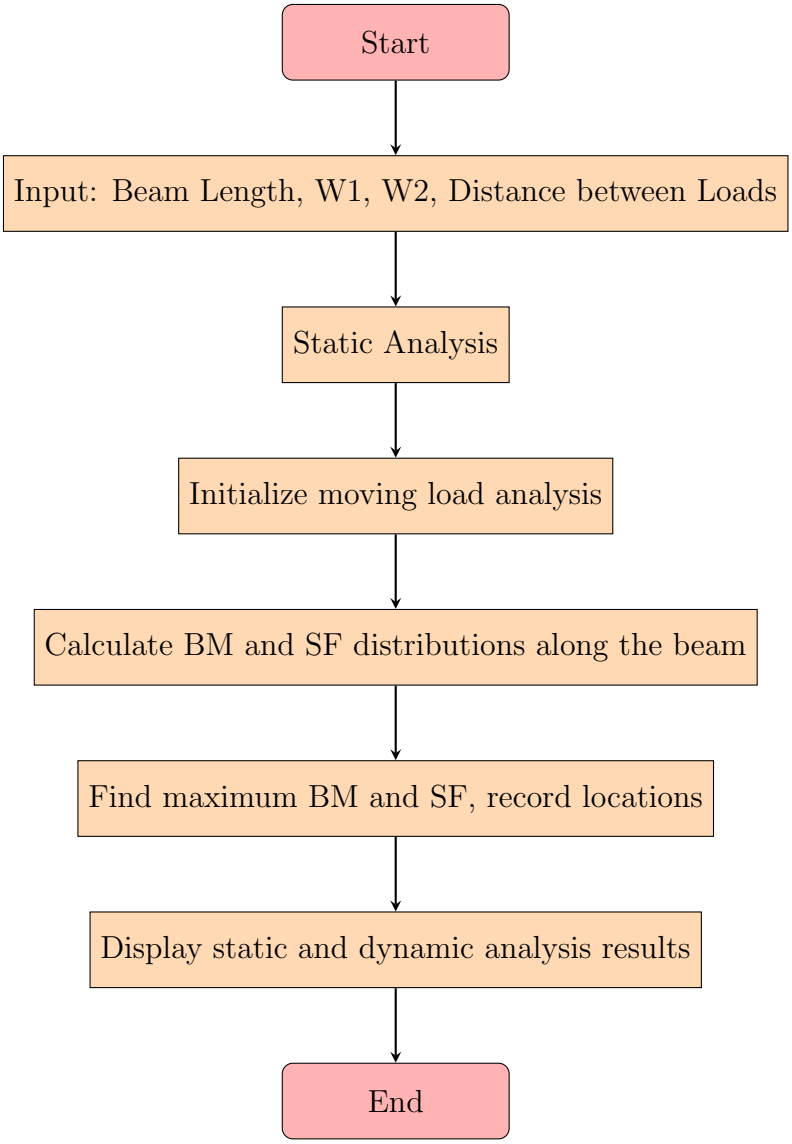

Figure 1: Flowchart of the Design Procedure

7 Example Solution in Python

```
import sys
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.animation import FuncAnimation
```

```
from matplotlib.backends.backend_qt5agg import
    FigureCanvasQTAgg as FigureCanvas
from PyQt5.QtWidgets import (
    QApplication, QMainWindow, QWidget, QVBoxLayout,
    QHBoxLayout,
    QFormLayout, QLabel, QLineEdit, QPushButton, QGroupBox
)
from PyQt5.QtCore import Qt

################################################
# Analysis Functions (as defined previously)
################################################

def analyze_beam(L, W1, W2, x):
    """
    Compute static analysis outputs for a simply supported
    beam with two moving loads.
    Loads are assumed to be applied at positions 0 (W1) and x
    (W2).
    Returns a dictionary with:
      - R_A: Reaction at Support A (kN)
      - R_B: Reaction at Support B (kN)
      - BM_01: Bending moment at x=0 (kN m)
      - SF_01: Shear force at mid-span (kN)
      - SF_max: Maximum shear force (kN)
      - SF_max_loc: Location of maximum shear force (m from A
    )
      - BM_max: Maximum bending moment (kN m)
      - BM_max_loc: Location of maximum bending moment (m
    from A)
    """
    R_B = (W2 * x) / L
    R_A = W1 + W2 - R_B
    BM_01 = 0  # At the support of a simply supported beam
    mid_span = 0.5 * L
    if mid_span < x:
        SF_01 = R_A - W1
    else:
        SF_01 = R_A - (W1 + W2)

    num_positions = 200
    num_sections = 200
    p1_positions = np.linspace(0, L - x, num=num_positions)
    y_positions = np.linspace(0, L, num=num_sections)

    max_shear = -np.inf
    max_shear_loc = None
    max_moment = -np.inf
    max_moment_loc = None
```

```
48
49      for p1 in p1_positions:
50          p2 = p1 + x
51          RA_config = W1 * (L - p1) / L + W2 * (L - p2) / L
52          for y in y_positions:
53              shear = RA_config
54              if y >= p1:
55                  shear -= W1
56              if y >= p2:
57                  shear -= W2
58              moment = RA_config * y
59              if y >= p1:
60                  moment -= W1 * (y - p1)
61              if y >= p2:
62                  moment -= W2 * (y - p2)
63              if shear > max_shear:
64                  max_shear = shear
65                  max_shear_loc = y
66              if moment > max_moment:
67                  max_moment = moment
68                  max_moment_loc = y
69
70      return {
71          'R_A': R_A,
72          'R_B': R_B,
73          'BM_01': BM_01,
74          'SF_01': SF_01,
75          'SF_max': max_shear,
76          'SF_max_loc': max_shear_loc,
77          'BM_max': max_moment,
78          'BM_max_loc': max_moment_loc
79      }
80
81  def calculate_BM_SF(L, W1, W2, p1, x, y_positions):
82      """
83      Calculate the bending moment (BM) and shear force (SF)
    distribution along the beam.
84
85      Parameters:
86          L           : Beam length (m)
87          W1, W2      : Load values (kN)
88          p1          : Position of first load (m)
89          x           : Distance between loads (m) so that p2 =
    p1 + x
90          y_positions: Array of positions along the beam (m)
91
92      Returns:
93          BM, SF: Arrays containing the bending moment (kN m)
    and shear force (kN) values.
```

```
    """
    p2 = p1 + x
    RA = W1 * (L - p1) / L + W2 * (L - p2) / L
    BM = np.zeros_like(y_positions)
    SF = np.zeros_like(y_positions)

    for i, y in enumerate(y_positions):
        shear = RA
        if y >= p1:
            shear -= W1
        if y >= p2:
            shear -= W2
        SF[i] = shear

        moment = RA * y
        if y >= p1:
            moment -= W1 * (y - p1)
        if y >= p2:
            moment -= W2 * (y - p2)
        BM[i] = moment

    return BM, SF

################################################
# GUI with PyQt and Matplotlib Animation
################################################

class MplCanvas(FigureCanvas):
    """Matplotlib Canvas widget for embedding plots in PyQt.
    """
    def __init__(self, parent=None, width=5, height=8, dpi
    =100):
        # Create figure with two subplots and adjust vertical
     spacing.
        self.fig, (self.ax1, self.ax2) = plt.subplots(2, 1,
    figsize=(width, height), dpi=dpi)
        self.fig.subplots_adjust(hspace=0.5)
        super().__init__(self.fig)

class MainWindow(QMainWindow):
    def __init__(self):
        super().__init__()
        self.setWindowTitle("Beam Analysis GUI")
        self.setGeometry(100, 100, 1000, 600)

        # Main widget and layout
        main_widget = QWidget()
        self.setCentralWidget(main_widget)
        main_layout = QHBoxLayout()
```

```
        main_widget.setLayout(main_layout)

        # Left side: Animated plot
        self.canvas = MplCanvas(self, width=5, height=8, dpi
    =100)
        main_layout.addWidget(self.canvas, 2)

        # Right side: Input and Output
        right_widget = QWidget()
        right_layout = QVBoxLayout()
        right_widget.setLayout(right_layout)
        main_layout.addWidget(right_widget, 1)

        # Input Section
        input_group = QGroupBox("Input Parameters")
        input_layout = QFormLayout()
        input_group.setLayout(input_layout)

        self.le_length = QLineEdit("10")
        self.le_load1  = QLineEdit("20")
        self.le_load2  = QLineEdit("30")
        self.le_distance = QLineEdit("4")

        input_layout.addRow("Beam Length (m):", self.
    le_length)
        input_layout.addRow("Load 1 (kN):", self.le_load1)
        input_layout.addRow("Load 2 (kN):", self.le_load2)
        input_layout.addRow("Distance between loads (m):",
    self.le_distance)
        right_layout.addWidget(input_group)

        # Button for update
        self.btn_update = QPushButton("Update Analysis")
        self.btn_update.clicked.connect(self.update_analysis)
        right_layout.addWidget(self.btn_update)

        # Output Section
        output_group = QGroupBox("Output Results")
        output_layout = QVBoxLayout()
        output_group.setLayout(output_layout)
        self.lbl_output = QLabel("")
        self.lbl_output.setAlignment(Qt.AlignLeft | Qt.
    AlignTop)
        output_layout.addWidget(self.lbl_output)
        right_layout.addWidget(output_group)

        # Animation parameters
        self.num_frames = 100
        self.num_sections = 300
```

```
184         self.animation = None
185         self.animation_started = False  # Animation will
    start after update
186 
187     def update_analysis(self):
188         """Update outputs and start animation based on user
    inputs."""
189         try:
190             L = float(self.le_length.text())
191             W1 = float(self.le_load1.text())
192             W2 = float(self.le_load2.text())
193             x  = float(self.le_distance.text())
194             if x > L:
195                 self.lbl_output.setText("Error: Distance
    between loads cannot exceed beam length.")
196                 return
197 
198             # Compute static outputs via analyze_beam
199             results = analyze_beam(L, W1, W2, x)
200             output_text = (
201                 f"Reaction at A: {results['R_A']:.2f} kN\n"
202                 f"Reaction at B: {results['R_B']:.2f} kN\n"
203                 f"Bending Moment at x=0 (BM_01): {results['
    BM_01']:.2f} kN m\n"
204                 f"Shear Force at mid-span (SF_01): {results['
    SF_01']:.2f} kN\n"
205                 f"Maximum Shear Force (SF_max): {results['
    SF_max']:.2f} kN at {results['SF_max_loc']:.2f} m\n"
206                 f"Maximum Bending Moment (BM_max): {results['
    BM_max']:.2f} kN m at {results['BM_max_loc']:.2f} m"
207             )
208             self.lbl_output.setText(output_text)
209 
210             # Start animation after update
211             self.init_animation()
212             self.animation_started = True
213         except Exception as e:
214             self.lbl_output.setText("Error: " + str(e))
215 
216     def init_animation(self):
217         """Set up and start the animation with current input
    parameters."""
218         # Stop any existing animation
219         if self.animation:
220             self.animation.event_source.stop()
221 
222         try:
223             L = float(self.le_length.text())
224             W1 = float(self.le_load1.text())
```

```
            W2 = float(self.le_load2.text())
            x  = float(self.le_distance.text())
        except Exception:
            return

        # Prepare beam sections and load positions for animation
        y_positions = np.linspace(0, L, self.num_sections)
        p1_positions = np.linspace(0, L - x, self.num_frames)

        # Clear axes and configure
        self.canvas.ax1.clear()
        self.canvas.ax2.clear()
        self.canvas.ax1.set_xlim(0, L)
        self.canvas.ax2.set_xlim(0, L)
        self.canvas.ax1.set_title("Bending Moment Distribution")
        self.canvas.ax1.set_xlabel("Beam Length (m)")
        self.canvas.ax1.set_ylabel("Bending Moment (kN m)")
        self.canvas.ax2.set_title("Shear Force Distribution")
        self.canvas.ax2.set_xlabel("Beam Length (m)")
        self.canvas.ax2.set_ylabel("Shear Force (kN)")

        # Draw vertical reference line at x=0 on both plots
        self.canvas.ax1.axhline(y=0, color='gray', linestyle='--')
        self.canvas.ax2.axhline(y=0, color='gray', linestyle='--')

        # Set heuristic y-limits
        self.canvas.ax1.set_ylim(-max(W1, W2)*L, max(W1, W2)*L)
        self.canvas.ax2.set_ylim(-max(W1, W2)*2, max(W1, W2)*2)

        # Initialize plot lines and annotation text
        self.line_bm, = self.canvas.ax1.plot([], [], 'b-', lw=2, label="BM")
        self.line_sf, = self.canvas.ax2.plot([], [], 'r-', lw=2, label="SF")
        self.text_pos = self.canvas.ax1.text(0.05, 0.9, '', transform=self.canvas.ax1.transAxes, fontsize=10)

        def update(frame):
            # For each frame, compute current load position and update BM, SF
            p1 = p1_positions[frame]
            p2 = p1 + x
            BM, SF = calculate_BM_SF(L, W1, W2, p1, x,
```

```
    y_positions)
264             self.line_bm.set_data(y_positions, BM)
265             self.line_sf.set_data(y_positions, SF)
266             self.text_pos.set_text(f"p1 = {p1:.2f} m, p2 = {
    p2:.2f} m")
267             return self.line_bm, self.line_sf, self.text_pos
268 
269         # Create and start animation; blit is set to False to
     update the entire canvas.
270         self.animation = FuncAnimation(self.canvas.fig,
    update, frames=self.num_frames,
271                                        interval=100, blit=
    False, repeat=True)
272         self.canvas.draw()
273 
274 ################################################
275 # Main Execution
276 ################################################
277 
278 def main():
279     app = QApplication(sys.argv)
280     window = MainWindow()
281     window.show()
282     sys.exit(app.exec_())
283 
284 if __name__ == "__main__":
285     main()
```

8 Conclusion

This project demonstrates an integrated approach to structural analysis by combining classical static analysis with dynamic moving load simulations. The use of Influence Line Diagrams provides a robust method for determining critical points in the beam. Furthermore, the incorporation of a PyQt-based GUI with animated visualizations makes the tool accessible and interactive, which is valuable for both educational and practical engineering applications..

9 References

1. Matplotlib Documentation: https://matplotlib.org/stable/contents.html
2. PyQt5 Documentation: https://www.riverbankcomputing.com/static/Docs/PyQt5/
3. NumPy Documentation: https://numpy.org/doc/

Chapter 3

Internship Task 2: Local Environment Setup for Osdag Development

3.1 Task 1: Problem Statement

To contribute to the development of the open-source structural steel design software **Osdag**, it is necessary to set up a local development environment. The original Osdag repository is hosted at:

- **GitHub URL:** https://github.com/osdag-admin/Osdag.git

The setup should:

- Allow for contribution via a personal fork.
- Maintain a connection to the upstream repository for syncing updates.
- Use an isolated Conda environment with all dependencies.
- Install the Osdag package in **editable mode**, so that changes in code reflect immediately.

3.2 Task 1: Tasks Done

3.2.1 1. Forked and Cloned the Repository

1. Forked the Osdag repository from GitHub.

2. Cloned the fork locally:

```
git clone https://github.com/<your-username>/Osdag.git
cd Osdag
```

3.2.2 2. Configured Upstream Remote

```
git remote add upstream https://github.com/osdag-admin/Osdag.git
git remote -v
```

3.2.3 3. Checked Out the Main Branch from Upstream

```
git fetch upstream
git checkout main
git pull upstream main
```

3.2.4 4. Created and Activated Conda Environment

A new Conda environment was created with all the required dependencies:

```
conda create -n osdag-editable \
  conda-forge::python==3.10 \
  conda-forge::setuptools \
  conda-forge::numpy \
  conda-forge::openpyxl \
  conda-forge::pandas \
  conda-forge::pynput \
  conda-forge::pyqt \
  conda-forge::pythonocc-core \
  conda-forge::pylatex \
  conda-forge::pygithub \
  conda-forge::pyyaml \
  conda-forge::sqlite \
  conda-forge::smesh \
  conda-forge::tbb
```

Then activated the environment:

```
conda activate osdag-editable
```

3.2.5 5. Installed Osdag in Editable Mode

Executed the following command inside the Osdag root directory:

```
pip install --no-deps --editable .
```

This allows development changes to be reflected without reinstallation.

3.2.6 6. Launched Osdag

If the CLI entry point is configured correctly in `setup.py`, the GUI can be launched using:

```
osdag
```

3.2.7 Summary of Commands

```
# Clone fork
git clone https://github.com/<your-username>/Osdag.git
cd Osdag

# Add upstream
git remote add upstream https://github.com/osdag-admin/Osdag.git

# Setup environment
conda create -n osdag-editable conda-forge::python==3.10 conda-
   forge::setuptools conda-forge::numpy conda-forge::openpyxl
   conda-forge::pandas conda-forge::pynput conda-forge::pyqt
   conda-forge::pythonocc-core conda-forge::pylatex conda-forge::
   pygithub conda-forge::pyyaml conda-forge::sqlite conda-forge::
   smesh conda-forge::tbb
conda activate osdag-editable
```

```
# Install package
pip install --no-deps --editable .


# Run Osdag
osdag
```

Chapter 4

Internship Task 3: Reimagining the Osdag UI

4.1 Problem Statement

The objective of Task-X is to reimagine the user interface (UI) of **Osdag**, an open-source structural steel design software developed by FOSSEE, IIT Bombay. The redesign focuses on enhancing usability and visual aesthetics while maintaining Osdag's core functionalities.

Main Goals:

- Familiarize with Osdag's architecture and functionalities.
- Redesign the Home Page and one Module Design Page with improved UX principles.
- Keep the green color scheme for brand consistency.
- Ensure a modular layout to accommodate multiple steel design components.

Constraints:

- Green color must be retained.
- Design must remain component-based (no structural analysis tools).
- Avoid high contrast or overly saturated colors.
- Be creative and user-focused.

Resources Used:

- GitHub Osdag Repository
- Osdag YouTube Channel: `https://www.youtube.com/@osdag.fossee`
- Official Website Videos: `https://osdag.fossee.in/resources/videos`
- Other structural design software like ETABS, STAAD.Pro, RCDC.

4.2 Tasks Done

4.2.1 1. Studied Osdag Structure and Modules

- Explored the source code and GUI layout in the Osdag repository.
- Understood the major components such as Tension Member, Beam-Column, Plate Girder, etc.

4.2.2 2. Designed New Home Page Layout

- Created a modern, sidebar-driven layout.
- Added distinct buttons for modules: *Connection, Tension Member, Compression Member, Beam-Column, Truss, 2D Frame, 3D Frame, Group Design.*
- Used light green for active states to retain Osdag's brand identity.

4.2.3 3. Designed a Module Design Page

- Divided layout into four sections: Input Dock, CAD Window, Output Dock, and Log Window.
- Buttons provided for: **Reset, Design, Save Output, Create Design Report**.
- Emphasis on usability, with large clickable areas and logical workflow.

4.2.4 4. Tools Used

- UI layout created using vector/graphic tools like Figma or Illustrator.
- Mocked up interface interactions and layout behavior.

4.3 Documentation

4.3.1 Reimagined Home Page UI

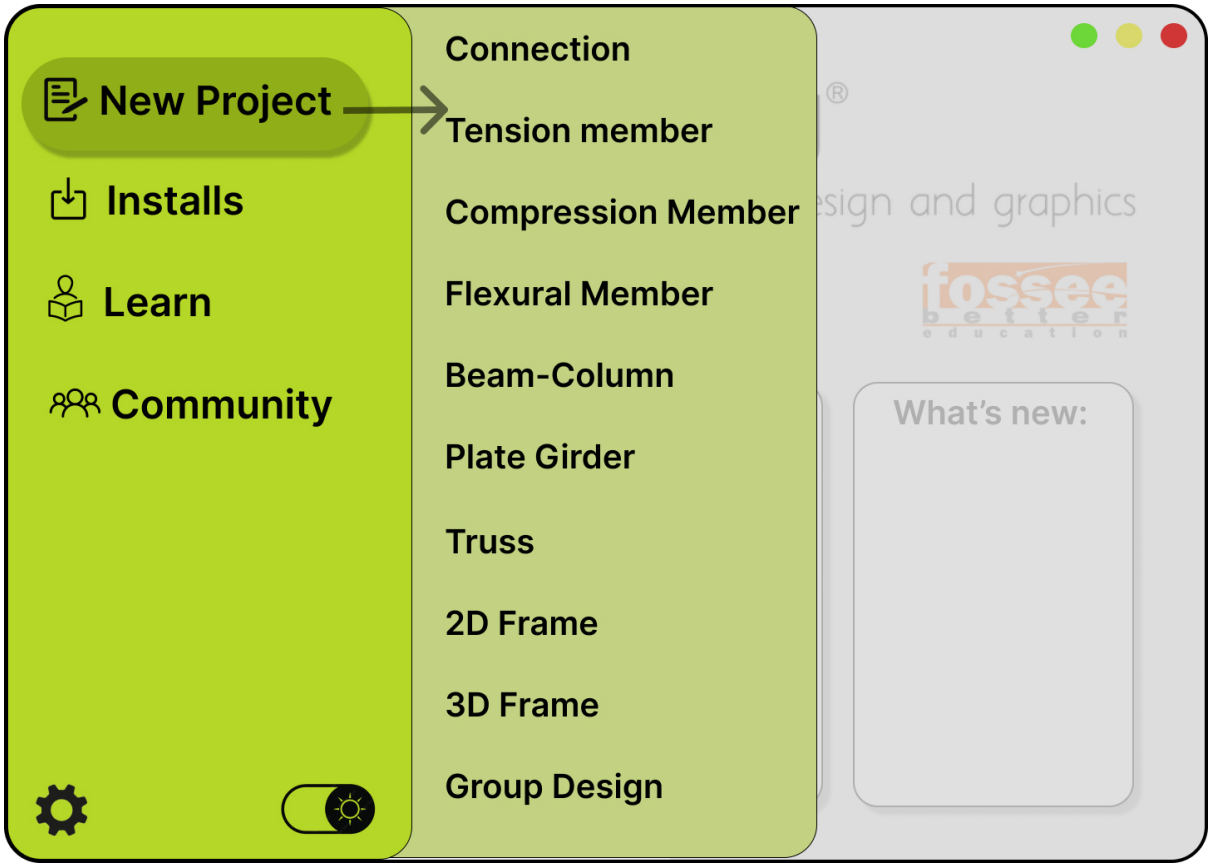

Figure 4.1: New Project Launch Page with Sidebar Navigation

4.3.2 Reimagined Module Design Page UI

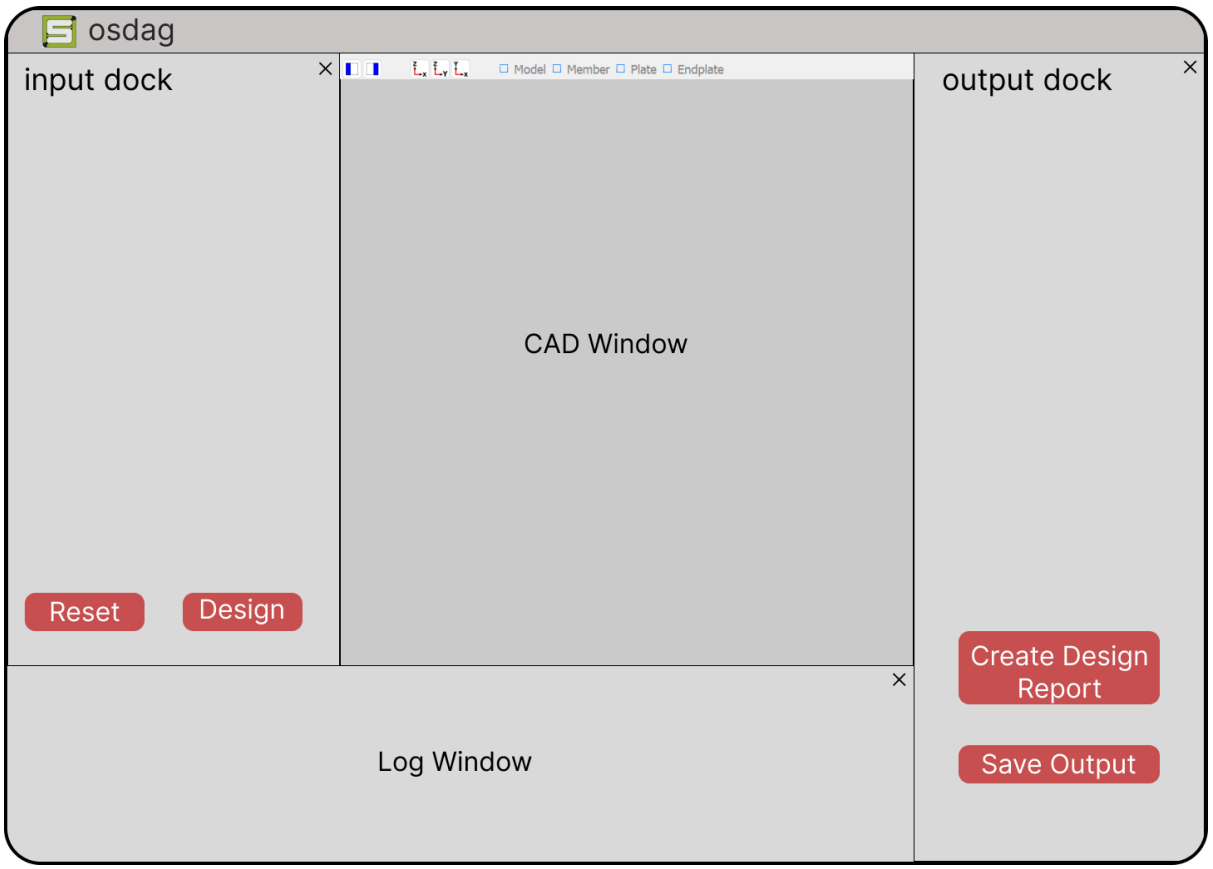

Figure 4.2: Single Module Design Page Layout

4.3.3 Design Philosophy

- Focused on clean and intuitive layout with minimal distractions.
- Retained core usability and workflows familiar to current Osdag users.
- Modular layout supports future scaling and new design modules.
- Accessibility and ease of navigation were core to the design decisions.

Chapter 5

Internship Task 3: Design and Detailing Checklist (DDCL) Report for Base Plate Connection

5.1 Problem Statement

The task is to prepare a **Design and Detailing Checklist (DDCL)** for the **Base Plate Connection** in the Osdag software. This checklist outlines the theoretical background, code-based formulations, detailing requirements, and verification criteria for the development of this module.

Objectives:

- Define all structural and material inputs required for the design of base plates.
- Provide detailed steps for column design, base plate geometry, anchor rods, welds, and shear key.
- Include clause-based verification from Indian Standards such as IS 800:2007 and IS 456:2000.
- Develop a final detailing checklist for implementation in the Osdag interface.

5.2 Tasks Done

- Studied existing literature and IS code provisions relevant to base plate design.
- Identified and structured all required input parameters and user preferences.
- Developed formulas and step-wise calculations for:
  - Column axial, bending, and shear capacity
  - Base plate bearing area and thickness
  - Anchor rod tension and shear design
  - Weld size and capacity
  - Shear key design
- Created a detailed final checklist to validate design parameters and fabrication details.
- Prepared a professionally formatted report in PDF form for integration and submission.

5.3 Documentation

The full Design and Detailing Checklist (DDCL) report for the Base Plate connection is attached below.

Osdag

Open steel design and graphics

Design and detailing checklist (DDCL)

Base plate connection

Prepared by:
Aditya Donde

Mentor:
Parth Karia

Under the guidance of
Prof. Siddhartha Ghosh

Indian Institute of Technology Bombay
July 25, 2025

Contents

1 Theory **1**
1.1 Introduction . . . 1

2 Design and Detailing Checklist for Osdag Software **2**
2.1 Input Parameters . . . 2
2.2 Column Design . . . 4
2.3 Anchor Rod Design . . . 6
2.3.1 Bolt Properties . . . 6
2.3.2 Detailing Requirements . . . 7
2.4 Base Plate Design . . . 8
2.4.1 Friction Grip Type Bolting . . . 10
2.4.2 Reduction Factors for Bolted Connection . . . 10
2.4.3 Intermittent Connections . . . 11
2.5 Design of Shear Key . . . 12
2.5.1 Purpose of Shear Key . . . 12
2.5.2 Load Analysis . . . 12
2.5.3 Geometry of Shear Key . . . 12
2.5.4 Shear Key Material Strength . . . 13
2.5.5 Weld Connection of Shear Key to Base Plate . . . 13
2.5.6 Final Checklist for Shear Key Design . . . 13
2.6 Detailing Checklist . . . 14
2.6.1 Pitch and Gauge Distances . . . 14
2.6.2 End and Edge Distances . . . 14
2.6.3 Hole Dimensions . . . 14
2.6.4 Weld Details . . . 15
2.6.5 Grout and Surface Preparation . . . 15
2.6.6 Corrosion Protection and Durability . . . 15
2.6.7 Final Checklist . . . 15

3 Tutorial for Design of Base plate from Osdag **16**

4 Verification Examples for the Calibration of Osdag **17**

Chapter 2

Design and Detailing Checklist for Osdag Software

2.1 Input Parameters

The following are the input parameters that the user will have to input on the Osdag Software.

- **Column Profile:**
  The user must choose the type of column section, such as I-section, hollow circular section, or rectangular section.
- **Column Size:**
  The user must specify the size of the column section, including flange and web dimensions for I-sections or diameter and thickness for hollow sections.
- **Material Property:**
  The user will have the option to select the grade of steel for the column section and base plate (e.g., Fe250, Fe345).
- **Factored Axial Load (in kN):**
  The user must input the factored axial load acting on the column.
- **Factored Shear Load (in kN):**
  The user must input the shear loads along both the major (z-z) and minor (y-y) axes.
- **Factored Moment (in kNm):**
  The user must specify any factored moments acting about the major and minor axes.
- **Concrete Grade:**
  The user must input the grade of concrete for the pedestal (e.g., M20, M25).
- **Base Plate Dimensions:**
  The user may specify the length and width of the base plate or allow the software to optimize these dimensions.
- **Grout Thickness (in mm):**
  The user must input the thickness of the grout layer beneath the base plate.
- **Anchor Bolt Diameter:**
  The user can either specify the bolt diameter or allow the software to choose the optimal size.
- **Anchor Bolt Grade:**
  The user can specify the property class of the anchor bolt (e.g., 4.6, 8.8, 12.9) or select the optimized option.
- **Weld Size:**
  The user must input the size of the weld connecting the column to the base plate.

The user will also have the option of changing the design preferences from Edit>Design Preferences or CTRL + P. These options for the design of a base plate include:

- **Bolt Type:**
  Specify whether the anchor bolts are standard or high-strength friction grip (HSFG) bolts.
- **Bolt Hole Type:**
  Choose between standard, oversized, or slotted holes.
- **Concrete Bearing Strength:**
  Adjust settings to reflect special cases, such as increased confinement or reduced grout thickness.
- **Weld Quality:**
  Specify weld type (shop weld or field weld) and inspection levels for critical connections.
- **Edge Distances:**
  Specify if adjustments are required for corrosion exposure or fabrication tolerances.

***Input Compulsory.**

2.2 Column Design

The design of a steel column involves checking its strength and stability under axial compression, bending, and combined loads. This section adheres to the provisions of **IS 800:2007** for limit state design.

2.2.0.1 Axial Load Capacity

The design axial load capacity (P_d) of the column is determined based on its cross-sectional area, material properties, and effective length. As per IS 800:2007 Cl. 7.1.2:

$$P_d = \frac{A \cdot f_y}{\gamma_{m0}}, \tag{2.1}$$

where:

- A: Cross-sectional area of the column section,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength (typically 1.1).

The applied axial load P_u must satisfy:

$$P_u \leq P_d.$$

2.2.0.2 Flexural Capacity (Bending Strength)

The moment capacity of the column section (M_d) is calculated separately for the major and minor axes. As per IS 800:2007 Cl. 8.2.1.2:

$$M_d = \frac{Z \cdot f_y}{\gamma_{m0}},$$

where:

- Z: Section modulus about the respective axis,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength.

Ensure that the applied moment about each axis ($M_{z,u}, M_{y,u}$) satisfies:

$$M_{z,u} \leq M_{z,d}, \quad M_{y,u} \leq M_{y,d}.$$

2.2.0.3 Shear Capacity

The design shear strength of the column (V_d) is calculated as per IS 800:2007 Cl. 8.4:

$$V_d = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{m0}},$$

where:

- A_v: Shear area of the section, depending on the orientation and type of section.

The applied shear forces along the major and minor axes ($V_{z,u}, V_{y,u}$) must satisfy:

$$V_{z,u} \leq V_{z,d}, \quad V_{y,u} \leq V_{y,d}.$$

2.2.0.4 Stability Checks

- **Effective Length:** Determine the effective length L_e using IS 800:2007 Table 11 based on end conditions.
- **Slenderness Ratio:** Calculate slenderness ratio λ as:

$$\lambda = \frac{L_e}{r},$$

  where r is the radius of gyration of the section. Ensure $\lambda \leq 180$ for compression members as per IS 800:2007 Cl. 3.7.1.

- **Buckling Resistance:** The design buckling resistance is given by:

$$P_{cr} = \phi \cdot A \cdot f_y,$$

  where ϕ is the reduction factor for buckling as per IS 800:2007 Cl. 7.1.2.2.

2.2.0.5 Combined Axial Load and Bending

For members subjected to combined axial compression and bending, the following interaction equation must be satisfied as per IS 800:2007 Cl. 9.3.1:

$$\frac{P_u}{P_d} + \frac{M_{z,u}}{M_{z,d}} + \frac{M_{y,u}}{M_{y,d}} \leq 1.0.$$

This ensures that the combined utilization of the section does not exceed its capacity.

2.2.0.6 Serviceability Checks

- **Deflection:** Verify that the deflection under service loads does not exceed the limits specified in IS 800:2007 Cl. 5.6.1:

$$\delta \leq \frac{L}{300},$$

  where L is the unsupported length of the column.

- **Vibration:** Ensure that vibration limits are satisfied if the column supports dynamic loads.

2.2.0.7 Final Checklist

All design checks must conform to IS 800:2007:

- Verify that $P_u \leq P_d$ (axial compression check).
- Ensure that $M_{z,u} \leq M_{z,d}$ and $M_{y,u} \leq M_{y,d}$ (bending checks).
- Check $V_{z,u} \leq V_{z,d}$ and $V_{y,u} \leq V_{y,d}$ (shear checks).
- Perform combined load interaction and stability checks.
- Verify that serviceability criteria (deflection and vibration) are met.

2.3 Anchor Rod Design

The *Anchor Rod Design* involves checking the capacity of bolts in tension, shear, and bearing, as well as determining the required embedment length to safely transfer loads to the concrete foundation. All calculations and clauses conform to IS 800:2007 and IS 5624:1993.

2.3.1 Bolt Properties

- Bolt diameter, d_0 (e.g. 20 mm for M20).
- Net area:

$$A_{nb} \;=\; \frac{\pi}{4}(d_0 - 2)^2$$

  (2 mm allowance for threads).
- Bolt material: ultimate strength f_{ub}, partial factor γ_{mb}.

2.3.1.1 Shear Capacity

Per IS 800:2007 Cl. 10.3.3, design shear capacity of each bolt is

$$V_{dsb} \;=\; \frac{f_{ub}\,A_{nb}}{\sqrt{3}\,\gamma_{mb}}$$

Check that applied shear forces $V_1, V_2 \le V_{dsb}$.

2.3.1.2 Bearing Capacity

Per IS 800:2007 Cl. 10.3.4, compute reduction factor

$$k_b = \min\Big(\frac{e}{3\,d_0},\; \frac{f_{ub}}{f_u},\; 1.0\Big)$$

and bearing capacity

$$V_{dpb} \;=\; 0.7\,\frac{2.5\,k_b\,d_0\,t_p\,f_u}{\gamma_{mb}}.$$

Ensure $V_{dpb} \ge$ applied shear per bolt.

2.3.1.3 Governing Shear Capacity

$$V_{db} = \min(V_{dsb},\, V_{dpb}).$$

Verify applied shear per bolt $\le V_{db}$.

2.3.1.4 Tension Capacity

Per IS 800:2007 Cl. 10.3.5,

$$T_{db} = \frac{0.9\,f_{ub}\,A_{nb}}{\gamma_{mb}}.$$

Check uplift demand per bolt $\le T_{db}$.

2.3.1.5 Embedment Length

From IS 5624:1993 Table 1, embedment depth l_2. For M20 in M20 concrete, $l_2 = 238$ mm.
Total anchor length:

$$l_a = t_g + t_p + t_w + t_n + t_{\text{washer}} + l_2,$$

with $200 \le l_a \le 800$ mm (IS 800:2007 Cl. 10.4.4).

2.3.2 Detailing Requirements

- **Bolt hole size:** standard $= d_0 + 2\,\text{mm}$, oversized $= d_0 + 6\,\text{mm}$.
- **End/edge distances** e, e':

$$1.5\,d_0 \le e, e' \le 40 + 4\,t_p$$

  (rolled edges $1.5d_0$, sheared $1.7d_0$; IS 800:2007 Cl. 10.2.4).

All checks comply with IS 800:2007 and IS 5624:1993.

2.4 Base Plate Design

The design of a base plate involves determining its geometry, thickness, and the bearing stress distribution to safely transfer loads from the column to the concrete pedestal. This section adheres to the guidelines of **IS 800:2007** and **IS 456:2000**.

2.4.0.1 Geometry of the Base Plate

- **Length and Width:** The base plate dimensions, L and W, are calculated to ensure adequate bearing area and edge distances:
$$L = D + 2e, \quad W = 0.85B + 2e',$$
where:
  - D = column web depth (for I-sections) or column diameter (for hollow sections),
  - B = column flange width,
  - e = end distance from column face to the plate edge,
  - e' = edge distance from bolt hole center to the plate edge.
- **End and Edge Distances:** As per IS 800:2007 Cl. 10.2.4, ensure:
$$e, e' \geq 1.5\, d_0 \quad \text{(rolled edges)}, \quad e, e' \geq 1.7\, d_0 \quad \text{(sheared edges)}.$$
The maximum distances are limited by:
$$e, e' \leq 40 + 4\, t_p,$$
where t_p is the base plate thickness.

2.4.0.2 Bearing Area and Stress Distribution

- **Concrete Bearing Strength:** As per IS 456:2000 Cl. 34.4, the permissible bearing strength of concrete is:
$$\sigma_{br} = 0.45\, f_{ck},$$
where f_{ck} is the characteristic compressive strength of concrete.
- **Required Bearing Area:** The required bearing area is calculated as:
$$A_{req} = \frac{P_u}{\sigma_{br}},$$
where P_u is the factored axial load.
- **Provided Bearing Area:** The provided area is:
$$A_{prov} = L \cdot W.$$
Ensure $A_{prov} \geq A_{req}$.
- **Effective Bearing Area (Projection c):** For pinned bases, the effective bearing area considers the projection c beyond the column footprint. As per IS 800:2007 Cl. 10.5.2:
$$c = \min\left(\frac{L - D}{2}, \frac{W - B}{2}\right).$$

2.4.0.3 Base Plate Thickness

The base plate thickness is determined to resist bending from bearing pressure:

- **For Axial Loading Only (Pinned Base):** As per IS 800:2007 Cl. 10.5.2.1, the plate thickness must satisfy:
$$t_p \geq \sqrt{\frac{2.5\, \sigma_{br,actual}\, \gamma_{m0}}{f_{y,plate}}} \cdot c,$$
where:
  - $\sigma_{br,actual}$ = actual bearing stress, P_u / A_{eff},
  - γ_{m0} = partial safety factor for steel,
  - $f_{y,plate}$ = yield strength of the base plate material.

2.4.0.4 Weld Design

The welds connecting the column to the base plate are sized to resist forces:

- **Weld Strength:** As per IS 800:2007 Cl. 10.5.7, the weld strength is determined based on throat area and ultimate weld strength:

$$f_{uw} = \frac{T_w}{A_w},$$

  where T_w is the applied tension and A_w is the throat area of the weld.

- **Weld Size:** For flange welds, the size must satisfy:

$$a_w \geq \frac{V}{2\, L_w\, f_{uw}},$$

  where L_w is the weld length and V is the applied shear.

2.4.0.5 Grout and Surface Preparation

- **Grout Thickness:** Maintain grout thickness t_g as per input (typically 20–50 mm). Ensure full bearing by checking tolerance.
- **Surface Flatness:** As per IS 800:2007 Cl. 10.4.4, ensure the plate and concrete pedestal are within flatness tolerance of ± 2 mm for uniform bearing.

2.4.0.6 Final Checklist

All checks must comply with the provisions of IS 800:2007 and IS 456:2000. Ensure that:

- The plate area satisfies $A_{prov} \geq A_{req}$.
- The thickness t_p meets the bending resistance criteria.
- End and edge distances are within prescribed limits.
- Weld sizes and lengths are adequate for the applied forces.
- Grout and surface preparation ensure full and uniform bearing.

2.4.1 Friction Grip Type Bolting

In friction grip type bolting, initial pretension in the bolt develops clamping force at the interfaces of the elements being joined. The frictional resistance to slip between the plate surfaces subjected to clamping force opposes slip due to externally applied shear. Where the slip between bolted plates cannot be tolerated at working loads, the connection shall be designed for slip resistance conforming to Cl.10.4.3 of IS:800:2007.
Consequently, it may also be noted that as per Cl. 10.4.4 of Is:800:2007 when friction-type bolts are designed for slip resistance at service loads, the design capacity at ultimate load may be calculated as per bearing type connection as per Cl. 10.3.3 of IS:800:2007. However, in the design of tension members using bolted connections for Osdag software, we take input from factored loads only. Hence, the design strength for bearing for friction type of bolt is not considered.

2.4.1.1 Slip Resistance (V_{dsf})

As per Cl. 10.4.3 of IS:800:2007, the design strength of the bolt owing to slip resistance V_{dsf} is given by,

$$V_{dsf} = \frac{V_{nsf}}{\gamma_{mf}} \tag{2.2}$$

V_{nsf} = Nominal shear strength of a bolt as governed by slip for friction type connection, calculated as follows,

$$V_{nsf} = \mu \cdot n_e \cdot K_h \cdot F_o$$

μ_f = Coefficient of friction (slip factor) as specified in Table 20 of IS:800:2007
n_e = Number of effective interfaces offering frictional resistance to slip
K_h = 1.0 for fasteners in clearance holes, 0.85 for fasteners in oversized and short slotted holes and for fasteners in long slotted holes loaded perpendicular to the slot, 0.7 for fasteners in long slotted holes loaded parallel to the slot
γ_{mf} = 1.10 (if slip resistance is designed at service load), 1.25 (if slip resistance is designed at ultimate load)
F_o = Minimum bolt tension (proof load) at installation and may be taken as,

$$F_o = A_{nb} \cdot f_0$$

Where,
A_{nb} = Net area of bolt at threads
f_0 = Proof stress (= $0.70 \cdot f_{ub}$)

2.4.2 Reduction Factors for Bolted Connection

The reduction factors summarised in this section are various provisions in IS:800:2007, which recommends reduction in the capacity of section.

2.4.2.1 Long Joints

As per Cl. 10.3.3.1 of IS:800:2007, when the length of the joint l_j, of the tension member containing more than two bolts (that is the distance between the first and last row of bolts in the joint measured in the direction of the load transfer) exceeds $15d$ in the direction of load, the nominal shear capacity (calculated as per Section 2.3.1.1 of this document), shall be reduced by a factor β_{lj}, give by,

$$\beta_{lj} = 1.075 - \frac{l_j}{200 \cdot d} \quad \text{but} \quad 0.75 \leq \beta_{lj} \leq 1.0 \tag{2.3}$$

Where, d = Nominal diameter of the bolt

As per Cl. 10.4.3.1, The long joint reduction factor is also applicable to friction grip type bolts. However, the long joint reduction factor is not applicable when the shear distribution is uniform, for example when web of a section is connected to the flanges of another section.

2.4.2.2 Large grip lengths

As per Cl. 10.3.3.2 of IS:800:2007, when large grip length l_g (equal to the total thickness of the connected plate) exceeds five times the diameter d, the design shear capacity shall be reduced by a factor β_{lg}, given by:

$$\beta_{lg} = \frac{8 \cdot d}{(3 \cdot d + l_g)} = \frac{8}{(3 + \frac{l_g}{d})} \tag{2.4}$$

The grip length l_g in any case shall not be greater than $8 \cdot d$. It may also be noted that β_{lg} shall not be greater than β_{lj} (calculated in section 2.3.3.1 of this document).

2.4.2.3 Bearing capacity reduction for oversized, short-slotted and long-slotted holes

As per Cl. 10.3.4 of IS:800:2007, the bearing resistance of bolts calculated in section 2.3.1.2 of this document may be reduced by the factors mentioned below in a case where standard hole clearance is not provided.

- For over-size and short-slotted holes - 0.7
- For long-slotted holes - 0.5

The above values hold true for bearing type of bolts only. A similar factor K_h is also applicable to friction type grip bolts, the values for which are mentioned in the design strength for slip resistance (section 2.3.2.1) of this document.

2.4.3 Intermittent Connections

As per Cl. 10.2.5.4 of IS:800:2007, members in tension composed of two flats, angles, channels or tees connected back to back by a distance not exceeding the aggregate thickness of the connected parts, tacking fasteners with solid distance pieces shall be provided at a spacing in line not exceeding 1000mm.

2.5 Design of Shear Key

A shear key is used in base plate connections to resist large shear forces that exceed the frictional resistance between the base plate and the concrete pedestal. The shear key prevents sliding and ensures stability under significant lateral loads. This section outlines the design of a shear key in compliance with **IS 800:2007** and **IS 456:2000**.

2.5.1 Purpose of Shear Key

The shear key transfers shear forces from the base plate to the concrete foundation by providing additional bearing area. It is generally a welded or bolted element projecting into the concrete pedestal.

2.5.2 Load Analysis

- **Factored Shear Force (V_u):** The applied shear force (V_u) is the factored shear load acting on the base plate:

$$V_u = 1.5 \cdot V,$$

  where V is the characteristic shear load.

- **Frictional Resistance (V_r):** The frictional resistance at the interface between the base plate and the concrete pedestal is given by **IS 456:2000 Cl. 20.2**:

$$V_r = \mu \cdot P_u,$$

  where:

  - μ: Coefficient of friction (commonly 0.45 for steel-to-concrete interface),
  - P_u: Factored axial load.

- **Shear Key Force (V_k):** If $V_u > V_r$, the excess shear is resisted by the shear key:

$$V_k = V_u - V_r.$$

2.5.3 Geometry of Shear Key

The dimensions of the shear key are determined to ensure sufficient bearing area on the concrete to resist the applied force:

- **Width of Shear Key (b_k):** The width of the shear key is generally equal to the thickness of the base plate (t_p).

- **Depth of Shear Key (h_k):** The depth of the shear key projecting into the concrete is designed to ensure sufficient concrete bearing strength. The effective bearing area is:

$$A_k = b_k \cdot h_k,$$

  and the permissible bearing strength of the concrete is:

$$\sigma_{br} = 0.45 \cdot f_{ck},$$

  as per **IS 456:2000 Cl. 34.4**.

- **Required Depth (h_k):** The required depth is calculated as:

$$h_k = \frac{V_k}{b_k \cdot \sigma_{br}}.$$

2.5.4 Shear Key Material Strength

The material of the shear key must resist the applied shear force without failure:

- **Shear Capacity of the Shear Key (V_{key}):** The shear capacity of the key is governed by the material strength of the steel:
$$V_{key} = \frac{f_y \cdot A_k}{\sqrt{3} \cdot \gamma_{m0}},$$
where:
  - f_y: Yield strength of the steel,
  - A_k: Shear key cross-sectional area,
  - γ_{m0}: Partial safety factor for steel (typically 1.1).
- Ensure:
$$V_k \leq V_{key}.$$

2.5.5 Weld Connection of Shear Key to Base Plate

The shear key is fillet-welded to the base plate. The weld must resist the shear force transferred by the key:

- **Weld Throat Size (a_w):** As per **IS 800:2007 Cl. 10.5.7**, the throat size is:
$$a_w = 0.7 \cdot \text{leg size}.$$
- **Weld Strength:** The weld must satisfy:
$$T_w \leq f_{uw} \cdot A_w,$$
where:
  - T_w: Shear force on the weld,
  - f_{uw}: Ultimate strength of the weld,
  - A_w: Weld throat area.

2.5.6 Final Checklist for Shear Key Design

Ensure the following:

- The shear key is designed to resist $V_k = V_u - V_r$.
- The depth of the shear key (h_k) ensures sufficient concrete bearing strength.
- The material of the shear key is adequate to resist the applied shear force.
- Welds connecting the shear key to the base plate are sufficient to transfer forces.
- All detailing requirements are met to ensure proper fabrication and installation.

Chapter 6

Internship Task 4: Design and Detailing Checklist (DDCL) Report for Pinned Base Plate under Small Eccentric Load

6.1 Problem Statement

The objective of this task is to prepare a comprehensive **Design and Detailing Checklist (DDCL)** for a **Pinned Base Plate subjected to a Small Eccentric Load** for integration into the Osdag software. Such base plate connections are commonly used in structural steel frameworks where the load is not perfectly axial, resulting in additional moment effects.

Goals:

- Define input parameters for eccentric base plate connections.
- Cover the impact of small eccentricity on axial and moment interaction.
- Detail IS code-based design steps for column, base plate, anchor rods, and welds.
- Provide failure conditions and final checks as per IS 800:2007 and IS 456:2000.
- Help future contributors integrate this module into Osdag's workflow.

6.2 Tasks Done

- Studied relevant clauses in IS 800:2007 and IS 456:2000 for eccentric load design.
- Defined a complete set of inputs required for the design module (e.g., column section, loads, material grades, base plate size, anchor bolts, welds).
- Included theoretical formulations to handle small eccentricity:
  - Load-moment interaction equations
  - Combined stress check
  - Anchor bolt tension under eccentric loading
- Created detailing checklists for anchor bolts, washer thickness, plate edge distances, weld size, and grout layer.
- Compiled all findings and checks into a structured PDF document for direct reference and integration.

6.3 Documentation

The following pages contain the complete DDCL for the **Pinned Base Plate subjected to Small Eccentric Load**.

Osdag

Open steel design and graphics

Design and detailing checklist (DDCL)

Pinned Base plate connection for small eccentric load

Prepared by:
Aditya Donde

Mentor:
Parth Karia

Under the guidance of
Prof. Siddhartha Ghosh

Indian Institute of Technology Bombay
July 25, 2025

Contents

1 Theory **1**
1.1 Introduction . . . 1

2 Design and Detailing Checklist for Osdag Software **2**
2.1 Input Parameters . . . 2
2.2 Column Design . . . 4
2.3 Plate Washer and Nut Thickness . . . 6
2.3.1 Plate Washer Thickness . . . 6
2.3.2 Nut Thickness . . . 6
2.3.3 Material Properties . . . 6
2.4 Anchor Rod Design . . . 8
2.4.1 Bolt Properties . . . 8
2.4.2 Detailing Requirements . . . 9
2.5 Base Plate Design . . . 10
2.5.1 Geometry of the Base Plate . . . 10
2.5.2 Bearing Area and Stress Distribution . . . 10
2.5.3 Base Plate Thickness . . . 11
2.5.4 Weld Design . . . 11
2.5.5 Grout and Surface Preparation . . . 11
2.5.6 Friction Grip Type Bolting . . . 11
2.5.7 Reduction Factors for Bolted Connection . . . 12
2.6 Design of Shear Key . . . 14
2.6.1 Purpose of Shear Key . . . 14
2.6.2 Load Analysis . . . 14
2.6.3 Geometry of Shear Key . . . 14
2.6.4 Shear Key Material Strength . . . 15
2.6.5 Weld Connection of Shear Key to Base Plate . . . 15
2.6.6 Final Checklist for Shear Key Design . . . 15
2.7 Minimum Failure Condition for Base Plate with Small Eccentric Load . . . 16
2.8 Detailing Checklist . . . 18
2.8.1 Pitch and Gauge Distances . . . 18
2.8.2 End and Edge Distances . . . 18
2.8.3 Hole Dimensions . . . 18
2.8.4 Weld Details . . . 19
2.8.5 Grout and Surface Preparation . . . 19
2.8.6 Corrosion Protection and Durability . . . 19
2.8.7 Final Checklist . . . 19

3 Tutorial for Design of Base plate from Osdag **20**

4 Verification Examples for the Calibration of Osdag **21**

Chapter 2

Design and Detailing Checklist for Osdag Software

2.1 Input Parameters

The following are the input parameters that the user will have to input on the Osdag Software.

- **Column Profile:**
  The user must choose the type of column section, such as I-section, hollow circular section, or rectangular section.
- **Column Size:**
  The user must specify the size of the column section, including flange and web dimensions for I-sections or diameter and thickness for hollow sections.
- **Material Property:**
  The user will have the option to select the grade of steel for the column section and base plate (e.g., Fe250, Fe345).
- **Factored Axial Load (in kN):**
  The user must input the factored axial load acting on the column.
- **Factored Shear Load (in kN):**
  The user must input the shear loads along both the major (z-z) and minor (y-y) axes.
- **Factored Moment (in kNm):**
  The user must specify any factored moments acting about the major and minor axes.
- **Concrete Grade:**
  The user must input the grade of concrete for the pedestal (e.g., M20, M25).
- **Base Plate Dimensions:**
  The user may specify the length and width of the base plate or allow the software to optimize these dimensions.
- **Grout Thickness (in mm):**
  The user must input the thickness of the grout layer beneath the base plate.
- **Anchor Bolt Diameter:**
  The user can either specify the bolt diameter or allow the software to choose the optimal size.
- **Anchor Bolt Grade:**
  The user can specify the property class of the anchor bolt (e.g., 4.6, 8.8, 12.9) or select the optimized option.
- **Weld Size:**
  The user must input the size of the weld connecting the column to the base plate.

The user will also have the option of changing the design preferences from Edit>Design Preferences or CTRL + P. These options for the design of a base plate include:

- **Bolt Type:**
  Specify whether the anchor bolts are standard or high-strength friction grip (HSFG) bolts.
- **Bolt Hole Type:**
  Choose between standard, oversized, or slotted holes.
- **Concrete Bearing Strength:**
  Adjust settings to reflect special cases, such as increased confinement or reduced grout thickness.
- **Weld Quality:**
  Specify weld type (shop weld or field weld) and inspection levels for critical connections.
- **Edge Distances:**
  Specify if adjustments are required for corrosion exposure or fabrication tolerances.

***Input Compulsory.**

2.2 Column Design

The design of a steel column involves checking its strength and stability under axial compression, bending, and combined loads. This section adheres to the provisions of **IS 800:2007** for limit state design.

2.2.0.1 Axial Load Capacity

The design axial load capacity (P_d) of the column is determined based on its cross-sectional area, material properties, and effective length. As per IS 800:2007 Cl. 7.1.2:

$$P_d = \frac{A \cdot f_y}{\gamma_{m0}}, \tag{2.1}$$

where:

- A: Cross-sectional area of the column section,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength (typically 1.1).

The applied axial load P_u must satisfy:

$$P_u \leq P_d.$$

2.2.0.2 Flexural Capacity (Bending Strength)

The moment capacity of the column section (M_d) is calculated separately for the major and minor axes. As per IS 800:2007 Cl. 8.2.1.2:

$$M_d = \frac{Z \cdot f_y}{\gamma_{m0}},$$

where:

- Z: Section modulus about the respective axis,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength.

Ensure that the applied moment about each axis ($M_{z,u}, M_{y,u}$) satisfies:

$$M_{z,u} \leq M_{z,d}, \quad M_{y,u} \leq M_{y,d}.$$

2.2.0.3 Shear Capacity

The design shear strength of the column (V_d) is calculated as per IS 800:2007 Cl. 8.4:

$$V_d = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{m0}},$$

where:

- A_v: Shear area of the section, depending on the orientation and type of section.

The applied shear forces along the major and minor axes ($V_{z,u}, V_{y,u}$) must satisfy:

$$V_{z,u} \leq V_{z,d}, \quad V_{y,u} \leq V_{y,d}.$$

2.2.0.4 Stability Checks

- **Effective Length:** Determine the effective length L_e using IS 800:2007 Table 11 based on end conditions.
- **Slenderness Ratio:** Calculate slenderness ratio λ as:

$$\lambda = \frac{L_e}{r},$$

  where r is the radius of gyration of the section. Ensure $\lambda \leq 180$ for compression members as per IS 800:2007 Cl. 3.7.1.

- **Buckling Resistance:** The design buckling resistance is given by:

$$P_{cr} = \phi \cdot A \cdot f_y,$$

  where ϕ is the reduction factor for buckling as per IS 800:2007 Cl. 7.1.2.2.

2.2.0.5 Combined Axial Load and Bending

For members subjected to combined axial compression and bending, the following interaction equation must be satisfied as per IS 800:2007 Cl. 9.3.1:

$$\frac{P_u}{P_d} + \frac{M_{z,u}}{M_{z,d}} + \frac{M_{y,u}}{M_{y,d}} \leq 1.0.$$

This ensures that the combined utilization of the section does not exceed its capacity.

2.2.0.6 Serviceability Checks

- **Deflection:** Verify that the deflection under service loads does not exceed the limits specified in IS 800:2007 Cl. 5.6.1:

$$\delta \leq \frac{L}{300},$$

  where L is the unsupported length of the column.

- **Vibration:** Ensure that vibration limits are satisfied if the column supports dynamic loads.

2.2.0.7 Final Checklist

All design checks must conform to IS 800:2007:

- Verify that $P_u \leq P_d$ (axial compression check).
- Ensure that $M_{z,u} \leq M_{z,d}$ and $M_{y,u} \leq M_{y,d}$ (bending checks).
- Check $V_{z,u} \leq V_{z,d}$ and $V_{y,u} \leq V_{y,d}$ (shear checks).
- Perform combined load interaction and stability checks.
- Verify that serviceability criteria (deflection and vibration) are met.

2.3 Plate Washer and Nut Thickness

The thickness of plate washers and nuts is critical in ensuring uniform force distribution and preventing localized crushing or deformation under high loads. This section outlines the design of plate washers and nuts in compliance with **IS 800:2007** and **IS 1363:2002** for hexagonal nuts and bolts.

2.3.1 Plate Washer Thickness

Plate washers are used to distribute the load from the bolt over a larger area of the base plate. The thickness of the washer must satisfy the following criteria:

- **Thickness Requirement:** As per IS 800:2007 Cl. 10.4.3, the washer thickness (t_w) should be sufficient to prevent local bearing failure of the base plate and crushing of the washer. It is given by:

  $$t_w \geq \frac{d_0}{3},$$

  where:

  - t_w: Thickness of the washer,
  - d_0: Bolt hole diameter.

  For example, for a bolt hole diameter of $d_0 = 26\,\text{mm}$:

  $$t_w \geq \frac{26}{3} \approx 8.67\,\text{mm}.$$

  A washer thickness of 10 mm is typically used.

- **Outer Diameter:** The outer diameter of the washer (d_w) should comply with IS 2016:2000, which specifies:

  $$d_w = 2 \cdot d_0.$$

  For $d_0 = 26\,\text{mm}$, the washer diameter should be:

  $$d_w = 2 \cdot 26 = 52\,\text{mm}.$$

2.3.2 Nut Thickness

The thickness of the nut ensures adequate thread engagement and prevents thread shear failure. The following guidelines apply:

- **Nominal Nut Thickness:** As per IS 1363:2002, the nominal thickness of a standard hexagonal nut (t_n) is given as:

  $$t_n = 0.8 \cdot d,$$

  where d is the nominal bolt diameter. For an M20 bolt:

  $$t_n = 0.8 \cdot 20 = 16\,\text{mm}.$$

- **Thread Engagement Length:** The thread engagement length (l_t) should be at least equal to the bolt diameter (d) as per IS 800:2007 Cl. 10.4.4:

  $$l_t \geq d.$$

  For M20 bolts:

  $$l_t \geq 20\,\text{mm}.$$

- **Overtightening Allowance:** To account for overtightening or misalignment, the nut height should be checked against shear and compressive forces. This ensures that the nut does not fail before the bolt.

2.3.3 Material Properties

The material of the washers and nuts should match or exceed the strength of the bolt material. The ultimate tensile strength of the washer (f_{uw}) and nut should conform to IS 2062:2011 for structural steel.

2.3.3.1 Final Checklist

Ensure the following:

- The washer thickness (t_w) is sufficient to prevent local deformation, and its outer diameter (d_w) complies with IS 2016:2000.
- The nut thickness (t_n) and thread engagement length (l_t) satisfy IS 1363:2002 and IS 800:2007 requirements.
- The material properties of washers and nuts meet or exceed the strength of the bolt material.

2.4 Anchor Rod Design

The *Anchor Rod Design* involves checking the capacity of bolts in tension, shear, and bearing, as well as determining the required embedment length to safely transfer loads to the concrete foundation. All calculations and clauses conform to IS 800:2007 and IS 5624:1993.

2.4.1 Bolt Properties

- Bolt diameter, d_0 (e.g. 20 mm for M20).
- Net area:

$$A_{nb} \;=\; \frac{\pi}{4}(d_0 - 2)^2$$

  (2 mm allowance for threads).
- Bolt material: ultimate strength f_{ub}, partial factor γ_{mb}.

2.4.1.1 Shear Capacity

Per IS 800:2007 Cl. 10.3.3, design shear capacity of each bolt is

$$V_{dsb} \;=\; \frac{f_{ub}\,A_{nb}}{\sqrt{3}\,\gamma_{mb}}$$

Check that applied shear forces $V_1, V_2 \le V_{dsb}$.

2.4.1.2 Bearing Capacity

Per IS 800:2007 Cl. 10.3.4, compute reduction factor

$$k_b = \min\Big(\frac{e}{3\,d_0},\; \frac{f_{ub}}{f_u},\; 1.0\Big)$$

and bearing capacity

$$V_{dpb} \;=\; 0.7\,\frac{2.5\,k_b\,d_0\,t_p\,f_u}{\gamma_{mb}}.$$

Ensure $V_{dpb} \ge$ applied shear per bolt.

2.4.1.3 Governing Shear Capacity

$$V_{db} = \min(V_{dsb},\, V_{dpb}).$$

Verify applied shear per bolt $\le V_{db}$.

2.4.1.4 Tension Capacity

Per IS 800:2007 Cl. 10.3.5,

$$T_{db} = \frac{0.9\,f_{ub}\,A_{nb}}{\gamma_{mb}}.$$

Check uplift demand per bolt $\le T_{db}$.

2.4.1.5 Embedment Length

From IS 5624:1993 Table 1, embedment depth l_2. For M20 in M20 concrete, $l_2 = 238$ mm.
Total anchor length:

$$l_a = t_g + t_p + t_w + t_n + t_{\text{washer}} + l_2,$$

with $200 \le l_a \le 800$ mm (IS 800:2007 Cl. 10.4.4).

2.4.2 Detailing Requirements

- **Bolt hole size:** standard $= d_0 + 2\,\text{mm}$, oversized $= d_0 + 6\,\text{mm}$.
- **End/edge distances** e, e':

$$1.5\,d_0 \le e, e' \le 40 + 4\,t_p$$

  (rolled edges $1.5d_0$, sheared $1.7d_0$; IS 800:2007 Cl. 10.2.4).

All checks comply with IS 800:2007 and IS 5624:1993.

2.5 Base Plate Design

The design of a base plate involves determining its geometry, thickness, and the bearing stress distribution to safely transfer loads from the column to the concrete pedestal. This section adheres to the guidelines of **IS 800:2007** and **IS 456:2000**.

2.5.1 Geometry of the Base Plate

- **Length and Width:** The base plate dimensions, L and W, are calculated to ensure adequate bearing area and edge distances:

$$L = D + 2e, \quad W = 0.85B + 2e',$$

where:

  - D = column web depth (for I-sections) or column diameter (for hollow sections),
  - B = column flange width,
  - e = end distance from column face to the plate edge,
  - e' = edge distance from bolt hole center to the plate edge.

- **End and Edge Distances:** As per IS 800:2007 Cl. 10.2.4, ensure:

$$e, e' \geq 1.5\, d_0 \quad \text{(rolled edges)}, \quad e, e' \geq 1.7\, d_0 \quad \text{(sheared edges)}.$$

The maximum distances are limited by:

$$e, e' \leq 40 + 4\, t_p,$$

where t_p is the base plate thickness.

2.5.2 Bearing Area and Stress Distribution

- **Concrete Bearing Strength:** As per IS 456:2000 Cl. 34.4, the permissible bearing strength of concrete is:

$$\sigma_{br} = 0.45\, f_{ck},$$

where f_{ck} is the characteristic compressive strength of concrete.

- **Required Bearing Area:** The required bearing area is calculated as:

$$A_{req} = \frac{P_u}{\sigma_{br}},$$

where P_u is the factored axial load.

- **Provided Bearing Area:** The provided area is:

$$A_{prov} = L \cdot W.$$

Ensure $A_{prov} \geq A_{req}$.

- **Effective Bearing Area (Projection c):** For pinned bases, the effective bearing area considers the projection c beyond the column footprint. As per IS 800:2007 Cl. 10.5.2:

$$c = \min\left(\frac{L - D}{2}, \frac{W - B}{2}\right).$$

2.5.3 Base Plate Thickness

The base plate thickness is determined to resist bending from bearing pressure:

- **For Axial Loading Only (Pinned Base):** As per IS 800:2007 Cl. 10.5.2.1, the plate thickness must satisfy:

$$t_p \geq \sqrt{\frac{2.5\,\sigma_{br,actual}\,\gamma_{m0}}{f_{y,plate}}} \cdot c,$$

  where:

  - $\sigma_{br,actual}$ = actual bearing stress, P_u/A_{eff},
  - γ_{m0} = partial safety factor for steel,
  - $f_{y,plate}$ = yield strength of the base plate material.

- **For Moment Resisting Base (With M_z or M_y):** As per IS 800:2007 Cl. 10.5.2.2, the plate must resist bending moment:

$$M_{cr} = \min\left(\sigma_{br} \cdot W \cdot \frac{t_p^2}{4},\, T_{bolt} \cdot e\right),$$

  where T_{bolt} is the bolt tension capacity. The thickness is then:

$$t_p \geq \sqrt{\frac{4\,M_{cr}}{W \cdot f_{y,plate}/\gamma_{m0}}}.$$

2.5.4 Weld Design

The welds connecting the column to the base plate are sized to resist forces:

- **Weld Strength:** As per IS 800:2007 Cl. 10.5.7, the weld strength is determined based on throat area and ultimate weld strength:

$$f_{uw} = \frac{T_w}{A_w},$$

  where T_w is the applied tension and A_w is the throat area of the weld.

- **Weld Size:** For flange welds, the size must satisfy:

$$a_w \geq \frac{V}{2\,L_w\,f_{uw}},$$

  where L_w is the weld length and V is the applied shear.

2.5.5 Grout and Surface Preparation

- **Grout Thickness:** Maintain grout thickness t_g as per input (typically 20–50 mm). Ensure full bearing by checking tolerance.
- **Surface Flatness:** As per IS 800:2007 Cl. 10.4.4, ensure the plate and concrete pedestal are within flatness tolerance of ± 2 mm for uniform bearing.

2.5.6 Friction Grip Type Bolting

In friction grip type bolting, initial pretension in the bolt develops clamping force at the interfaces of the elements being joined. The frictional resistance to slip between the plate surfaces subjected to clamping force opposes slip due to externally applied shear. Where the slip between bolted plates cannot be tolerated at working loads, the connection shall be designed for slip resistance conforming to Cl.10.4.3 of IS:800:2007.
Consequently, it may also be noted that as per Cl. 10.4.4 of Is:800:2007 when friction-type bolts are designed for slip resistance at service loads, the design capacity at ultimate load may be calculated as per bearing type connection as per Cl. 10.3.3 of IS:800:2007. However, in the design of tension members using bolted connections for Osdag software, we take input from factored loads only. Hence, the design strength for bearing for friction type of bolt is not considered.

2.5.6.1 Slip Resistance (V_{dsf})

As per Cl. 10.4.3 of IS:800:2007, the design strength of the bolt owing to slip resistance V_{dsf} is given by,

$$V_{dsf} = \frac{V_{nsf}}{\gamma_{mf}} \tag{2.2}$$

V_{nsf} = Nominal shear strength of a bolt as governed by slip for friction type connection, calculated as follows,

$$V_{nsf} = \mu \cdot n_e \cdot K_h \cdot F_o$$

μ_f = Coefficient of friction (slip factor) as specified in Table 20 of IS:800:2007
n_e = Number of effective interfaces offering frictional resistance to slip
K_h = 1.0 for fasteners in clearance holes, 0.85 for fasteners in oversized and short slotted holes and for fasteners in long slotted holes loaded perpendicular to the slot, 0.7 for fasteners in long slotted holes loaded parallel to the slot
γ_{mf} = 1.10 (if slip resistance is designed at service load), 1.25 (if slip resistance is designed at ultimate load)
F_o = Minimum bolt tension (proof load) at installation and may be taken as,

$$F_o = A_{nb} \cdot f_0$$

Where,
A_{nb} = Net area of bolt at threads
f_0 = Proof stress (= $0.70 \cdot f_{ub}$)

2.5.7 Reduction Factors for Bolted Connection

The reduction factors summarised in this section are various provisions in IS:800:2007, which recommends reduction in the capacity of section.

2.5.7.1 Long Joints

As per Cl. 10.3.3.1 of IS:800:2007, when the length of the joint l_j, of the tension member containing more than two bolts (that is the distance between the first and last row of bolts in the joint measured in the direction of the load transfer) exceeds $15d$ in the direction of load, the nominal shear capacity (calculated as per Section 2.3.1.1 of this document), shall be reduced by a factor β_{lj}, give by,

$$\beta_{lj} = 1.075 - \frac{l_j}{200 \cdot d} \quad \text{but} \quad 0.75 \leq \beta_{lj} \leq 1.0 \tag{2.3}$$

Where, d = Nominal diameter of the bolt

As per Cl. 10.4.3.1, The long joint reduction factor is also applicable to friction grip type bolts. However, the long joint reduction factor is not applicable when the shear distribution is uniform, for example when web of a section is connected to the flanges of another section.

2.5.7.2 Large grip lengths

As per Cl. 10.3.3.2 of IS:800:2007, when large grip length l_g (equal to the total thickness of the connected plate) exceeds five times the diameter d, the design shear capacity shall be reduced by a factor β_{lg}, given by:

$$\beta_{lg} = \frac{8 \cdot d}{(3 \cdot d + l_g)} = \frac{8}{(3 + \frac{l_g}{d})} \tag{2.4}$$

The grip length l_g in any case shall not be greater than $8 \cdot d$. It may also be noted that β_{lg} shall not be greater than β_{lj} (calculated in section 2.3.3.1 of this document).

2.5.7.3 Bearing capacity reduction for oversized, short-slotted and long-slotted holes

As per Cl. 10.3.4 of IS:800:2007, the bearing resistance of bolts calculated in section 2.3.1.2 of this document may be reduced by the factors mentioned below in a case where standard hole clearance is not provided.

- For over-size and short-slotted holes - 0.7
- For long-slotted holes - 0.5

The above values hold true for bearing type of bolts only. A similar factor K_h is also applicable to friction type grip bolts, the values for which are mentioned in the design strength for slip resistance (section 2.3.2.1) of this document.

2.6 Design of Shear Key

A shear key is used in base plate connections to resist large shear forces that exceed the frictional resistance between the base plate and the concrete pedestal. The shear key prevents sliding and ensures stability under significant lateral loads. This section outlines the design of a shear key in compliance with **IS 800:2007** and **IS 456:2000**.

2.6.1 Purpose of Shear Key

The shear key transfers shear forces from the base plate to the concrete foundation by providing additional bearing area. It is generally a welded or bolted element projecting into the concrete pedestal.

2.6.2 Load Analysis

- **Factored Shear Force (V_u):** The applied shear force (V_u) is the factored shear load acting on the base plate:

$$V_u = 1.5 \cdot V,$$

  where V is the characteristic shear load.

- **Frictional Resistance (V_r):** The frictional resistance at the interface between the base plate and the concrete pedestal is given by **IS 456:2000 Cl. 20.2**:

$$V_r = \mu \cdot P_u,$$

  where:

  - μ: Coefficient of friction (commonly 0.45 for steel-to-concrete interface),
  - P_u: Factored axial load.

- **Shear Key Force (V_k):** If $V_u > V_r$, the excess shear is resisted by the shear key:

$$V_k = V_u - V_r.$$

2.6.3 Geometry of Shear Key

The dimensions of the shear key are determined to ensure sufficient bearing area on the concrete to resist the applied force:

- **Width of Shear Key (b_k):** The width of the shear key is generally equal to the thickness of the base plate (t_p).

- **Depth of Shear Key (h_k):** The depth of the shear key projecting into the concrete is designed to ensure sufficient concrete bearing strength. The effective bearing area is:

$$A_k = b_k \cdot h_k,$$

  and the permissible bearing strength of the concrete is:

$$\sigma_{br} = 0.45 \cdot f_{ck},$$

  as per **IS 456:2000 Cl. 34.4**.

- **Required Depth (h_k):** The required depth is calculated as:

$$h_k = \frac{V_k}{b_k \cdot \sigma_{br}}.$$

2.6.4 Shear Key Material Strength

The material of the shear key must resist the applied shear force without failure:

- **Shear Capacity of the Shear Key (V_{key}):** The shear capacity of the key is governed by the material strength of the steel:
$$V_{key} = \frac{f_y \cdot A_k}{\sqrt{3} \cdot \gamma_{m0}},$$
where:
  - f_y: Yield strength of the steel,
  - A_k: Shear key cross-sectional area,
  - γ_{m0}: Partial safety factor for steel (typically 1.1).
- Ensure:
$$V_k \leq V_{key}.$$

2.6.5 Weld Connection of Shear Key to Base Plate

The shear key is fillet-welded to the base plate. The weld must resist the shear force transferred by the key:

- **Weld Throat Size (a_w):** As per **IS 800:2007 Cl. 10.5.7**, the throat size is:
$$a_w = 0.7 \cdot \text{leg size}.$$
- **Weld Strength:** The weld must satisfy:
$$T_w \leq f_{uw} \cdot A_w,$$
where:
  - T_w: Shear force on the weld,
  - f_{uw}: Ultimate strength of the weld,
  - A_w: Weld throat area.

2.6.6 Final Checklist for Shear Key Design

Ensure the following:

- The shear key is designed to resist $V_k = V_u - V_r$.
- The depth of the shear key (h_k) ensures sufficient concrete bearing strength.
- The material of the shear key is adequate to resist the applied shear force.
- Welds connecting the shear key to the base plate are sufficient to transfer forces.
- All detailing requirements are met to ensure proper fabrication and installation.

2.7 Minimum Failure Condition for Base Plate with Small Eccentric Load

The minimum failure condition for a base plate under a small eccentric load is designed to identify the critical limit state where the base plate, bolts, or concrete pedestal fails under combined axial and moment loads. This section is based on the provisions of **IS 800:2007** and **IS 456:2000**.

2.7.0.1 Design Philosophy

The design considers:

- A small eccentricity of the axial load introduces additional bending moments.
- The combined effect of axial load, eccentricity, and bearing stresses governs the failure condition.
- The base plate and supporting concrete pedestal are tested against bearing, bending, and shear capacities.

2.7.0.2 Load and Eccentricity Analysis

- **Factored Axial Load (P_u):** The axial load is factored as per IS 800:2007 Cl. 5.3.3:

  $$P_u = 1.5 \cdot P,$$

  where P is the characteristic axial load.

- **Eccentricity (e):** A small eccentricity e creates a moment:

  $$M_u = P_u \cdot e.$$

  The eccentricity is typically specified as $e = 0.05 \cdot L$, where L is the column depth or base plate length.

- **Combined Effect of Axial Load and Moment:** The interaction of axial load and bending moment must satisfy IS 800:2007 Cl. 9.3.1:

  $$\frac{P_u}{P_d} + \frac{M_u}{M_d} \leq 1.0,$$

  where:

  - $P_d = \frac{A \cdot f_y}{\gamma_{m0}}$ is the design axial load capacity,
  - $M_d = \frac{Z \cdot f_y}{\gamma_{m0}}$ is the design moment capacity.

2.7.0.3 Bearing Stress Check

- **Permissible Bearing Stress:** As per IS 456:2000 Cl. 34.4, the permissible bearing stress for the concrete pedestal is:

  $$\sigma_{br} = 0.45 \cdot f_{ck}.$$

- **Actual Bearing Stress:** The actual bearing stress is calculated considering the eccentric load:

  $$\sigma_{br,actual} = \frac{P_u}{A_{eff}} + \frac{6 \cdot M_u}{L \cdot W^2},$$

  where:

  - A_{eff}: Effective bearing area of the base plate,
  - L: Base plate length,
  - W: Base plate width.

  Ensure:

  $$\sigma_{br,actual} \leq \sigma_{br}.$$

2.7.0.4 Base Plate Thickness Check

The base plate thickness is designed to resist the bending moment induced by eccentricity. As per IS 800:2007 Cl. 10.5.2.1:

$$t_p \geq \sqrt{\frac{2.5 \cdot \sigma_{br,actual} \cdot \gamma_{m0}}{f_{y,plate}}} \cdot c,$$

where:

- $\sigma_{br,actual}$: Actual bearing stress,
- c: Effective projection of the base plate beyond the column face,
- γ_{m0}: Partial safety factor for steel,
- $f_{y,plate}$: Yield strength of the base plate material.

2.7.0.5 Anchor Bolt Design

- **Tension Capacity:** The tension in the anchor bolts due to uplift from the eccentric moment is checked as per IS 800:2007 Cl. 10.3.5:

  $$T_{db} = \frac{0.9 \cdot f_{ub} \cdot A_{nb}}{\gamma_{mb}},$$

  where f_{ub} is the ultimate tensile strength of the bolt material and A_{nb} is the net area of the bolt.
- **Embedment Length:** The embedment depth of the anchor bolt (l_2) must satisfy IS 5624:1993 Table 1.

2.7.0.6 Failure Condition Verification

- **Combined Stress Check:** Ensure the combined stresses from axial load, moment, and bearing meet the interaction criteria:

  $$\frac{\sigma_{br,actual}}{\sigma_{br}} + \frac{\sigma_b}{f_{y,plate}} \leq 1.0,$$

  where σ_b is the bending stress in the base plate:

  $$\sigma_b = \frac{6 \cdot M_u}{t_p^2 \cdot W}.$$

- **Weld Strength:** The welds connecting the column to the base plate must resist the moment and shear forces. As per IS 800:2007 Cl. 10.5.7:

  $$T_w \leq f_{uw} \cdot A_w,$$

  where f_{uw} is the ultimate weld strength and A_w is the weld throat area.

2.7.0.7 Final Checklist

Ensure the following:

- Axial and moment capacities (P_d and M_d) satisfy interaction conditions.
- Bearing stress does not exceed the permissible stress for concrete.
- Base plate thickness meets bending requirements.
- Anchor bolts are sufficient for shear, tension, and embedment requirements.
- Combined stresses do not exceed allowable limits.
- Welds are adequate for the applied forces.

2.8 Detailing Checklist

The detailing checklist ensures that all geometric, material, and connection-specific requirements are met for safe and efficient performance of the base plate connection.

2.8.1 Pitch and Gauge Distances

- **Pitch Distance (p):** Since there is a single row of bolts on the tension side, pitch distance is not applicable. For designs requiring multiple rows, the pitch distance should satisfy:

$$p \geq 2.5 \cdot d_0,$$

where d_0 is the bolt hole diameter.

- **Gauge Distance (g):** As no internal rows are present, gauge distance is also not applicable in this design. For future designs with additional rows, ensure $g \geq 2.5 \cdot d_0$.

2.8.2 End and Edge Distances

- **End Distance (e):** As per IS 800:2007 Cl. 10.2.4.2, the end distance from the bolt hole center to the nearest edge of the plate must satisfy:

$$e \geq 1.5 \cdot d_0 \quad \text{(rolled edges)}, \quad e \geq 1.7 \cdot d_0 \quad \text{(sheared edges)}.$$

In **3.pdf**, the provided end distance is:

$$e = 55\,\text{mm},$$

which satisfies the minimum requirement for $d_0 = 24\,\text{mm}$:

$$1.5 \cdot 24 = 36\,\text{mm} \quad \text{(rolled edge)}.$$

- **Edge Distance (e'):** The edge distance from the bolt hole center to the outer edge of the plate is checked similarly. For this design:

$$e' = 55\,\text{mm},$$

which meets the minimum requirement:

$$e' \geq 1.5 \cdot d_0 = 36\,\text{mm}.$$

- **Maximum End and Edge Distance:** Per IS 800:2007 Cl. 10.2.4.3, the maximum end and edge distances are:

$$e, e' \leq 40 + 4 \cdot t_p,$$

where t_p is the base plate thickness. For $t_p = 10\,\text{mm}$:

$$e, e' \leq 40 + 4 \cdot 10 = 80\,\text{mm}.$$

The provided values ($55\,\text{mm}$) are within the allowable range.

2.8.3 Hole Dimensions

- **Standard Bolt Holes:** The hole diameter for standard bolts is:

$$d_h = d_0 + 2 = 24 + 2 = 26\,\text{mm}.$$

- **Oversized Bolt Holes:** Oversized holes are not applicable in this design. For future cases, the oversized hole diameter would be:

$$d_h = d_0 + 6 = 24 + 6 = 30\,\text{mm}.$$

2.8.4 Weld Details

- **Weld Type:** Continuous fillet welds are provided for the connection of the column to the base plate.
- **Weld Throat Size (a_w):** As per IS 800:2007 Cl. 10.5.7, the weld throat size is sufficient to resist the applied shear. For flange welds:
$$a_w = 0.7 \cdot \text{leg size}.$$
- **Weld Length:** The provided weld lengths fully enclose the column flange. No web welds are included as this is a pinned-base connection.

2.8.5 Grout and Surface Preparation

- **Grout Thickness (t_g):** As per IS 800:2007 Cl. 10.4.4, the grout thickness is specified as $t_g = 50\,\text{mm}$. Ensure the grout is non-shrink and properly leveled.
- **Surface Flatness:** Ensure that both the base plate and concrete pedestal are within flatness tolerances of $\pm 2\,\text{mm}$ for uniform bearing pressure.

2.8.6 Corrosion Protection and Durability

- **Corrosion Allowance:** In environments exposed to weather or corrosive conditions, increase the end and edge distances by appropriate corrosion allowance.
- **Surface Treatment:** The base plate and bolts must be painted or galvanized to prevent corrosion.

2.8.7 Final Checklist

The following must be verified:

- End and edge distances (e, e') satisfy IS 800:2007 requirements.
- Bolt hole dimensions conform to standard sizes.
- Weld sizes and lengths are adequate for the applied forces.
- Grout thickness and surface flatness are within allowable tolerances.
- Proper corrosion protection is applied for exposed environments.

Chapter 7

Internship Task 5: Bug Report: Base Plate Module in Osdag

7.1 Problem Statement

During the evaluation of the base plate module in Osdag, several critical issues were discovered related to the design and detailing of shear strength and effective bearing area calculations. These discrepancies may lead to unsafe or non-compliant design outputs, particularly under IS 800:2007 design standards.

The issues specifically pertain to:

- Incorrect calculation of shear strength of the column due to improper evaluation of the effective shear area (A_v).
- Incorrect formula used for computing the effective bearing area of the base plate, deviating from IS 800:2007 Figure 9.

7.2 Tasks Done

- Reviewed Clause 8.4.1 of IS 800:2007 to verify shear strength calculation procedures.
- Identified that the implemented shear area does not correctly account for geometric reductions due to holes or openings.

- Examined and corrected the formula used for effective bearing area of the base plate by referencing **Figure 9** of IS 800:2007.
- Proposed correct formulae for both:
  - Effective shear area: $A_v = d \cdot t - n \cdot \frac{\pi}{4} d_h^2$
  - Effective bearing area: $A_{eff} = (D - 2c)(2c + t_{web}) + 2(2c + T_{flange})(B + 2c)$
- Summarized corrections with explanation, design clause reference, and visual illustration (from IS 800:2007).

7.3 Documentation

The following pages (Chapter 5: Base Plate Connection) are extracted directly from the full bug report(Bugs in Osdag), focusing exclusively on the issues and fixes for the base plate module.

Chapter 5

Base plate connection

Shear Strength of Column: Calculation Issue

Clause Reference from IS 800:2007

The issue in the calculation of shear strength of the column pertains to the area not being calculated correctly. According to **IS 800:2007**, the shear strength of a member can be determined as specified in **Clause 8.4.1**. The effective shear area is defined based on the geometry of the section, and proper calculation of this area is crucial for accurate determination of the shear strength.
The relevant clause from IS 800:2007 is as follows:

> "The design shear strength of the cross-section shall be calculated using the effective shear area (A_v). For rolled sections and built-up sections, the effective shear area is taken as the area of the web. For sections with holes or openings, appropriate deductions shall be made."

Problem Statement

The calculation error arises due to an incorrect evaluation of the **effective shear area (A_v)**. It is essential to:

- Identify the correct geometry of the column section.
- Deduct any area reductions due to holes, openings, or other discontinuities as specified.
- Use the net area for determining the shear capacity.

Recommended Solution

To resolve the issue:

1. Verify the cross-sectional geometry of the column and calculate the web area precisely.
2. For sections with holes or openings, subtract the area of such discontinuities.
3. Recompute the shear strength using the corrected effective shear area, as defined in IS 800:2007.

Example Calculation

Assume a column with a web depth of d and thickness t. The effective shear area is given by:

$$A_v = d \cdot t$$

If there are n holes with a diameter d_h, the corrected effective shear area becomes:

$$A_v = (d \cdot t) - n \cdot \frac{\pi}{4} d_h^2$$

This corrected area should be used in further design calculations.

Effective Bearing Area of Base Plate: Correction as per IS 800:2007

Issue in the Reported Formula

The formula provided in the report for calculating the effective bearing area of the base plate is:

$$A = (D + 2c)(B + 2c) - [D - 2(T + c)]\,[B - 2(T + c)]$$

While the term $(D+2c)(B+2c)$ correctly represents the gross area of the base plate as per *N. Subramanian* (Clause 9.17.2), the subtraction term $[D - 2(T + c)][B - 2(T + c)]$ is incorrect. This term does not align with the effective bearing area requirements specified in **Figure 9** of **IS 800:2007**.

Correct Formula as per IS 800:2007

According to Figure 9 of IS 800:2007, the correct formula for the effective bearing area of the base plate is:

$$A_{\text{eff}} = (D - 2c)(2c + t_{\text{web}}) + 2(2c + T_{\text{flange}})(B + 2c),$$

where:

- D: Depth of the column.
- B: Width of the column.
- c: Projection of the base plate beyond the column face.
- t_{web}: Thickness of the web of the column.
- T_{flange}: Thickness of the flange of the column.

This formula accounts for the contributions of both the web and the flanges of the column in determining the effective bearing area.

Comparison and Correction

The reported formula incorrectly subtracts an area term based on uniform projections, while the correct formula integrates the structural details of the column, including the web thickness and flange contributions. This ensures compliance with IS 800:2007 and reflects the actual load transfer mechanism.

Illustration from IS 800:2007

The following figure, referenced from **Figure 9** of IS 800:2007, illustrates the effective bearing area of the base plate:

Conclusion

The subtraction term in the report's formula must be replaced with the correct expression derived from IS 800:2007, as detailed above. This correction ensures accurate and standard-compliant calculation of the effective bearing area.

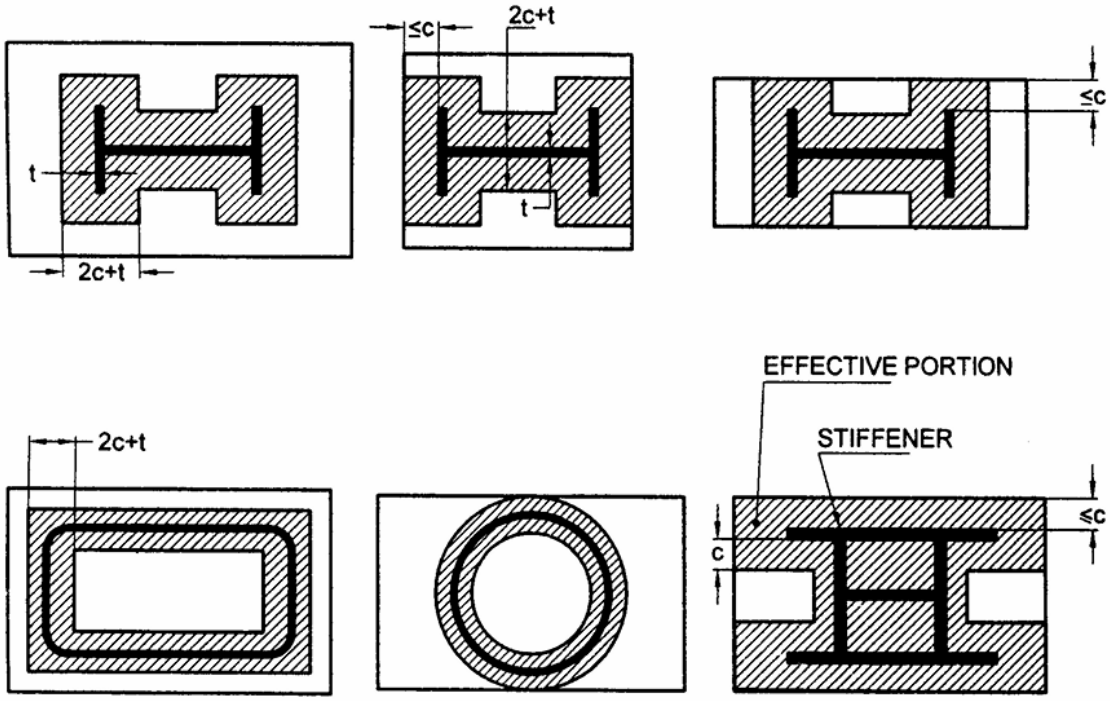

FIG. 9 EFFECTIVE AREA OF A BASE PLATE

Figure 5.1: Effective Bearing Area of Base Plate (Figure 9 from IS 800:2007)

Chapter 8

Internship Task 6: Design and Detailing Checklist (DDCL) of Fixed Base Plate Report for Osdag

8.1 Problem Statement

The purpose of this task is to develop a **Design and Detailing Checklist (DDCL)** for a **Fixed Moment Base Plate** in the Osdag software. This checklist will serve as a comprehensive guideline to ensure that the software adheres to proper engineering design procedures and detailing as per IS codes. It bridges the gap between theoretical design concepts and practical implementation within the software architecture.

Objectives:

- Create a structured design and detailing framework for base plates subjected to fixed moments.
- Define all required input parameters, formulas, code references, and limit state checks.
- Include detailing checks for welds, stiffeners, anchor rods, shear keys, and plate washers.
- Help future developers and users ensure design consistency and accuracy within Osdag.

8.2 Tasks Done

- Studied IS 800:2007, IS 456:2000, and IS 1363 for relevant design procedures.
- Defined all input parameters required for the Fixed Moment Base Plate module.
- Created theoretical background for axial, moment, and shear load interactions.
- Documented design logic for:
  - Column Design
  - Plate Washer and Nut Thickness
  - Anchor Rod Design
  - Stiffener Design
  - Base Plate Geometry, Thickness, and Welds
  - Shear Key Design
  - Final Detailing Checklist
- Ensured all calculations conform to Indian Standards (IS) and structural safety norms.
- Prepared a well-formatted and illustrated PDF document for submission.

8.3 Documentation

The following pages contain the complete Design and Detailing Checklist (DDCL) document for the Fixed Moment Base Plate, submitted as part of the Osdag software enhancement task.

Osdag

Open steel design and graphics

Design and detailing checklist (DDCL)

Fixed Moment Base Plate

Prepared by:
Aditya Donde

Mentor:
Parth Karia

Under the guidance of
Prof. Siddhartha Ghosh

Indian Institute of Technology Bombay
July 25, 2025

Contents

1 Theory **1**
1.1 Introduction . . . 1

2 Design and Detailing Checklist for Osdag Software **2**
2.1 Input Parameters . . . 2
2.2 Column Design . . . 4
2.3 Plate Washer and Nut Thickness . . . 6
2.3.1 Plate Washer Thickness . . . 6
2.3.2 Nut Thickness . . . 6
2.3.3 Material Properties . . . 6
2.4 Anchor Rod Design . . . 8
2.4.1 Anchor Rod Edge and End Distances . . . 8
2.4.2 Anchor Rod Design Outside Column Flange . . . 8
2.4.3 Anchor Rod Design Inside Column Flange . . . 9
2.4.4 Embedment Length of Anchor Rods . . . 9
2.4.5 Detailing Requirements . . . 9
2.5 Stiffener Design for Fixed Base Plate . . . 10
2.5.1 Types of Stiffeners in Fixed Base Plate Design . . . 10
2.5.2 Design of Column Flange Stiffeners . . . 10
2.5.3 Design of Web Stiffeners . . . 10
2.5.4 Weld Design for Stiffeners . . . 11
2.5.5 Optional Diagonal Stiffeners . . . 11
2.5.6 Final Checklist for Stiffener Design . . . 11
2.6 Base Plate Design . . . 12
2.6.1 Geometry of Base Plate . . . 12
2.6.2 Bearing Area and Stress Distribution . . . 12
2.6.3 Base Plate Thickness . . . 13
2.6.4 Weld Design . . . 13
2.6.5 Grout and Surface Preparation . . . 13
2.6.6 Friction Grip Type Bolting . . . 13
2.6.7 Reduction Factors for Bolted Connection . . . 14
2.7 Design of Shear Key . . . 16
2.7.1 Purpose of Shear Key . . . 16
2.7.2 Load Analysis . . . 16
2.7.3 Geometry of Shear Key . . . 16
2.7.4 Shear Key Material Strength . . . 17
2.7.5 Weld Connection of Shear Key to Base Plate . . . 17
2.7.6 Final Checklist for Shear Key Design . . . 17
2.8 Detailing Checklist . . . 18
2.8.1 Pitch and Gauge Distances . . . 18
2.8.2 End and Edge Distances . . . 18
2.8.3 Hole Dimensions . . . 18
2.8.4 Weld Details . . . 19
2.8.5 Grout and Surface Preparation . . . 19
2.8.6 Corrosion Protection and Durability . . . 19
2.8.7 Final Checklist . . . 19

3 Tutorial for Design of Base plate from Osdag **20**

4 Verification Examples for the Calibration of Osdag **21**

Chapter 2

Design and Detailing Checklist for Osdag Software

2.1 Input Parameters

The following are the input parameters that the user will have to input on the Osdag Software.

- **Column Profile:**
  The user must choose the type of column section, such as I-section, hollow circular section, or rectangular section.
- **Column Size:**
  The user must specify the size of the column section, including flange and web dimensions for I-sections or diameter and thickness for hollow sections.
- **Material Property:**
  The user will have the option to select the grade of steel for the column section and base plate (e.g., Fe250, Fe345).
- **Factored Axial Load (in kN):**
  The user must input the factored axial load acting on the column.
- **Factored Shear Load (in kN):**
  The user must input the shear loads along both the major (z-z) and minor (y-y) axes.
- **Factored Moment (in kNm):**
  The user must specify any factored moments acting about the major and minor axes.
- **Concrete Grade:**
  The user must input the grade of concrete for the pedestal (e.g., M20, M25).
- **Base Plate Dimensions:**
  The user may specify the length and width of the base plate or allow the software to optimize these dimensions.
- **Grout Thickness (in mm):**
  The user must input the thickness of the grout layer beneath the base plate.
- **Anchor Bolt Diameter:**
  The user can either specify the bolt diameter or allow the software to choose the optimal size.
- **Anchor Bolt Grade:**
  The user can specify the property class of the anchor bolt (e.g., 4.6, 8.8, 12.9) or select the optimized option.
- **Weld Size:**
  The user must input the size of the weld connecting the column to the base plate.

The user will also have the option of changing the design preferences from Edit>Design Preferences or CTRL + P. These options for the design of a base plate include:

- **Bolt Type:**
  Specify whether the anchor bolts are standard or high-strength friction grip (HSFG) bolts.
- **Bolt Hole Type:**
  Choose between standard, oversized, or slotted holes.
- **Concrete Bearing Strength:**
  Adjust settings to reflect special cases, such as increased confinement or reduced grout thickness.
- **Weld Quality:**
  Specify weld type (shop weld or field weld) and inspection levels for critical connections.
- **Edge Distances:**
  Specify if adjustments are required for corrosion exposure or fabrication tolerances.

***Input Compulsory.**

2.2 Column Design

The design of a steel column involves checking its strength and stability under axial compression, bending, and combined loads. This section adheres to the provisions of **IS 800:2007** for limit state design.

2.2.0.1 Axial Load Capacity

The design axial load capacity (P_d) of the column is determined based on its cross-sectional area, material properties, and effective length. As per IS 800:2007 Cl. 7.1.2:

$$P_d = \frac{A \cdot f_y}{\gamma_{m0}}, \tag{2.1}$$

where:

- A: Cross-sectional area of the column section,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength (typically 1.1).

The applied axial load P_u must satisfy:

$$P_u \leq P_d.$$

2.2.0.2 Flexural Capacity (Bending Strength)

The moment capacity of the column section (M_d) is calculated separately for the major and minor axes. As per IS 800:2007 Cl. 8.2.1.2:

$$M_d = \frac{Z \cdot f_y}{\gamma_{m0}},$$

where:

- Z: Section modulus about the respective axis,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength.

Ensure that the applied moment about each axis ($M_{z,u}, M_{y,u}$) satisfies:

$$M_{z,u} \leq M_{z,d}, \quad M_{y,u} \leq M_{y,d}.$$

2.2.0.3 Shear Capacity

The design shear strength of the column (V_d) is calculated as per IS 800:2007 Cl. 8.4:

$$V_d = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{m0}},$$

where:

- A_v: Shear area of the section, depending on the orientation and type of section.

The applied shear forces along the major and minor axes ($V_{z,u}, V_{y,u}$) must satisfy:

$$V_{z,u} \leq V_{z,d}, \quad V_{y,u} \leq V_{y,d}.$$

2.2.0.4 Stability Checks

- **Effective Length:** Determine the effective length L_e using IS 800:2007 Table 11 based on end conditions.
- **Slenderness Ratio:** Calculate slenderness ratio λ as:

$$\lambda = \frac{L_e}{r},$$

  where r is the radius of gyration of the section. Ensure $\lambda \leq 180$ for compression members as per IS 800:2007 Cl. 3.7.1.

- **Buckling Resistance:** The design buckling resistance is given by:

$$P_{cr} = \phi \cdot A \cdot f_y,$$

  where ϕ is the reduction factor for buckling as per IS 800:2007 Cl. 7.1.2.2.

2.2.0.5 Combined Axial Load and Bending

For members subjected to combined axial compression and bending, the following interaction equation must be satisfied as per IS 800:2007 Cl. 9.3.1:

$$\frac{P_u}{P_d} + \frac{M_{z,u}}{M_{z,d}} + \frac{M_{y,u}}{M_{y,d}} \leq 1.0.$$

This ensures that the combined utilization of the section does not exceed its capacity.

2.2.0.6 Serviceability Checks

- **Deflection:** Verify that the deflection under service loads does not exceed the limits specified in IS 800:2007 Cl. 5.6.1:

$$\delta \leq \frac{L}{300},$$

  where L is the unsupported length of the column.

- **Vibration:** Ensure that vibration limits are satisfied if the column supports dynamic loads.

2.2.0.7 Final Checklist

All design checks must conform to IS 800:2007:

- Verify that $P_u \leq P_d$ (axial compression check).
- Ensure that $M_{z,u} \leq M_{z,d}$ and $M_{y,u} \leq M_{y,d}$ (bending checks).
- Check $V_{z,u} \leq V_{z,d}$ and $V_{y,u} \leq V_{y,d}$ (shear checks).
- Perform combined load interaction and stability checks.
- Verify that serviceability criteria (deflection and vibration) are met.

2.3 Plate Washer and Nut Thickness

The thickness of plate washers and nuts is critical in ensuring uniform force distribution and preventing localized crushing or deformation under high loads. This section outlines the design of plate washers and nuts in compliance with **IS 800:2007** and **IS 1363:2002** for hexagonal nuts and bolts.

2.3.1 Plate Washer Thickness

Plate washers are used to distribute the load from the bolt over a larger area of the base plate. The thickness of the washer must satisfy the following criteria:

- **Thickness Requirement:** As per IS 800:2007 Cl. 10.4.3, the washer thickness (t_w) should be sufficient to prevent local bearing failure of the base plate and crushing of the washer. It is given by:

  $$t_w \geq \frac{d_0}{3},$$

  where:

  - t_w: Thickness of the washer,
  - d_0: Bolt hole diameter.

  For example, for a bolt hole diameter of $d_0 = 26\,\text{mm}$:

  $$t_w \geq \frac{26}{3} \approx 8.67\,\text{mm}.$$

  A washer thickness of 10 mm is typically used.

- **Outer Diameter:** The outer diameter of the washer (d_w) should comply with IS 2016:2000, which specifies:

  $$d_w = 2 \cdot d_0.$$

  For $d_0 = 26\,\text{mm}$, the washer diameter should be:

  $$d_w = 2 \cdot 26 = 52\,\text{mm}.$$

2.3.2 Nut Thickness

The thickness of the nut ensures adequate thread engagement and prevents thread shear failure. The following guidelines apply:

- **Nominal Nut Thickness:** As per IS 1363:2002, the nominal thickness of a standard hexagonal nut (t_n) is given as:

  $$t_n = 0.8 \cdot d,$$

  where d is the nominal bolt diameter. For an M20 bolt:

  $$t_n = 0.8 \cdot 20 = 16\,\text{mm}.$$

- **Thread Engagement Length:** The thread engagement length (l_t) should be at least equal to the bolt diameter (d) as per IS 800:2007 Cl. 10.4.4:

  $$l_t \geq d.$$

  For M20 bolts:

  $$l_t \geq 20\,\text{mm}.$$

- **Overtightening Allowance:** To account for overtightening or misalignment, the nut height should be checked against shear and compressive forces. This ensures that the nut does not fail before the bolt.

2.3.3 Material Properties

The material of the washers and nuts should match or exceed the strength of the bolt material. The ultimate tensile strength of the washer (f_{uw}) and nut should conform to IS 2062:2011 for structural steel.

2.3.3.1 Final Checklist

Ensure the following:

- The washer thickness (t_w) is sufficient to prevent local deformation, and its outer diameter (d_w) complies with IS 2016:2000.
- The nut thickness (t_n) and thread engagement length (l_t) satisfy IS 1363:2002 and IS 800:2007 requirements.
- The material properties of washers and nuts meet or exceed the strength of the bolt material.

2.4 Anchor Rod Design

Anchor rods are critical for transferring axial, shear, and moment forces from the base plate to the concrete foundation. The following section provides the anchor rod design procedure, adhering to **IS 800:2007** and **IS 456:2000**.

2.4.1 Anchor Rod Edge and End Distances

- **End Distance (e):** As per **IS 800:2007 Cl. 10.2.4.2**, the minimum distance from the center of the bolt hole to the edge of the base plate is:

$$e \geq 1.5 \cdot d_0 \quad \text{(for rolled edges)}, \quad e \geq 1.7 \cdot d_0 \quad \text{(for sheared edges)}.$$

  For $d_0 = 20\,\text{mm}$, the minimum end distances are:

$$e \geq 30\,\text{mm} \quad \text{(rolled edges)}, \quad e \geq 34\,\text{mm} \quad \text{(sheared edges)}.$$

- **Edge Distance (e'):** The edge distance must satisfy the same criteria as end distance.
- **Maximum Distance (e_{max}):** As per **IS 800:2007 Cl. 10.2.4.3**, the maximum permissible distance is:

$$e, e' \leq 40 + 4 \cdot t_p,$$

  where t_p is the plate thickness. For $t_p = 45\,\text{mm}$:

$$e, e' \leq 40 + 4 \cdot 45 = 220\,\text{mm}.$$

2.4.2 Anchor Rod Design Outside Column Flange

Anchor rods outside the column flange handle tension forces caused by moments and uplift. The following checks are performed:

- **Tension Capacity (T_{db}):** As per **IS 800:2007 Cl. 10.3.5**:

$$T_{db} = \frac{0.9 \cdot f_{ub} \cdot A_{nb}}{\gamma_{mb}},$$

  where:

  - f_{ub}: Ultimate tensile strength of the bolt,
  - A_{nb}: Net area of the bolt $(\pi \cdot (d_0 - 2)^2/4)$,
  - γ_{mb}: Partial safety factor.

  For an M20 bolt:

$$T_{db} = \frac{0.9 \cdot 1220 \cdot 245}{1.25} \approx 215.2\,\text{kN}.$$

- **Shear Capacity (V_{dsb}):** As per **IS 800:2007 Cl. 10.3.3**:

$$V_{dsb} = \frac{f_{ub} \cdot A_{nb}}{\sqrt{3} \cdot \gamma_{mb}}.$$

  For an M20 bolt:

$$V_{dsb} = \frac{1220 \cdot 245}{\sqrt{3} \cdot 1.25} \approx 138.06\,\text{kN}.$$

- **Combined Tension and Shear Check:** When tension and shear act simultaneously, ensure compliance with IS 800:2007 Cl. 10.3.6:

$$\left(\frac{T_u}{T_{db}}\right)^2 + \left(\frac{V_u}{V_{dsb}}\right)^2 \leq 1.0.$$

2.4.3 Anchor Rod Design Inside Column Flange

Anchor rods inside the column flange handle uplift forces caused by eccentric moments. These rods are primarily subjected to tensile forces:

- **Tension Capacity:** The tension capacity (T_{db}) is calculated similarly to rods outside the flange.
- **Embedment Length:** The embedment depth (l_2) is determined as per IS 5624:1993 Table 1.
- **Spacing and Distribution:** The spacing of the anchor rods must ensure uniform load distribution and avoid concrete splitting as per IS 456:2000 Cl. 34.3.

2.4.4 Embedment Length of Anchor Rods

The embedment depth (l_2) ensures that the rod can transfer loads to the concrete without pullout failure.
As per IS 5624:1993 Table 1, The total bolt length (l_a) is calculated as:

$$l_a = t_g + t_p + t_w + t_n + t_{washer} + l_2,$$

where:

- t_g: Grout thickness (e.g., 50 mm),
- t_p: Base plate thickness,
- t_w: Washer thickness,
- t_n: Nut thickness.

For example, with $t_p = 45\,\text{mm}$, $t_g = 50\,\text{mm}$, $t_w = 10\,\text{mm}$, and $t_n = 16\,\text{mm}$:

$$l_a = 50 + 45 + 10 + 16 + 238 \approx 359\,\text{mm}.$$

2.4.5 Detailing Requirements

- **Bolt Hole Dimensions:** As per IS 800:2007 Cl. 10.2.4.4:

  $$d_h = d_0 + 2\,\text{mm} \quad \text{(standard holes)}.$$

  For oversized holes, refer to IS 800:2007 Table 5.

- **End and Edge Distances:** As per IS 800:2007 Cl. 10.2.4:

  $$e, e' \geq 1.5 \cdot d_0 \quad \text{(rolled edges)}, \quad e, e' \geq 1.7 \cdot d_0 \quad \text{(sheared edges)}.$$

- **Combined Load Check:** Ensure that all bolts meet the combined tension and shear utilization equation.
- **Corrosion Protection:** Apply galvanization or paint to protect the anchor rods from corrosion.

2.5 Stiffener Design for Fixed Base Plate

Stiffeners are structural elements used to increase the strength and rigidity of the base plate and to ensure the safe transfer of forces and moments. In a fixed base plate, stiffeners are critical to resist bending moments, shear forces, and axial loads. This section outlines the design of stiffeners adhering to the provisions of **IS 800:2007**.

2.5.1 Types of Stiffeners in Fixed Base Plate Design

- Column Flange Stiffeners: These stiffeners are welded to the base plate and the column flange to resist local bending caused by moments.
- Web Stiffeners: These stiffeners are placed along the web of the column to resist shear forces and enhance rigidity.
- **Diagonal Stiffeners (Optional):** Diagonal stiffeners may be used in heavily loaded connections to prevent distortion of the base plate.

2.5.2 Design of Column Flange Stiffeners

Column flange stiffeners are designed to resist bending moments transmitted by the column. The following checks are performed:

- Thickness of Stiffeners: As per **IS 800:2007 Cl. 8.7.2.1**, the thickness of flange stiffeners (t_s) should satisfy:

  $$t_s \geq 0.75 \cdot t_f,$$

  where t_f is the thickness of the column flange. For a column with $t_f = 12\,\text{mm}$:

  $$t_s \geq 0.75 \cdot 12 = 9\,\text{mm}.$$

- Width of Stiffeners: The width of the stiffener (b_s) should match the width of the column flange or slightly exceed it to provide uniform force transfer.
- Connection to Base Plate and Column Flange: The stiffeners are fillet-welded to the column flange and the base plate. The weld size is determined as per IS 800:2007 Cl. 10.5.7.

2.5.3 Design of Web Stiffeners

Web stiffeners are provided to enhance the shear capacity of the column web and prevent local buckling under high shear forces. The design is as follows:

- Thickness of Web Stiffeners: As per **IS 800:2007 Cl. 8.7.2.2**, the thickness of the web stiffener (t_w) should satisfy:

  $$t_w \geq 0.6 \cdot t'_w,$$

  where t'_w is the web thickness of the column. For a column with $t'_w = 8\,\text{mm}$:

  $$t_w \geq 0.6 \cdot 8 = 4.8\,\text{mm}.$$

- Height of Web Stiffeners: The height of the stiffener (h_s) should match the depth of the column web (D_w) for uniform load distribution.
- Weld Connection: The stiffeners are fillet-welded to the column web and base plate. The weld size and length are determined based on the shear forces acting on the connection.

2.5.4 Weld Design for Stiffeners

The stiffeners are welded to the column and the base plate to ensure load transfer. The weld throat size (a_w) is calculated as per **IS 800:2007 Cl. 10.5.7**:

$$a_w = 0.7 \cdot \text{leg size}.$$

The weld size is sufficient to resist the forces acting on the stiffener:

$$T_w \leq f_{uw} \cdot A_w,$$

where:

- T_w: Force on the weld,
- f_{uw}: Ultimate strength of the weld,
- A_w: Weld throat area.

2.5.5 Optional Diagonal Stiffeners

Diagonal stiffeners can be provided for heavily loaded base plates to resist distortion and enhance stability. These stiffeners are designed based on the forces acting diagonally across the base plate and are welded similarly to the flange and web stiffeners.

2.5.6 Final Checklist for Stiffener Design

Ensure the following:

- Stiffener thicknesses satisfy the minimum requirements as per IS 800:2007.
- Stiffener dimensions are adequate to resist the applied loads and moments.
- Weld connections are sufficient to transfer forces from the stiffeners to the base plate and column.
- Optional diagonal stiffeners are included if required for additional stability.
- All stiffeners are adequately detailed for fabrication and erection.

2.6 Base Plate Design

The design of a base plate involves determining its geometry, thickness, and the bearing stress distribution to safely transfer loads from the column to the concrete pedestal. This section adheres to the guidelines of **IS 800:2007** and **IS 456:2000**.

2.6.1 Geometry of Base Plate

The geometry of the base plate is determined to ensure that the plate provides sufficient area for bearing and accommodates the required number of anchor bolts while maintaining adequate edge and end distances. As per **IS 800:2007 Cl. 10.5.2**, the plate dimensions are determined as follows:

- **Length (L) and Width (W):**
$$L = D + 2e, \quad W = 0.85B + 2e',$$
where:
  - D: Depth of the column (or outer width for hollow sections),
  - B: Width of the column flange (or diameter for hollow sections),
  - e, e': End and edge distances from bolt hole centers to the plate edges.
- **End and Edge Distances:** The minimum distances are:
$$e, e' \geq 1.5 \cdot d_0 \quad \text{(rolled edges)}, \quad e, e' \geq 1.7 \cdot d_0 \quad \text{(sheared edges)},$$
as per **IS 800:2007 Cl. 10.2.4.2**.
- The maximum permissible distances are:
$$e, e' \leq 40 + 4 \cdot t_p,$$
as per **IS 800:2007 Cl. 10.2.4.3**.

2.6.2 Bearing Area and Stress Distribution

The bearing area of the base plate must be sufficient to resist the axial and moment-induced forces without exceeding the permissible concrete bearing stress:

- **Permissible Bearing Stress:** As per **IS 456:2000 Cl. 34.4**, the permissible bearing stress for concrete is:
$$\sigma_{br} = 0.45 \cdot f_{ck},$$
where f_{ck} is the characteristic compressive strength of concrete.
- **Required Bearing Area (A_{req}):** The required bearing area to resist the axial load is:
$$A_{req} = \frac{P_u}{\sigma_{br}},$$
where P_u is the factored axial load.
- **Provided Bearing Area (A_{prov}):** The provided area of the base plate is:
$$A_{prov} = L \cdot W.$$
Ensure:
$$A_{prov} \geq A_{req}.$$
- **Stress Distribution Under Moments:** For fixed base plates, moments cause a non-uniform stress distribution, and the actual bearing stress is:
$$\sigma_{br,actual} = \frac{P_u}{A_{eff}} + \frac{6 \cdot M_u}{L \cdot W^2},$$
where:
  - A_{eff}: Effective bearing area,
  - M_u: Factored moment about the respective axis.

  Ensure:
$$\sigma_{br,actual} \leq \sigma_{br}.$$

2.6.3 Base Plate Thickness

The thickness of the base plate is governed by the bending moment induced by non-uniform bearing stresses. As per **IS 800:2007 Cl. 10.5.2.2**, the plate thickness must satisfy:

$$t_p \geq \sqrt{\frac{4 \cdot M_{cr}}{W \cdot f_{y,plate}/\gamma_{m0}}},$$

where:

- M_{cr}: Critical moment capacity of the plate, determined from:

$$M_{cr} = \sigma_{br,actual} \cdot W \cdot \frac{t_p^2}{4}.$$

- $f_{y,plate}$: Yield strength of the plate material,
- γ_{m0}: Partial safety factor for material strength.

For axial loads only (no moment), the thickness is simplified as:

$$t_p \geq \sqrt{\frac{2.5 \cdot \sigma_{br,actual} \cdot \gamma_{m0}}{f_{y,plate}}} \cdot c,$$

where c is the effective projection of the plate beyond the column face.

2.6.4 Weld Design

The welds connecting the column to the base plate are sized to resist forces:

- **Weld Strength:** As per IS 800:2007 Cl. 10.5.7, the weld strength is determined based on throat area and ultimate weld strength:

$$f_{uw} = \frac{T_w}{A_w},$$

  where T_w is the applied tension and A_w is the throat area of the weld.

- **Weld Size:** For flange welds, the size must satisfy:

$$a_w \geq \frac{V}{2\, L_w\, f_{uw}},$$

  where L_w is the weld length and V is the applied shear.

2.6.5 Grout and Surface Preparation

- **Grout Thickness:** Maintain grout thickness t_g as per input (typically 20–50 mm). Ensure full bearing by checking tolerance.
- **Surface Flatness:** As per IS 800:2007 Cl. 10.4.4, ensure the plate and concrete pedestal are within flatness tolerance of ± 2 mm for uniform bearing.

2.6.6 Friction Grip Type Bolting

In friction grip type bolting, initial pretension in the bolt develops clamping force at the interfaces of the elements being joined. The frictional resistance to slip between the plate surfaces subjected to clamping force opposes slip due to externally applied shear. Where the slip between bolted plates cannot be tolerated at working loads, the connection shall be designed for slip resistance conforming to Cl.10.4.3 of IS:800:2007.
Consequently, it may also be noted that as per Cl. 10.4.4 of Is:800:2007 when friction-type bolts are designed for slip resistance at service loads, the design capacity at ultimate load may be calculated as per bearing type connection as per Cl. 10.3.3 of IS:800:2007. However, in the design of tension members using bolted connections for Osdag software, we take input from factored loads only. Hence, the design strength for bearing for friction type of bolt is not considered.

2.6.6.1 Slip Resistance (V_{dsf})

As per Cl. 10.4.3 of IS:800:2007, the design strength of the bolt owing to slip resistance V_{dsf} is given by,

$$V_{dsf} = \frac{V_{nsf}}{\gamma_{mf}} \tag{2.2}$$

V_{nsf} = Nominal shear strength of a bolt as governed by slip for friction type connection, calculated as follows,

$$V_{nsf} = \mu \cdot n_e \cdot K_h \cdot F_o$$

μ_f = Coefficient of friction (slip factor) as specified in Table 20 of IS:800:2007
n_e = Number of effective interfaces offering frictional resistance to slip
K_h = 1.0 for fasteners in clearance holes, 0.85 for fasteners in oversized and short slotted holes and for fasteners in long slotted holes loaded perpendicular to the slot, 0.7 for fasteners in long slotted holes loaded parallel to the slot
γ_{mf} = 1.10 (if slip resistance is designed at service load), 1.25 (if slip resistance is designed at ultimate load)
F_o = Minimum bolt tension (proof load) at installation and may be taken as,

$$F_o = A_{nb} \cdot f_0$$

Where,
A_{nb} = Net area of bolt at threads
f_0 = Proof stress (= $0.70 \cdot f_{ub}$)

2.6.7 Reduction Factors for Bolted Connection

The reduction factors summarised in this section are various provisions in IS:800:2007, which recommends reduction in the capacity of section.

2.6.7.1 Long Joints

As per Cl. 10.3.3.1 of IS:800:2007, when the length of the joint l_j, of the tension member containing more than two bolts (that is the distance between the first and last row of bolts in the joint measured in the direction of the load transfer) exceeds $15d$ in the direction of load, the nominal shear capacity (calculated as per Section 2.3.1.1 of this document), shall be reduced by a factor β_{lj}, give by,

$$\beta_{lj} = 1.075 - \frac{l_j}{200 \cdot d} \quad \text{but} \quad 0.75 \leq \beta_{lj} \leq 1.0 \tag{2.3}$$

Where, d = Nominal diameter of the bolt

As per Cl. 10.4.3.1, The long joint reduction factor is also applicable to friction grip type bolts. However, the long joint reduction factor is not applicable when the shear distribution is uniform, for example when web of a section is connected to the flanges of another section.

2.6.7.2 Large grip lengths

As per Cl. 10.3.3.2 of IS:800:2007, when large grip length l_g (equal to the total thickness of the connected plate) exceeds five times the diameter d, the design shear capacity shall be reduced by a factor β_{lg}, given by:

$$\beta_{lg} = \frac{8 \cdot d}{(3 \cdot d + l_g)} = \frac{8}{(3 + \frac{l_g}{d})} \tag{2.4}$$

The grip length l_g in any case shall not be greater than $8 \cdot d$. It may also be noted that β_{lg} shall not be greater than β_{lj} (calculated in section 2.3.3.1 of this document).

2.6.7.3 Bearing capacity reduction for oversized, short-slotted and long-slotted holes

As per Cl. 10.3.4 of IS:800:2007, the bearing resistance of bolts calculated in section 2.3.1.2 of this document may be reduced by the factors mentioned below in a case where standard hole clearance is not provided.

- For over-size and short-slotted holes - 0.7
- For long-slotted holes - 0.5

The above values hold true for bearing type of bolts only. A similar factor K_h is also applicable to friction type grip bolts, the values for which are mentioned in the design strength for slip resistance (section 2.3.2.1) of this document.

2.7 Design of Shear Key

A shear key is used in base plate connections to resist large shear forces that exceed the frictional resistance between the base plate and the concrete pedestal. The shear key prevents sliding and ensures stability under significant lateral loads. This section outlines the design of a shear key in compliance with **IS 800:2007** and **IS 456:2000**.

2.7.1 Purpose of Shear Key

The shear key transfers shear forces from the base plate to the concrete foundation by providing additional bearing area. It is generally a welded or bolted element projecting into the concrete pedestal.

2.7.2 Load Analysis

- **Factored Shear Force (V_u):** The applied shear force (V_u) is the factored shear load acting on the base plate:

$$V_u = 1.5 \cdot V,$$

  where V is the characteristic shear load.

- **Frictional Resistance (V_r):** The frictional resistance at the interface between the base plate and the concrete pedestal is given by **IS 456:2000 Cl. 20.2**:

$$V_r = \mu \cdot P_u,$$

  where:

  - μ: Coefficient of friction (commonly 0.45 for steel-to-concrete interface),
  - P_u: Factored axial load.

- **Shear Key Force (V_k):** If $V_u > V_r$, the excess shear is resisted by the shear key:

$$V_k = V_u - V_r.$$

2.7.3 Geometry of Shear Key

The dimensions of the shear key are determined to ensure sufficient bearing area on the concrete to resist the applied force:

- **Width of Shear Key (b_k):** The width of the shear key is generally equal to the thickness of the base plate (t_p).

- **Depth of Shear Key (h_k):** The depth of the shear key projecting into the concrete is designed to ensure sufficient concrete bearing strength. The effective bearing area is:

$$A_k = b_k \cdot h_k,$$

  and the permissible bearing strength of the concrete is:

$$\sigma_{br} = 0.45 \cdot f_{ck},$$

  as per **IS 456:2000 Cl. 34.4**.

- **Required Depth (h_k):** The required depth is calculated as:

$$h_k = \frac{V_k}{b_k \cdot \sigma_{br}}.$$

2.7.4 Shear Key Material Strength

The material of the shear key must resist the applied shear force without failure:

- **Shear Capacity of the Shear Key (V_{key}):** The shear capacity of the key is governed by the material strength of the steel:
$$V_{key} = \frac{f_y \cdot A_k}{\sqrt{3} \cdot \gamma_{m0}},$$
where:
  - f_y: Yield strength of the steel,
  - A_k: Shear key cross-sectional area,
  - γ_{m0}: Partial safety factor for steel (typically 1.1).
- Ensure:
$$V_k \leq V_{key}.$$

2.7.5 Weld Connection of Shear Key to Base Plate

The shear key is fillet-welded to the base plate. The weld must resist the shear force transferred by the key:

- **Weld Throat Size (a_w):** As per **IS 800:2007 Cl. 10.5.7**, the throat size is:
$$a_w = 0.7 \cdot \text{leg size}.$$
- **Weld Strength:** The weld must satisfy:
$$T_w \leq f_{uw} \cdot A_w,$$
where:
  - T_w: Shear force on the weld,
  - f_{uw}: Ultimate strength of the weld,
  - A_w: Weld throat area.

2.7.6 Final Checklist for Shear Key Design

Ensure the following:

- The shear key is designed to resist $V_k = V_u - V_r$.
- The depth of the shear key (h_k) ensures sufficient concrete bearing strength.
- The material of the shear key is adequate to resist the applied shear force.
- Welds connecting the shear key to the base plate are sufficient to transfer forces.
- All detailing requirements are met to ensure proper fabrication and installation.

2.8 Detailing Checklist

The detailing checklist ensures that all geometric, material, and connection-specific requirements are met for safe and efficient performance of the base plate connection.

2.8.1 Pitch and Gauge Distances

- **Pitch Distance (p):** Since there is a single row of bolts on the tension side, pitch distance is not applicable. For designs requiring multiple rows, the pitch distance should satisfy:

$$p \geq 2.5 \cdot d_0,$$

where d_0 is the bolt hole diameter.

- **Gauge Distance (g):** As no internal rows are present, gauge distance is also not applicable in this design. For future designs with additional rows, ensure $g \geq 2.5 \cdot d_0$.

2.8.2 End and Edge Distances

- **End Distance (e):** As per IS 800:2007 Cl. 10.2.4.2, the end distance from the bolt hole center to the nearest edge of the plate must satisfy:

$$e \geq 1.5 \cdot d_0 \quad \text{(rolled edges)}, \quad e \geq 1.7 \cdot d_0 \quad \text{(sheared edges)}.$$

In **3.pdf**, the provided end distance is:

$$e = 55\,\text{mm},$$

which satisfies the minimum requirement for $d_0 = 24\,\text{mm}$:

$$1.5 \cdot 24 = 36\,\text{mm} \quad \text{(rolled edge)}.$$

- **Edge Distance (e'):** The edge distance from the bolt hole center to the outer edge of the plate is checked similarly. For this design:

$$e' = 55\,\text{mm},$$

which meets the minimum requirement:

$$e' \geq 1.5 \cdot d_0 = 36\,\text{mm}.$$

- **Maximum End and Edge Distance:** Per IS 800:2007 Cl. 10.2.4.3, the maximum end and edge distances are:

$$e, e' \leq 40 + 4 \cdot t_p,$$

where t_p is the base plate thickness. For $t_p = 10\,\text{mm}$:

$$e, e' \leq 40 + 4 \cdot 10 = 80\,\text{mm}.$$

The provided values ($55\,\text{mm}$) are within the allowable range.

2.8.3 Hole Dimensions

- **Standard Bolt Holes:** The hole diameter for standard bolts is:

$$d_h = d_0 + 2 = 24 + 2 = 26\,\text{mm}.$$

- **Oversized Bolt Holes:** Oversized holes are not applicable in this design. For future cases, the oversized hole diameter would be:

$$d_h = d_0 + 6 = 24 + 6 = 30\,\text{mm}.$$

2.8.4 Weld Details

- **Weld Type:** Continuous fillet welds are provided for the connection of the column to the base plate.
- **Weld Throat Size (a_w):** As per IS 800:2007 Cl. 10.5.7, the weld throat size is sufficient to resist the applied shear. For flange welds:
$$a_w = 0.7 \cdot \text{leg size}.$$
- **Weld Length:** The provided weld lengths fully enclose the column flange. No web welds are included as this is a pinned-base connection.

2.8.5 Grout and Surface Preparation

- **Grout Thickness (t_g):** As per IS 800:2007 Cl. 10.4.4, the grout thickness is specified as $t_g = 50\,\text{mm}$. Ensure the grout is non-shrink and properly leveled.
- **Surface Flatness:** Ensure that both the base plate and concrete pedestal are within flatness tolerances of $\pm 2\,\text{mm}$ for uniform bearing pressure.

2.8.6 Corrosion Protection and Durability

- **Corrosion Allowance:** In environments exposed to weather or corrosive conditions, increase the end and edge distances by appropriate corrosion allowance.
- **Surface Treatment:** The base plate and bolts must be painted or galvanized to prevent corrosion.

2.8.7 Final Checklist

The following must be verified:

- End and edge distances (e, e') satisfy IS 800:2007 requirements.
- Bolt hole dimensions conform to standard sizes.
- Weld sizes and lengths are adequate for the applied forces.
- Grout thickness and surface flatness are within allowable tolerances.
- Proper corrosion protection is applied for exposed environments.

Chapter 9

Internship Task 7: Design and Detailing Checklist (DDCL) Report for Base Plate with Hollow/Tubular Column

9.1 Problem Statement

This task involves creating a comprehensive **Design and Detailing Checklist (DDCL)** for a base plate connection involving a **Hollow or Tubular Column**. This type of structural connection requires careful consideration of unique parameters like circular geometry, ring stiffeners, bolt layout around the circumference, and shear keys to ensure full compliance with IS 800:2007 and IS 456:2000.

Objectives:

- Document theoretical background and practical design checks for circular or rectangular hollow column base plates.
- Address input requirements, column and plate geometry, anchor bolt strength, welds, and stiffener provisions.
- Follow IS 800:2007 code explicitly.
- Provide a complete and ready-to-integrate DDCL document for the Osdag software.

9.2 Tasks Done

- Studied IS 800:2007 clauses related to base plate, anchor bolt, and stiffener design.
- Documented theoretical formulas, geometric constraints, and material strength checks.
- Developed step-by-step design procedures for:
  - Column capacity
  - Anchor bolt layout and strength
  - Ring and radial stiffeners
  - Welds and shear key design
  - Effective bearing stress and plate thickness
- Created a final detailing checklist to verify all connection parameters before fabrication.
- Compiled all findings in a structured PDF format suitable for direct use in Osdag's UI or backend.

9.3 Documentation

The following pages include the full DDCL report for the **Base Plate with Hollow/-Tubular Column** connection.

Osdag

Open steel design and graphics

Design and detailing checklist (DDCL)

Base plate connection hollow/tubular

Prepared by:
Aditya Donde

Mentor:
Parth Karia

Under the guidance of
Prof. Siddhartha Ghosh

Indian Institute of Technology Bombay
July 25, 2025

Contents

1 Theory **1**
1.1 Introduction . . . 1

2 Design and Detailing Checklist for Osdag Software **2**
2.1 Input Parameters . . . 2
2.2 Column Design . . . 4
2.3 Anchor Bolt Design for Hollow/Tubular Column . . . 6
2.3.1 Bolt Properties . . . 6
2.3.2 Shear Capacity (IS 800:2007 Cl. 10.3.3) . . . 6
2.3.3 Bearing Capacity (IS 800:2007 Cl. 10.3.4) . . . 6
2.3.4 Governing Shear Capacity . . . 6
2.3.5 Tension Capacity (IS 800:2007 Cl. 10.3.5) . . . 6
2.3.6 Embedment Length (IS 5624:1993 Table 1) . . . 6
2.3.7 Bolt Pattern and Spacing (IS 800:2007 Cl. 10.2.3) . . . 6
2.3.8 Edge and End Distances (IS 800:2007 Cl. 10.2.4) . . . 6
2.4 Base Plate Design for Hollow/Tubular Columns . . . 7
2.4.1 Geometry of the Base Plate . . . 7
2.4.2 Bearing Area and Stress Distribution . . . 7
2.4.3 Base Plate Thickness . . . 8
2.5 Stiffener Design for Hollow/Tubular Columns . . . 9
2.5.1 Types and Arrangement of Stiffeners . . . 9
2.5.2 Ring Stiffener Design . . . 9
2.5.3 Radial Stiffener Design . . . 9
2.5.4 Weld Design for Stiffeners . . . 9
2.5.5 Final Checklist . . . 10
2.6 Design of Shear Key . . . 11
2.6.1 Purpose of Shear Key . . . 11
2.6.2 Load Analysis . . . 11
2.6.3 Geometry of Shear Key . . . 11
2.6.4 Shear Key Material Strength . . . 12
2.6.5 Weld Connection of Shear Key to Base Plate . . . 12
2.6.6 Final Checklist for Shear Key Design . . . 12
2.7 Detailing Checklist for Hollow/Tubular Columns . . . 13
2.7.1 Bolt Spacing Around Circumference . . . 13
2.7.2 End and Edge Distances . . . 13
2.7.3 Hole Dimensions . . . 13
2.7.4 Weld Details . . . 13
2.7.5 Grout and Surface Preparation . . . 13
2.7.6 Corrosion Protection and Durability . . . 13
2.7.7 Final Checklist . . . 14

3 Tutorial for Design of Base plate from Osdag **15**

4 Verification Examples for the Calibration of Osdag **16**

Chapter 2

Design and Detailing Checklist for Osdag Software

2.1 Input Parameters

The following are the input parameters that the user will have to input on the Osdag Software.

- **Column Profile:**
  The user must choose the type of column section, such as I-section, hollow circular section, or rectangular section.
- **Column Size:**
  The user must specify the size of the column section, including flange and web dimensions for I-sections or diameter and thickness for hollow sections.
- **Material Property:**
  The user will have the option to select the grade of steel for the column section and base plate (e.g., Fe250, Fe345).
- **Factored Axial Load (in kN):**
  The user must input the factored axial load acting on the column.
- **Factored Shear Load (in kN):**
  The user must input the shear loads along both the major (z-z) and minor (y-y) axes.
- **Factored Moment (in kNm):**
  The user must specify any factored moments acting about the major and minor axes.
- **Concrete Grade:**
  The user must input the grade of concrete for the pedestal (e.g., M20, M25).
- **Base Plate Dimensions:**
  The user may specify the length and width of the base plate or allow the software to optimize these dimensions.
- **Grout Thickness (in mm):**
  The user must input the thickness of the grout layer beneath the base plate.
- **Anchor Bolt Diameter:**
  The user can either specify the bolt diameter or allow the software to choose the optimal size.
- **Anchor Bolt Grade:**
  The user can specify the property class of the anchor bolt (e.g., 4.6, 8.8, 12.9) or select the optimized option.
- **Weld Size:**
  The user must input the size of the weld connecting the column to the base plate.

The user will also have the option of changing the design preferences from Edit>Design Preferences or CTRL + P. These options for the design of a base plate include:

- **Bolt Type:**
  Specify whether the anchor bolts are standard or high-strength friction grip (HSFG) bolts.
- **Bolt Hole Type:**
  Choose between standard, oversized, or slotted holes.
- **Concrete Bearing Strength:**
  Adjust settings to reflect special cases, such as increased confinement or reduced grout thickness.
- **Weld Quality:**
  Specify weld type (shop weld or field weld) and inspection levels for critical connections.
- **Edge Distances:**
  Specify if adjustments are required for corrosion exposure or fabrication tolerances.

***Input Compulsory.**

2.2 Column Design

The design of a steel column involves checking its strength and stability under axial compression, bending, and combined loads. This section adheres to the provisions of **IS 800:2007** for limit state design.

2.2.0.1 Axial Load Capacity

The design axial load capacity (P_d) of the column is determined based on its cross-sectional area, material properties, and effective length. As per IS 800:2007 Cl. 7.1.2:

$$P_d = \frac{A \cdot f_y}{\gamma_{m0}}, \tag{2.1}$$

where:

- A: Cross-sectional area of the column section,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength (typically 1.1).

The applied axial load P_u must satisfy:

$$P_u \leq P_d.$$

2.2.0.2 Flexural Capacity (Bending Strength)

The moment capacity of the column section (M_d) is calculated separately for the major and minor axes. As per IS 800:2007 Cl. 8.2.1.2:

$$M_d = \frac{Z \cdot f_y}{\gamma_{m0}},$$

where:

- Z: Section modulus about the respective axis,
- f_y: Yield strength of the steel,
- γ_{m0}: Partial safety factor for material strength.

Ensure that the applied moment about each axis ($M_{z,u}, M_{y,u}$) satisfies:

$$M_{z,u} \leq M_{z,d}, \quad M_{y,u} \leq M_{y,d}.$$

2.2.0.3 Shear Capacity

The design shear strength of the column (V_d) is calculated as per IS 800:2007 Cl. 8.4:

$$V_d = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{m0}},$$

where:

- A_v: Shear area of the section, depending on the orientation and type of section.

The applied shear forces along the major and minor axes ($V_{z,u}, V_{y,u}$) must satisfy:

$$V_{z,u} \leq V_{z,d}, \quad V_{y,u} \leq V_{y,d}.$$

2.2.0.4 Stability Checks

- **Effective Length:** Determine the effective length L_e using IS 800:2007 Table 11 based on end conditions.
- **Slenderness Ratio:** Calculate slenderness ratio λ as:

$$\lambda = \frac{L_e}{r},$$

  where r is the radius of gyration of the section. Ensure $\lambda \leq 180$ for compression members as per IS 800:2007 Cl. 3.7.1.

- **Buckling Resistance:** The design buckling resistance is given by:

$$P_{cr} = \phi \cdot A \cdot f_y,$$

  where ϕ is the reduction factor for buckling as per IS 800:2007 Cl. 7.1.2.2.

2.2.0.5 Combined Axial Load and Bending

For members subjected to combined axial compression and bending, the following interaction equation must be satisfied as per IS 800:2007 Cl. 9.3.1:

$$\frac{P_u}{P_d} + \frac{M_{z,u}}{M_{z,d}} + \frac{M_{y,u}}{M_{y,d}} \leq 1.0.$$

This ensures that the combined utilization of the section does not exceed its capacity.

2.2.0.6 Serviceability Checks

- **Deflection:** Verify that the deflection under service loads does not exceed the limits specified in IS 800:2007 Cl. 5.6.1:

$$\delta \leq \frac{L}{300},$$

  where L is the unsupported length of the column.

- **Vibration:** Ensure that vibration limits are satisfied if the column supports dynamic loads.

2.2.0.7 Final Checklist

All design checks must conform to IS 800:2007:

- Verify that $P_u \leq P_d$ (axial compression check).
- Ensure that $M_{z,u} \leq M_{z,d}$ and $M_{y,u} \leq M_{y,d}$ (bending checks).
- Check $V_{z,u} \leq V_{z,d}$ and $V_{y,u} \leq V_{y,d}$ (shear checks).
- Perform combined load interaction and stability checks.
- Verify that serviceability criteria (deflection and vibration) are met.

2.3 Anchor Bolt Design for Hollow/Tubular Column

The anchor bolt design for a tubular column base plate follows the same strength and detailing checks as for flat sections, with bolts arranged circumferentially. All clauses refer to IS 800:2007 and IS 5624:1993.

2.3.1 Bolt Properties

- Diameter: d_0 (e.g. 20 mm for M20).
- Net area:
$$A_{nb} \;=\; \frac{\pi}{4}\,(d_0 - 2)^2 \quad \text{(thread allowance 2 mm)}.$$
- Material: ultimate strength f_{ub}, partial safety factor γ_{mb}.

2.3.2 Shear Capacity (IS 800:2007 Cl. 10.3.3)

$$V_{dsb} \;=\; \frac{f_{ub}\,A_{nb}}{\sqrt{3}\,\gamma_{mb}}.$$

Check applied shear $V_u \le V_{dsb}$ for each bolt.

2.3.3 Bearing Capacity (IS 800:2007 Cl. 10.3.4)

Compute reduction factor:

$$k_b = \min\Big(\tfrac{e}{3\,d_0},\; \tfrac{f_{ub}}{f_u},\; 1\Big),$$

where e is radial edge distance. Then

$$V_{dpb} \;=\; 0.7\,\frac{2.5\,k_b\,d_0\,t_p\,f_u}{\gamma_{mb}}.$$

Ensure $V_{dpb} \ge V_u$.

2.3.4 Governing Shear Capacity

$$V_{db} = \min(V_{dsb},\, V_{dpb}),$$

and verify $V_u \le V_{db}$.

2.3.5 Tension Capacity (IS 800:2007 Cl. 10.3.5)

$$T_{db} \;=\; \frac{0.9\,f_{ub}\,A_{nb}}{\gamma_{mb}}.$$

Check uplift demand $T_u \le T_{db}$.

2.3.6 Embedment Length (IS 5624:1993 Table 1)

Select l_2 for bolt diameter and concrete grade (e.g. $l_2 = 238$ mm for M20 in M20 concrete). Total anchor length:

$$l_a = t_g + t_p + t_w + t_n + l_2, \quad 200 \le l_a \le 800 \text{ (IS 800:2007 Cl. 10.4.4)}.$$

2.3.7 Bolt Pattern and Spacing (IS 800:2007 Cl. 10.2.3)

Bolts are placed equally around the tube circumference:

$$s_{\min} \ge 2.5\,d_0, \qquad s_{\max} \le \min(32\,t_p,\; 300\,\text{mm}).$$

2.3.8 Edge and End Distances (IS 800:2007 Cl. 10.2.4)

Radial clearance e and circumferential spacing e' must satisfy:

$$1.5\,d_0 \le e, e' \le 40 + 4\,t_p \quad \text{(rolled edges)},$$
$$1.7\,d_0 \le e, e' \quad \text{(sheared/flame-cut edges)}.$$

2.4 Base Plate Design for Hollow/Tubular Columns

The design of a base plate for a hollow/tubular column involves determining its plan dimensions, thickness, and bearing stress distribution so as to safely transfer loads to the concrete pedestal. All clauses refer to **IS 800:2007** and **IS 456:2000**.

2.4.1 Geometry of the Base Plate

- **Plan Dimensions:** For a circular column of outer diameter D_o:

$$L = D_o + 2e, \quad W = D_o + 2e',$$

  where

  - e = radial end-distance from column face to plate edge,
  - e' = circumferential edge-distance from bolt-hole centre to plate edge.

  (**IS 800:2007 Cl. 10.5.2** adaptations for tubular sections.)

- **Edge and End Distances:** As per **IS 800:2007 Cl. 10.2.4.2–.3**:

$$e,\, e' \;\geq\; \begin{cases} 1.5\,d_0, & \text{rolled/machined edges,} \\ 1.7\,d_0, & \text{sheared/flame-cut edges,} \end{cases}$$

$$e,\, e' \;\leq\; 40 + 4\,t_p.$$

- **Bolt Layout:** Bolts arranged equispaced around circumference; ensure circumferential spacing s meets

$$2.5\,d_0 \leq s \leq \min(32\,t_p,\ 300\,\text{mm}) \quad (\textbf{IS 800:2007 Cl. 10.2.3}).$$

2.4.2 Bearing Area and Stress Distribution

- **Permissible Concrete Bearing Stress:**

$$\sigma_{br} = 0.45\,f_{ck} \quad (\textbf{IS 456:2000 Cl. 34.4}).$$

- **Required Bearing Area:**

$$A_{req} = \frac{P_u}{\sigma_{br}},$$

  where P_u is the factored axial load.

- **Effective Bearing Projection (c):**

$$c = \min\!\left(\tfrac{L-D_o}{2},\ \tfrac{W-D_o}{2}\right) \quad (\textbf{IS 800:2007 Cl. 10.5.2 adapted}).$$

- **Actual Effective Bearing Area:** Projecting radially by c around the tube gives

$$A_{eff} = \pi\!\left(\tfrac{D_o}{2} + c\right)^2 - \pi\!\left(\tfrac{D_o}{2}\right)^2.$$

- **Check:**

$$A_{eff} \;\geq\; A_{req}, \quad \sigma_{br,act} = \frac{P_u}{A_{eff}} \;\leq\; \sigma_{br}.$$

2.4.3 Base Plate Thickness

- **Pinned Base (Axial Only):** As per **IS 800:2007 Cl. 10.5.2.1**,

$$t_p \ \geq \ \sqrt{\frac{2.5\,\sigma_{br,act}\,\gamma_{m0}}{f_{y,plate}}}\ c.$$

- **Moment-Resisting Base (If Moments Present):** As per **IS 800:2007 Cl. 10.5.2.2**,

$$M_{cr} = \sigma_{br} \cdot W \cdot \frac{t_p^2}{4}, \quad t_p \ \geq \ \sqrt{\frac{4\,M_{cr}}{W\,f_{y,plate}/\gamma_{m0}}}.$$

- **Verification:** Ensure chosen t_p satisfies the appropriate criterion.

2.5 Stiffener Design for Hollow/Tubular Columns

Stiffeners under a hollow/tubular column base plate improve rigidity, distribute shear and bending, and prevent local buckling of the plate and column wall. The design follows **IS 800:2007** provisions for stiffeners and welds.

2.5.1 Types and Arrangement of Stiffeners

- **Ring (Circular) Stiffener:** A closed-ring plate welded around the tube base to spread loads uniformly into the plate and prevent local deformation.
- **Radial Stiffeners (Spokes):** Flat plates welded radially from the tube flange to the base plate edge to resist shear and bending in high-load cases.

2.5.2 Ring Stiffener Design

- **Thickness (t_s):** As per **IS 800:2007 Cl. 8.7.1**, the ring stiffener thickness shall not be less than the base plate thickness:

$$t_s \;\geq\; t_p.$$

- **Cross-sectional Area (A_s):** The ring stiffener ring area must resist the design shear V_u that exceeds plate shear capacity. Use:

$$V_{ds} = \frac{f_y\, A_s}{\sqrt{3}\,\gamma_{m0}} \quad (\textbf{IS 800:2007 Cl. 8.4 \& 8.7.1}),$$

  and ensure $V_u \leq V_{ds}$.

- **Width of Ring (b_s):** The ring width should at least equal the tube diameter D_o or plate projection c, whichever is larger, to spread the load.

2.5.3 Radial Stiffener Design

- **Thickness (t_r):** In accordance with **IS 800:2007 Cl. 8.7.2**, radial stiffeners thickness shall satisfy:

$$t_r \;\geq\; 0.6\, t_p.$$

- **Length and Spacing:** Each stiffener runs from the tube flange perimeter to the plate edge. Provide at least four equally spaced around the circumference.
- **Shear Capacity per Stiffener:** Check each radial stiffener's shear capacity:

$$V_{dr} = \frac{f_y\,(t_r \cdot L_r)}{\sqrt{3}\,\gamma_{m0}},$$

  where L_r is the effective length of the stiffener, and ensure $V_u/(\text{number of spokes}) \leq V_{dr}$.

2.5.4 Weld Design for Stiffeners

- **Weld Throat Size (a_w):** As per **IS 800:2007 Cl. 10.5.7**, the fillet-weld throat shall satisfy:

$$a_w \;=\; 0.7 \times \text{leg size},$$

  and provide sufficient throat area A_w such that

$$T_w \;\leq\; f_{uw}\, A_w,$$

  where T_w is the force on the weld and f_{uw} is weld strength.

- **Weld Length (L_w):** Provide continuous fillet welds along the ring stiffener-to-tube and ring stiffener-to-plate seams, and along both edges of each radial stiffener.

2.5.5 Final Checklist

- Ring and radial stiffener thicknesses meet Cl. 8.7.1–8.7.2 requirements.
- Shear capacities V_{ds} and V_{dr} are adequate for applied loads.
- Weld throat sizes and lengths conform to Cl. 10.5.7.
- Stiffener layout provides uniform load distribution and prevents local plate buckling.

2.6 Design of Shear Key

A shear key is used in base plate connections to resist large shear forces that exceed the frictional resistance between the base plate and the concrete pedestal. The shear key prevents sliding and ensures stability under significant lateral loads. This section outlines the design of a shear key in compliance with **IS 800:2007** and **IS 456:2000**.

2.6.1 Purpose of Shear Key

The shear key transfers shear forces from the base plate to the concrete foundation by providing additional bearing area. It is generally a welded or bolted element projecting into the concrete pedestal.

2.6.2 Load Analysis

- **Factored Shear Force (V_u):** The applied shear force (V_u) is the factored shear load acting on the base plate:

$$V_u = 1.5 \cdot V,$$

  where V is the characteristic shear load.

- **Frictional Resistance (V_r):** The frictional resistance at the interface between the base plate and the concrete pedestal is given by **IS 456:2000 Cl. 20.2**:

$$V_r = \mu \cdot P_u,$$

  where:

  - μ: Coefficient of friction (commonly 0.45 for steel-to-concrete interface),
  - P_u: Factored axial load.

- **Shear Key Force (V_k):** If $V_u > V_r$, the excess shear is resisted by the shear key:

$$V_k = V_u - V_r.$$

2.6.3 Geometry of Shear Key

The dimensions of the shear key are determined to ensure sufficient bearing area on the concrete to resist the applied force:

- **Width of Shear Key (b_k):** The width of the shear key is generally equal to the thickness of the base plate (t_p).

- **Depth of Shear Key (h_k):** The depth of the shear key projecting into the concrete is designed to ensure sufficient concrete bearing strength. The effective bearing area is:

$$A_k = b_k \cdot h_k,$$

  and the permissible bearing strength of the concrete is:

$$\sigma_{br} = 0.45 \cdot f_{ck},$$

  as per **IS 456:2000 Cl. 34.4**.

- **Required Depth (h_k):** The required depth is calculated as:

$$h_k = \frac{V_k}{b_k \cdot \sigma_{br}}.$$

2.6.4 Shear Key Material Strength

The material of the shear key must resist the applied shear force without failure:

- **Shear Capacity of the Shear Key (V_{key}):** The shear capacity of the key is governed by the material strength of the steel:
$$V_{key} = \frac{f_y \cdot A_k}{\sqrt{3} \cdot \gamma_{m0}},$$
where:
  - f_y: Yield strength of the steel,
  - A_k: Shear key cross-sectional area,
  - γ_{m0}: Partial safety factor for steel (typically 1.1).
- Ensure:
$$V_k \leq V_{key}.$$

2.6.5 Weld Connection of Shear Key to Base Plate

The shear key is fillet-welded to the base plate. The weld must resist the shear force transferred by the key:

- **Weld Throat Size (a_w):** As per **IS 800:2007 Cl. 10.5.7**, the throat size is:
$$a_w = 0.7 \cdot \text{leg size}.$$
- **Weld Strength:** The weld must satisfy:
$$T_w \leq f_{uw} \cdot A_w,$$
where:
  - T_w: Shear force on the weld,
  - f_{uw}: Ultimate strength of the weld,
  - A_w: Weld throat area.

2.6.6 Final Checklist for Shear Key Design

Ensure the following:

- The shear key is designed to resist $V_k = V_u - V_r$.
- The depth of the shear key (h_k) ensures sufficient concrete bearing strength.
- The material of the shear key is adequate to resist the applied shear force.
- Welds connecting the shear key to the base plate are sufficient to transfer forces.
- All detailing requirements are met to ensure proper fabrication and installation.

2.7 Detailing Checklist for Hollow/Tubular Columns

The detailing checklist ensures that all geometric, material, and connection-specific requirements are met for safe and efficient performance of a tubular base plate connection. Clauses refer to IS 800:2007 unless otherwise noted.

2.7.1 Bolt Spacing Around Circumference

- **Minimum Circumferential Spacing ($s_{\min}$):** Bolts equally spaced around the tube must satisfy

$$s_{\min} \;\geq\; 2.5\,d_0 \quad (\textbf{IS 800:2007 Cl. 10.2.3.1}).$$

- **Maximum Circumferential Spacing ($s_{\max}$):**

$$s_{\max} \;\leq\; \min\bigl(32\,t_p,\; 300\,\text{mm}\bigr) \quad (\textbf{IS 800:2007 Cl. 10.2.3.2}).$$

2.7.2 End and Edge Distances

- **Radial Distance (e):** Distance from bolt center to outer plate edge along radius must satisfy

$$e \;\geq\; \begin{cases} 1.5\,d_0, & \text{rolled/machined edges,} \\ 1.7\,d_0, & \text{sheared/flame-cut edges,} \end{cases} \qquad e \;\leq\; 40 + 4\,t_p \quad (\textbf{IS 800:2007 Cl. 10.2.4.2–.3}).$$

- **Circumferential Distance (e'):** Distance along plate edge between bolt center and adjacent bolt or plate corner (measured tangentially) uses the same limits as e.

2.7.3 Hole Dimensions

- **Standard Bolt Holes:**

$$d_h = d_0 + 2\,\text{mm} \quad (\textbf{IS 800:2007 Cl. 10.2.4.4}).$$

- **Oversized Bolt Holes (if used):**

$$d_h = d_0 + 6\,\text{mm} \quad (\textbf{IS 800:2007 Table 5}).$$

2.7.4 Weld Details

- **Weld Type:** Continuous fillet weld around the tube perimeter to the base plate.
- **Weld Throat Size (a_w):**

$$a_w \;=\; 0.7 \times \text{leg size} \quad (\textbf{IS 800:2007 Cl. 10.5.7}).$$

- **Weld Length (L_w):** Full-length weld around the tube base ensures moment and shear transfer.

2.7.5 Grout and Surface Preparation

- **Grout Thickness (t_g):** Maintain non-shrink grout thickness 20–50 mm and level to within ± 2 mm of plate underside (**IS 800:2007 Cl. 10.4.4**).
- **Surface Flatness:** Plate and concrete pedestal surfaces must be flat to ± 2 mm for uniform bearing.

2.7.6 Corrosion Protection and Durability

- **Corrosion Allowance:** Increase radial and circumferential distances by specified corrosion allowance where exposed.
- **Surface Treatment:** Apply galvanization or paint to plate, bolts, and welds to prevent corrosion.

2.7.7 Final Checklist

- Verify circumferential bolt spacing meets IS 800:2007 Cl. 10.2.3.
- Verify radial (e) and circumferential (e') distances per Cl. 10.2.4.
- Confirm bolt hole diameters follow Cl. 10.2.4.4 and Table 5.
- Ensure weld throat size and length comply with Cl. 10.5.7.
- Check grout thickness and surface flatness per Cl. 10.4.4.
- Confirm corrosion protection measures are specified.

Chapter 10

Internship Task 8 Development of Laced Column Compression Member

10.1 Problem Statement

10.1.1 Background

Laced columns are built-up compression members designed to carry heavy loads in steel structures. These columns consist of two or more main structural elements (such as channels, I-sections, or angles) connected together by a system of inclined lacing bars or battens. The lacing system ensures that the individual components act as a single unit while providing structural efficiency for large, tall structures.

10.1.2 Design Requirements

According to IS 800:2007, the design of laced columns involves specific requirements including angle of inclination (typically 40°-70°), slenderness ratio limitations, effective length calculations, width/thickness ratios, transverse shear force considerations, and strength checks. The design must ensure adequate strength, stability, and serviceability of the composite column system.

10.1.3 Project Objective

The primary objective was to develop a comprehensive Python module for the dynamic calculation and design of laced columns based on IS 800:2007 specifications. This module extends the existing column design framework in OSDAG (Open Source Design and Analysis of Gusset plates) to include specialized calculations for:

- Spacing calculations between laced members
- Tie plate design and dimensioning
- Lacing bar design including angle optimization, force calculations, and strength verification

10.2 Tasks Accomplished

The development of the laced column module involved several key tasks:

10.2.1 Module Architecture

- Extended the existing `Member` class to create a specialized `LacedColumn` class
- Integrated with the existing OSDAG framework maintaining compatibility with UI components

10.2.2 Core Calculation Functions

- **Spacing Calculation**: Developed algorithms to determine optimal spacing between laced members
- **Tie Plate Design**: Implemented comprehensive tie plate sizing and design calculations
- **Lacing Design**: Created complete lacing system design including angle optimization and strength verification

10.2.3 Code Integration

- Maintained compatibility with existing section property databases
- Integrated with material property systems and safety factor calculations

10.3 Python Code Implementation

10.3.1 Module Imports and Initialization

Script Description

The initialization section establishes the foundation of the laced column module by importing necessary libraries and setting up the class structure. It inherits from the existing `Member` class and initializes all required properties for laced column design.

Python Code

Listing 10.1: Laced Column Design in Osdag

```
%--------------------begin code-------------

class LacedColumn(Member):

    def __init__(self):
        # print(f"Here10")
        super(LacedColumn, self).__init__()

        # -----------------------------------------
        # Input Properties & Design Preferences
        # -----------------------------------------
        self.module = ""
        self.mainmodule = ""
        self.sec_profile = ""
        self.sec_list = []
        self.material = ""
        self.length_zz = 0.0
        self.length_yy = 0.0
        self.end_1_z = ""
```

```
        self.end_2_z = ""
        self.end_1_y = ""
        self.end_2_y = ""
        self.load = None  # Will be set by Load() later
        self.material_property = None # Will be set by Material() later
        self.allowable_utilization_ratio = 1.0
        self.effective_area_factor = 1.0
        self.lacing_type = ""  #Single Lacing or Double Lacing

        # ----------------------------------------
        # Status Flags
        # ----------------------------------------
        self.design_status = False
        self.design_status_list = []
        self.flag = False

        # ----------------------------------------
        # Result Dictionaries and Lists
        # ----------------------------------------
        self.failed_design_dict = {}
        self.input_section_list = []
        self.input_section_classification = {}

        self.optimum_section_ur_results = {}
        self.optimum_section_ur = []
        self.optimum_section_cost_results = {}
        self.optimum_section_cost = []

        # ----------------------------------------
        # Final Output Variables
        # ----------------------------------------
        self.result_designation = ""
        self.result_UR = 0.0
        self.result_section_class = ""
        self.result_effective_area = 0.0
        self.result_eff_len_zz = 0.0
        self.result_eff_len_yy = 0.0
        self.result_capacity = 0.0
        self.result_fcd = 0.0
```

```
59
60          # ----------------------------------------
61          #spacing between lacing members
62          # ----------------------------------------
63          self.spacing = 0.0
64          # ----------------------------------------
65          # Tie Plate Properties
66          # ----------------------------------------
67          self.effective_length_tie = 0.0
68          self.overall_depth = 0.0
69          self.length_of_tie = 0.0
70          self.tie_thick = 0.0
71
72
73  %-------------------- end code ---------------
```

Explanation of the Code

The initialization method sets up the complete framework for laced column design:

- **Inheritance**: The class inherits from the `Member` base class, ensuring compatibility with the existing OSDAG framework.
- **Input Properties**: Variables store user inputs including section profiles, dimensions, end conditions, and loads.
- **Design Preferences**: Properties like `allowable_utilization_ratio` and `effective_area_fact` allow user customization.
- **Status Management**: Boolean flags track design success/failure states throughout the calculation process.
- **Result Storage**: Dictionaries and lists store intermediate and final results for different section options.
- **Laced-Specific Properties**: Variables like `spacing`, `tie_thick` store calculations specific to laced column design.

10.3.2 Spacing Calculation Function

Script Description

The spacing calculation determines the optimal distance between the two main members of a laced column. This calculation is critical as it affects the overall stability and buckling behavior of the composite column system.

Python Code

Listing 10.2: Laced Column Design in Osdag

```
%--------------------begin code-------------
    def calculate_spacing(self):
        """
        Calculate the spacing S between the members of a compound column (channels).
        Uses the properties of the final selected section.
        Returns:
            S: Spacing between two members (rounded up to nearest 10 for toe-to-toe)
        """

        root = (self.section_property.mom_inertia_z - self.section_property.mom_inertia_y) / self.section_property.area
        if root < 0:
            logger.error("Invalid input: (I_zz - I_yy) / A is negative.")
            return None

        if self.sec_profile == VALUES_SEC_PROFILE4[2]:  # Channel (back-to-back)
            self.spacing = 2 * (math.sqrt(root) - self.section_property.Cy)
        elif self.sec_profile == VALUES_SEC_PROFILE4[1]:  # Channel (toe-to-toe)
            self.spacing = 2 * (math.sqrt(root) + self.section_property.Cy)
            self.spacing = int(math.ceil(self.spacing / 10.0)) * 10
```

```
20          elif self.sec_profile == VALUES_SEC_PROFILE4[0]:  # I section
21              self.spacing = 2 * (math.sqrt(root) + (self.
                    section_property.flange_thickness/2))
22              self.spacing = int(math.ceil(self.spacing / 10.0)) * 10
23          else:
24              logger.error("Unsupported section profile for spacing
                    calculation.")
25              self.design_status = False
26              return None
27
28          if self.spacing < 0:
29              logger.error("Calculated spacing S is negative. Check your
                    input values.")
30              self.design_status = False
31              return None
32          #return self.spacing
33
34          if self.design_status:
35              logger.info(f"Spacing between the members of the compound
                    column is {self.spacing} mm.")
36          return self.spacing
37  %-------------------- end code ---------------
```

Explanation of the Code

The spacing calculation implements the fundamental principle that ensures equal moments of inertia about both principal axes:

- **Theoretical Basis**: The calculation is based on the condition $I_{zz} = I_{yy}$ for the composite section, ensuring equal buckling resistance in both directions.
- **Root Calculation**: The term $\sqrt{(I_{zz} - I_{yy})/A}$ represents the radius of gyration difference between the two axes.
- **Section-Specific Formulas**: Different formulas are applied based on section type:
  - Back-to-back channels: $S = 2(\sqrt{\text{root}} - C_y)$
  - Toe-to-toe channels: $S = 2(\sqrt{\text{root}} + C_y)$

– I-sections: $S = 2(\sqrt{\text{root}} + t_f/2)$

- **Rounding Logic**: For practical construction, spacing is rounded up to the nearest 10 mm increment.
- **Error Handling**: Comprehensive validation ensures physically meaningful results and appropriate error reporting.

10.3.3 Tie Plate Design Function

Script Description

Tie plates are horizontal connecting elements that maintain the spacing between the main members and provide additional stiffness at specific intervals along the column height. The design function calculates the required dimensions based on spacing and construction requirements.

Python Code

Listing 10.3: Laced Column Design in Osdag

```
%--------------------begin code-------------
    def design_tie_plate(self):
        """
        Designs the tie plate for the current section.
        Returns:
            dict: Dictionary with keys effective_length_tie,
                overall_depth, length_of_tie, tie_thick
        """
        self.gauge = 25    #find gauge from the IS 808:2007

        if self.sec_profile == VALUES_SEC_PROFILE4[0]:  # Column (I-
            section)
            self.effective_length_tie = self.spacing - 2 * self.
                section_property.flange_width
            self.overall_depth = self.effective_length_tie + 2 * self.
                gauge
            self.length_of_tie = self.spacing + 2 * self.gauge
            self.tie_thick = (1 / 50) * (self.spacing + 2 * self.gauge)
```

```
15
16
17          elif self.sec_profile == VALUES_SEC_PROFILE4[1]:  # Channel (
                Toe to Toe)
18              self.effective_length_tie = self.spacing - 2 * self.
                    section_property.Cy
19              self.overall_depth = self.effective_length_tie + 2 * self.
                    gauge
20              self.length_of_tie = self.spacing + 2 * self.gauge
21              self.tie_thick = (1 / 50) * (self.spacing + 2 * self.gauge)
22
23
24          elif self.sec_profile == VALUES_SEC_PROFILE4[2]:  # Back to
                Back Channel
25              self.effective_length_tie = self.spacing + 2 * self.
                    section_property.Cy
26              # Ensure effective length >= 2 * flange width
27              if self.effective_length_tie < 2 * self.section_property.
                    flange_width:
28                  self.effective_length_tie = 2 * self.section_property.
                        flange_width
29              self.overall_depth = self.effective_length_tie + 2 * self.
                    gauge
30              self.length_of_tie = self.spacing + 2 * self.gauge
31              self.tie_thick = (1 / 50) * (self.spacing + 2 * self.gauge)
32
33          else:
34              self.design_status = False
35              logger.error("Error calculating the tie plate for the
                    section profile")
36              return None
37
38          logger.info(f"Effective length of tie: {self.
                effective_length_tie} mm, "
39                      f"Overall depth: {self.overall_depth} mm, "
40                      f"Length of tie: {self.length_of_tie} mm, "
41                      f"Tie thickness: {self.tie_thick} mm.")
42          return {
43          "effective_length_tie": self.effective_length_tie,
```

```
        "overall_depth": self.overall_depth,
        "length_of_tie": self.length_of_tie,
        "tie_thick": self.tie_thick
    }
%-------------------- end code ---------------
```

Explanation of the Code

The tie plate design function calculates dimensions based on structural and constructional requirements:

- **Gauge Distance**: A standard gauge of 25 mm is adopted based on IS 808:2007 specifications for connection details.
- **Effective Length Calculation**:
  - For I-sections: Clear span between flange edges.
  - For toe-to-toe channels: Clear span between web centerlines.
  - For back-to-back channels: Span including flange projections.
- **Thickness Calculation**: The empirical ratio of 1:50 (thickness to overall length) ensures adequate stiffness while maintaining economy.
- **Minimum Requirements**: For back-to-back channels, minimum effective length is enforced to ensure adequate connection area.
- **Return Dictionary**: Structured output facilitates integration with other design functions and report generation.

10.3.4 Lacing Design Function

Script Description

The lacing design function is the most comprehensive component, handling the complete design of the inclined lacing system. It calculates forces, angles, member sizes, and performs strength verification according to IS 800:2007.

Python Code

Listing 10.4: Laced Column Design in Osdag

```
%--------------------begin code-------------
    def design_lacing(self):
        """
        Designs the lacing for the current section.
        Returns:
            dict: Dictionary with keys
        """
        #this part is only for calculation testing, remove later while developing UI
        self.dia_bolt = 16 # Diameter of bolt in mm
        VALUES_LACING_PATTERN = ['Single','Double']  # Single lacing
        VALUES_LACING_CONNECTION = ['Bolted', 'Welded']  # Bolted connection
        self.lacing_type = VALUES_LACING_PATTERN[0]  # Default to Single lacing
        self.connection_type = VALUES_LACING_CONNECTION[0]  # Default to Bolted connection


        # 1. Initial spacing between lacings (L0i)
        self.initial_spacing_between_lacings = round(2 * (self.spacing + 2 * self.gauge) * (1 / math.tan(math.radians(45))), 2) # mm

        # 2. Number of lacings (NL)
        numerator = self.length_zz - 2 * self.overall_depth - 4 * 20  # 20 mm is the minimum lacing length as per IS 800:2007
        self.number_of_lacings = int(round(numerator / self.initial_spacing_between_lacings + 1))

        # 3. Actual spacing between lacings (L0)
        if self.number_of_lacings > 1:
            self.actual_spacing_between_lacings = round(numerator / (self.number_of_lacings - 1), 2)  # mm
        else:
```

```
            self.actual_spacing_between_lacings = numerator  # fallback

        # 4. Lacing angle (theta, in degrees)
        denominator = 2 * (self.spacing + 2 * self.gauge)
        cot_theta = self.actual_spacing_between_lacings / denominator
        self.lacing_angle_deg = round(math.degrees(math.atan(1 /
            cot_theta)), 2)  # degrees

        # Check if angle is within limits (40 < theta < 70)
        if self.lacing_angle_deg < 40 or self.lacing_angle_deg > 70:
            logger.error("Lacing angle is out of bounds (40 < theta <
                70 degrees). Please check your inputs.")
            self.design_status = False
            return None

        # 5. Total transverse shear force (Vt)
        if self.lacing_type == VALUES_LACING_PATTERN[0]:  # Single
            lacing
            self.transverse_shear_force = round(((2.5 / 100) * 1 * self
                .load.axial_force) / 1000, 2)  # Cl. 7.6.6.1 of IS
                800:2007
            theta_rad = math.radians(self.lacing_angle_deg)
            self.compressive_force_lacing = round((self.
                transverse_shear_force / 1) * (1 / math.sin(theta_rad)),
                 2) # Cl.
        elif self.lacing_type == VALUES_LACING_PATTERN[1]:  # Double
            lacing
            self.transverse_shear_force = round(((2.5 / 100) * 2 * self
                .load.axial_force) / 1000, 2)  # Cl.7.6.6.1 of IS
                800:2007
            theta_rad = math.radians(self.lacing_angle_deg)
            self.compressive_force_lacing = round((self.
                transverse_shear_force / 2) * (1 / math.sin(theta_rad)),
                 2)  # Cl.
        else:
            logger.error("Invalid lacing type. Please select either '
                Single' or 'Double'.")
            self.design_status = False
            return None
```

```
53
54          # 6. width of lacing
55          self.minimum_lacing_width = 3 * self.dia_bolt #Cl. 7.6.2 of IS
                :800:2007
56          self.minimum_lacing_width = int(math.ceil(self.
                minimum_lacing_width / 25.0)) * 25  # Round up to the next
                multiple of 25
57
58          # 7. Calculation of radius of gyration of lacing
59          self.effective_length_lacing = self.spacing + 2 * self.gauge *
                (1 / math.tan(math.radians(45)))
60          if self.connection_type == VALUES_LACING_CONNECTION[0]:   #
                Bolted
61              self.thick_lacing = (1 / 40) * self.effective_length_lacing
62          elif self.connection_type == VALUES_LACING_CONNECTION[1]:  #
                Welded
63              self.thick_lacing = (1 / 60) * self.effective_length_lacing
64
65          self.min_r_gyration_lacing = self.thick_lacing / math.sqrt(12)
                # Cl.
66
67          # 8. Slenderness Ratio of Lacings (Cl. 7.6.5.1 of IS 800:2007)
68          self.effective_slenderness_ratio = self.effective_length_lacing
                / self.min_r_gyration_lacing  # m
69          self.max_slenderness_ratio_lacing = self.
                actual_spacing_between_lacings / self.min_r_gyration_lacing
                # m
70          self.max_slenderness_ratio_lacing = min(50, 0.7 * self.
                effective_slenderness_ratio)  # Cl.
71          if self.max_slenderness_ratio_lacing >= 145:          # Cl.
72              logger.error("Slenderness ratio of lacing is greater than
                    145. Check your input values.")
73              self.design_status = False
74              return None
75
76          #Calculation of design strength of lacing
77
78          # 1. Euler buckling stress of lacing
```

```
79          self.euler_buckling_stress_lacing = (math.pi ** 2 * self.
               material_property.modulus_of_elasticity) / self.
               effective_slenderness_ratio ** 2
80
81          # 2. Non-dimensional effective slenderness ratio of lacing
82          self.non_dimensional_effective_slenderness_ratio_lacing = math.
               sqrt(self.material_property.fy / self.
               euler_buckling_stress_lacing)
83
84          # 3. phi_lacing
85          self.phi_lacing = 0.5 * (1 + (self.imperfection_factor_lacing *
                (self.non_dimensional_effective_slenderness_ratio_lacing -
               0.2)) + self.
               non_dimensional_effective_slenderness_ratio_lacing ** 2)
86
87          # 4. Calculation of chi
88          self.chi_lacing = 1 / (self.phi_lacing + (self.phi_lacing ** 2
               - self.non_dimensional_effective_slenderness_ratio_lacing **
                2) ** 0.5)
89
90          # 5. Design compressive stress in lacing
91          self.design_compressive_stress_lacing = self.chi_lacing * self.
               material_property.fy / self.gamma_m0
92
93          if self.design_compressive_stress_lacing >= self.
               material_property.fy / self.gamma_m0:
94              logger.error("Design compressive stress in lacing is less
                   than required compressive stress. Check your input
                   values.")
95              self.design_status = False
96              return None
97
98          # 6. Design compressive capacity in lacing
99          self.cross_sectional_area_lacing = self.minimum_lacing_width *
               self.thick_lacing  #Cross-sectional area for flat lace
100         self.design_compressive_capacity_lacing = self.
               design_compressive_stress_lacing * self.
               cross_sectional_area_lacing
```

```
101         if self.design_compressive_capacity_lacing <= self.
                compressive_force_lacing:
102             logger.error("Design compressive capacity in lacing is less
                    than required compressive force. Check your input
                    values.")
103             self.design_status = False
104             return None
105 
106         # 7. Design tensile strength governed by yielding of gross
                section Tdg
107         self.design_tensile_strength_lacing = self.material_property.fy
                * self.cross_sectional_area_lacing / self.gamma_m0
108         if self.design_tensile_strength_lacing <= self.
                compressive_force_lacing:
109             logger.error("Design tensile strength in lacing is less
                    than required compressive force. Check your input values
                    .")
110             self.design_status = False
111             return None
112 
113         logger.info(f"Initial spacing between lacings: {self.
                initial_spacing_between_lacings} mm, "
114                     f"Number of lacings: {self.number_of_lacings}, "
115                     f"Actual spacing between lacings: {self.
                            actual_spacing_between_lacings} mm, "
116                     f"Lacing angle: {self.lacing_angle_deg} degrees, "
117                     f"Effective slenderness ratio: {self.
                            effective_slenderness_ratio}, "
118                     f"lMax slenderness ratio of lacing: {self.
                            max_slenderness_ratio_lacing}, "
119                     f"Transverse shear force: {self.
                            transverse_shear_force} KN, "
120                     f"Compressive force in lacing: {self.
                            compressive_force_lacing} KN."
121                     f"Minimum lacing width: {self.minimum_lacing_width}
                            mm, "
122                     f"Effective length of lacing: {self.
                            effective_length_lacing} mm, "
123                     f"Thickness of lacing: {self.thick_lacing} mm, "
```

```
124                     f"Minimum radius of gyration of lacing: {self.
                            min_r_gyration_lacing} mm, "
125                     f"Euler buckling stress of lacing: {self.
                            euler_buckling_stress_lacing} MPa, "
126                     f"Non-dimensional effective slenderness ratio of
                            lacing: {self.
                            non_dimensional_effective_slenderness_ratio_lacing
                            }, "
127                     f"phi_lacing: {self.phi_lacing}, "
128                     f"Chi_lacing: {self.chi_lacing}, "
129                     f"Design compressive stress in lacing: {self.
                            design_compressive_stress_lacing} MPa, "
130                     f"Design compressive capacity in lacing: {self.
                            design_compressive_capacity_lacing} KN, "
131                     f"Design tensile strength in lacing: {self.
                            design_tensile_strength_lacing} KN.")
132
133         result_lacing = [
134         self.initial_spacing_between_lacings,
135         self.number_of_lacings,
136         self.actual_spacing_between_lacings,
137         self.lacing_angle_deg,
138         self.effective_slenderness_ratio,
139         self.max_slenderness_ratio_lacing,
140         self.transverse_shear_force,
141         self.compressive_force_lacing,
142         self.minimum_lacing_width,
143         self.effective_length_lacing,
144         self.thick_lacing,
145         self.min_r_gyration_lacing,
146         self.euler_buckling_stress_lacing,
147         self.non_dimensional_effective_slenderness_ratio_lacing,
148         self.phi_lacing,
149         self.chi_lacing,
150         self.design_compressive_stress_lacing,
151         self.design_compressive_capacity_lacing,
152         self.design_tensile_strength_lacing
153         ]
154
```

```
155         return result_lacing
156 %-------------------- end code ---------------
```

Explanation of the Code

The lacing design function implements a comprehensive design procedure following IS 800:2007:

- **Geometric Calculations**:
  - Initial spacing assumes a 45° angle for preliminary layout.
  - Number of lacings is determined by column height and minimum spacing requirements.
  - Actual angle is calculated from geometric constraints.
- **Force Analysis**:
  - Transverse shear force taken as 2.5% of axial load per IS 800:2007, Clause 7.6.6.1.
  - Force in lacing calculated using $F = V_t / \sin\theta$.
  - Different factors applied for single vs. double lacing systems.
- **Member Sizing**:
  - Width based on bolt spacing requirements (minimum 3 times bolt diameter).
  - Thickness ratios: 1:40 for bolted, 1:60 for welded connections.
  - Radius of gyration for flat sections: $r = t/\sqrt{12}$.
- **Stability Checks**:
  - Slenderness ratio limited to 145 per IS 800:2007.
  - Euler buckling stress calculation for compression members.
  - Buckling curve approach with imperfection factors.
- **Strength Verification**:
  - Compressive capacity using buckling reduction factor χ.
  - Tensile strength based on yielding of gross section.
  - Safety margin verification against required forces.

10.3.5 Full code

You can access the `laced_column.py` full code using the GitHub link:

https://github.com/Aditya-Donde/Osdag.git.

This corresponds to the commit:

```
commit 93bcb13a3f0cf6b26a63aa4bea970a76b326aa91 (origin/osdag_b1)
Author: Aditya <dondead1tya9@gmail.com@gmail.com>
Date:   Sat Jul 26 16:54:57 2025 +0530
```

10.4 Documentation

10.4.1 Directory Structure

```
Osdag
├── src/osdag
│   ├── design_report
│   ├── design_type
│   │   ├── beam_column
│   │   ├── compression
│   │   │   ├── Column.py
│   │   │   ├── Compression.py
│   │   │   └── laced_column.py
│   │   ├── connection
│   │   └── flexural_member
│   └── drawing_2D
├── Common.py
├── is800_2007exp.py
├── osdagMainPage.py
├── LICENSE
├── README.md
└── requirements.txt
```

Program Start Calls The main entry point for the program is `osdagMainPage.py` . To start the program, open the Osdag folder and start the terminal with that path, execute the following command from the project root:

```
$ python osdagMainPage.py
```

Chapter 11

Conclusions

11.1 Tasks Accomplished

During the course of this internship, various modules, design checklists, and improvements were developed and documented for integration into the Osdag software. These tasks spanned Module Development, Python code development, structural component design, and error correction based on IS 800:2007. Below is a summary of key accomplishments:

- **Design and Detailing Checklists (DDCL):**
  - Developed DDCL for Fixed Moment Base Plate
  - Developed DDCL for Pinned Base Plate under Eccentric Load
  - Developed DDCL for Base Plate for Hollow/Tubular Columns
- **Laced Column Design Module:** Implemented a complete Python module for the design of laced columns according to IS 800:2007, including spacing, tie plates, lacing bars, and axial force distribution.
- **Bug Report:** Identified and documented errors in Osdag's existing base plate module calculations including:
  - Incorrect shear area computation for column
  - Wrong effective bearing area formula for base plate

- **Version-Controlled Workflow:** Set up a Conda-based editable development environment from the GitHub repository using forking, cloning, and upstream integration.

11.1.1 Module Architecture

- Extended the existing `Member` class to create a specialized `LacedColumn` class
- Integrated with the existing Osdag framework maintaining compatibility with UI components

11.1.2 Core Calculation Functions

- **Spacing Calculation:** Developed algorithms to determine optimal spacing between laced members
- **Tie Plate Design:** Implemented comprehensive tie plate sizing and design calculations
- **Lacing Design:** Created complete lacing system design including angle optimization and strength verification

*10.2.3 Code Integration

- Maintained compatibility with existing section property databases
- Integrated with material property systems and safety factor calculations

11.2 Skills Developed

Throughout the internship, a diverse set of technical and professional skills were developed while working on the Osdag software ecosystem. This experience contributed to both engineering proficiency and software development capabilities, with particular emphasis on structural design, collaborative coding, and professional documentation.

- **Structural Design Proficiency:** Gained hands-on experience in steel design and detailing as per **IS 800:2007**, including components like base plates, laced columns, and stiffeners. Understood real-world applications of structural theory in software form.
- **Python Programming:** Designed and implemented Python modules for structural calculations using object-oriented principles. Developed reusable, modular code for laced columns and various DDCL workflows.
- **Engineering Calculations:** Applied engineering judgment in calculating axial, shear, and bending capacities, lacing forces, and base plate geometries. Developed logic for automated checks based on codal clauses.
- **Git and GitHub Workflow:** Worked with version control tools for collaborative software development. Tasks included forking repositories, managing branches, setting up upstream remotes, and submitting changes through pull requests.
- **Editable Conda Environment Setup:** Learned to configure an editable Python environment using Conda, ensuring fast testing and development cycles for the Osdag codebase.
- **Bug Identification and Resolution:** Analyzed and documented bugs in existing modules. Suggested corrections with IS code references and proposed updated formulas and logic.
- **Documentation and Reporting:** Authored high-quality reports using LaTeX for all major tasks, including:
  - Design and Detailing Checklists (DDCLs) for various base plate configurations

  - A detailed bug report for the base plate connection module
  - Comprehensive module documentation for laced column design

- **Professional Competencies:** Enhanced problem-solving, time management, and teamwork skills. Effectively balanced documentation, design logic and backend integration within the internship timeline.
- **Communication and Presentation:** Presented engineering work clearly through structured documentation, diagrams, and IS-code-backed rationale, making the work reproducible and valuable for future contributors to the Osdag project.

This internship served as a bridge between theoretical civil engineering knowledge and practical software development for structural design automation, contributing significantly to professional growth.

Chapter A

Appendix

A.1 Work Reports

Internship Work Report			
Name:	Aditya Donde		
Project:	Osdag		
Internship:	FOSSEE SUMMER FELLOWSHIP (Full Time On Campus)		
Date	Day	Task	Hours Worked
15-May-25	Thursday	Local environment setup	8
16-May-25	Friday	Local environment setup, Git and GitHub Workshop	8
17-May-25	Saturday	Task 1: Reimagning Osdag UI	8
18-May-25	Sunday		
19-May-25	Monday	Task 1: Reimagning Osdag UI	8
20-May-25	Tuesday	Base plate corrections	8
21-May-25	Wednesday	Base plate corrections	8
22-May-25	Thursday	Base plate corrections	8
23-May-25	Friday	Base plate corrections	8
24-May-25	Saturday	Pinned Base plate calculations	8
25-May-25	Sunday		
26-May-25	Monday	Pinned Base plate calculations	8
27-May-25	Tuesday	Tension member module addition of a section	8
28-May-25	Wednesday	Pinned Base plate with small eccentric load calculation	8
29-May-25	Thursday	Pinned Base plate with small eccentric load calculation	8
30-May-25	Friday	Pinned Base plate/ Pinned Base plate with small eccentri load DDCL	
31-May-25	Saturday	Pinned Base plate/ Pinned Base plate with small eccentri load DDCL	8
1-Jun-25	Sunday		
2-Jun-25	Monday	Bugs in Osdag	8
3-Jun-25	Tuesday	Bugs in Osdag	8
4-Jun-25	Wednesday	Bugs in Osdag	8
5-Jun-25	Thursday	Tension member module addition of a section	8
6-Jun-25	Friday	Installing new version of Osdag in lab	8
7-Jun-25	Saturday	Base plate corrections	8
8-Jun-25	Sunday		
9-Jun-25	Monday	Fixed Base Plate Caculations	8
10-Jun-25	Tuesday	Fixed Base Plate Caculations, Bugs in Osdag	8
11-Jun-25	Wednesday	Fixed Base Plate Caculations	8
12-Jun-25	Thursday	Fixed Base Plate DDCL	8
13-Jun-25	Friday	Hollow/Tubular Base plate caculations	8
14-Jun-25	Saturday	Hollow/Tubular Base plate DDCL	8
15-Jun-25	Sunday		
16-Jun-25	Monday	Laced Column Module Development	8
17-Jun-25	Tuesday	Understanding UI of Osdag	8
18-Jun-25	Wednesday	Understanding UI of Osdag	8
19-Jun-25	Thursday	Bugs in Osdag	8

20-Jun-25	Friday	Bugs in Osdag	8
21-Jun-25	Saturday	Laced Column Module Development- Spacing between members	8
22-Jun-25	Sunday		
23-Jun-25	Monday	Installing software in Civil Engineering lab	8
24-Jun-25	Tuesday	Laced Column Module Development- Spacing between members	8
25-Jun-25	Wednesday	Laced Column Module Development- Understanding Section Classification	8
26-Jun-25	Thursday	Laced Column Module Development- Understanding Section Classification	8
27-Jun-25	Friday	Laced Column Module Development- Understanding Design of Column	8
28-Jun-25	Saturday	Laced Column Module Development- Understanding Design of Column	8
29-Jun-25	Sunday		
30-Jun-25	Monday	Laced Column Module Development- Design of Tie plates	8
1-Jul-25	Tuesday	Laced Column Module Development- Design of Tie plates	8
2-Jul-25	Wednesday	Laced Column Module Development- Design of Tie plates	8
3-Jul-25	Thursday	Laced Column Module Development- Design of Tie plates	8
4-Jul-25	Friday	Laced Column Module Development- Solving errors in code	8
5-Jul-25	Saturday	Laced Column Module Development- Solving errors in code	8
6-Jul-25	Sunday		
7-Jul-25	Monday	Laced Column Module Development- Design of Lacing	8
8-Jul-25	Tuesday	Laced Column Module Development- Design of Lacing	8
9-Jul-25	Wednesday	Laced Column Module Development- Design of Lacing	8
10-Jul-25	Thursday	Laced Column Module Development- Design of Lacing	8
11-Jul-25	Friday	Laced Column Module Development- Design of Lacing	8
12-Jul-25	Saturday	Laced Column Module Development- Design of Lacing	8
13-Jul-25	Sunday		
14-Jul-25	Monday	Laced Column Module Development- solving errors in code	8
15-Jul-25	Tuesday	Laced Column Module Development- solving errors in code	8

16-Jul-25	Wednesday	Laced Column Module Development- solving errors in code	8

Bibliography

[1] Siddhartha Ghosh, Danish Ansari, Ajmal Babu Mahasrankintakam, Dharma Teja Nuli, Reshma Konjari, M. Swathi, and Subhrajit Dutta. Osdag: A Software for Structural Steel Design Using IS 800:2007. In Sondipon Adhikari, Anjan Dutta, and Satyabrata Choudhury, editors, *Advances in Structural Technologies*, volume 81 of *Lecture Notes in Civil Engineering*, pages 219–231, Singapore, 2021. Springer Singapore.

[2] FOSSEE Project. FOSSEE News - January 2018, vol 1 issue 3. Accessed: 2024-12-05.

[3] FOSSEE Project. Osdag website. Accessed: 2024-12-05.