FOSSEE Summer Fellowship Report

On

Osdag Module Development and Animation

Submitted by

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Acknowledgments

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- My sincere thanks also go to Prof. Siddhartha Ghosh, Principal Investigator of the Osdag project, for his leadership and vision.
- I am also grateful to Prof. Kannan M. Moudgalya, Principal Investigator of the FOSSEE Project, for providing this opportunity and for his continued encouragement.
- I'd like to extend my sincere gratitude to my fellow interns for their collaboration, hard work, and support. Working alongside such a talented and dedicated group was a truly rewarding experience, and I am grateful for all that we accomplished together.

Contents

Chapter 1

Introduction

1.1 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.

1.1.1 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.

1.1.2 Fellowships

FOSSEE offers various internship and fellowship opportunities for students:

Figure 1.1: FOSSEE Projects and Activities

- 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.

1.2 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 [?, ?, ?]. 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.

1.2.1 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.

1.2.2 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.

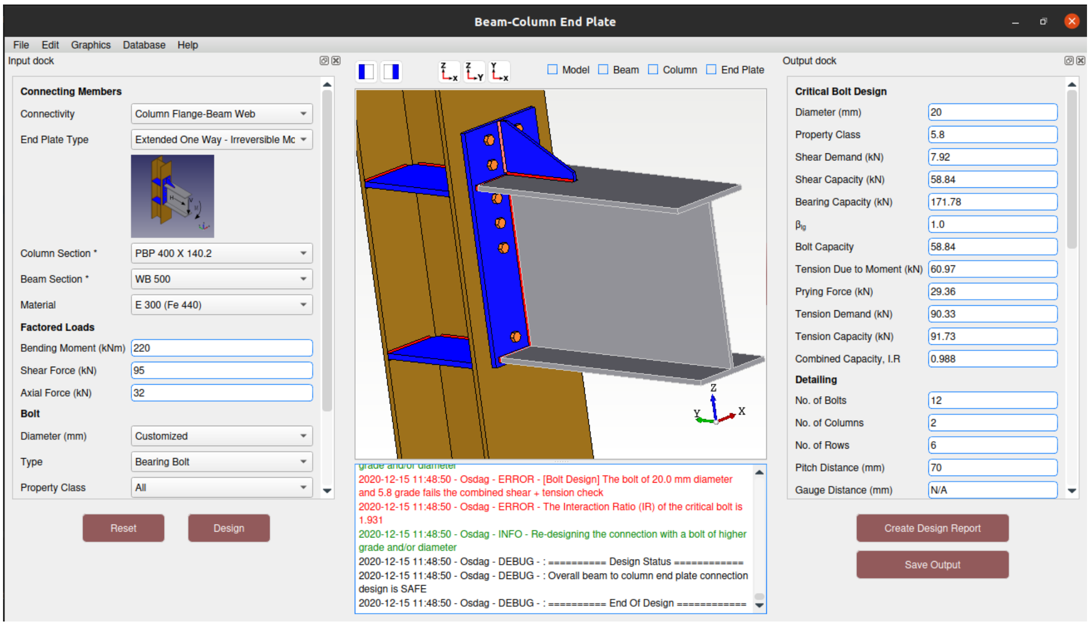


Figure 1.2: Osdag GUI

Chapter 2

Screening Task

2.1 Problem Statement

Individuals were supposed to make a animation for Lateral torsional buckling aswell as Block Shear failure in steel plates using only open source softwares.

2.2 Tasks Done

I approached the tasks by referring how the certain given topics work and studied about it on a civil engineering perspective aswell as how to integrate into a animation perspective for the audience to understand it as simple as possible.

Videos regarding the block shear failure in steel plates as well as the Lateral Torsional Buckling is made primarily in blender and the softwares kdenlive as well as audacity has been integrated for video editing and audio recording purposes.

BLENDER:- The concept and then later modelling was done all in blender from scratch and then animations was keyframed altogether for each and every object. A lot of modifiers and animating techniques and unique art styles is integrated with this project. The video is made to convey more information in a small amount of time with easier understanding.

KDENLIVE:- All the renders from the blender was integrated and edited in kdenlive and then later exported to a suitable video format while also including audio.

AUDACITY:- Voice recording is done with this software and some effects are added at last minute to reduce noise and increase volume gain.

VIDEO LINKS:- LATERAL TORSIONAL BUCKLING:-
https://youtu.be/aocmhqS50fM

BLOCK SHEAR FAILURE IN STEEL PLATES:-
https://youtu.be/kCJMl9w6sw4

Chapter 3

Task 1: Reimagining Osdag GUI

3.1 Problem Statement

Create a basic UI template of the Home Page and a particular Module Design Page

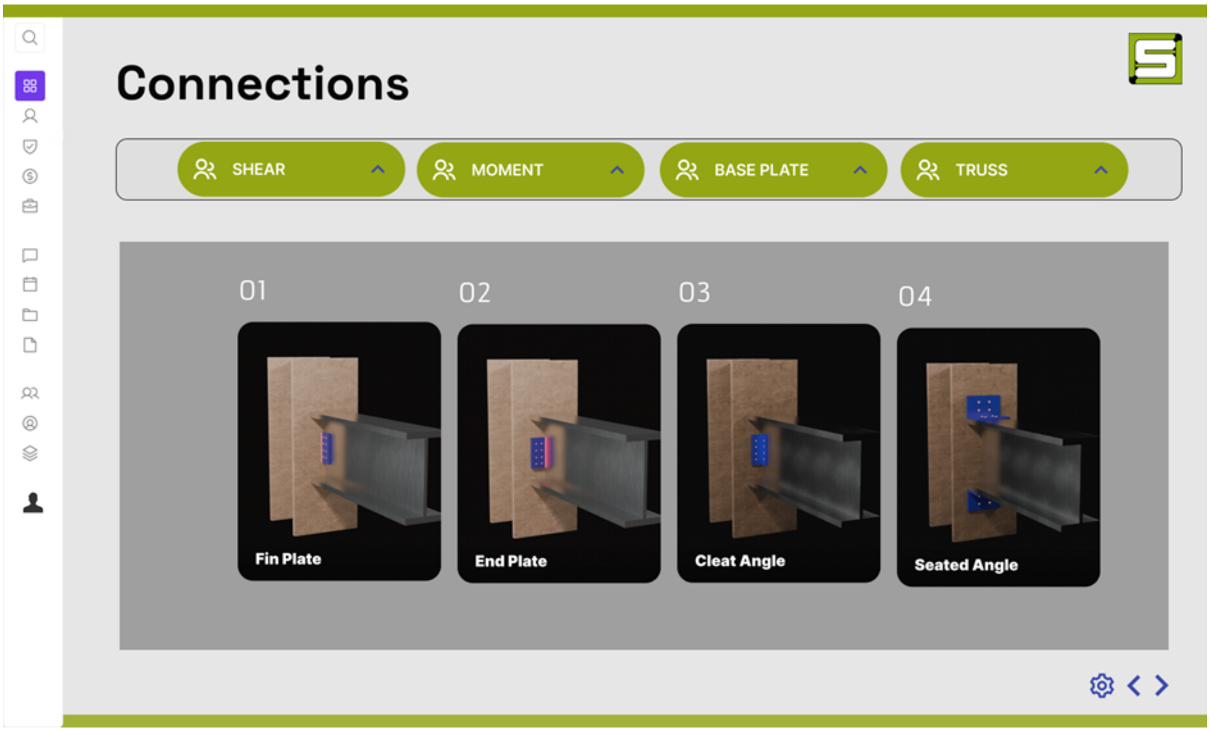
3.2 Tasks Done

To address the limitations of the previous interface, I conducted a user experience (UX) analysis and identified key areas for improvement, such as navigation, visual clarity, and accessibility. By using Figma, I translated these insights into a modernized GUI that introduces a clean sidebar for intuitive navigation, a streamlined input-output panel for connections, and a dark mode option to enhance user comfort. The new design focuses on a contemporary aesthetic and logical information hierarchy, aiming to make the Osdag software more efficient and user-friendly for engineers and students alike.

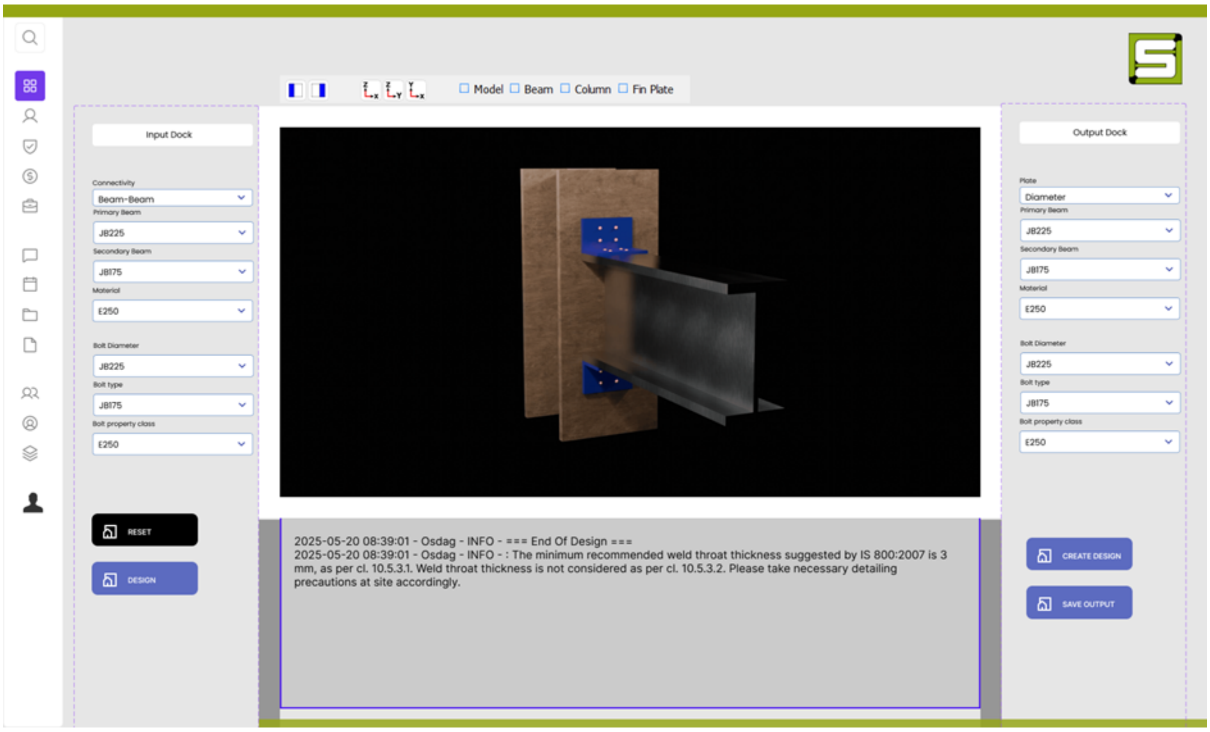
- Slightly altered the colour palette by removing the rose traupe colour and bringing more light shades.
- Still maintaining the triad formation of colour palette surrounded around green
- Hovering action of selection buttons

Figure 3.1: Home page

- Drop down menu
- Minimalistic and easy to work on
- Better fonts that goes with the ui
- 3d GIFs



Connections
SHEAR
MOMENT
BASE PLATE
TRUSS
01
02
03
04
Fin Plate
End Plate
Cleat Angle
Seated Angle



Model
Beam
Column
Fin Plate
Input Dock
Connectivity
Beam-Beam
Primary Beam
JB225
Secondary Beam
JB175
Material
E250
Bolt Diameter
JB225
Bolt type
JB175
Bolt property class
E250
RESET
DESIGN
2025-05-20 08:39:01 - Osdag - INFO - === End Of Design ===
2025-05-20 08:39:01 - Osdag - INFO - : The minimum recommended weld throat thickness suggested by IS 800:2007 is 3 mm, as per cl. 10.5.3.1. Weld throat thickness is not considered as per cl. 10.5.3.2. Please take necessary detailing precautions at site accordingly.
Output Dock
Plate
Diameter
Primary Beam
JB225
Secondary Beam
JB175
Material
E250
Bolt Diameter
JB225
Bolt type
JB175
Bolt property class
E250
CREATE DESIGN
SAVE OUTPUT

Chapter 4

Task 2: Animations for UTM, Steel failure sections

4.1 Problem Statement

A animated informative video to portray the working of Universal testing machine where a steel rebar has been loaded on it and to showcase how the stress-strain graph will vary based on the force applied and to show the cup-cone failure and key points in it.
The other task was to show how a steel section would react based on the difference in amount of force applied to it namely Yielding at gross section, Rupture at net section and Block shear failure.

4.2 Tasks Done

To create an effective visual aid for complex engineering concepts, I utilized Blender to develop 3D animations. The project involved two main components: an animation of a Universal Testing Machine (UTM) and a series of animations demonstrating various steel section failures.
Through this process, I gained experience in 3D modeling, texturing, and keyframe animation to accurately depict the forces and deformations at play.
The final videos serve as a powerful educational tool, simplifying abstract principles and providing a clear, dynamic illustration of how steel structures behave under stress, which is invaluable for students and professionals alike.

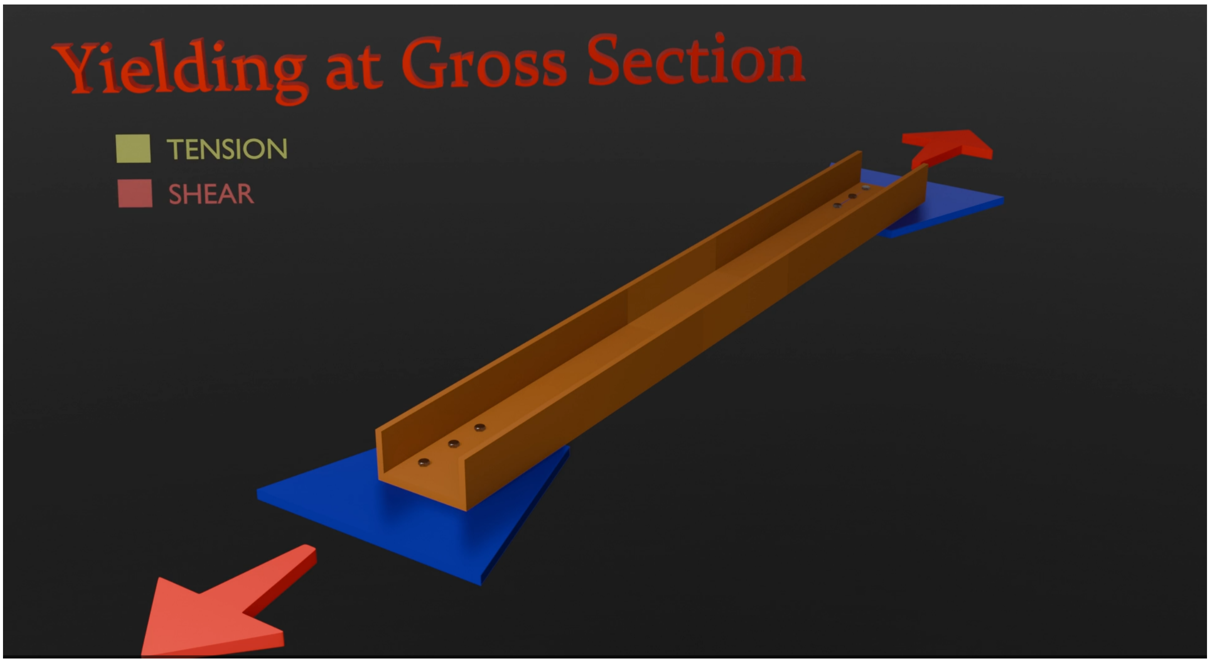


Figure 4.1: Yielding at gross section

Here are the links provided for the video files of the following:-

Cup-Cone Failure :-

https://drive.google.com/file/d/1qzurrk5sOQqsKVUvwxI69SXeTzvDenqp/view?usp=drive$_{l}$ink

SteelchannelFailure : −

https : *//drive.google.com/file/d/13TpfJ7C7kQ52cvB2zPvXaxZArjqb4unp/view?usp* =
drive$_{l}$*ink*

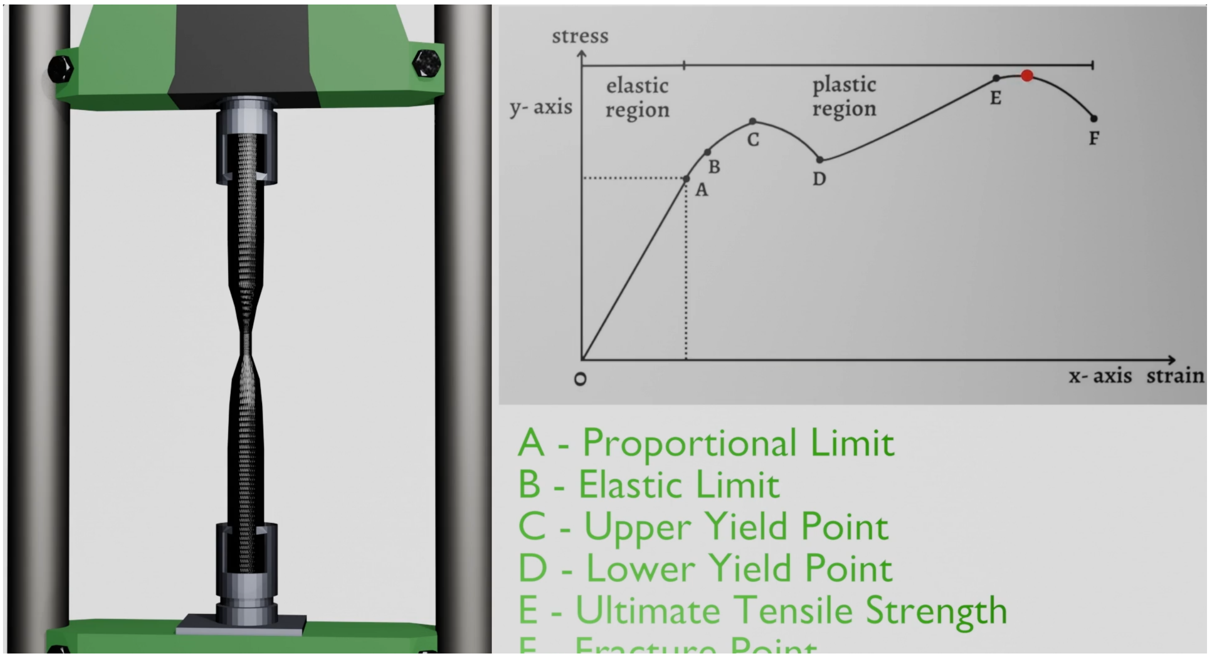


Figure 4.2: Universal Testing Machine

Chapter 5

Task 3: Animations for Steel channel sections, Truss and icons for UI

5.1 Problem Statement

Another video was to be made showcasing four types of sections namely T-section, Square hollow section, L-shape section and C-section.

The other task was to show how a truss would react to loads being applied on it and the different compressive and tension members.

The last task given in these 2 week span was to make icons and subtle animations and renders to enhance the new UI experience.

5.2 Tasks Done

Again i had to rely on Blender solely for all these tasks. The steel section task was approached in a way so as to connect to the real life experience. So a simple house was modeled at first and how and where the steel rebars are located is shown. Next the web, flange parts of the sections are highlighted.

Truss animation was conducted in a way to show how the truss would deform in an exaggerated way when car loads(moving loads) has been subjected to truss bridges. And the tensile compressive members of the truss was highlighted.

Simple UI icons and animations was made for the UI for plate connections and so on.

Figure 5.1: Truss

Here are the links provided for the video files of the following:-

Sections :-

https://drive.google.com/file/d/14f9P1rj7weLYb9vJEsdx9DWV2G1fjXft/view?usp=drive$_l$ink

$Truss:-$

$https://drive.google.com/file/d/1FciI6TrqB5ulfyhI7ct5N3DoMxXaOhAD/view?usp=$
$drive_link$

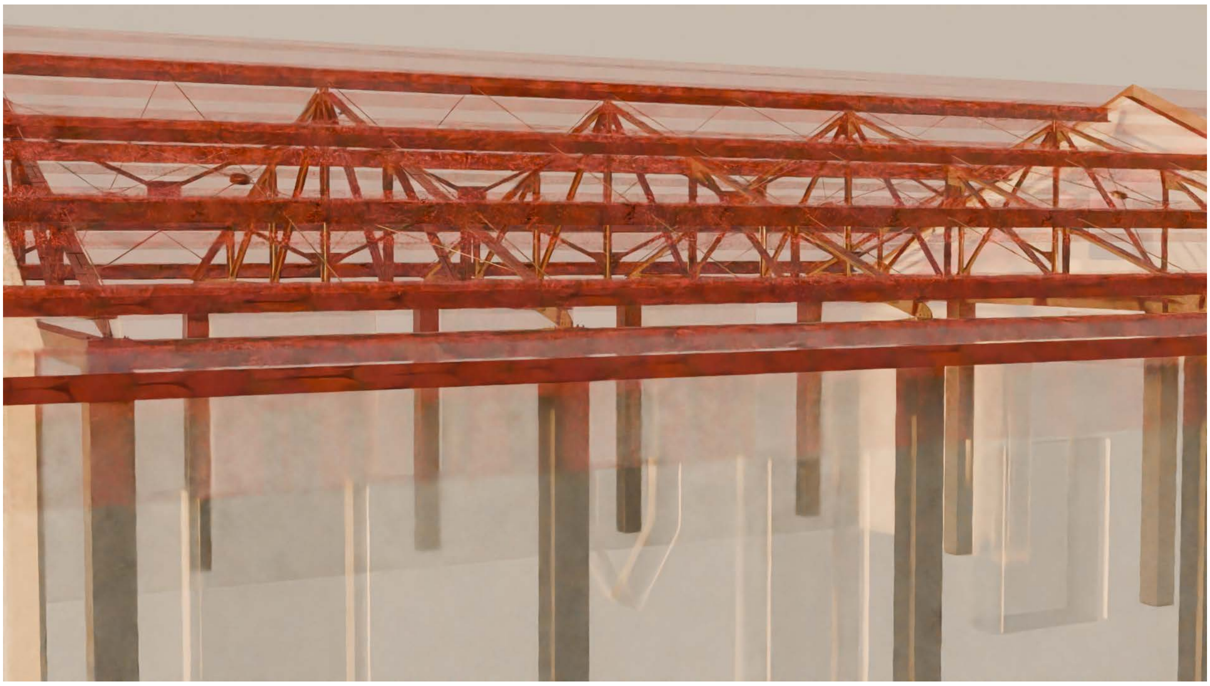
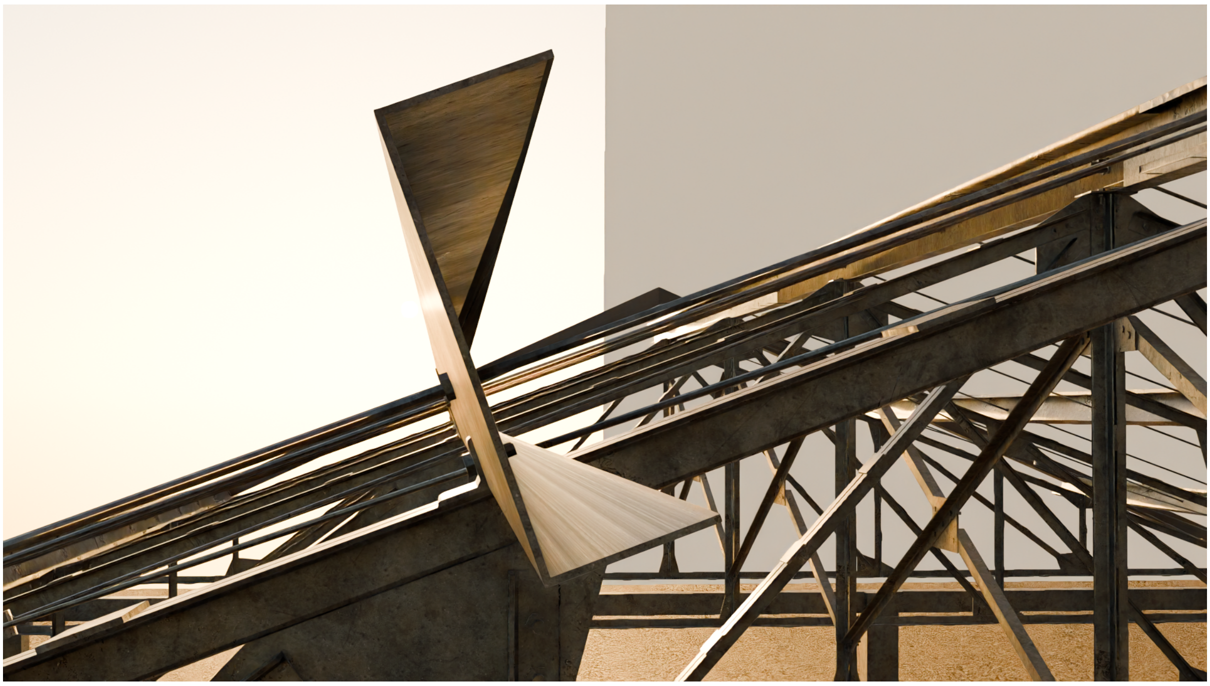


Figure 5.2: Sections



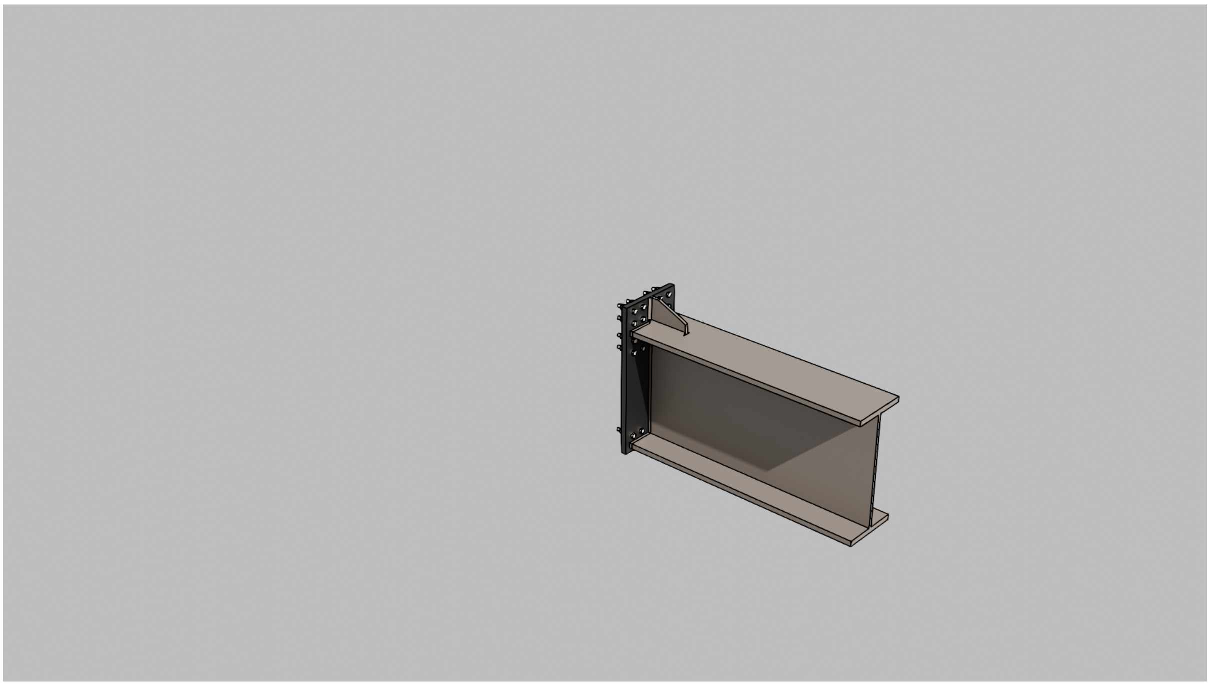
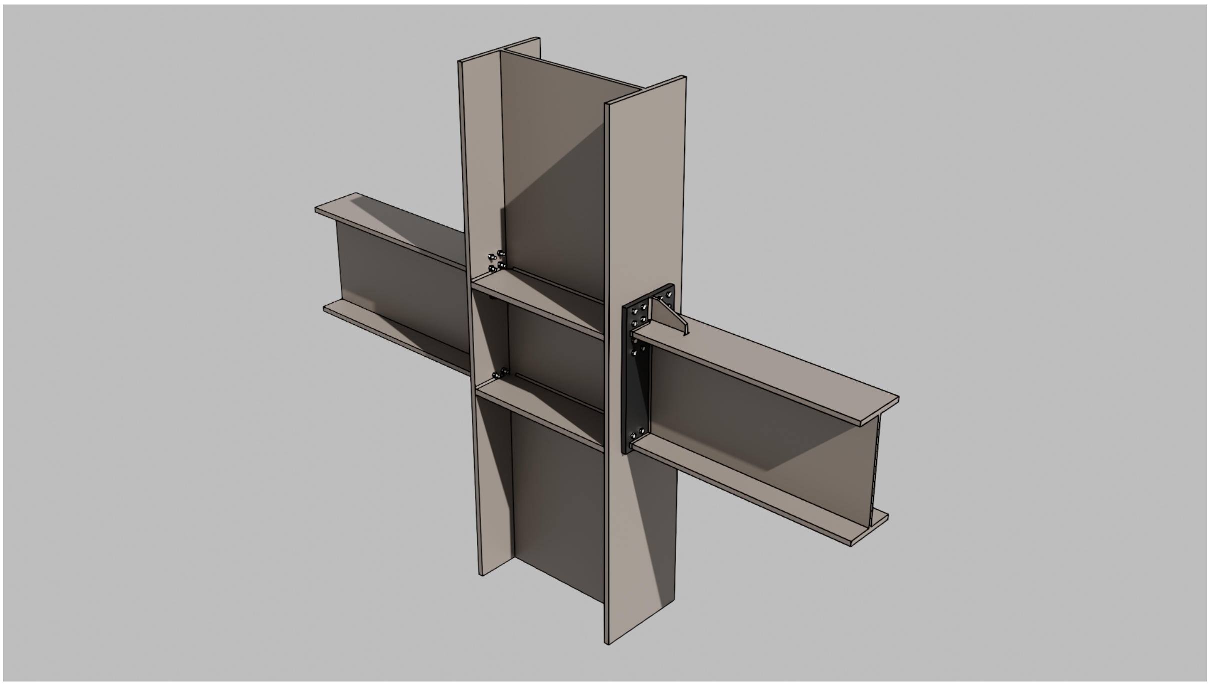


Figure 5.3: Icons



Chapter 6

Task 4: DDLC for Beam-Beam End Plate Connections

6.1 Problem Statement

Fetch Reports from osdag module analyse the reports, check its formulas aligning with IS code or not, and make a comprehensive DDCL for Beam-Beam end plate connections. Also if any errors in formula or any mismatch in it ,record them into a separate overleaf file.

6.2 Tasks Done

x[11.5pt,a4paper,oneside]report graphicx xcolor url palatino tabularx [T1]fontenc amsmath amsfonts amssymb graphicx float siunitx [top=1in, bottom=1in, left=0.8in, right=0.6in]geometry fancyhdr multirow [bookmarks=false]hyperref comment hyperref caption subcaption gensymb textcomp array

Tension Members Osdag - Open steel design and graphics logoOsdag.png

Design and detailing checklist (DDCL)

Beam-Beam End Plate Connection

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IITBLogo.png

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August 12, 2025

Contents

6.3 Theory

6.4 Introduction

End plate connections are a common method for joining steel beams and columns. They are widely used due to their simplicity and ease of erection. The basic principle involves welding a steel plate, known as the end plate, to the end of a beam. This plate is then bolted to the supporting member

The design of a beam-beam end plate connection involves ensuring that all components can safely transfer the loads from the supported beam to the supporting member. The analysis considers the strength, stiffness, and deformation capacity of the connection. End plate connections can be classified based on their geometry and the moment they are designed to resist. The two main types are:

- Flush End Plate: The end plate is the same depth as the beam. These connections are typically designed as simple connections, meaning they primarily transfer shear forces and have a minimal capacity to resist bending moments. They are considered "nominally pinned" and are expected to allow for some rotation at the joint.
- Extended End Plate: The end plate extends beyond the top and/or bottom flanges of the beam. These connections are designed to be moment-resisting, also known as rigid connections. The extended portions of the plate allow for more bolts to be placed, creating a larger lever arm to resist bending moments. Stiffeners are often added to the beam or end plate to enhance the connection's strength and stiffness.

6.5 Design and Detailing Checklist for Osdag Software

6.6 Input Parameters

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

- Connectivity:* The user will have a choice to choose between Coplanar Tension-Compression Flange, Coplanar Tension Flange, and Coplanar Compression Flange..
- End Plate Type:* The user has the option to select the End Plate Type based on its geometry and moment transfer across splices.
- Beam Section:* The user may choose any section of their choice for the beam.
- Material Property:* The user will have the option to choose from the available grades of steel.
- Factored Bending Moment (in kN):* The user will have to input the factored bending moment.
- Factored Shear Force (in kN):* The user will have to input the factored shear force.
- Factored Axial Force (in kN):* The user will have to input the factored axial force.
- Diameter of Bolt:* The user has the choice of specifying the diameter of the bolt or choosing the most optimized design provided by the software.
- Type of the bolt:* The user will have a choice to specify the bolt type as friction type (HSFG) or bearing type.
- Property (Grade) of Bolt:* The user has the choice of specifying the grade of the bolt or choosing the most optimized design provided by the software.
- End Plate Thickness:* The user has the choice of specifying the thickness of the end plate or choosing the most optimized design provided by the software.

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 bolted tension member include:

- Connector: The user can choose the grade of structural steel used for the end plate between E 165, E 250 and E 300.
- Type of Bolt: The choice in this section is between a pre-tensioned bolt and a non pre-tensioned bolt.
- Type of Hole: The user can choose between a standard hole or an oversized hole.
- Slip Factor: For a high-strength friction grip (HSFG) bolt, the user can define the slip factor.
- Type of Weld Fabrication: The user can choose welding type based on its environment.
- Edge Preparation Method: This relates to the fabrication aspect where the user can specify whether the hole has sheared or hand flame cut edges or Rolled, machine-flame cut, sawn and planed edges. This helps in determining the formula for the diameter of hole.
- Gap between Beam and Support: The user can add gap between beam and support according to design specification.
- Exposure of Members to Corrosive Surfaces: The user can specify whether the members will be exposed corrosive surfaces or not. This will help in effective calculation of minimum and maximum end and edge distances.

*Input Compulsory.

6.7 Initial Section Check

6.7.1 Shear Yielding Capacity of Beam Web

The shear in beam to beam connection is taken by web of the secondary beam.Thus Shear Yielding Capacity is given by:

$$V_{dy} = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{m0}} \tag{6.1}$$

Where,

V_{dy} = design shear strength of the cross-section

f_y = yield stress of the material

γ_{m0} = partial safety factor for failure in tension by yielding

(Ref: IS 800:2007, Cl.10.4.3)

6.7.2 Allowable Shear Capacity of Secondary Beam

The connection design shear capacity should not exceed the shear yielding capacity of the secondary beam.It should be less than 60 percent of shear yielding capacity.

$$V_d < 0.6 \times V_{dy} \tag{6.2}$$

6.7.3 Design Bending Strength

The maximum moment the beam can resist under bending after applying partial safety factors, ensuring safety against flexural failure is given by:

$$M_d = \frac{\beta_b \cdot Z_p \cdot f_y}{\gamma_{m0}} \tag{6.3}$$

Where,

β_b = bending strength factor

Z_p = plastic section modulus

(Ref: IS 800:2007, Cl.8.2.1.2)

6.8 Load Consideration

6.8.1 Applied Axial Force

This takes input for axial force(in kN) considered in calculation.

6.8.2 Applied Shear Force

This takes input for shear force(in kN) considered in calculation.

$$V_{y_{min}} = min(0.15V_{dy}, 40) \tag{6.4}$$

$$v_u = max(v_y, v_{y_{min}}) \tag{6.5}$$

Ref: IS 800:2007, Cl.10.7

6.8.3 Applied Bending Moment

This takes input for bending moment(in kNm) considered in calculation.

$$M_{z_{min}} = 1M_d \tag{6.6}$$

$$M_u = max(M_z, M_{z_{min}}) \tag{6.7}$$

Ref: IS 800:2007, Cl.8.2.1.2

6.8.4 Effective Bending Moment

The effective bending moment is the adjusted design moment that takes into account the additional moment caused by the axial force acting at the eccentricity.

$$M_{ue} = M_u + P_x \times \left(\frac{D}{2} - \frac{T}{2}\right) \times 10^{-3} \tag{6.8}$$

6.9 Bolt Design

Bolt should be designed with proper pitch distance, gauge distance, edge distance and end distance in Range. Further, it should be checked against shear and bearing.

6.9.1 Pitch

Pitch should be provided in below range , minimum it should be taken as 2.5 times the diameter of the bolt.

$$P_{min} = 2.5d$$

$$P_{max} = min(32t, 300)$$

Ref: IS 800:2007, Cl.10.2.2, Cl.10.2.3

6.9.2 Gauge

Gauge should be provided in below range , minimum it should be taken as 2.5 times the diameter of the bolt.

$$g_{min} = 2.5d$$

$$g_{max} = min(32t, 300)$$

6.9.3 End Distances

$$e^{'}_{min} = 1.7d_0$$

$$e^{'}_{max} = min(12t\epsilon)$$

Ref: IS 800:2007, Cl.10.2.4.2, Cl.10.2.4.3

6.9.4 Shear Capacity of Bolt (V_{dsb})

As per Cl. 10.3.3 of IS:800:2007, the design strength of bolt governed by shear V_{dsb} is given by,

$$V_{dsb} = \frac{f_u \cdot n_n \cdot A_{nb}}{\sqrt{3} \cdot \gamma_{mb}} \tag{6.9}$$

Where,

f_u = Ultimate tensile strength of bolt

n_n = Number of shear planes with threads intercepting the shear plane

A_{nb} = Net shear area of the bolt at threads, may be taken as the area corresponding to root diameter at the thread

γ_{mb} = Partial safety factor for bolted connection as per Table-5 IS:800:2007

6.9.5 Bearing Capacity of Bolts

As per Cl. 10.3.4 of IS:800:2007, the design strength governed by bearing is given by,

$$V_{dpb} = \frac{V_{npb}}{\gamma_{mb}} \tag{6.10}$$

Where,

V_{npb} = Nominal bearing strength of bolt, calculated as follows,

$$V_{npb} = 2.5 \cdot k_b \cdot d \cdot t \cdot f_u$$

Where,

$k_b = min(\frac{e}{3 \cdot d_0}, \frac{p}{3 \cdot d_0} - 0.25, \frac{f_{ub}}{f_u}, 1.0)$

e = End distance

p = Pitch distance

d_0 = Diameter of hole

f_{ub} = Ultimate tensile stress of the bolt

f_u = Ultimate tensile stress of the plate

d = Nominal diameter of the bolt

t = Summation of thicknesses of the connected plates experiencing bearing stress in the same direction, or if the bolts are countersunk, the thickness of the plate minus one-half of the depth of countersinking// γ_{mb} = Partial safety factor for bolted connection as per Table-5 IS:800:2007 //

6.9.6 Bolt Capacity

Minimum of the two: bolt shear capacity and bolt bearing capacity is taken as bolt capacity.Bolt Capacity should be higher than Bolt Force calculated above.

$$V_{db} = min(V_{dsp}, V_{dpb})$$

Ref: IS 800:2007, Cl.10.3.2

6.9.7 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.

6.9.7.1 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,

$$\beta_{lj} = 1.075 - \frac{l_j}{200 \cdot d} \quad \text{but} \quad 0.75 \leq \beta_{lj} \leq 1.0 \tag{6.11}$$

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.

6.9.7.2 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:

$$\beta_{lg} = \frac{8 \cdot d}{(3 \cdot d + l_g)} = \frac{8}{(3 + \frac{l_g}{d})} \tag{6.12}$$

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).

6.9.8 Bolt Capacity(Post Reduction Factor)

$$V_{db} = V_{db} \cdot \beta_{lg} \tag{6.13}$$

6.9.9 Prying Force)(kN)

$$Q = \frac{l_v}{2l_e}\left[T_e - \frac{\beta\eta f_o b_c t^4}{27 l_e l_v^2}\right] \tag{6.14}$$

where

l_v =

distance from the bolt centreline to the toe of the fillet weld or to half the root radius for a rolled section,

l_e = distance between prying force and bolt centreline and is the minimum of either the end distance or the value given by:

$l_e = 1.1t\sqrt{\frac{\beta f_o}{f_y}}$

where

6.9.10 Tension Demand(kN)

$\eta = 1.5$,

b_e = effective width of flange per pair of bolts,

f_o = proof stress in consistent units, and

t = thickness of the end plate.

Ref. IS 800:2007, Cl.10.4.7

6.9.11 Tension Demand(kN)

A bolt subjected to a factored tensile force, T_b shall satisfy:

$$T_b \leq T_{db}$$

where

$$T_{db} = \frac{T_{nb}}{\gamma_{mb}}$$

T_{nb} = nominal tensile capacity of the bolt, calculated as:

$$0.90 f_{ub} A_n < f_{yb} A_{sb} \left(\frac{\gamma_{mb}}{\gamma_{m0}} \right)$$

where

f_{ub} = ultimate tensile stress of the bolt,

f_{yb} = yield stress of the bolt,

A_n = net tensile stress area as specified in the appropriate Indian Standard (for bolts where the tensile stress area is not defined, A_n shall be taken as the area at the bottom of the threads),

A_{sb} = shank area of the bolt.

Ref. IS 800:2007, Cl.10.3.5

6.9.12 Combined Capacity

A bolt required to resist both design shear force (V_{sd}) and design tensile force (T_b) at the same time should satisfy:

$$\left(\frac{V_{sb}}{V_{db}} \right)^2 + \left(\frac{T_b}{T_{db}} \right)^2 \leq 1.0$$

6.10 Weld Design

6.10.1 Minimum and Maximum Weld Size

According to IS 800:2007 (Cl. 11.5.1), the weld size must be selected within a prescribed range to ensure structural adequacy and proper fusion between the base metals.

- The minimum weld size is specified to ensure sufficient heat input and proper fusion during welding. IS 800 prescribes it as the greater of:
  - 3 mm (standard minimum), or
  - the minimum thickness of the connected plates.

See Table 21 and choose value of minimum thickness of weld (S_{min}).

- The maximum weld size is limited to avoid excessive heat input and distortion. It should not exceed the thinner of the plates being joined.

Ref: IS 800:2007, Cl. 11.5.1

6.10.2 Weld Strength

Welds must be capable of carrying the design loads safely. The resultant force in a weld (R_w) is calculated using the vector sum of in-plane and out-of-plane components.
where,

- T_{wh}: Horizontal shear due to torsion or moment
- A_{wh}: Applied horizontal load
- T_{wv}: Vertical shear due to torsion or moment
- V_{wv}: Applied vertical load

The design strength of the weld is given by:

$$f_w = \frac{f_u}{\sqrt{3}\gamma_{mw}}$$

- f_w: Throat thickness of weld (0.7 × leg size for fillet weld)
- f_u: Ultimate tensile strength of weld metal (usually same as base metal)

Osdag - Open steel design and graphics

Ref. IS 800:2007, Cl.9.3.1

Chapter 7

Task 5: DDLC for Column-Column End Plate Connections

7.1 Problem Statement

Fetch Reports from osdag module analyse the reports, check its formulas aligning with IS code or not, and make a comprehensive DDCL for Column-Column end plate connections. Also if any errors in formula or any mismatch in it ,record them into a separate overleaf file.

7.2 Tasks Done

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Tension Members Osdag - Open steel design and graphics

logoOsdag.png

Design and detailing checklist (DDCL)

Column-Column End Plate Connection

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7.3 Theory

7.4 Introduction

Column-column end plate connections are a crucial part of steel frame construction, providing a way to join two columns together, often to extend a column's length. This type of connection typically involves welding a flat steel plate, the end plate, to the end of each column.
These plates are then bolted together, creating a rigid or semi-rigid joint. The primary function of this connection is to transfer both axial compressive forces and bending moments from the upper column to the lower one. The design of these connections is critical because any failure could compromise the entire structural integrity of the frame.
One key design consideration is ensuring the end plates are thick enough to resist prying action and bending. The bolts must be correctly sized to handle both tensile and shear forces. Another important aspect is checking for weld strength and ensuring the welds can transfer all the forces to the plates.
The performance of these connections is vital for the stability of multi-story buildings and other large structures. Overall, a properly designed column-column end plate connection ensures a continuous and strong load path through the structure.

7.5 Design and Detailing Checklist for Osdag Software

7.6 Input Parameters

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

- Connectivity:* The user will have a choice to choose between Coplanar Tension-Compression Flange, Coplanar Tension Flange, and Coplanar Compression Flange..

- End Plate Type:* The user has the option to select the End Plate Type based on its geometry and moment transfer across splices.
- Column Section:* The user may choose any section of their choice for the column.
- Material Property:* The user will have the option to choose from the available grades of steel.
- Factored Bending Moment (in kN):* The user will have to input the factored bending moment.
- Factored Shear Force (in kN):* The user will have to input the factored shear force.
- Factored Axial Force (in kN):* The user will have to input the factored axial force.
- Diameter of Bolt:* The user has the choice of specifying the diameter of the bolt or choosing the most optimized design provided by the software.
- Type of the bolt:* The user will have a choice to specify the bolt type as friction type (HSFG) or bearing type.
- Property (Grade) of Bolt:* The user has the choice of specifying the grade of the bolt or choosing the most optimized design provided by the software.
- End Plate Thickness:* The user has the choice of specifying the thickness of the end plate or choosing the most optimized design provided by the software.

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 bolted tension member include:

- Connector: The user can choose the grade of structural steel used for the end plate between E 165, E 250 and E 300.
- Type of Bolt: The choice in this section is between a pre-tensioned bolt and a non pre-tensioned bolt.
- Type of Hole: The user can choose between a standard hole or an oversized hole.
- Slip Factor: For a high-strength friction grip (HSFG) bolt, the user can define the slip factor.

- Type of Weld Fabrication: The user can choose welding type based on its environment.

- Edge Preparation Method: This relates to the fabrication aspect where the user can specify whether the hole has sheared or hand flame cut edges or Rolled, machine-flame cut, sawn and planed edges. This helps in determining the formula for the diameter of hole.

- Gap between Beam and Support: The user can add gap between beam and support according to design specification.

- Exposure of Members to Corrosive Surfaces: The user can specify whether the members will be exposed corrosive surfaces or not. This will help in effective calculation of minimum and maximum end and edge distances.

*Input Compulsory.

7.7 Initial Section Check

7.7.1 Shear Capacity of Member

The shear capacity of a column is the maximum shear force that the column's cross-section can resist before experiencing shear failure.Thus Shear Capacity is given by:

$$V_{dy} = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{m0}} \tag{7.1}$$

Where,

V_{dy} = design shear strength of the cross-section

f_y = yield stress of the material

γ_{m0} = partial safety factor for failure in tension by yielding

(Ref: IS 800:2007, Cl.10.4.3)

7.7.2 Axial Capacity Member

The axial capacity of a member is the maximum axial load it can carry without failing — either by crushing, yielding, or buckling.

$$T_{dg} = A_g.f_y/\gamma_{m0} \tag{7.2}$$

(Ref: IS 800:2007, Cl.6.2)

7.7.3 Design Bending Strength

The maximum moment the column can resist under bending after applying partial safety factors, ensuring safety against flexural failure is given by:

$$M_d = \frac{\beta_b \cdot Z_p \cdot f_y}{\gamma_{m0}} \tag{7.3}$$

Where,

β_b = bending strength factor

Z_p = plastic section modulus

(Ref: IS 800:2007, Cl.8.2.1.2)

7.7.4 Moment Deformation Criteria

The moment–deformation criteria describes how a structural member's bending moment is related to its deformation.

$$M_{dc} = \frac{1.5 \cdot Z_e \cdot f_y}{\gamma_{m0} \times 10^6} \tag{7.4}$$

Where,

β_b = bending strength factor

Z_p = Elastic section modulus of the cross-section

(Ref: IS 800:2007, Cl.8.2.1.2)

7.8 Load Consideration

7.8.1 Interaction Ratio

This takes input for axial force(in kN) considered in calculation.

$$\text{I.R. axial} = \frac{P_x}{T_{dg}}$$
$$\text{I.R. moment} = \frac{M_z}{M_{dz}}$$

$$\text{I.R. sum} = \text{I.R. axial} + \text{I.R. moment}$$

7.8.2 Applied Shear Force

To check if the column can withstand the combined effects of axial force and bending moment.

$$V_{y_{min}} = min(0.15V_{dy}, 40) \quad (7.5)$$

$$v_u = max(v_y, v_{y_{min}}) \quad (7.6)$$

Ref: IS 800:2007, Cl.10.7

7.8.3 Applied Axial Force

The applied axial force of a column is the total compressive or tensile force acting along its longitudinal axis.

$$P_u = max(P_x, P_{x_{min}}) \quad (7.7)$$

$$v_u = max(v_y, v_{y_{min}}) \quad (7.8)$$

Ref: IS 800:2007, Cl.10.7 "'latex

7.8.4 Minimum Required Load

The minimum required axial force (P_{xmin}) and bending moment (M_{zmin}) for the column are determined based on conditional checks of the interaction ratios.

if I.R. axial ¡ 0.3 and I.R. moment ¡ 1

$$P_{x_{min}} = 0.3T_{dg}$$
$$M_{z_{min}} = 1M_{dz}$$

else if sum I.R. $\leq$ 1.0 and I.R. moment ¡ 1

if (1 $-$ I.R. moment) ¡ (1 $-$ sum I.R.)

$$M_{z_{min}} = 1 \times M_{dz}$$

else

$$M_{z_{min}} = M_z + ((1 - \text{sum I.R.}) \times M_{dz})$$

$$P_{x_{min}} = P_x$$

else if sum I.R. $\leq$ 1.0 and I.R. axial ¡ 0.3

if (0.3 $-$ I.R. axial) ¡ (1 $-$ sum I.R.)

$$P_{x_{min}} = 0.3T_{dg}$$

else

$$P_{x_{min}} = P_x + ((1 - \text{sum I.R.}) \times T_{dg})$$

$$M_{z_{min}} = M_z$$

else

$$P_{x_{min}} = P_x$$

$$M_{z_{min}} = M_z$$

Note: AL is the user input for load.

Ref: IS 800:2007, Cl.10.7

7.8.5 Applied Moment (kNm)

The applied moment for design, M_u, is taken as the maximum of the actual applied moment and the minimum required moment.

$$M_u = \max(M_z, M_{z_{min}}) \tag{7.10}$$

Ref: IS 800:2007, Cl.8.2.1.2

7.9 Bolt Design

Bolt should be designed with proper pitch distance, gauge distance, edge distance and end distance in Range. Further, it should be checked against shear and bearing.

7.9.1 Number of Bolts

The number of bolts along the web and the flange overhang is determined by the following equations:

$$n_{bw} = 2 \times \left(\frac{D - (2 \times T_f) - (2 \times e)}{p} + 1 \right) \tag{7.11}$$

$$n_{bf} = 2 \times \left(\frac{b/2 - (T_w/2) - (2 \times e)}{p} + 1 \right) \tag{7.12}$$

n_{bw} = the number of bolts along one side of the web.
n_{bf} = the number of bolts along one side of the flange overhang.

7.9.2 Pitch

Pitch should be provided in below range , minimum it should be taken as 2.5 times the diameter of the bolt.

$$P_{min} = 2.5d$$

$$P_{max} = min(32t, 300)$$

Ref: IS 800:2007, Cl.10.2.2, Cl.10.2.3

7.9.3 Gauge

Gauge should be provided in below range , minimum it should be taken as 2.5 times the diameter of the bolt.

$$g_{min} = 2.5d$$

$$g_{max} = min(32t, 300)$$

7.9.4 End Distances

$$e'_{min} = 1.7d_0$$

$$e'_{max} = min(12t\epsilon)$$

Ref: IS 800:2007, Cl.10.2.4.2, Cl.10.2.4.3

7.9.5 Shear Capacity of Bolt (V_{dsb})

As per Cl. 10.3.3 of IS:800:2007, the design strength of bolt governed by shear V_{dsb} is given by,

$$V_{dsb} = \frac{f_u \cdot n_n \cdot A_{nb}}{\sqrt{3} \cdot \gamma_{mb}} \tag{7.13}$$

Where,

f_u = Ultimate tensile strength of bolt

n_n = Number of shear planes with threads intercepting the shear plane

A_{nb} = Net shear area of the bolt at threads, may be taken as the area corresponding to root diameter at the thread

γ_{mb} = Partial safety factor for bolted connection as per Table-5 IS:800:2007

7.9.6 Bearing Capacity of Bolts

As per Cl. 10.3.4 of IS:800:2007, the design strength governed by bearing is given by,

$$V_{dpb} = \frac{V_{npb}}{\gamma_{mb}} \tag{7.14}$$

Where,

V_{npb} = Nominal bearing strength of bolt, calculated as follows,

$$V_{npb} = 2.5 \cdot k_b \cdot d \cdot t \cdot f_u$$

Where,

$k_b = min(\frac{e}{3 \cdot d_0}, \frac{p}{3 \cdot d_0} - 0.25, \frac{f_{ub}}{f_u}, 1.0)$

e = End distance

p = Pitch distance

d_0 = Diameter of hole

f_{ub} = Ultimate tensile stress of the bolt

f_u = Ultimate tensile stress of the plate

d = Nominal diameter of the bolt

t = Summation of thicknesses of the connected plates experiencing bearing stress in the same direction, or if the bolts are countersunk, the thickness of the plate minus one-half of the depth of countersinking// γ_{mb} = Partial safety factor for bolted connection as per Table-5 IS:800:2007 //

7.9.7 Bolt Capacity

Minimum of the two: bolt shear capacity and bolt bearing capacity is taken as bolt capacity.Bolt Capacity should be higher than Bolt Force calculated above.

$$V_{db} = min(V_{dsp}, V_{dpb})$$

Ref: IS 800:2007, Cl.10.3.2

7.9.8 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.

7.9.8.1 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,

$$\beta_{lj} = 1.075 - \frac{l_j}{200 \cdot d} \quad \text{but} \quad 0.75 \leq \beta_{lj} \leq 1.0 \tag{7.15}$$

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.

7.9.8.2 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:

$$\beta_{lg} = \frac{8 \cdot d}{(3 \cdot d + l_g)} = \frac{8}{(3 + \frac{l_g}{d})} \tag{7.16}$$

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).

7.9.9 Bolt Capacity(Post Reduction Factor)

$$V_{db} = V_{db} \cdot \beta_{lg} \tag{7.17}$$

7.9.10 Prying Force)(kN)

$$Q = \frac{l_v}{2l_e}\left[T_e - \frac{\beta\eta f_o b_c t^4}{27 l_e l_v^2}\right] \tag{7.18}$$

where

l_v =

distance from the bolt centreline to the toe of the fillet weld or to half the root radius for a rolled section,

l_e = distance between prying force and bolt centreline and is the minimum of either the end distance or the value given by:

$l_e = 1.1t\sqrt{\frac{\beta f_o}{f_y}}$

where

7.9.11 Tension Demand(kN)

$\eta = 1.5$,

b_e = effective width of flange per pair of bolts,

f_o = proof stress in consistent units, and

t = thickness of the end plate.

Ref. IS 800:2007, Cl.10.4.7

7.9.12 Tension Demand(kN)

A bolt subjected to a factored tensile force, T_b shall satisfy:

$$T_b \leq T_{db}$$

where

$$T_{db} = \frac{T_{nb}}{\gamma_{mb}}$$

T_{nb} = nominal tensile capacity of the bolt, calculated as:

$$0.90 f_{ub} A_n < f_{yb} A_{sb} \left(\frac{\gamma_{mb}}{\gamma_{m0}} \right)$$

where

f_{ub} = ultimate tensile stress of the bolt,

f_{yb} = yield stress of the bolt,

A_n = net tensile stress area as specified in the appropriate Indian Standard (for bolts where the tensile stress area is not defined, A_n shall be taken as the area at the bottom of the threads),

A_{sb} = shank area of the bolt.

Ref. IS 800:2007, Cl.10.3.5

7.9.13 Capacity of Bolt (kN)

The capacity of the bolt is checked against the applied shear force per bolt. The design bearing capacity is determined as the minimum of the shear and bearing strengths.

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

Ref: IS 800:2007, Cl.10.3.2

7.10 End Plate Checks

End plate checks are crucial in structural steel design to ensure the safe and efficient connection of beams to columns, or other structural elements. These checks verify that the end plate, which is a common type of bolted connection, can adequately resist the applied forces and moments without failure. The design involves ensuring sufficient dimensions (length, height, and thickness) and adequate moment capacity to transfer the loads effectively.

7.10.1 Min. Plate Length (mm)

$$\text{Min. Plate Length} = 450.0$$

7.10.2 Min. Plate Height (mm)

$$\text{Min. Plate Height} = 250.0$$

7.10.3 Min. Plate Thickness (mm)

$$t_p = \max\left(\sqrt[4]{\frac{4M_{cr}}{b_{eff} f_y/\gamma_{m0}}}, \sqrt[4]{T_1 - \frac{2Q_l t_e}{l_v} \times \frac{2T_l t_e^2}{\beta n f_c b_e}}\right) \tag{7.19}$$

Where:

- t_p: Minimum Plate Thickness
- M_{cr}: Critical Moment
- b_{eff}: Effective Width
- f_y: Yield Strength of the Plate
- γ_{m0}: Partial Safety Factor for Material
- T_1: Tension in the first bolt
- Q_l: Applied Load

- t_e: Equivalent Thickness
- l_v: Length of Bolt Lever Arm
- β: A coefficient
- n: Number of Bolts
- f_c: Compressive Force
- b_e: Effective Width

7.10.4 Moment Capacity (kNm)

$$M_{ep} = \max(1 \times \text{Tension in first bolt X end distance, Tension in second bolt X end distance}) \tag{7.20}$$

$$M_{dp} = \frac{b_{eff} t_p^2 f_y}{4\gamma_{m0}} \tag{7.21}$$

Where:

- M_{ep}: End Plate Moment
- M_{dp}: Design Plate Moment
- b_{eff}: Effective Width
- t_p: Plate Thickness
- f_y: Yield Strength of the Plate
- γ_{m0}: Partial Safety Factor for Material

Chapter 8

Conclusions

8.1 Tasks Accomplished

My internship at IIT Bombay with the FOSSEE OSDAG project was a transformative experience, allowing me to contribute to a significant open-source initiative in structural engineering. I gained hands-on experience in both animation and module development, which provided a comprehensive understanding of the software development lifecycle from a user-centric perspective.

8.1.0.1 Animation Team

Working with the animation team, I leveraged Blender to create a variety of instructional animations. My primary focus was on visualizing complex structural failures and component behaviors, such as the cup and cone failure of steel members, as well as the failure modes of truss members and steel channels. These animations are designed to simplify intricate engineering concepts for students and professionals. Furthermore, I contributed to the user interface (UI) design by creating icons and animations, enhancing the overall user experience and making the OSDAG software more intuitive.

8.1.0.2 Module Development Team

In the module development team, my work focused on the critical task of enhancing the Beam-Beam and Column-Column end plate connection modules. I was responsible for developing detailed design checklists and systematically identifying errors and bugs within the calculation algorithms. This involved a rigorous process of cross-referencing industry standards and theoretical principles to ensure the accuracy and reliability of the software's output. This experience honed my analytical skills and provided a deep understanding of the intricacies involved in designing steel connections. The ability to find and rectify errors in these modules directly contributes to the safety and reliability of the structures designed using the OSDAG software.