

**GSE SOFTWARE**

General Structural Engineering

**APPLICATION**

GSE Steel

**FUNCTIONALITY**

Using built up sections in SAFI

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## BUILT UP SECTIONS

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Built-up sections are sections built from other existing sections. The properties of the built-up sections are calculated based on the properties and dimensions of the source sections and the assembly schema.

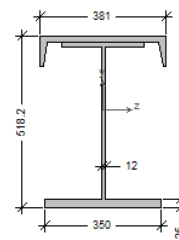
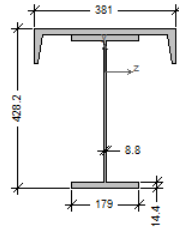
Unless noted otherwise, if the source sections defining the built-up sections are modified by the user, the properties of the built-up sections should be recalculated accordingly by re-editing the section.



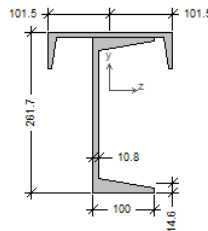
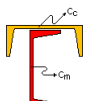
# LIST OF THE BUILT-UP SHAPES

The images below present a sample of the built-up sections available in SAFI.

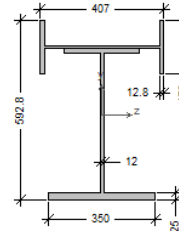
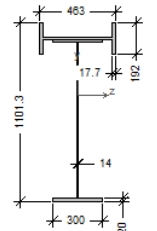
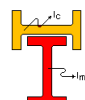
**I Shape with C Cap**



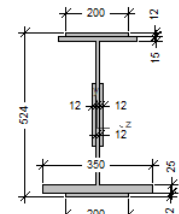
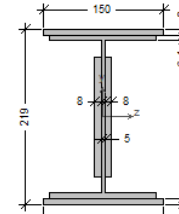
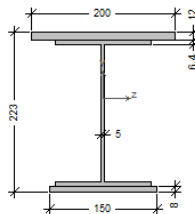
**C Shape with C Cap**



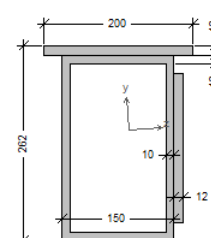
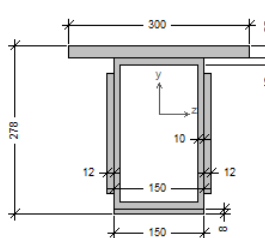
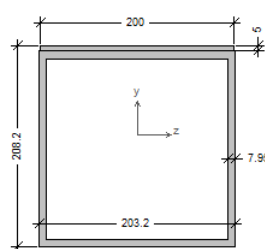
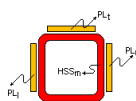
**I Shape with I Cap**



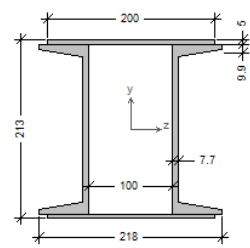
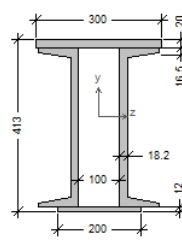
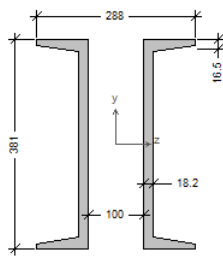
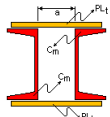
**I Shape with Reinforcing Plates**



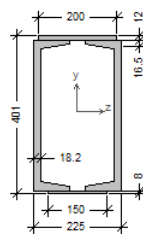
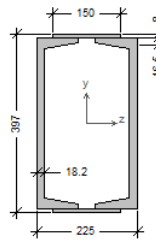
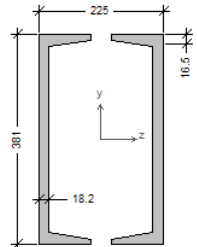
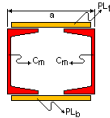
**Rectangular Tube with Reinforcing Plates**



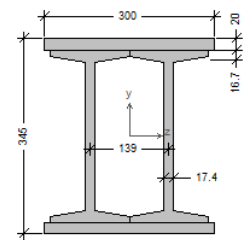
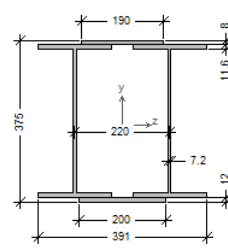
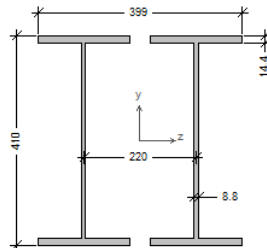
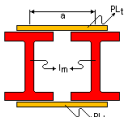
**C Shape Box Back to Back**



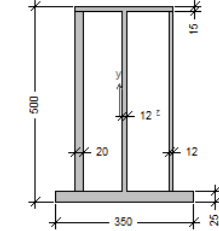
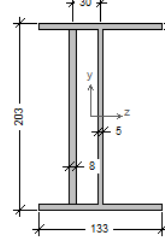
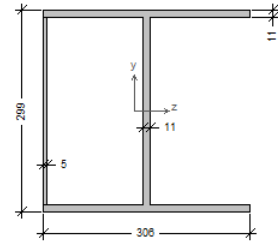
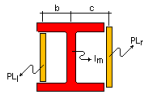
**C Shape Box Toe to Toe**



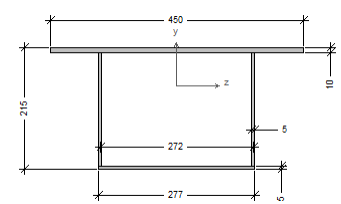
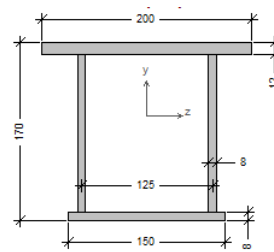
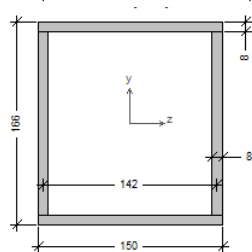
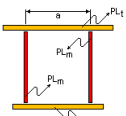
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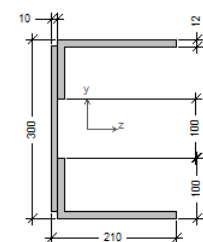
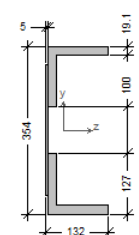
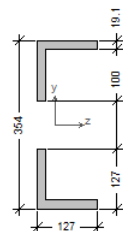
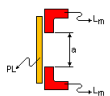
**I Shape with lateral plates**

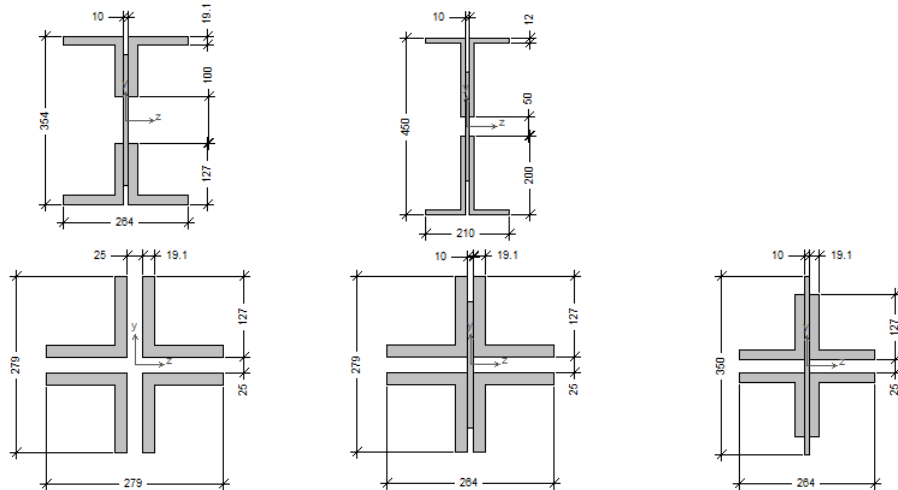
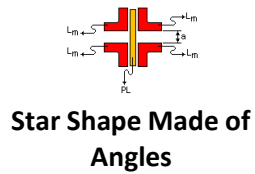
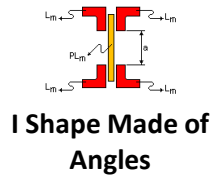


**Plate Box**



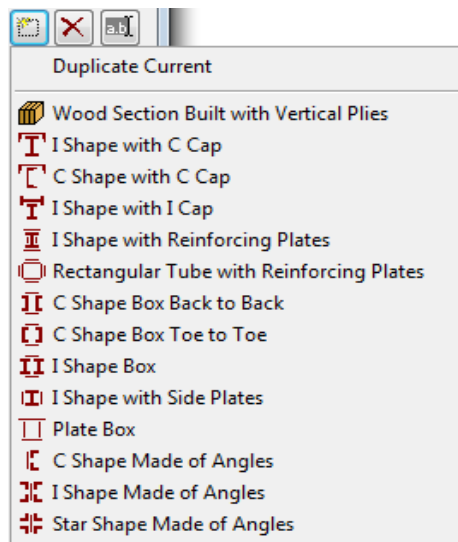
**C Shape Made of Angles**



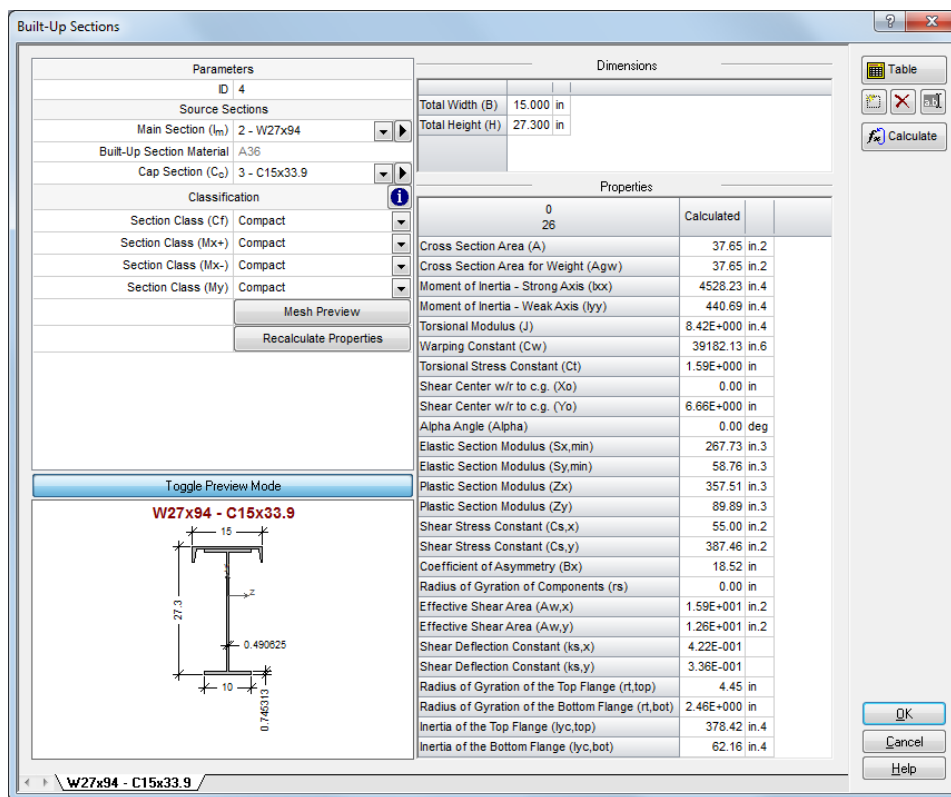


## CREATION OF A BUILT-UP SECTION

To create a built-up section, you need to use the **Built-Up Sections** command (🔧) from the **Table – Sections** menu. Then click on the **Add a new tab** button and select the desired shape.



Built-up sections are sections built from other existing sections. The properties of the built-up sections are calculated based on the properties and dimensions of the source sections and the assembly schema. Unless noted otherwise, if the source sections defining the built-up sections are modified by the user, the properties of the built-up sections should be recalculated accordingly by re-editing the section and clicking on the **Recalculate Properties** button.



## CLASSIFICATION AND LIMIT STATES CALCULATIONS

The calculation of the limit states is available for all built-up sections. However, the user is responsible of specifying the section class. If the class of the section is not specified, it will be considered as *Non compact* by default.

The class of the section in compression, positive bending, negative bending as well as bending on the weak axis must be specified for the program to calculate the resistances. In the case of a slender section, the appropriate effective properties must also be specified.

Classification		
Section Class (Cf)	Slender	
Section Class (Mx+)	Slender	
Section Class (Mx-)	Slender	
Section Class (My)	Slender	
Eff. Area in Compression (Ac,eff)	0	in.2
Eff. Elastic Sect. Modulus (Sx+,eff)	0	in.3
Eff. Elastic Sect. Modulus (Sx-,eff)	0	in.3
Eff. Elastic Sect. Modulus (Sy,eff)	0	in.3

The classes are described in more details in the design codes. A general overview of the classes is provided below:

**Unknown/No Design**

The corresponding resistance and associated limit states are not calculated.

**Plastic and compact classes**


May reach yield stress on the entire section before local buckling of the walls of the section (Mp). In general, the bending resistance is calculated using the plastic section modulus (Zx or Zy)

**Non compact class**

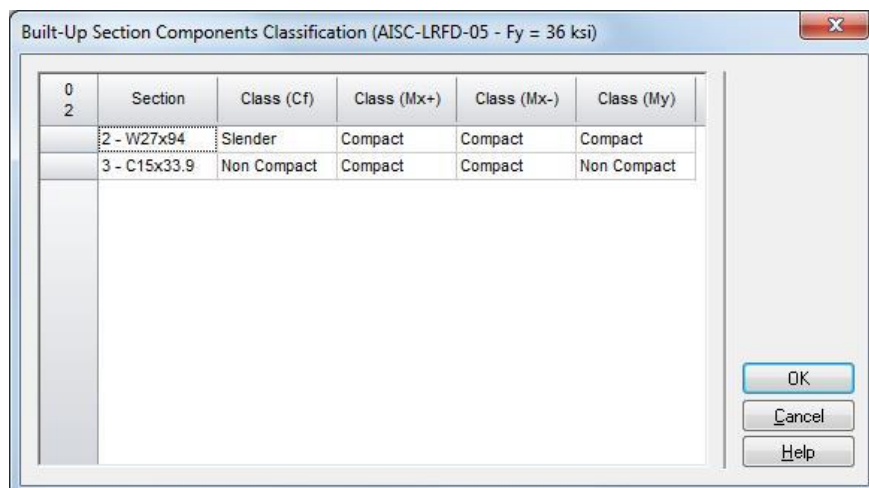
May reach yield stress on a part of the section before local buckling of the walls of the section (My). In general, the bending resistance is calculated using the elastic section modulus (Sx or Sy)

**Slender class**

The section is made of slender walls that may buckle before reaching the yield stress (Fy). Each design code specifies how to calculate the effective properties of slender sections.

SAFI does not automate the classification process for built-up sections. However, the  button allows to obtain the class of the components separately (as if they were not attached) according to the material properties and selected design code.

This information is provided as a reference, the final section classes must be specified by the user. For example, the connectors used to assemble the parts directly influence the classification. In the case of a slender section, the appropriate effective properties must be specified by the user.

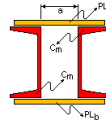


## SECTIONS WITH DIAGONAL LACING

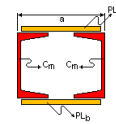
The **Consider plates as** option allows to specify if the plates attaching the built-up section components are continuous plates or diagonal lacing. This option is available only for shapes that may be assembled using plates or diagonal elements.

These shapes are shown below:

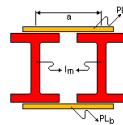
**C Shape Box Back to Back**



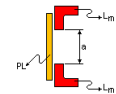
**C Shape Box Toe to Toe**



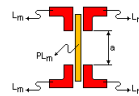
**I Shape Box**



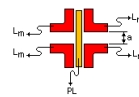
**C Shape Made of Angles**



**I Shape Made of Angles**



**Star Shape Made of Angles**



The plates attaching the main parts may be considered as *Continuous plates* or as *Diagonal lacing*. The diagonal lacing increases the torsional and warping properties but does not influence the axial and bending properties. When the *Diagonal lacing* option is selected, the area of the section as well as the bending properties listed below are calculated ignoring the plates.

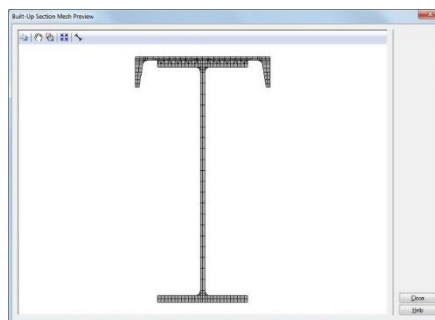
- Cross Section Area (A)
- Moment of Inertia - Strong Axis ( $I_{xx}$ )
- Moment of Inertia - Weak Axis ( $I_{yy}$ )
- Elastic Section Modulus ( $S_{x,min}$ )
- Elastic Section Modulus ( $S_{y,min}$ )

- Plastic Section Modulus ( $Z_x$ )
- Plastic Section Modulus ( $Z_y$ )
- Radius of Gyration of the Top Flange ( $r_{t,top}$ )
- Radius of Gyration of the Bottom Flange ( $r_{t,bot}$ )
- Inertia of the Top Flange ( $I_{yc,top}$ )
- Inertia of the Bottom Flange ( $I_{yc,bot}$ )

Note that when the *Diagonal lacing* option is selected, it is still required to specify a plate of equivalent thickness as it is used to calculate the other properties of the section.

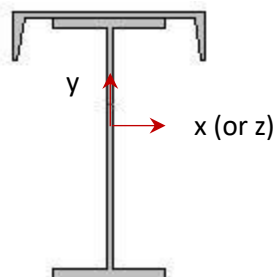
## BUILT-UP SECTIONS PROPERTIES

Many properties may be calculated exactly using simple equations. However, most references use approximate equations for the calculation of the torsional modulus ( $J$ ), the warping constant ( $C_w$ ) and the coefficient of asymmetry ( $\alpha_x$ ). SAFI does not use these simplified equations to calculate the built-up sections properties as they are not available for complex shapes.



Hence, all built-up sections properties are calculated with a general approach using finite elements which provides very accurate results. The Preview Mesh button allows to view the mesh used in the calculations. The mesh automatically generated by the program allows to obtain a particularly good precision.

The properties calculated are summarized below:





- Cross section area (A)
- Cross section area for weight (Agw)
- Moment of inertia – Strong axis (Ixx)

$$I_x = \int_A y^2 dA$$

- Moment of inertia – Weak axis (Iyy)

$$I_y = \int_A x^2 dA$$

- Torsional modulus (J)  
 $\omega$  : Warping function

$$\int_A \left[ \left( \frac{\partial \omega}{\partial y} + x \right) x - \left( \frac{\partial \omega}{\partial x} - y \right) y \right] dA$$

- Warping constant (Cw)  
 $\omega$  : Warping function

$$Q_\omega = \int_A \omega dA$$

$$\int_A \left( \omega - X_0 y + Y_0 x - \frac{Q_\omega}{A} \right)^2 dA$$

- Torsional stress constant (Ct)

$$\tau_t = \frac{M_{xp}}{J} C_t$$

$M_{xp}$  Pure torsion moment

$\tau_t$  Maximum torsional stress induced by  $M_{xp}$

- Shear center w/r to c.g. ( $X_0$ )
  - Shear center w/r to c.g. ( $Y_0$ )
- $\omega_c$  : Warping function evaluated w/r to c.g.

$$I_{\omega x} = \int_A \omega_c y dA$$

$$I_{\omega y} = \int_A \omega_c x dA$$

$$X_0 = - \frac{I_y I_{\omega x} - I_{xy} I_{\omega y}}{I_x I_y - I_{xy}^2}$$

$$Y_0 = \frac{I_x I_{\omega y} - I_{xy} I_{\omega x}}{I_x I_y - I_{xy}^2}$$

- Alpha angle  
Angle between the principal axes and the straight axes

- Elastic section modulus ( $S_x, \min$ )

$$\frac{I_x}{\bar{y}_{max}}$$

$\bar{y}_{max}$  Distance to the extreme fiber in the y direction

- Elastic section modulus ( $S_y, \min$ )

$$\frac{I_y}{\bar{x}_{max}}$$

$\bar{x}_{max}$  Distance to the extreme fiber in the x direction

- Plastic section modulus ( $Z_x$ )

$$\int_A y dA$$

- Plastic section modulus ( $Z_y$ )

$$\int_A x dA$$

- Shear stress constant ( $C_{s,z}$ )

$$\tau_{xz} = \frac{V_z}{I_y} C_{s,z}$$

$V_z$  Shear force along the internal z axis

$\tau_{xz}$  Maximum shear stress induced by  $V_z$

- Shear stress constant ( $C_{s,y}$ )

$$\tau_{xy} = \frac{V_y}{I_z} C_{s,y}$$

$V_y$  Shear force along the internal y axis

$\tau_{xy}$  Maximum shear stress induced by  $V_y$

- Coefficient of asymmetry in  $M_x$  ( $\alpha_x$ )

Note that the sign of the coefficient of asymmetry changes according to the compressed flange.

$$2Y_0 + \frac{1}{I_x} \int_A y(x^2 + y^2) dA$$

- Radius of gyration of the components ( $r_s$ )

$$r_s = \sqrt{I_s/A_s}$$

$I_s$  Minimum inertia of a built-up component

$A_s$  Area of the built-up component



Illustration of the radius of gyration

- Effective shear area ( $A_{w,x}$ )
- Effective shear area ( $A_{w,y}$ )
- Shear deflection constant ( $k_{s,x}$ )
- Shear deflection constant ( $k_{s,y}$ )

The effective shear area is used to calculate the shear resistance. The shear deflection constant is used to calculate the deflections due to shear.

$$A_{w,x} = k_{s,x}A$$

$$A_{w,y} = k_{s,y}A$$

- Radius of gyration of the top flange ( $r_{t,top}$ )
- Radius of gyration of the bottom flange ( $r_{t,bot}$ )
- Inertia of the top flange ( $I_{yc,top}$ )
- Inertia of the top bottom ( $I_{yc,bot}$ )

These values are used to calculate the lateral torsional buckling resistance of singly-symmetric sections.

The  $r_t$  radius corresponds to the radius of gyration of the compressed flange plus 1/3 of the compressed portion of the web according to the weak axis. The  $I_{yc}$  inertia corresponds to the inertia of the compressed flange plus 1/3 of the compressed portion of the web according to the weak axis.

## CONVERSION TO USER DEFINED SECTION

The properties of a built-up section cannot be modified by the user. However, it is possible to create a user defined section from an existing built-up section. Note that all properties of a user defined section can be modified.

To do so, select the **User defined section** command (📄) from the **Table – Sections** menu. Then click on the **Add a new tab** button and select the *Import built-up section* option.

## ADVANCED STRESS ANALYSIS

The stress analysis is available from the **Advanced section stress analysis** or **Advanced member stress analysis** command from the **Analysis – Charts – Analysis** menu. These commands allow to visualize the internal stresses distribution in the section at each calculation point along the members. The elastic stresses are calculated through a finite element analysis of the section and may differ slightly from the stresses presented in the **Internal stresses** command.

