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Development of a GUI Based Program for Design of various Steel Connections

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Abstract: *Steel frame buildings consist of a number of different types of structural elements. Every element must be attached properly to its neighbouring part of structure. This will involve use of various types of connections. Connections account for more than half the cost of structural steel work. Connection failure is not a ductile failure and hence it should be avoided before member failure. Large uncertainty is there in the design of connections. Connections are usually the most vulnerable part of the structure, failure of which may lead to the failure of whole structure. Thus, design of connection is an important and integral part of design of the steel structure. This MATLAB GUI program developed will be a very useful and user-friendly tool for the design of connections.*

Keywords: *GUI, MATLAB, shear connection, Web Angle, fillet weld, eccentric connection, seat connection*

I. INTRODUCTION

Unlike concrete, connections in steel structures need special design. Mainly three major connections are there: - bolted, welded, riveted but rivets are now seldom used. Steel connection calculations are the most complex and time-consuming phases of the steel structural design. This long and complex process requires precision and efficiency and can become a source of errors with unwanted consequences. This MATLAB GUI program can help reducing time in these complex calculations and also human calculation errors. This can increase precision and accuracy in design process. GUI is a very user-friendly tool and it can be easily used by people. In industry it can of great benefit as it will reduce the long-time consuming process. Connections should satisfy the requirements of structural behaviour. They should be strong enough to transmit the design loads and at the same time have the intended degree of flexibility and rigidity.

There are various types of steel connections based on following: -

- 1) On the basis of connecting medium: -
 - a) Bolted
 - b) Welded
 - c) Riveted
- 2) According to nature and location of load: -
 - a) Direct shear connections
 - b) Pure moment connections
 - c) Eccentric connections
 - d) Moment shear connections
- 3) According to the type of structural elements: -
 - a) Single plate angle connections
 - b) Double web angle connections
 - c) Top and seated angle connections
 - d) Seated beam connections
- 4) According to type of members joining:
 - a) Beam to beam connection
 - b) Beam to column connection
 - c) Column base plate connection
 - d) Column to column connection

Various types of steel connections are analysed and GUI program is developed for design of connections. Classification of connections is shown in the figure below: -

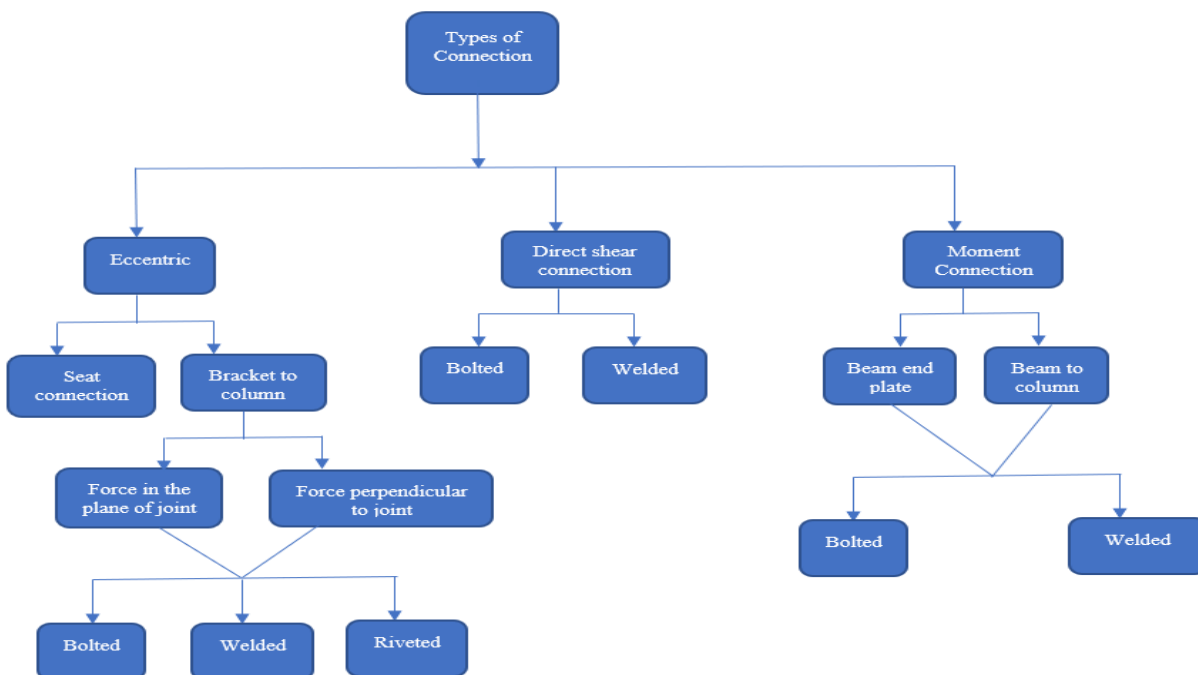


Fig. 1 Division of connections

II. DESIGN METHODOLOGY

1) Eccentric Connections

1) Load lying in the Plane of Joint

a) Riveted Connection

- First number of rivets is found out using the direct axial shear

$$\text{No of rivets} = 1.25 \cdot P/R;$$

R=rivet value.

P= shear force

- Then from bending stress the number of rivets is found out

$$\text{Number of rivets in a line} = \frac{\sqrt{6M}}{mpR}$$

Where, M=moment

m= no. of rivets line

p=pitch

R=rivet value

Thus, total rivets=m*n

- Check if force in extreme rivet is under limit of rivet value.

b) Welded Connection

- Force from direct shear and bending is found out in terms of throat thickness of weld
- Resultant force is found out
- Equating the resultant force with limit of weld(108Mpa) throat thickness is found
- Size of weld=t/0.707

2) *Load Perpendicular to Joint*

a) *Welded Connection*

- Same process as for load lying in the plane of joint except that for forces are perpendicular to each other.

Force due to bending = $M \cdot y / I$;

i.e.

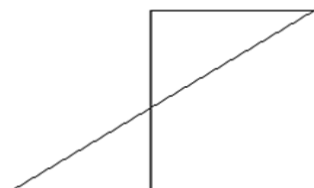


Fig. 2 Stress diagram of weld

Thus, maximum force due to bending develops in the top portion of the joint. The resultant force for that part is found.

F_a (stress due to direct shear) = factor load/area of weld

The resultant of the stresses should be less than the maximum stress limit of weld (108 MPa). Equating the force with this value we can find out the size of weld.

III. DIRECT SHEAR CONNECTIONS

1) *Bolted Connection*

1) *Between Plates:*

- First bolt value is found out considering whether bolt is in single shear or double shear
- Then number of bolts is found out by dividing factored load by bolt value
- End distance and pitch is calculated considering the codal provision of IS800:2007

2) *Welded Connection:*

1) *Fillet weld:*

- Design strength of fillet weld is calculated on its throat area using the formula

$$P_{dw} = \frac{f_u L_w t_e}{\sqrt{3} \gamma_{mw}}$$

Where, P_{dw} = design strength of weld

L_w =

- End returns of length equal to twice the size of weld are provided at each end of longitudinal fillet weld

2) *Butt Weld:*

- When plates to be joined are in the same plane then butt weld is used as shown below: -

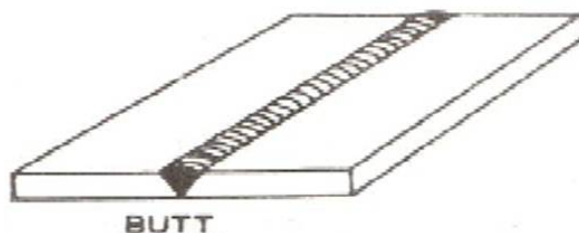


Fig. 3 A typical butt weld

IV. RESULTS AND DISCUSSION

GUI codes for different types of connection are made and shown below.

A. Types of connections

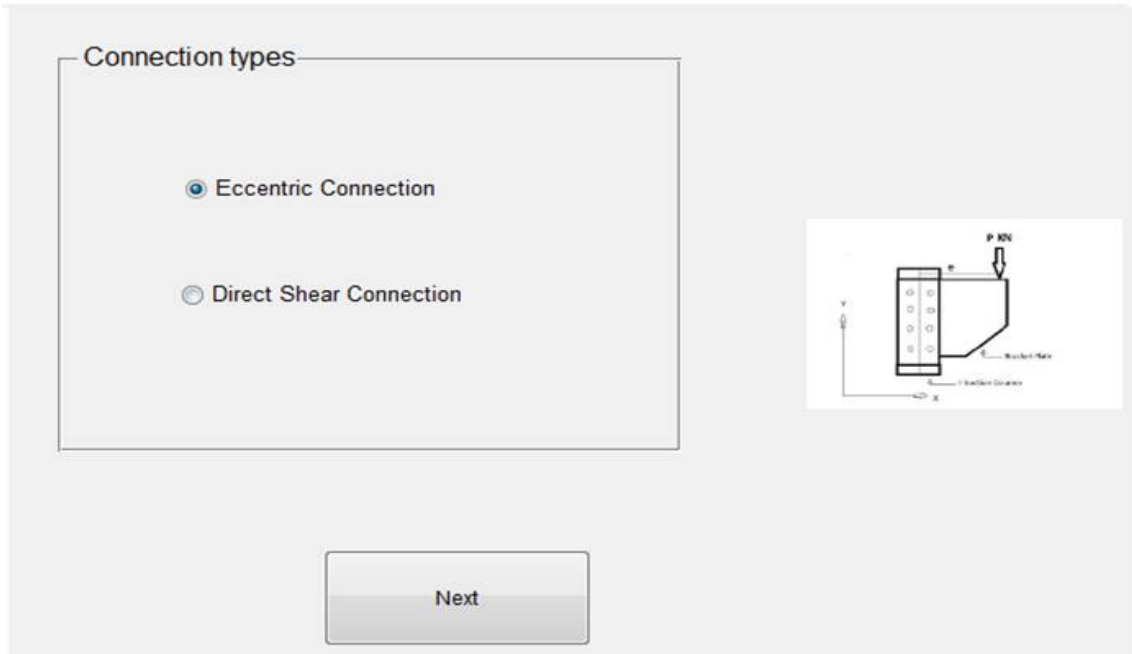


Fig. 4. Types of connections GUI

1) Eccentric Connection

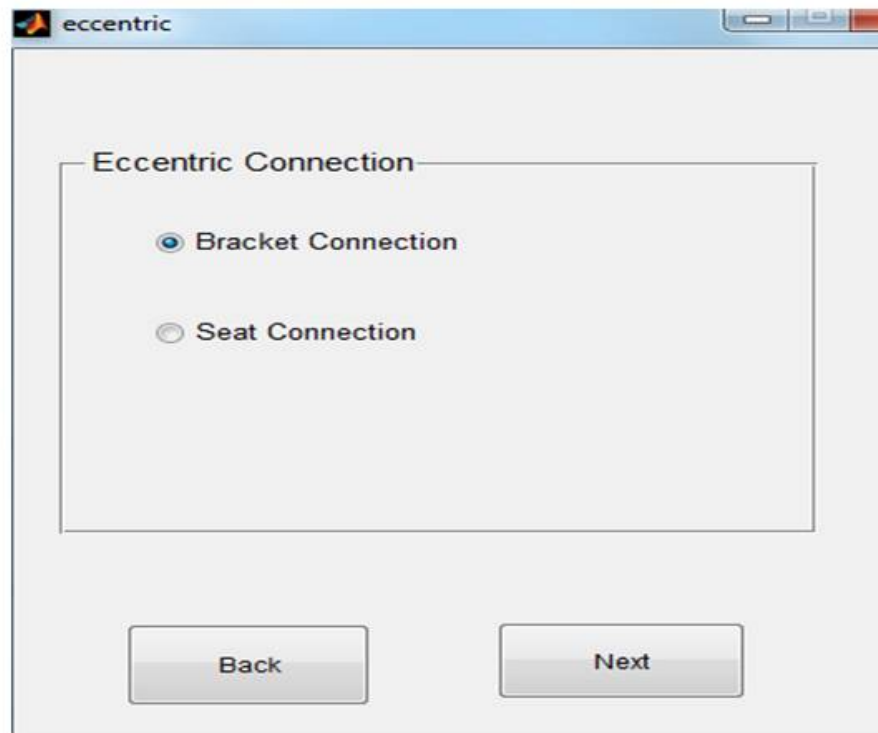
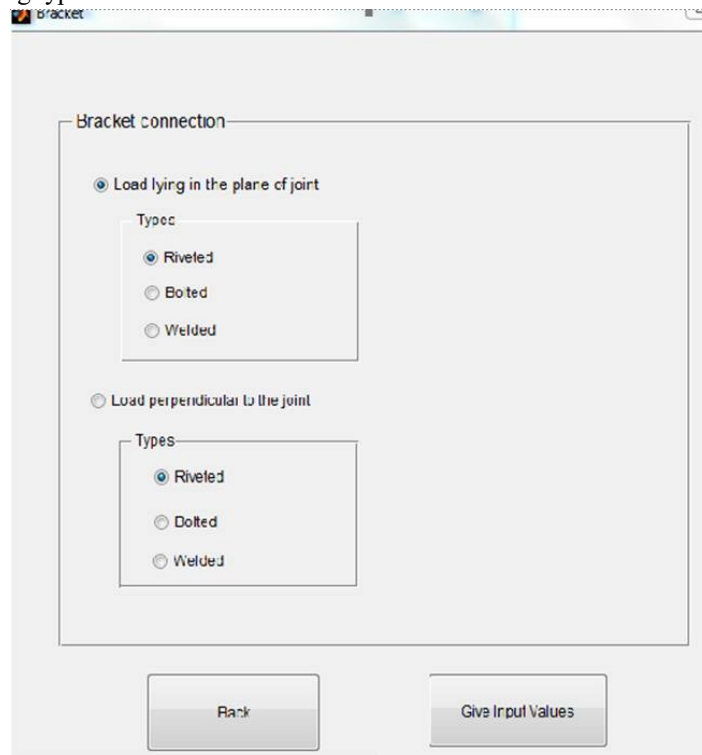


Fig. 5. Eccentric connection types GUI

a) *Bracket Connection*: Different types of bracket connections design are made in GUI as shown in the figures below:
First, we have interface for choosing types of bracket connections.



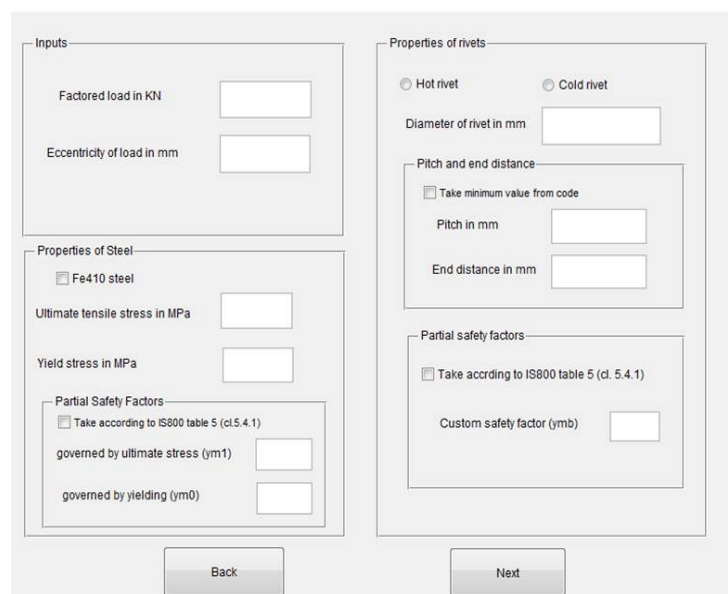
The image shows a software window titled "Bracket". Inside, there is a section titled "Bracket connection". It contains two radio button options: "Load lying in the plane of joint" (which is selected) and "Load perpendicular to the joint". Below each option is a box labeled "Types" containing three radio button options: "Riveted" (selected), "Bolted", and "Welded". At the bottom of the window are two buttons: "Back" and "Give Input Values".

Fig. 6. Types of Bracket connections GUI

We have two cases for bracket connection: - a) load lying in the plane of joint and b) load perpendicular to the joint

b) *Load Lying In The Plane Of Joint*

- Riveted connection



The image shows a software window titled "Rivet connections for load in plane of joint". It is divided into two main sections: "Inputs" and "Properties of rivets". The "Inputs" section has two text input fields: "Factored load in KN" and "Eccentricity of load in mm". The "Properties of rivets" section has two radio button options: "Hot rivet" and "Cold rivet" (selected). Below these are two text input fields: "Diameter of rivet in mm" and "Pitch and end distance". The "Pitch and end distance" section has a checkbox "Take minimum value from code" (unchecked) and two text input fields: "Pitch in mm" and "End distance in mm". The "Partial safety factors" section has a checkbox "Take according to IS800 table 5 (cl. 5.4.1)" (unchecked) and a text input field "Custom safety factor (gamma_m)" with the value "1.25" entered. At the bottom are two buttons: "Back" and "Next".

Fig. 7 rivet connections for load in plane of joint GUI

Given the below sample inputs, we can find the number of rivets and check it for extreme force developed in the extreme of rivet.

Sample input: -

Eccentricity = 160mm

Factor load = 225KN

Hot rivets and cold rivet show whether rivets are in pretension or not.

Results: - 2*8 no of rivets. 8 in each line.

And it is safe to carry to above load

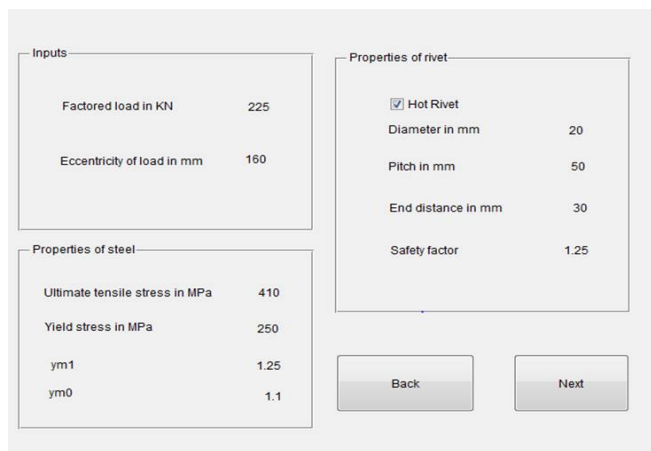


Fig. 8 Value check for above GUI



Fig. 9 Result for the above case

- Welded connection

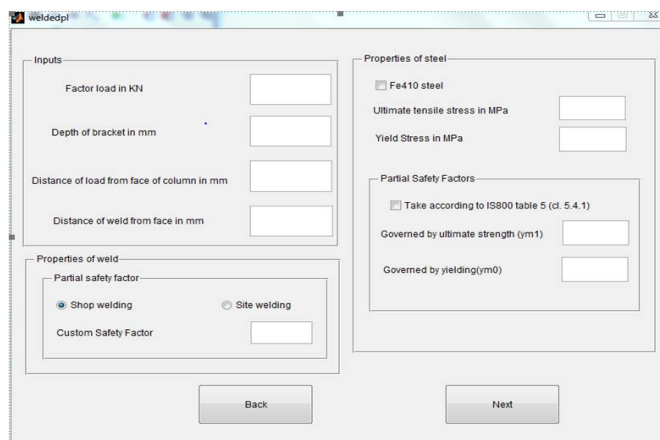
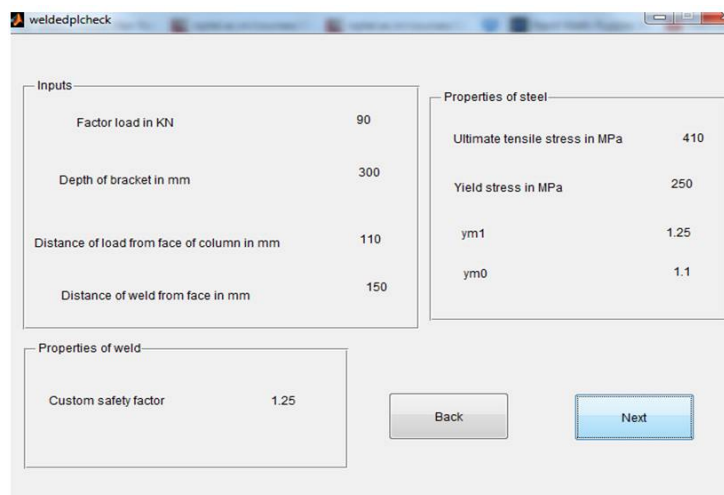


Fig. 10 Welded connections for load in plane of joint GUI

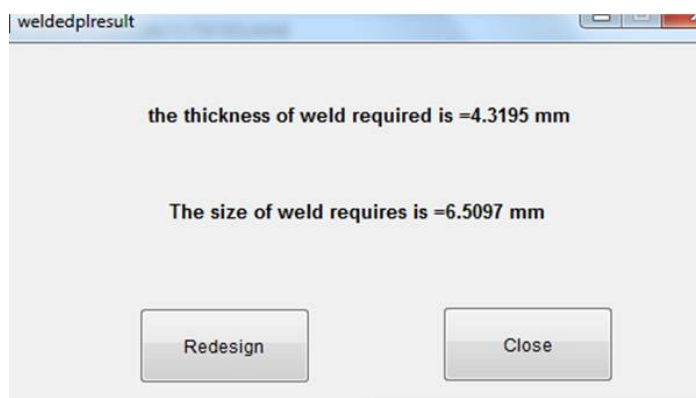
Giving the input value and finding the weld size. First the value is checked and then result is then found out.

Direct shear stress and maximum shear stress due to bending is calculated and resultant stress is calculated and from where thickness of weld is calculated.



The 'weldedplcheck' window displays input and steel properties. The 'Inputs' section contains: Factor load in KN (90), Depth of bracket in mm (300), Distance of load from face of column in mm (110), and Distance of weld from face in mm (150). The 'Properties of steel' section contains: Ultimate tensile stress in MPa (410), Yield stress in MPa (250), ym1 (1.25), and ym0 (1.1). The 'Properties of weld' section contains: Custom safety factor (1.25). There are 'Back' and 'Next' buttons.

Fig. 11 Values check for above case

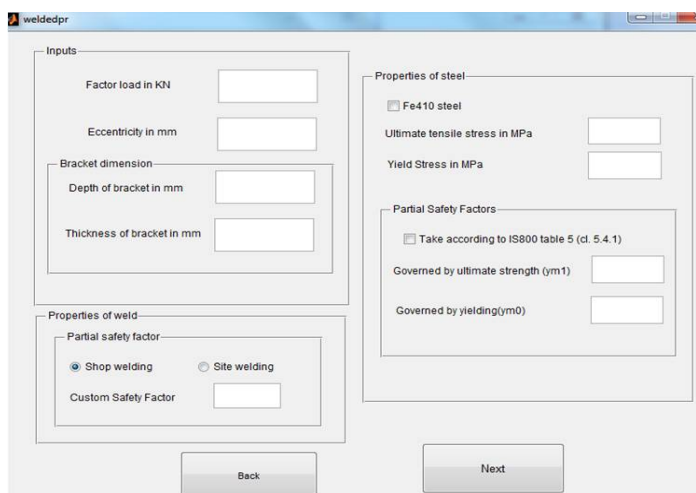


The 'weldedplresult' window displays the results: 'the thickness of weld required is =4.3195 mm' and 'The size of weld requires is =6.5097 mm'. There are 'Redesign' and 'Close' buttons.

Fig. 12 Result for above case

c) *Load Perpendicular To Plane Of Joint*

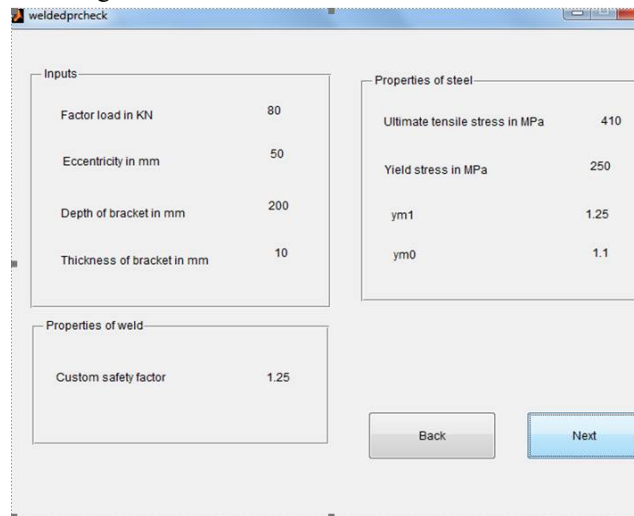
• *Welded Joint*



The 'weldedpr' window displays input fields for eccentric load perpendicular to the plane of joint. The 'Inputs' section contains: Factor load in KN, Eccentricity in mm, Bracket dimension (Depth of bracket in mm, Thickness of bracket in mm). The 'Properties of steel' section contains: Fe410 steel (checked), Ultimate tensile stress in MPa, Yield Stress in MPa. The 'Partial Safety Factors' section contains: Take according to IS800 table 5 (cl. 5.4.1) (checked), Governed by ultimate strength (ym1), Governed by yielding (ym0). The 'Properties of weld' section contains: Shop welding (selected), Site welding, Custom Safety Factor. There are 'Back' and 'Next' buttons.

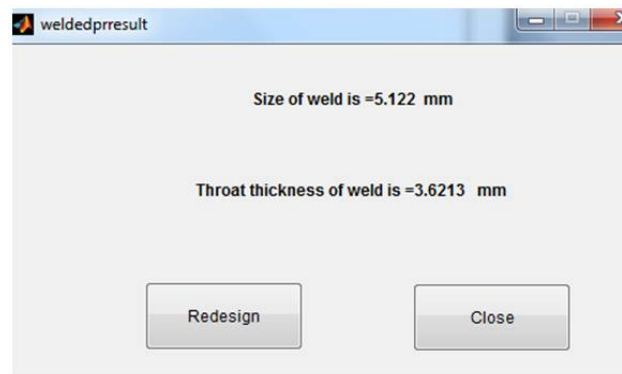
Fig. 13 Weld joint for eccentric load perpendicular to the plane of joint GUI

Check for value for some input case and then get the result



The 'weldedprcheck' window contains three input sections and two buttons. The 'Inputs' section has: Factor load in KN (80), Eccentricity in mm (50), Depth of bracket in mm (200), and Thickness of bracket in mm (10). The 'Properties of steel' section has: Ultimate tensile stress in MPa (410), Yield stress in MPa (250), y_{m1} (1.25), and y_{m0} (1.1). The 'Properties of weld' section has: Custom safety factor (1.25). At the bottom right are 'Back' and 'Next' buttons.

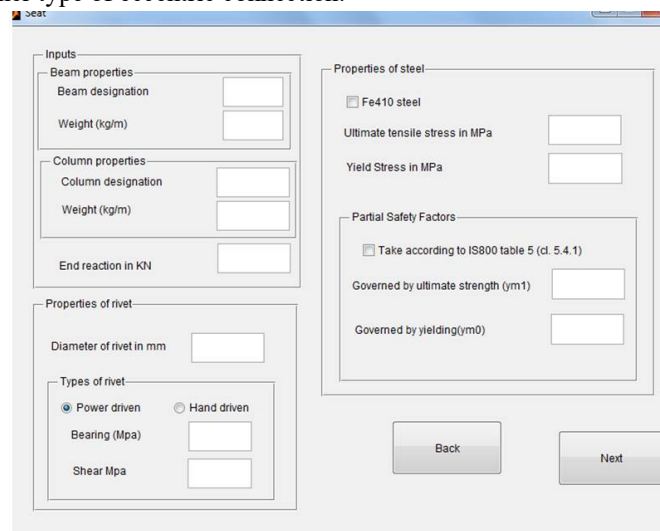
Fig. 14 check for value of above case



The 'weldedprresult' window displays the results of the check. It shows: 'Size of weld is =5.122 mm' and 'Throat thickness of weld is =3.6213 mm'. At the bottom are 'Redesign' and 'Close' buttons.

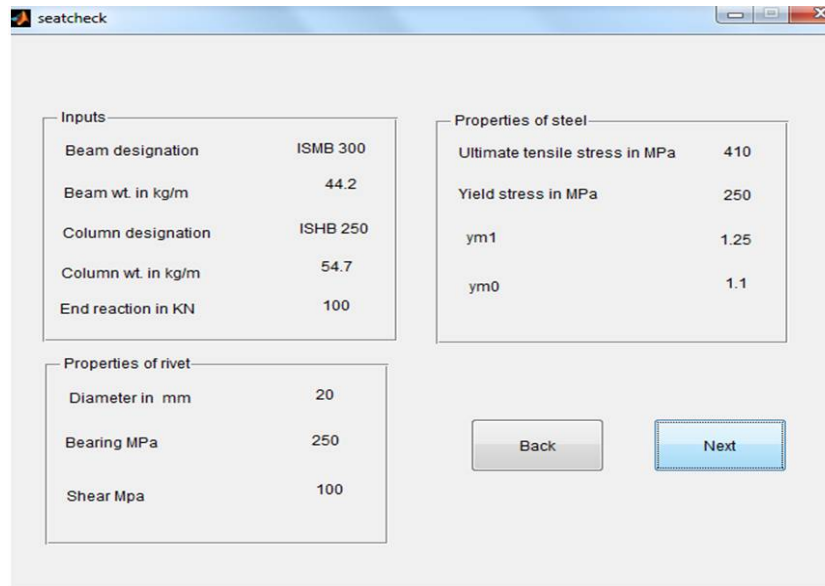
Fig. 15 Result for above case

d) *Seat Connection*: This is another type of eccentric connection.



The 'seat' window is divided into several sections. 'Inputs' includes 'Beam properties' (Beam designation, Weight (kg/m)), 'Column properties' (Column designation, Weight (kg/m)), and 'End reaction in KN'. 'Properties of rivet' includes 'Diameter of rivet in mm', 'Types of rivet' (Power driven selected, Hand driven), 'Bearing (Mpa)', and 'Shear Mpa'. 'Properties of steel' includes a checkbox for 'Fe410 steel', 'Ultimate tensile stress in MPa', 'Yield Stress in MPa', a checkbox for 'Take according to IS800 table 5 (cl. 5.4.1)', and 'Governed by ultimate strength (y_{m1})' and 'Governed by yielding (y_{m0})'. At the bottom are 'Back' and 'Next' buttons.

Fig. 16 Seat connection design GUI



The 'seatcheck' window contains three tables of input data and two navigation buttons.

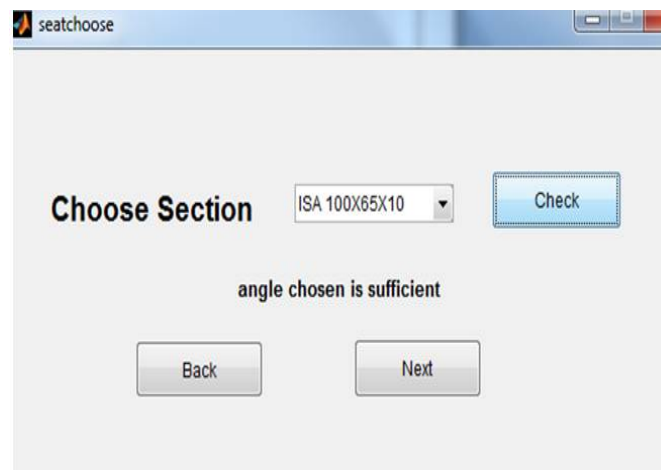
Inputs	
Beam designation	ISMB 300
Beam wt. in kg/m	44.2
Column designation	ISHB 250
Column wt. in kg/m	54.7
End reaction in KN	100

Properties of steel	
Ultimate tensile stress in MPa	410
Yield stress in MPa	250
ym1	1.25
ym0	1.1

Properties of rivet	
Diameter in mm	20
Bearing MPa	250
Shear Mpa	100

Buttons: Back, Next

Fig. 17 Value check for above case



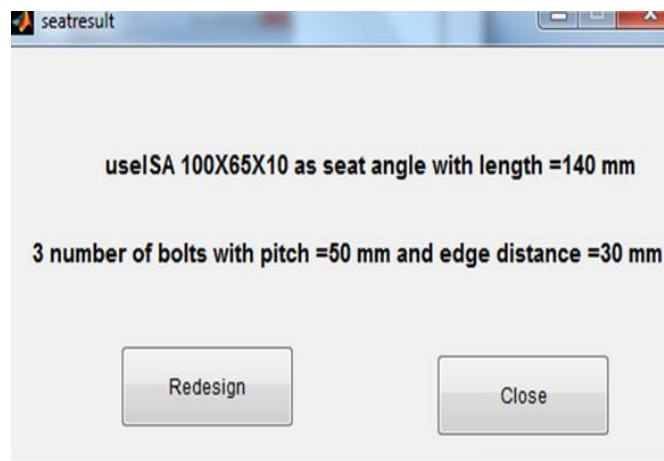
The 'seatchoose' window displays a dropdown menu for section selection and a 'Check' button.

Choose Section | ISA 100X65X10 | Check

angle chosen is sufficient

Buttons: Back, Next

Fig. 18 Angle choice GUI for above case



The 'seatresult' window displays the final design specifications and two action buttons.

use ISA 100X65X10 as seat angle with length =140 mm

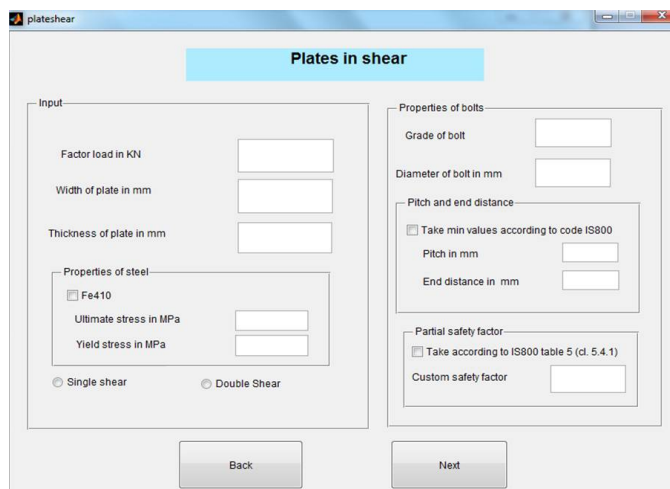
3 number of bolts with pitch =50 mm and edge distance =30 mm

Buttons: Redesign, Close

Fig. 19 Result for above case

2) Direct Shear Connection

- a) *Bolted Connection*: we will consider two cases for this connection one will be between plates and another will be between plate and angle.
 - *Between Plates*

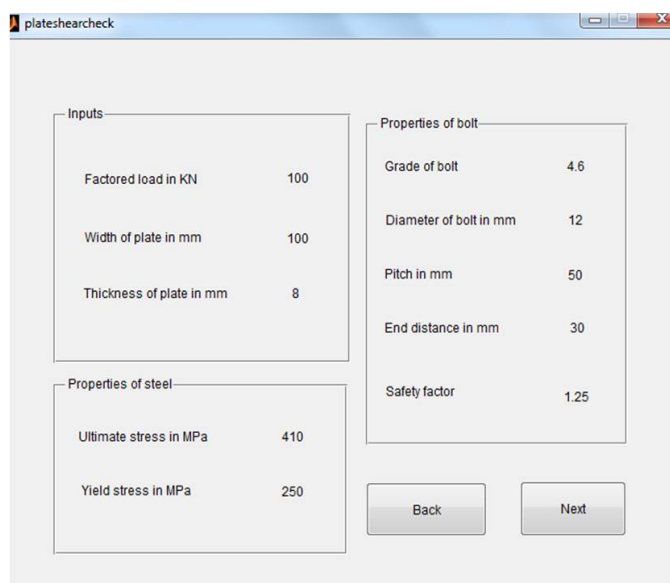


The 'Plates in shear' GUI contains the following input fields and options:

- Input:**
 - Factor load in KN
 - Width of plate in mm
 - Thickness of plate in mm
- Properties of steel:**
 - ☒ Fe410
 - Ultimate stress in MPa
 - Yield stress in MPa
 - ☐ Single shear ☐ Double Shear
- Properties of bolts:**
 - Grade of bolt
 - Diameter of bolt in mm
 - Pitch and end distance:**
 - ☐ Take min values according to code IS800
 - Pitch in mm
 - End distance in mm
 - Partial safety factor:**
 - ☐ Take according to IS800 table 5 (cl. 5.4.1)
 - Custom safety factor

Buttons: Back, Next

Fig. 20 Shear bolted connection for plates GUI



The 'Plateshearcheck' GUI displays the following values:

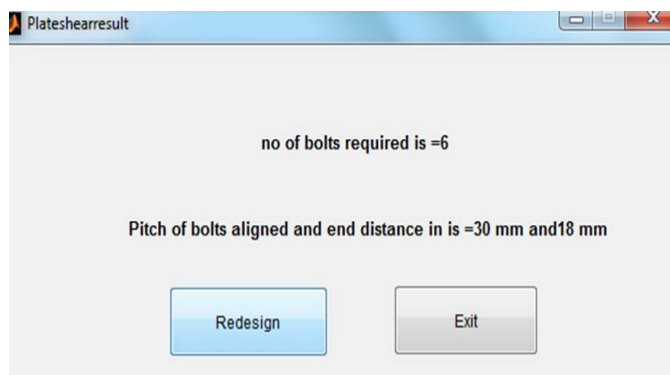
Inputs		Properties of bolt	
Factored load in KN	100	Grade of bolt	4.6
Width of plate in mm	100	Diameter of bolt in mm	12
Thickness of plate in mm	8	Pitch in mm	50
		End distance in mm	30
		Safety factor	1.25

Properties of steel:

Ultimate stress in MPa	410
Yield stress in MPa	250

Buttons: Back, Next

Fig. 21 Value check for above case



The 'Plateshearresult' GUI displays the following results:

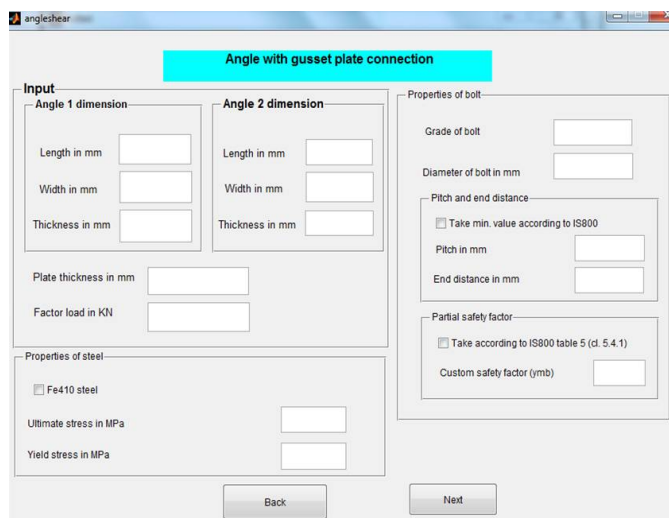
no of bolts required is =6

Pitch of bolts aligned and end distance in is =30 mm and 18 mm

Buttons: Redesign, Exit

Fig. 22 Result for above case

- Between Angle and Plates



Angle with gusset plate connection

Input

Angle 1 dimension

Length in mm

Width in mm

Thickness in mm

Angle 2 dimension

Length in mm

Width in mm

Thickness in mm

Plate thickness in mm

Factor load in KN

Properties of steel

☐ Fe410 steel

Ultimate stress in MPa

Yield stress in MPa

Properties of bolt

Grade of bolt

Diameter of bolt in mm

Pitch and end distance

☐ Take min. value according to IS800

Pitch in mm

End distance in mm

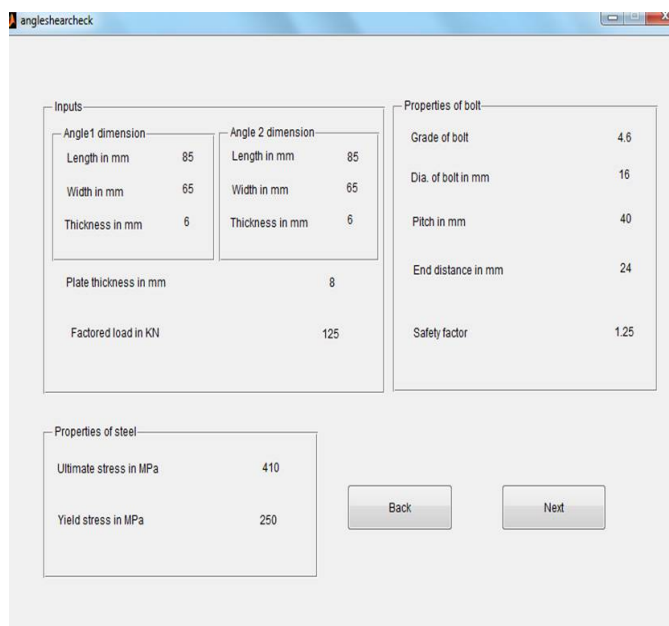
Partial safety factor

☐ Take according to IS800 table 5 (cl. 5.4.1)

Custom safety factor (ymb)

Back Next

Fig. 23 Result for above case



angleshearcheck

Inputs

Angle1 dimension

Length in mm 85

Width in mm 65

Thickness in mm 6

Angle 2 dimension

Length in mm 85

Width in mm 65

Thickness in mm 6

Plate thickness in mm 8

Factored load in KN 125

Properties of steel

Ultimate stress in MPa 410

Yield stress in MPa 250

Properties of bolt

Grade of bolt 4.6

Dia. of bolt in mm 16

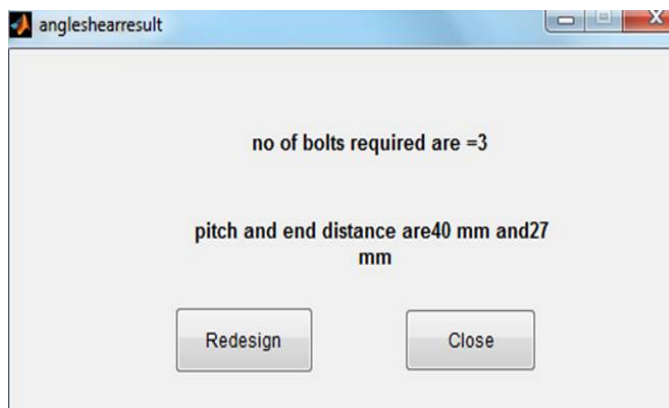
Pitch in mm 40

End distance in mm 24

Safety factor 1.25

Back Next

Fig. 24 Shear bolted connection between angle and plate



angleshearresult

no of bolts required are =3

pitch and end distance are 40 mm and 27 mm

Redesign Close

Fig. 25 Result for above case

b) *Welded Connection*: Two types of welded connection are designed.

- *Fillet weld design*: - fillet weld is used for lap joint and tee joint. A typical fillet weld is shown below:

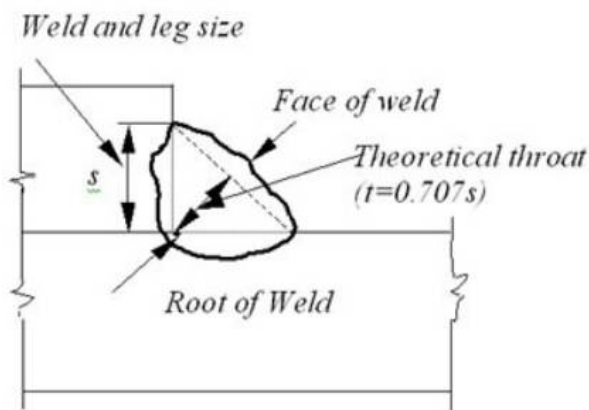
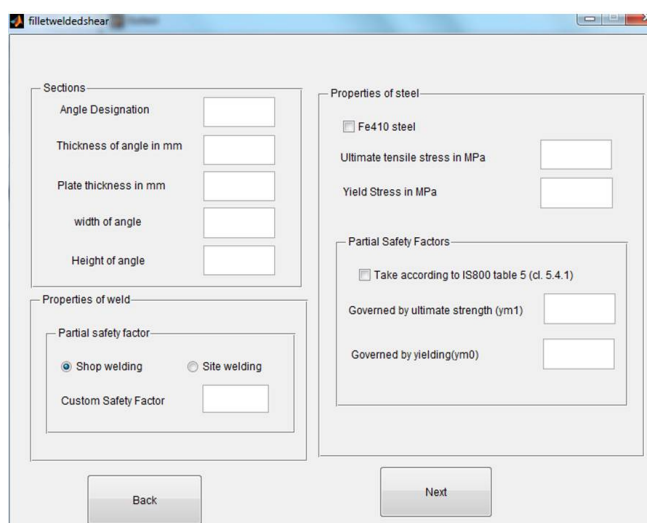


Fig. 26 A typical fillet weld

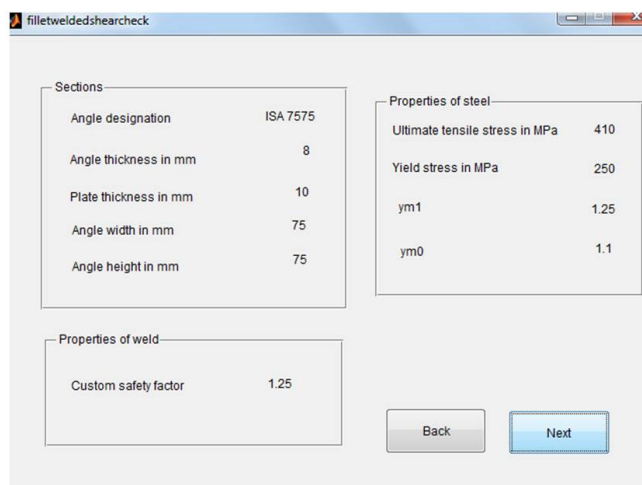


The screenshot shows the 'filletweldedshear' GUI with the following sections:

- Sections**:
 - Angle Designation: []
 - Thickness of angle in mm: []
 - Plate thickness in mm: []
 - width of angle: []
 - Height of angle: []
- Properties of steel**:
 - ☐ Fe410 steel
 - Ultimate tensile stress in MPa: []
 - Yield Stress in MPa: []
- Partial Safety Factors**:
 - ☐ Take according to IS800 table 5 (cl. 5.4.1)
 - Governed by ultimate strength (ym1): []
 - Governed by yielding (ym0): []
- Properties of weld**:
 - Partial safety factor:
 - ☒ Shop welding
 - ☐ Site welding
 - Custom Safety Factor: []

Buttons: Back, Next

Fig. 27 Fillet weld design for shear connection GUI



The screenshot shows the 'filletweldedshearcheck' GUI with the following sections:

- Sections**:

Angle designation	ISA 7575
Angle thickness in mm	8
Plate thickness in mm	10
Angle width in mm	75
Angle height in mm	75
- Properties of steel**:

Ultimate tensile stress in MPa	410
Yield stress in MPa	250
ym1	1.25
ym0	1.1
- Properties of weld**:

Custom safety factor	1.25
----------------------	------

Buttons: Back, Next

Fig. 28 Value check for above case

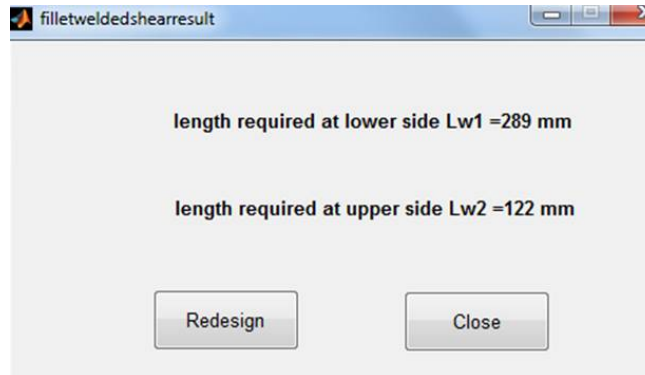


Fig. 29 Result for above case

- *Butt weld design*: - Butt weld is mainly used to connect members which are in the same plane. A typical butt weld is shown below:

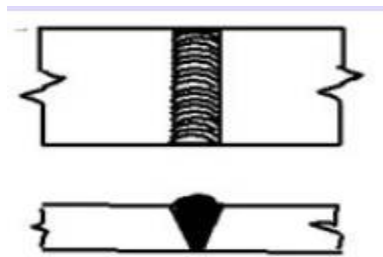


Fig. 30 A typical butt weld

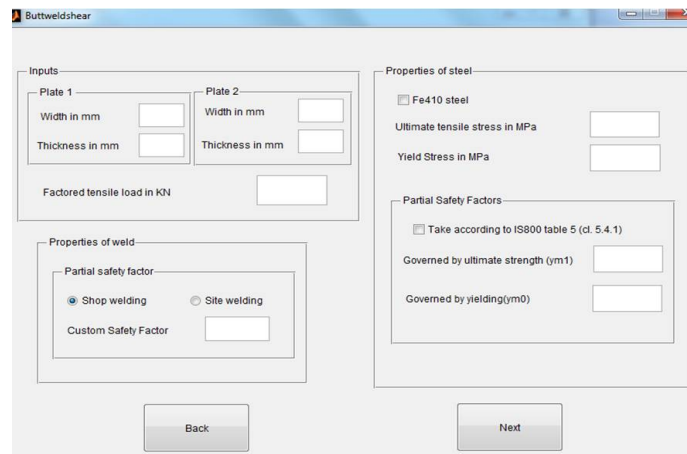


Fig. 31 Butt weld design for shear connections GUI

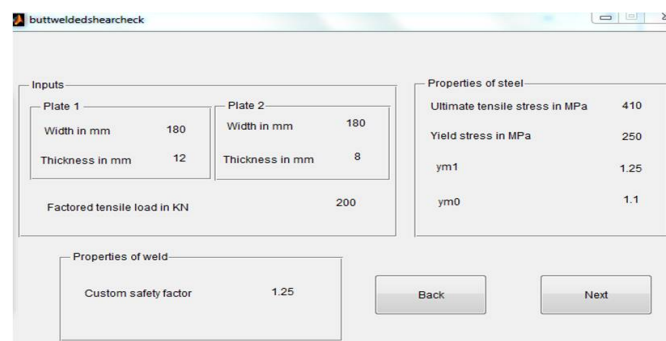


Fig. 32 Value check for above case

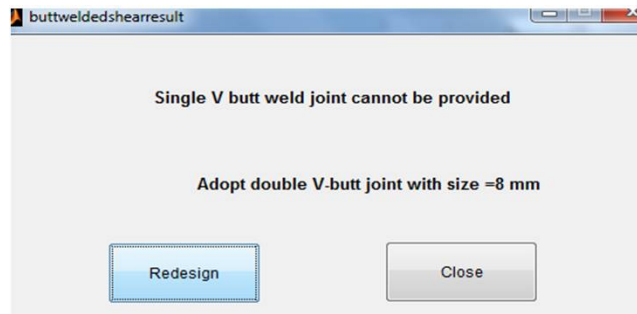


Fig. 33 Result for above case

IV. CONCLUSION

This GUI program made can be very helpful in industrial sector. Connections account for more than half of structural steel work. This program is very user friendly and easy to handle. It finds out the number of bolts and size of welds for various types of connections.

V. ACKNOWLEDGEMENT

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