ANALYSIS OF STRUCTURES

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Ahmed Yassin 3076314

Devang Kachhadiya 3127394

Mahmoud Sherbiny 3090530

Supervisor:

Dr.-Ing. Richard Ostwald

Content

Object-oriented programming in python.

- For the first task Python is used for object-oriented programming.
- Object Oriented programming is a programming method that depends on the concept of classes and objects.
- The aim of the method is to create a program into simple, reusable pieces of code.
- In object-oriented programming, computer programs are designed by using objects that interact with each other.

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Thin-walled approximation

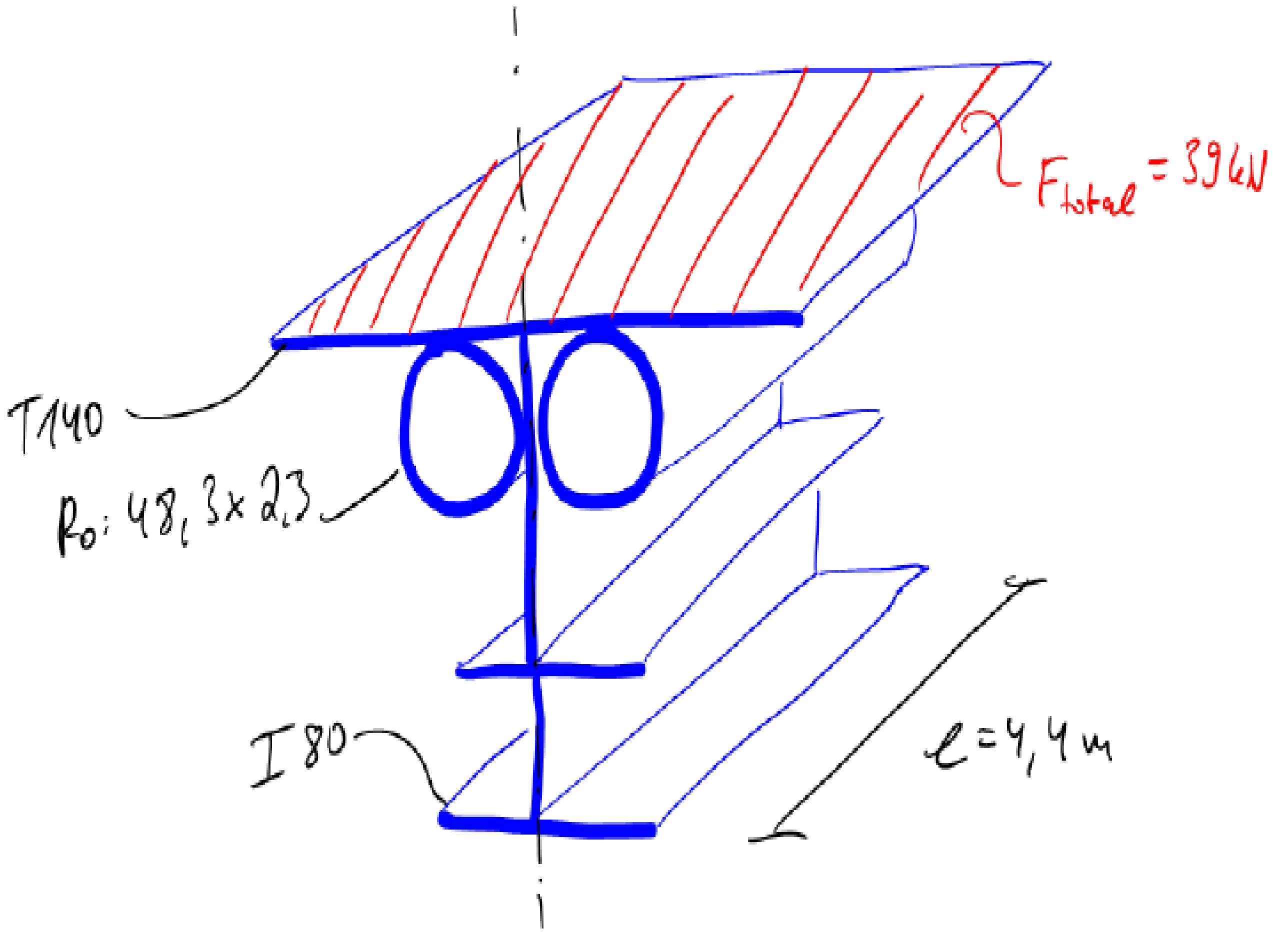
- Thin-walled approximation (TWA) is a simplification concept in which the parts of a section are replaced by a set of lines which shows the profile section geometry at the centre-line of the profile.
- This is similar to a 3-D shell structure, where in we use shell elements, i.e., faces with a given thickness.
- Here we use lines (elements) which are connected by nodes or dots.
- When the thickness is given, we get an approximation for the given profile.

Problem overview

- For task 1, it is required to calculate the section properties for a given cross-section by developing OOP code.

- For task 2, it is required to calculate maximum deflection in cantilever beam using the same OOP principle.

- For task 3, We use Abaqus script to model the beam to calculate the maximum deflection of the beam.



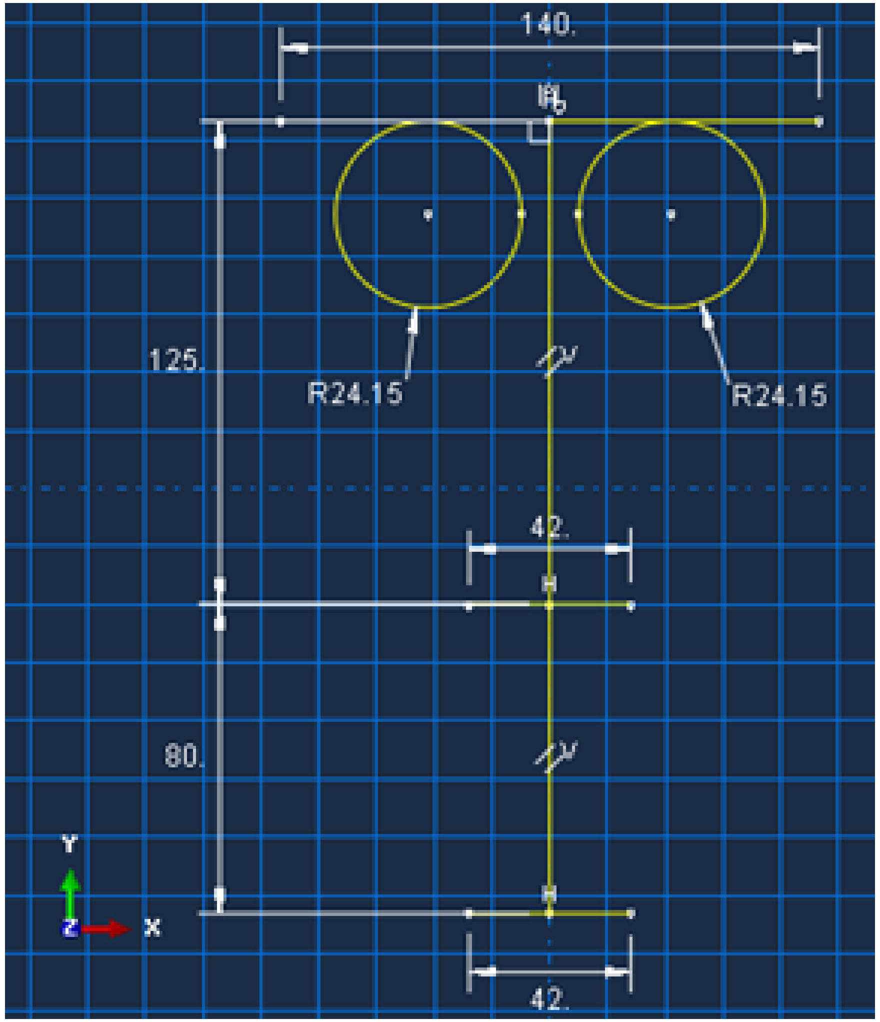


Figure: sketch of the cross section

Calculation of Area

- The complete area of a thin-walled approximation model is approximately equal to the sum of the areas of the line elements.
- The mathematical formulation is as follows,

$$A = \int_A e_\mu \cdot dA \approx \sum_{i=1}^{n} e_{\mu.i} \cdot L_i \cdot t_i$$

- Where i is the number of the element of the profile section, L is the length of the element, t denotes thickness of element and e_μ the relative elasticity of element (taken as 1 everywhere).
- Here, we are considering just one material for the entire profile.

Calculation of First Moment of Area

- The first moments of an area are given in the form of area integrals. The (x, y) values are related to a used coordinate system.

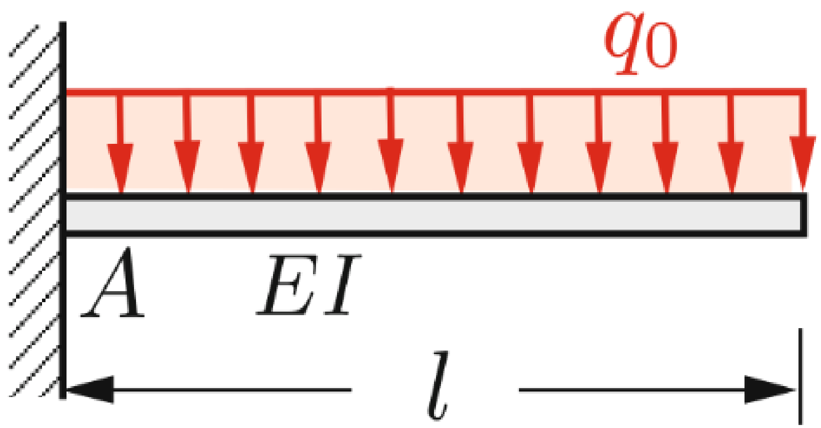
$$S_x = \int_A e_\mu \cdot y \cdot dA \approx \sum_{i=1}^{n} e_{\mu.i} \cdot \bar{y}_i \cdot A_i$$

$$S_y = \int_A e_\mu \cdot x \cdot dA \approx \sum_{i=1}^{n} e_{\mu.i} \cdot \bar{x}_i \cdot A_i$$

- where x and y are the x coordinate and y coordinate of the centre of element.
- The first moment of inertia of the profile is given by following sums,

$$S_x = \sum_{i=1}^{n} \bar{y}_i \cdot A_i \qquad S_y = \sum_{i=1}^{n} \bar{x}_i \cdot A_i$$

- **Deflection according to the beam theory.**



Moment

$$EI\frac{d^2y}{dx^2} = \frac{qx^2}{2}$$

By integrating both sides we get the sheer equation:-

$$EI\frac{d^3y}{dx^3} = \frac{qx^3}{6} + c$$

Shear at x= L = 0

$$c = -\frac{qL^3}{6}$$

$$EI\frac{d^3y}{dx^3} = \frac{qx^3}{6} - \frac{qL^3}{6}$$

By integrating both sides we get the deflection:-

$$EI\frac{d^4y}{dx^4} = \frac{qx^4}{24} - \frac{qL^3}{6}x - c$$

- Deflection at (x = 0) is 0

c = 0

$$\text{Deflection} = \frac{qx^4}{24} - \frac{qL^3}{6}x$$

- maximum deflection at the free end at x = L:-

$$\text{Deflection} = \frac{qL^4}{24} - \frac{qL^3}{6}$$

$$= -\frac{qL^4}{8EI_x}$$

Classes in the Python code

The code consists of 5 different classes, which are shown in following UML diagram:-

Base class

- Grandparent class. All the methods of the Base class are inherited by other classes. The aim of this class is to keep a track of the various instances which are involved in the program and to keep a log of these activities (appendLog).

Node class

- The Node Class is used to store node numbers and their coordinates. This container class uses two attributes to store the corresponding number and coordinates of nodes.

Element class

- The Element Class describes the connection and the type of connection between the nodal points. An element is defined as a line between two nodes with thickness.

Classes in the Python code

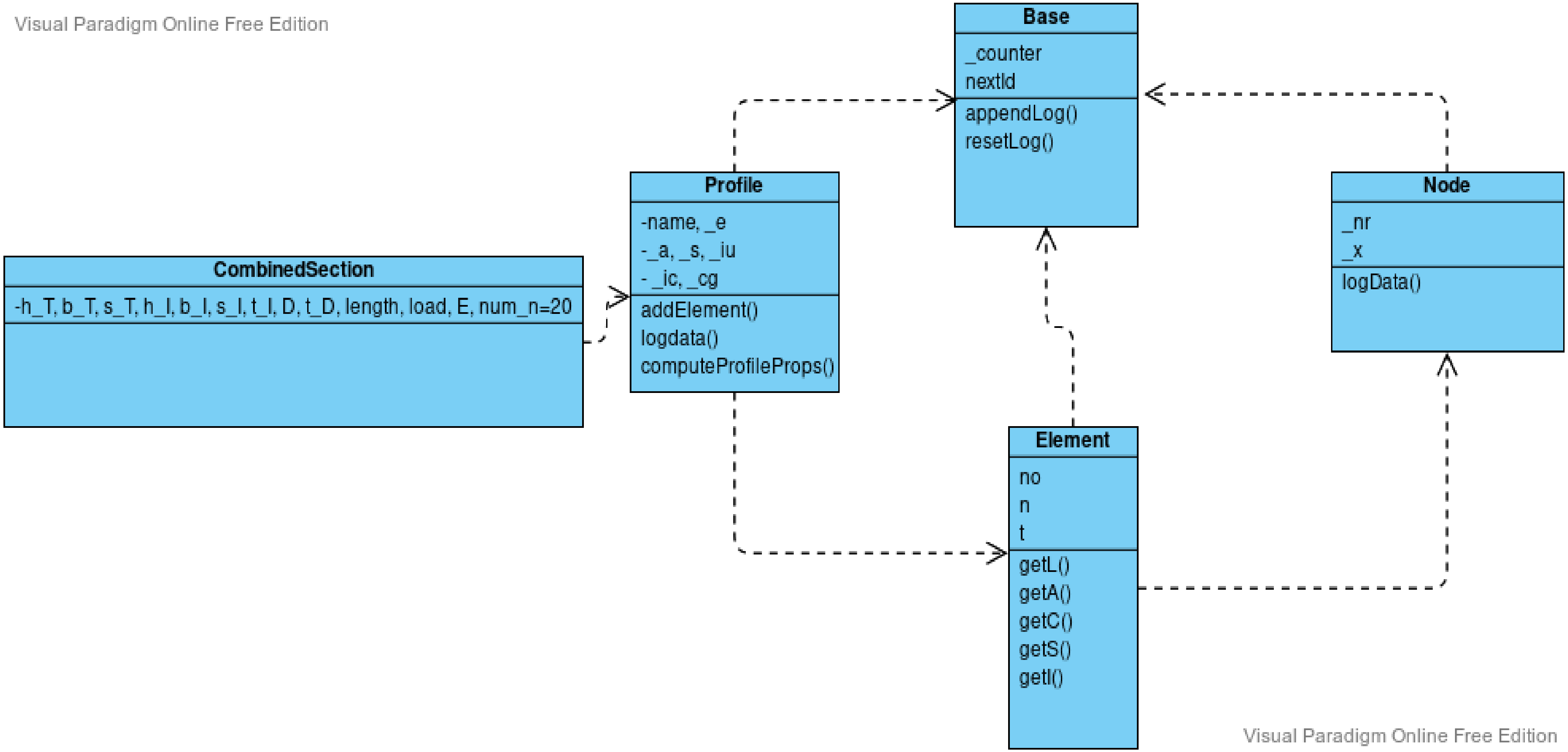
Profile class

- Profile class implement the thin-walled approximated model.

CombinedSection class

- This is the final class which is used to solve our given problem. It consists all the necessary parameters in order to define the geometry of the profile, calculate the section properties, and the maximum deflection in the beam.

UML diagram



Visual Paradigm Online Free Edition
Base
_counter
nextId
appendLog()
resetLog()
Profile
-name, _e
-_a, _s, _iu
-_ic, _cg
addElement()
logdata()
computeProfileProps()
Node
_nr
_x
logData()
CombinedSection
-h_T, b_T, s_T, h_l, b_l, s_l, t_l, D, t_D, length, load, E, num_n=20
Element
no
n
t
getL()
getA()
getC()
getS()
getI()
Visual Paradigm Online Free Edition

Input parameters for Python and Abaqus

Section	Height	Width	Flange	Web
T-section (mm)	140	140	15	15
I-section (mm)	80	42	3,9	5,9

Diameter:- 48,3 mm
Thickness:- 2,3 mm

Force q $= \frac{39000}{4400} = 8{,}863\ \mathrm{N/mm}$

Modulus of elasticity E:- 210 GPa
Poisson’s ration γ :- 0,3

Python result and analysis - Output

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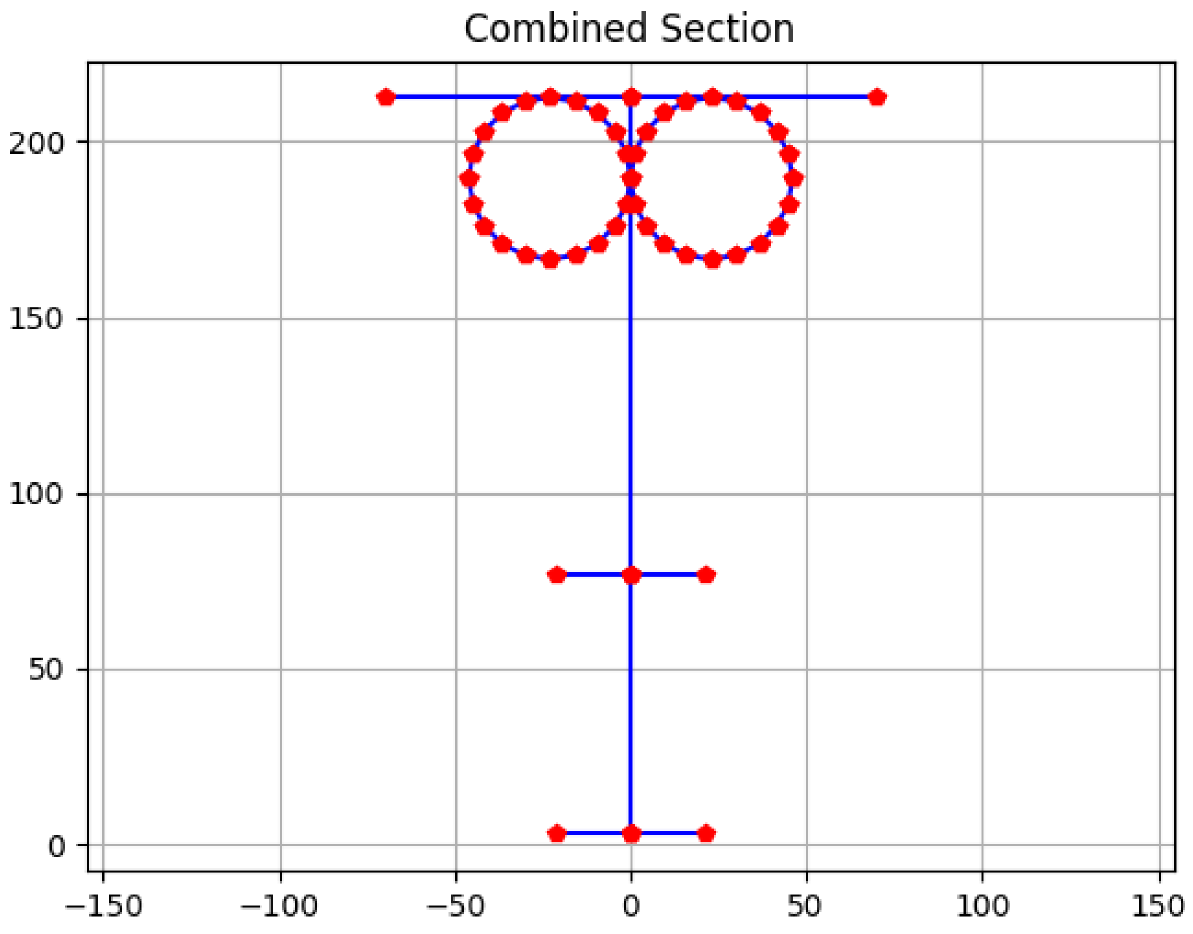
```
22.39.19| ---Profile Name: Combined Section
22.39.19| Area..................:            A:    5578.371
22.39.19| Static moment.........:      Sx,Sy.: 897235.016,     -0.000
22.39.19| 2nd moment of Area....: Ixx,Iyy,Ixy: 166533350.469,4025317.742,     -0.000
22.39.19| Center of Gravity.....:        Cx,Cy:      -0.000,    160.842
22.39.19| Shifed SMOA in CG CS : Ixx,Iyy,Ixy: 22220481.568,4025317.742,     -0.000
22.39.19| SMOA principal value.:    Ieta,Ixi: 22220481.568,22220481.568
22.39.19| rotation angle........:      pistar:      90.000°
22.39.19|  Maximum Deflection in mm is -88.99382798073852
```

Result and analysis - Output

- Using the view() method, we can plot section which is shown here:-



Analytical and Python result comparison

Terms	Analytical	Python
Area (mm^2)	5578,371	5401,341
Moment of inertia I_{xx} (mm^4)	21059974,61	22220481,56
Max Deflection (mm)	-93,89	-88,99

Table:- Analytical and Python result comparison

$$Relative\ Error(\%) = \left(\frac{Analytical\ Value - TWA\ Value}{Analytical\ Value}\right) \cdot 100$$

$$\text{Relative error} = \left(\frac{93{,}89-88{,}99}{88{,}99}\right) \cdot 100 = 5{,}22\%$$

Drawing the sketch

- sketching the Cross-Section so that the pipe-section interacts with the flanges of the T-Profile in one point (for better meshing and behaviour of the whole section)

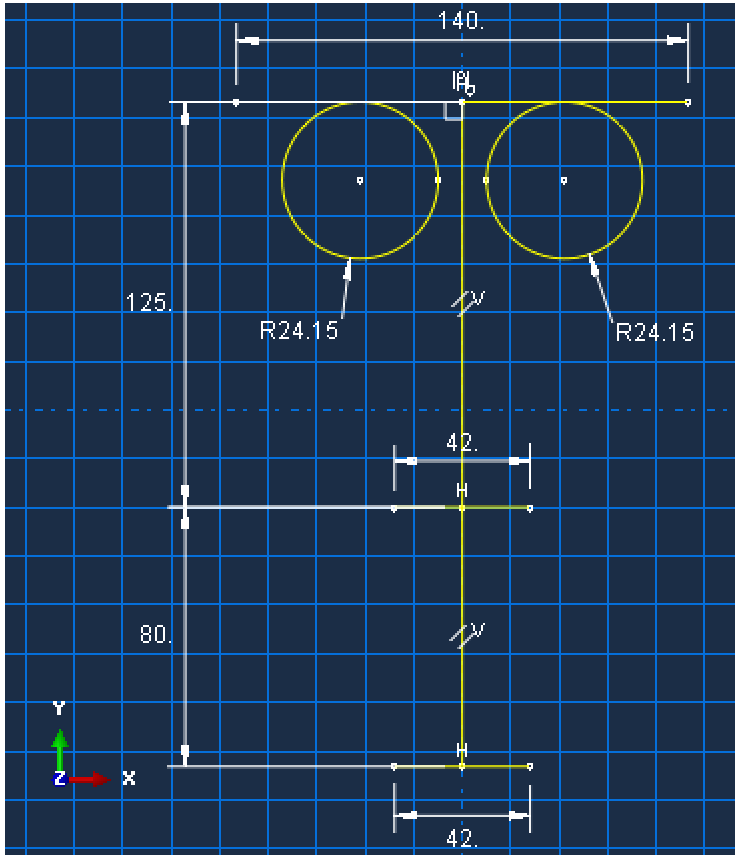


Figure: Sketch of the cross section

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Modeling

- Modeling the corresponding sections and assigning properties

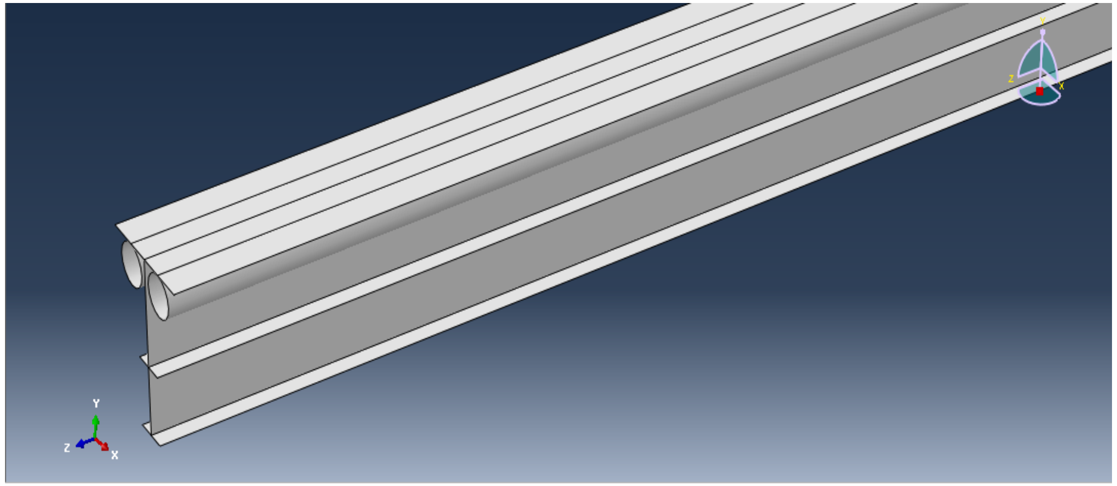

Figure: Sketch and model sections

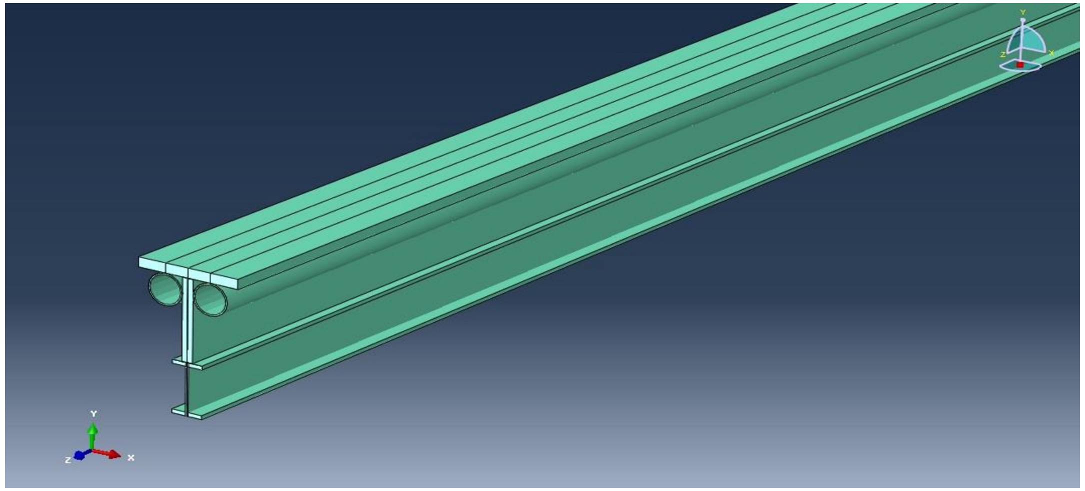

Figure: Assign properties to each section

Boundary condition and Load

- Applying BC as fixed supports
- Applying load q $= \dfrac{39000}{140 \text{ x } 4400} = 0{,}0633 \text{ N/mm2}$

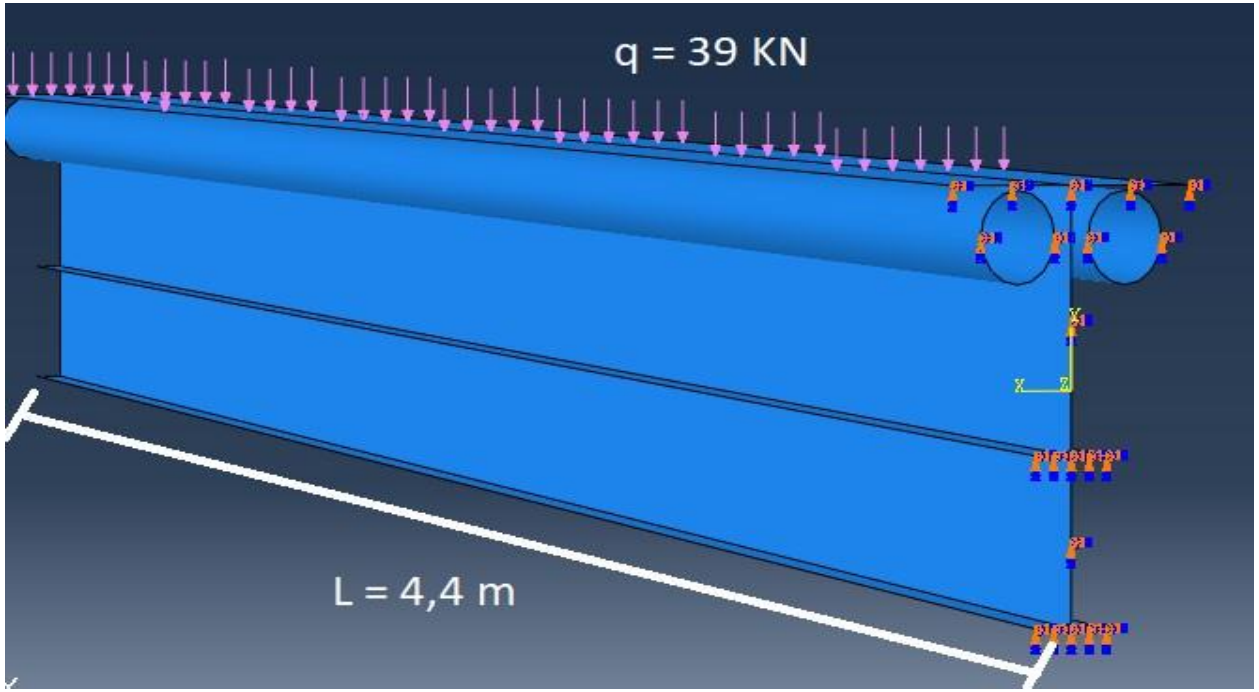

Figure: BC and Load

Meshing

- Meshing our section with the continuum mesh (only transverse displacement is applied)
- Number of nodes: 609
- Number of elements: 60

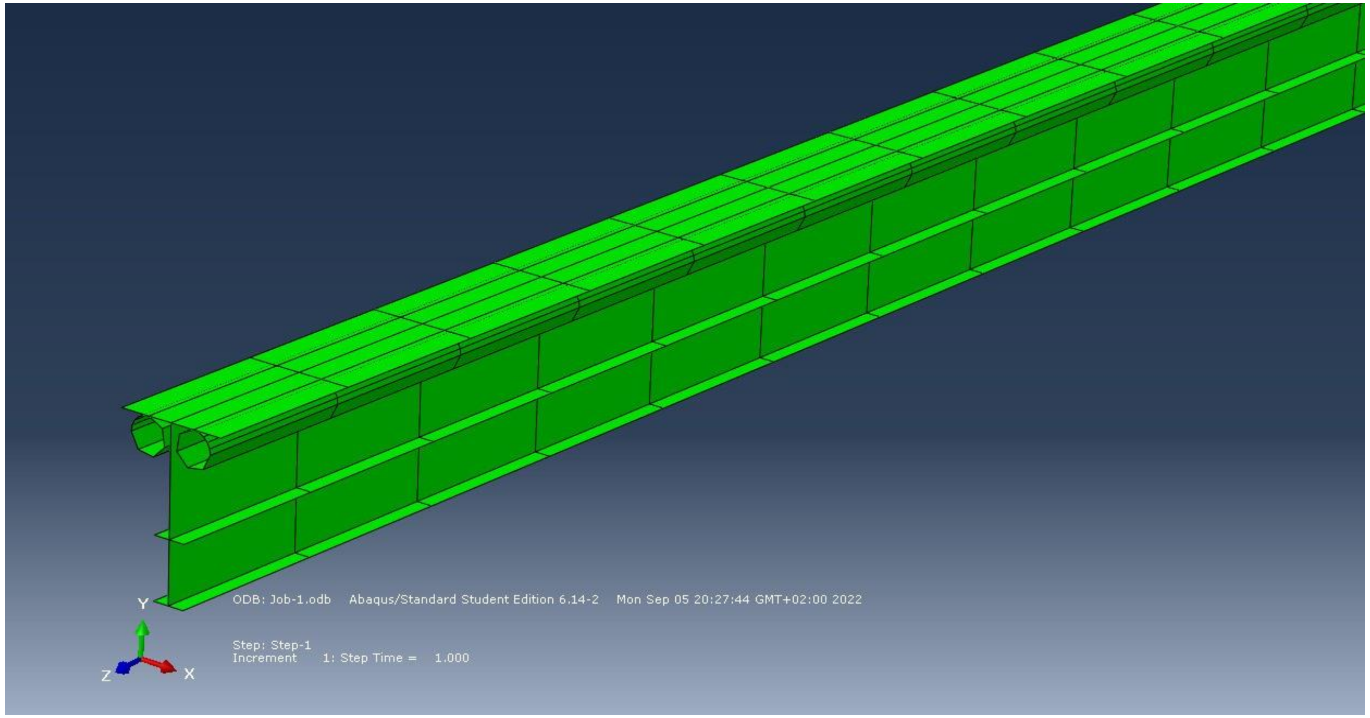

Figure: Applied Mesh

Deflection

- Value of deflection at the free end = 93,42 mm

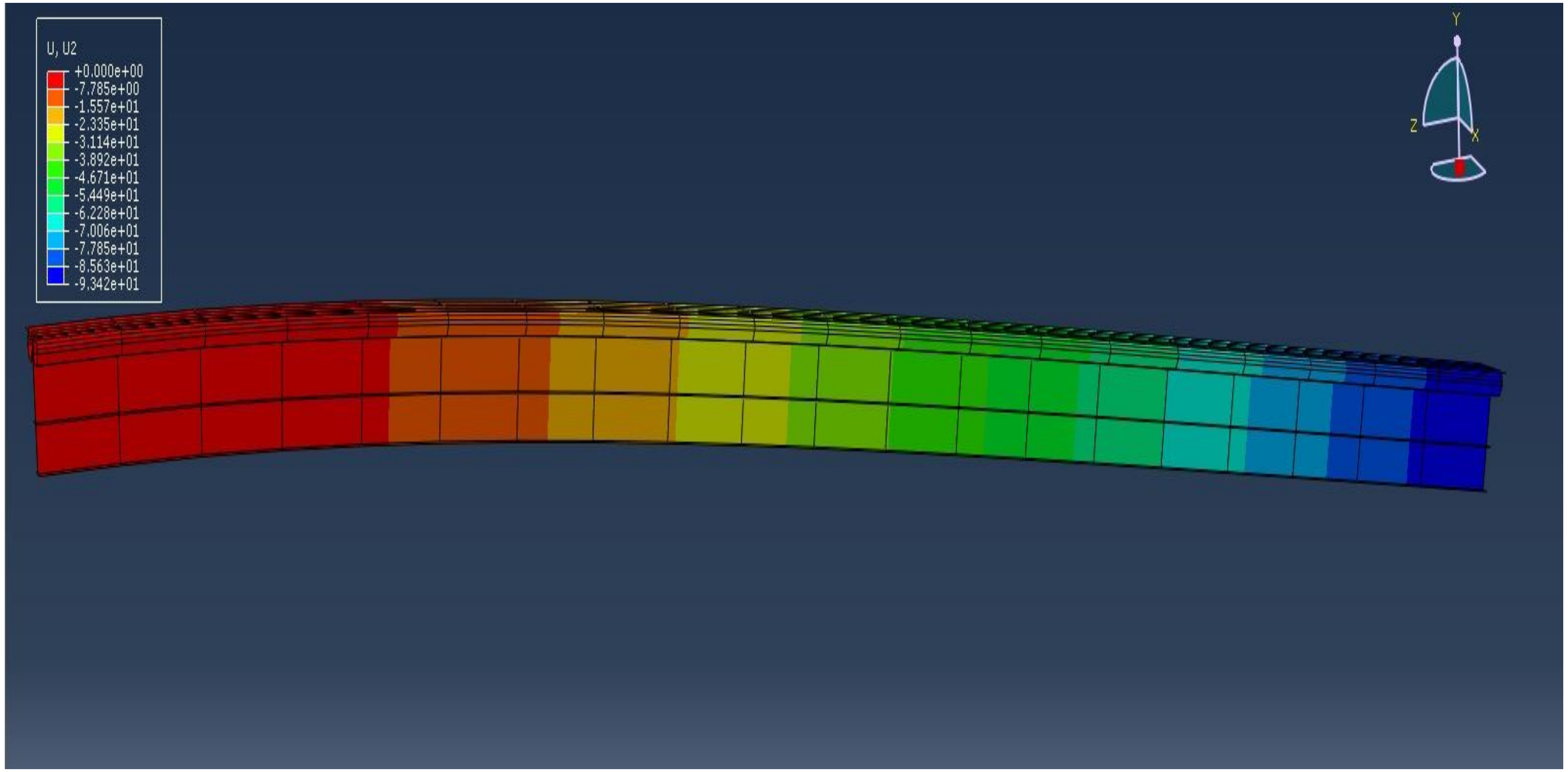

Figure: Deflection

Conclusion

Terms	Analytical	Python	Abaqus
Max Deflection (mm)	-93,89	-88,99	-93,42
Relative error of deflection	-	5,22 %	0,005 %

- By comparing data from given table, we can see that Abaqus has more accurate results

Thank you