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SCAD Office.
Creation of sections and calculation of their geometric properties

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V.S. Karpilovsky and others

SCAD Office. Creation of Sections and Calculation of their Geometric Properties. User Guide. V.S. Karpilovsky, E.Z. Kriksunov, A.A. Malyarenko, A.V. Perelmuter, M.A. Perelmuter — Kyiv, 2024.— 131 pages with pictures.

This book is intended for the users of SCAD computing system, SCAD satellite programs, and other programs performing the analysis of the stress-strained state of structures and dealing with the creation and calculation of the geometric properties of various sections. The guide considers the user interface and the data preparation rules of Section Builder, Consul, Tonus and Sezam, and provides the minimum theoretical information which is the basis of the analyses performed in these programs.

This book can be interesting for students of the respective specialities and for the developers of similar software.

Approved by the Academic Board of the V. Shimanovsky Ukrainian Institute of Steel Construction

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Acknowledgements

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Preface

The program package for creation of rod section forms, calculation and analysis of their geometric properties actually consists of four applications called **Consul**, **Section Builder**, **Tonus** and **Sezam.** All these programs operate in the Windows 10/11 environments and do not require any special computer configuration. User interface elements do not differ from the majority of other programs operating in the Windows environment.

Consul enables you to create arbitrary sections and calculate their geometric properties on the basis of the solid rods theory.

Section Builder (Builder) enables you to create arbitrary compound sections from rolled steel profiles and plates and calculate their geometric properties.

Tonus enables to build thin-walled sections (i.e. bars in the form of rather long cylindric shells) and calculate their geometric properties.

Sezam enables you to find a section (a hollow section, an I-beam, a Tee section, or a channel) which approximates an arbitrary section set by the user according to its geometric properties the best.

All the programs included in the package are integrated with each other and with **SCAD**. In particular, there is a possibility to invoke one program from the other one and in some cases to transfer information from one program to the other one. The diagram of possible interrelations is shown in Fig. 1, where **.SEC, .CNS, .CON**, **.TNS** are designations of file formats.

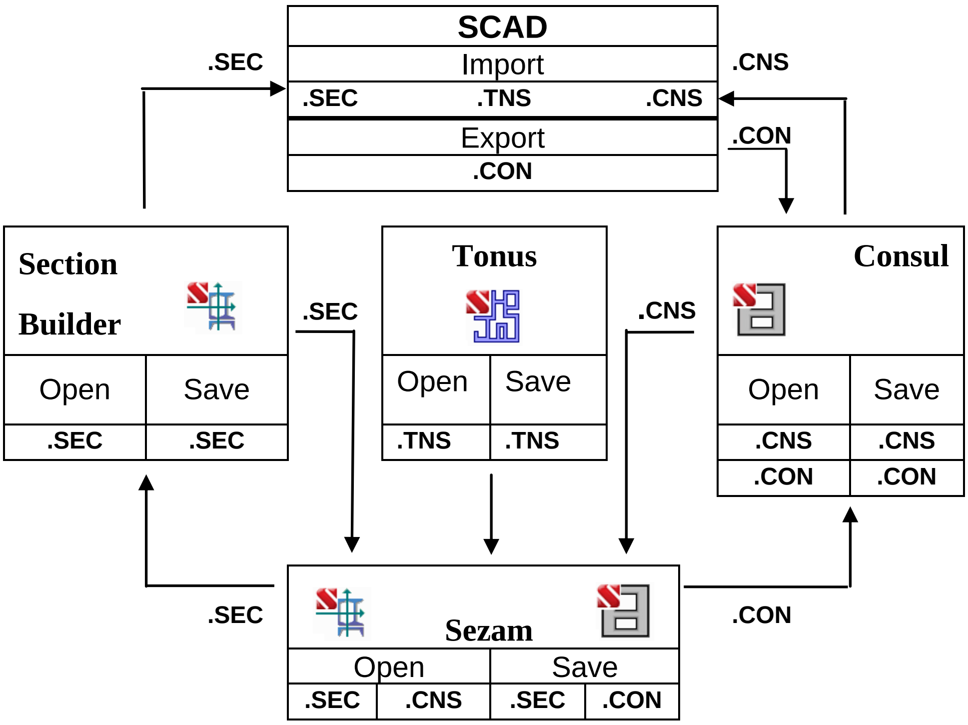


Figure 1. *The diagram of interrelations between programs*

Coordinate System

The right-handed Cartesian coordinate system (**X**, **Y**, **Z**) is used. **X**-axis is the rod longitudinal axis directed from the drawing plane toward the observer. **Z**-axis is conceived as a vertical one and directed upward in the drawing, **Y**-axis is the horizontal axis with the positive direction to the right. However, the user can change the names of the axes using the **Settings** dialog box (see below).

Principal centroidal axes of the section are designated as **U** and **V**.

Calculated Properties

For the designed section **Section Builder** determines:

- cross-sectional area A;
- values of the moments of inertia I_y and I_z about centroidal axes parallel to the coordinate axes;
- radii of gyration i_y and i_z about the same axes;
- torsional moment of inertia I_t;
- coordinates of the center of mass;
- value of the angle of the principal axes of inertia (angle α between **U** and **Y** axes);
- maximum I_u and minimum I_v moments of inertia;
- maximum i_u and minimum i_v radii of gyration;
- maximum W_{u+} and minimum W_{u-} section moduli about the **U**-axis;
- maximum W_{v+} and minimum W_{v-} section moduli about the **V**-axis;
- core size from **U**-axis along the positive (a_{u+}) and negative (a_{u-}) directions of **V**-axis;
- core size from **V**-axis along the positive (a_{v+}) and negative (a_{v-}) directions of **U**-axis;

If the section has been created by **Consul** or **Tonus**, the following properties are determined additionally:

- section perimeters: total — P, external — P_e and internal — P_i;
- conventional shear areas ($A_{v,y}$, $A_{v,z}$);
- moments of inertia with respect to the coordinate system within which the section has been created;
- coordinates of the shear center;
- sectorial moment of inertia.

To calculate some properties, for example, the position of the shear center or sectorial properties, it is necessary to solve the Laplacian differential equation on the section area with boundary conditions on the boundary line depending on whether a portion of the boundary line is a part of the external contour or it belongs to the internal hole. If sections have been created with the help of **Builder**, in many cases it is unclear what belongs to the boundary line (external or internal) of the section contour. Therefore **Section Builder** does not calculate all the geometric properties (in comparison with **Consul** and **Tonus**), e.g. the torsional moment of inertia is approximately determined as the sum of the torsional moments of inertia of profiles comprising the section.

In all the programs of the package the geometric properties are always calculated considering the section as continuous, neglecting the ductility of connecting grates and/or plates.

It should be noted that in case of a section with equal moments of inertia ($I_y = I_z$) the angle α is undefined. The axes shown on the screen are to some extent accidental, since in the considered case the ellipse of inertia degenerates into a circle of inertia ($i_y = i_z = i_u = i_v$), so any orthogonal couple of the centroidal axes can be considered as the principal one.

The calculation of geometric properties is not the end in itself. It is assumed, that the calculation results will be used during the further analysis of the stress-strained state, in particular, when specifying the initial data in **any** program of the structural calculation. Moreover, the program can be used to calculate ***the stiffness properties of buildings and structures*** and their elements. For example, **WEST** (see [9]), included in the SCAD Office system, enables to determine the geometric properties of the stiffening core with the help of **Tonus** to estimate the pulsating component of the wind load.

Consul, **Tonus** and **Section Builder** enable to obtain the fields of normal stresses if the internal forces in the section have been specified.

Files Created by the Programs

Consul can create, save results and read files in two different formats — **CNS** and **CON** (with **.cns** and **.con** extensions respectively).

The **CNS** format is the internal format and has a relatively complicated structure, however this format allows to save and read not only the information about a section form but the additional user settings as well, for example, the grid parameters.

The **CON** format has a very simple structure (described in the appendix) and is designed to exchange the data with other applications.

Builder can create, save results and read **SEC** files (with **.sec** extension) containing the information about elements which comprise the section and their mutual position.

Tonus can create, save results and read **TNS** files (with **.tns** extension) containing the information about a section.

Sezam can read files in the following formats: **Builder** (**SEC**), **Consul** (**CNS**) and **Tonus** (**TNS**).

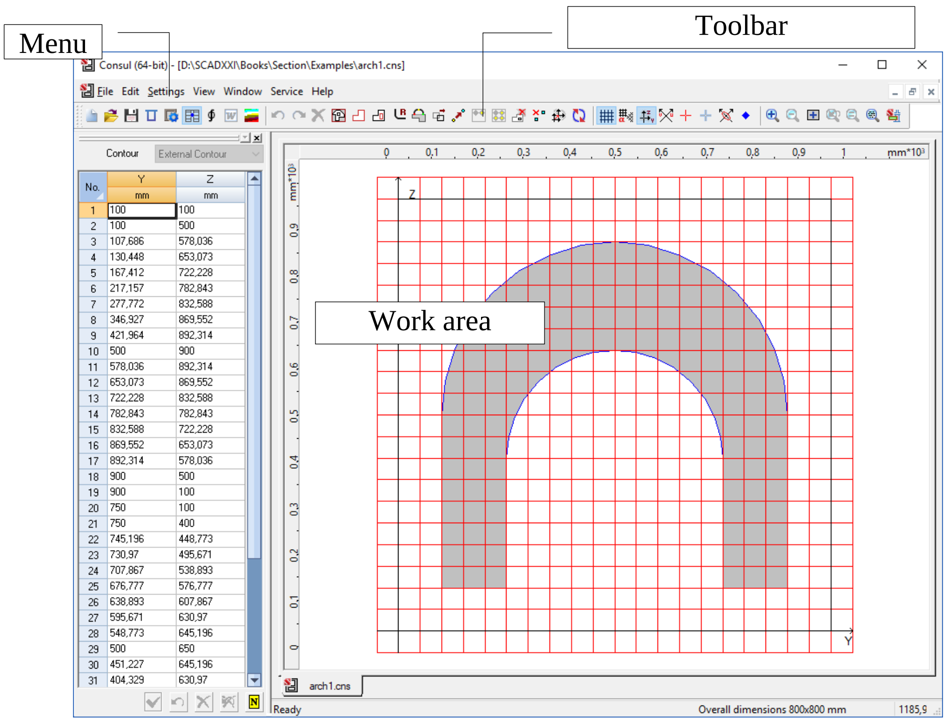
Common Controls

Different programs of the package have many common controls, which are described in this chapter (to avoid the duplication). Each subsection has the following table

•	•	•	•

,

where the sign « • »in the first cell means that the given operation (option) is related to **Consul**, in the second cell — to **Section Builder**, in the third one — to **Tonus**, and in the fourth on — to **Sezam**. The absence of the table (or if all the cells contain the sign « • ») means that the given description is related to all the programs of the package.



Settings

All the programs of the package include settings which enable to set the units of measurement of the main values and the rules of the report generation, select the steel sections assortments, select colors, fonts, etc. This can be performed in the multi-tab **Settings** dialog box, the content of which depends on the program it was invoked from. **Settings** dialog box can be invoked from the **Settings** menu in **Consul** and **Section Builder** and also from the toolbar (**Settings** button —) in all other programs of the package.

As a rule the dialog box contains the following tabs: **Units of Measurement, Report and Languages, Visualization, Sections, Other** and **General**.

Each tab opens a page where you can adjust certain types of settings.

Settings can be saved to an external file using the **Save** button, which can be subsequently loaded (the **Load** button).

Units of Measurement

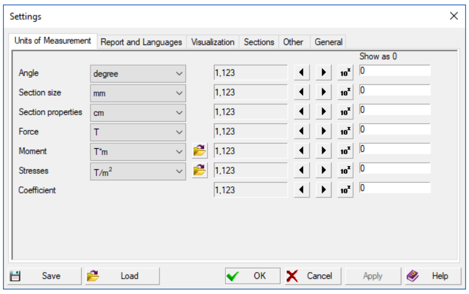


Figure 2. *The* **Units of measurement** *tab of the* ***Settings*** *dialog box*

The **Units of Measurement** tab (Fig. 2) enables you to define units of measurement used in the analysis. It contains two groups of data. The first group is used to specify measurement units of linear sizes, forces, moments, etc.

For compound units (such as those for moments and stresses), there is a possibility to define their component units (such as those for force and for moment arm) separately using the button.

The second group helps to choose a representation and precision of numerical data. Special controls are used here to select data representation formats. Make sure to specify the number of significant digits in either the fixed-point decimal representation or the floating-point scientific notation.

The precision of the data representation (the number of significant digits after the decimal point) can be assigned using the (decrease) and (increase) buttons, while the scientific notation is turned on by the button. You can also specify in respective text fields which values should be treated as negligibly small, so that all absolute values less than the given ones will be displayed as 0 in all visualizations.

Report and Languages

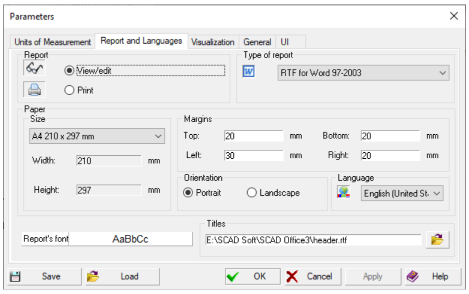


Figure 3. *The* **Report and Languages** *tab of the* ***Settings*** *dialog box*

The **Report and Languages** tab (Fig. 3) enables you to choose a language for the user interface and for the report.

There are two modes for working with a report document: **View/Edit** or **Print**.

In the **View/Edit** mode, clicking the **Report** button in any active dialog will open the report and allow you to view/edit it. An application associated with **RTF** (Rich Text Format) files (such as **MS Word Pad** or **MS Word**) will be invoked to serve this purpose.

Obviously, it is the user who is fully responsible for any changes made to the text of the report (note that even results of the calculation can be edited).

There are differences in RTF formats used by MS Word v.7, MS Word 97 (2000/XP) and Open Office. Therefore, the program allows you to choose one of the formats in the **Type of Report** mode (besides RTF a report can be created in the following formats DOC, PDF, HTML).

Clicking the **Print** button in the **Report** group will print the report in the form it has been generated by the program.

Use the **Titles** text field to specify an RTF file containing headers and footers for pages of the report document. The file can be selected from a standard list by clicking the button.

The **Paper Size** setting enables you to choose the paper format for printing the report (the size is selected from a drop-down list).

Moreover, the margins and the page orientation can be selected before generating the report.

Report Font is used to choose a font type for the report. A double left click invokes a standard Windows dialog for selecting the font. Only the selected font type will be used in the generated reports (style and size are assigned by the software).

Visualization

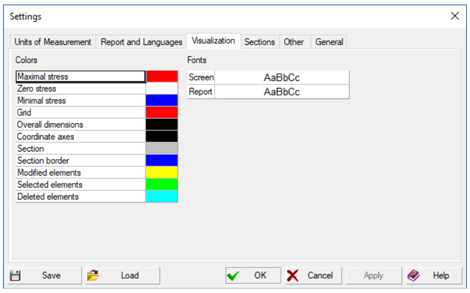


Figure 4. *The* **Visualization** *tab of the* ***Settings*** *dialog box*

The **Visualization** tab (Fig. 4) contains two groups of data: **Colors** and **Fonts**. Each group contains controls for selecting colors and fonts respectively. A double left click invokes a standard Windows dialog for selecting the color/font.

Sections

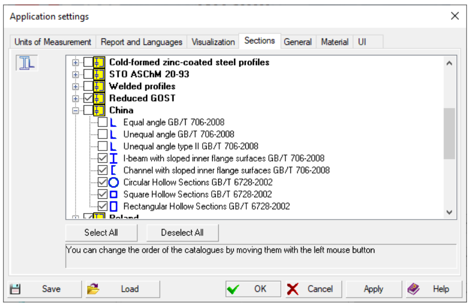


Figure. 5. *The* **Sections** *tab of the* ***Settings*** *dialog box*

The **Sections** tab (Fig. 5) is intended for selecting steel profile catalogues which will be used for creating compound sections. The left list presents titles of catalogues available in the program, and the right one lists catalogues selected for use. There is a checkbox next to each group of catalogues. If the checkbox is not checked, the respective group of catalogues will not be available in the application. Catalogues can be arranged in any convenient order (the same order will be used in the lists or the dialog boxes for the profile selection). To move an item, drag it while holding down the right mouse button.

The full list of assortments provided with the package is given in the appendix.

Other Parameters

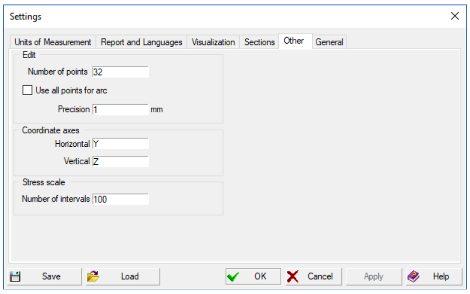


Figure 6. *The* **Other** *tab of the* ***Settings*** *dialog box*

The **Other** tab (Fig. 6) enables to specify names for vertical and horizontal axes (they are named **Z** and **Y** by default).

Depending on the number of intervals specified in the **Number of intervals** field the color scale will be more or less ‘smooth’.

The **Other** tab is also used to assign the tolerance for node coincidence when the section is being constructed (the **Precision** field).

The **Number of points on the circle** determines the number of nodes used during the approximation of the inscribed circle by a polyline, for example, when creating a round hole. If the angles are rounded, the number of points on the arc will be proportional to the central angle of the arc (if the **Use all points for arc** checkbox is not checked).

General

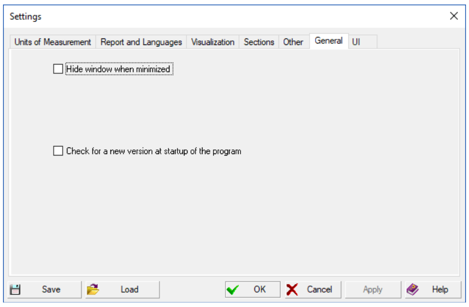


Figure 7. *The* **General** *tab of the* ***Settings*** *dialog box*

The **General** tab (Fig. 7) allows you to activate the **Hide window when minimized** checkbox. When it is active the window disappears from the task bar, and an icon appears in the tray area. The window can be opened from the tray area by the left click, and a context menu – by the right click.

Moreover, the **Check for a new version at startup of the program** checkbox can be activated as well. If it is active, the program will check for a new version on the company website at each startup, and it will give a respective message if it finds a new release.

UI

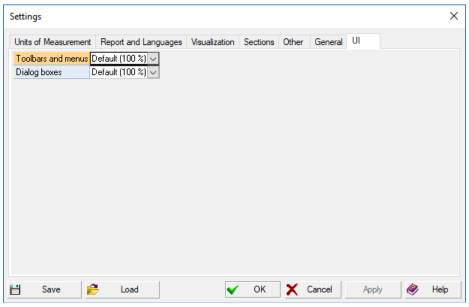


Figure 8. *The* **UI** *tab of the* ***Settings*** *dialog box*

The **UI** tab (Fig. 8) enables to set scales for various user interface elements:

- toolbars and menus;
- dialog boxes.

The settings provided in this tab are intended primarily for users with HiDPI displays.

Multi-tab Workspace

A characteristic feature of **Consul**, **Section Builder** and **Tonus** is the possibility of simultaneous displaying of multiple independent windows each containing a different section in the work area. The windows can be invoked either from tabs at the bottom left corner of the work area, or by pointing a cursor at them. All the windows are controlled using a single toolbar. The operations are performed only in the currently active window.

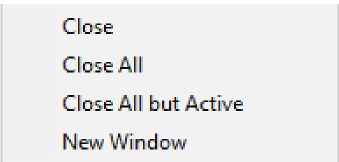


Fig. 9. Tab menu

Right-clicking on the tab of the window opens a menu (Fig. 9) which enables to perform the following operations:

- close the respective window;
- close all windows;
- close all windows, except for the one that corresponds to the tab;
- create a new window.

If the **Workbook** checkbox in the **Settings** menu is checked, tabs with the filenames of sections opened in the windows of the workspace appear in the lower left corner. Clicking on the tab activates the corresponding window.

Saving the Workspace

The settings for each window (workspace) can be saved, which will allow the next session with the program to begin with auto recovery of the settings of the previous session. Program settings are saved in a file, the name of which is specified in the **Save workspace** dialog box (Fig. 10). **File** menu contains the following operations with workspace customization files **Open Workspace, Save Workspace, Close Workspace** and **Save Workspace As**.

Open Workspace item is used to open sections and settings saved in the file in the window. Name of the file containing the workspace parameters is selected from the list in the **Open workspace** dialog box (Fig. 11).

Close Workspace item enables to remove all the windows with sections that have earlier been saved in the file with the workspace parameters from the screen (only). If at this moment new windows with sections are opened or the previously created sections are modified, then a message appears prompting to save the changes in the sections. If the answer is affirmative, then all the changes in sections saved earlier in a workspace file will not only be included in the files with the properties of sections, but also in the file with workspace parameters. Properties of the sections in the "new" windows will not be saved in the file with the workspace parameters. Use **Save Workspace** or **Save Workspace As** items to save them.

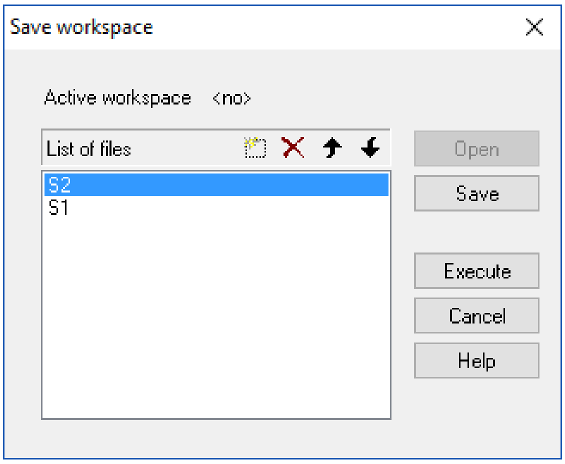


Figure. 10. *The* **Save workspace** *dialog box*

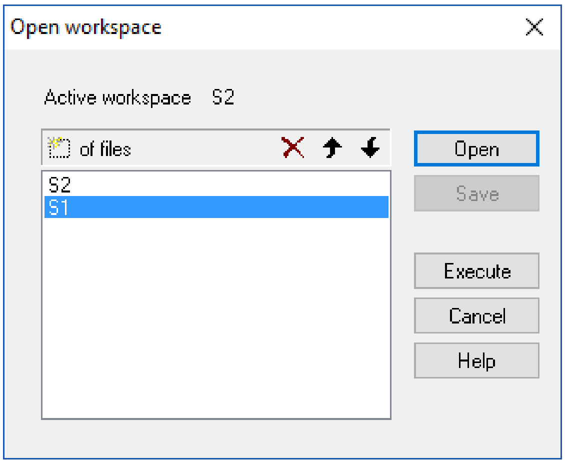


Figure 11. *The* **Open workspace** *dialog box*

If the workspace was not loaded by the **Open Workspace** item, **Save workspace** dialog box appears where you either have to select an existing name of a file, which will be used to save the workspace parameters, or to specify a new name using the respective button. **Save Workspace As** item is used in a similar way.

Menu

Consul, **Section Builder** and **Tonus** have the following pull-down menus in the upper part of the window: **File**, **Edit**, **Settings**, **View**, **Window**, **Service** and **Help**. Information on these menus of each program is given in the table.

Icon	Item	Presence in the programs	Purpose
File menu			
	New		Creates a new section (“hot keys” combination — **Ctrl+N**)

	Open...	[•][•][•][ ]	Opens a previously created section ("hot keys" combination — **Ctrl+O**)
	Create Standard Section ...	[•][•][•][ ]	Creates a section from the set of prototypes
	Close	[•][•][•][ ]	Closes the current section
	Save	[•][•][•][ ]	Saves the created section ("hot keys" combination — **Ctrl+S**)
	Save As...	[•][•][•][ ]	Saves the created section (file) under a different name
	Send ...	[•][•][•][ ]	Sends the file with the description of a section by electronic mail
	Calculate ...	[•][•][•][ ]	Calculates the geometric properties of the section
	Stress Fields...	[•][•][•][ ]	Plots normal stress fields
	Report	[•][•][•][ ]	Generates the report with the properties of the section
	Invoke Consul	[ ][•][ ][ ]	Invokes **Consul**
	Import...	[•][ ][•][ ]	Imports the description of the section created by AutoCAD or other graphic programs
	Structural Steel Sections...	[•][ ][•][ ]	Creates sections from steel profiles
	Find Equivalent Section	[•][•][•][ ]	Invokes **Sezam** which enables to find an equivalent section (a hollow section, an I-beam, a Tee section, or a channel)
	Open Workspace ...	[•][•][•][ ]	Open a file with the workspace parameters
	Save Workspace	[•][•][•][ ]	Save the workspace parameters in a file
	Save Workspace As…	[•][•][•][ ]	Save the workspace parameters in a new file
	Close Workspace	[•][•][•][ ]	Close the workspace
	List of files	[•][•][•][ ]	List of 5 files the user has worked with recently
	Recent Workspaces	[•][•][•][ ]	List of 5 recent files with the workspace parameters
	Exit	[•][•][•][ ]	Finishes the current session
Edit menu			
	Undo	[•][•][•][ ]	Undo the last action
	Redo	[•][•][•][ ]	Redo the previously undone action
	Overall Dimensions...	[•][ ][•][ ]	Specifying the overall dimensions
	Polygonal External Contour	[•][ ][ ][ ]	Creating and modifying an external contour of the section
	Circular External Contour	[•][ ][ ][ ]	Creating a round external contour of a given radius
	Internal Contour	[•][ ][ ][ ]	Creating and modifying a hole of an arbitrary form specified as a polygon

	Circular Hole		Creating a round hole with a dynamically assigned radius
	Circular Hole of Given Radius		Creating a round hole of a given radius
	Parametric Hole...		Creating a rectangular or round hole with given dimensions and a snap point
	Move		Move the whole section or the selected internal contour
	Internal Contour		Type of the section being moved
	Section		
	Move Vertices		Move a group of selected vertices
	Single		Choose a cursor for selecting one object, a group of objects by a rectangular or polygonal marquee
	Rectangle		
	Polygon		
	Copy Internal Contour		Create a copy of a hole
	Single		Choose a cursor for selecting one object, a group of objects by a rectangular or polygonal marquee
	Rectangle		
	Polygon		
	Create Multiple Copies of Internal Contour		Create multiple copies of a hole
	Single		Choose a cursor for selecting one object, a group of objects by a rectangular or polygonal marquee
	Rectangle		
	Polygon		
	Delete		Delete an internal contour
	Delete Vertices		Delete one or several vertices
	Single		Choose a cursor for selecting one object, a group of objects by a rectangular or polygonal marquee
	Rectangle		
	Polygon		
	Round Corner…		Round a selected corner by an arc of the given radius
	Arc		Make a part of the contour in the form of an arc
	Origin …		Shift the origin

	Rotate Section ...	[•][•][•][ ]	Rotate the whole section by a given angle
	Delete	[ ][•][ ][ ]	Delete the selected element from the current section
	Shift, Rotate Element…	[ ][•][ ][ ]	Change the position of the selected element in a section
	Shift Element	[ ][•][ ][ ]	Shift the element selected by the cursor
	Copy Element…	[ ][•][ ][ ]	Copy the selected element n times with a given step
	Select Element…	[ ][•][ ][ ]	View the selected profile in the **Section Element** window
	Modify Element ...	[ ][•][ ][ ]	Change the type and/or the sizes of the selected profile
	Corrosion Layer Thickness...	[ ][•][ ][ ]	Specify the thickness of the corrosion layer
	Strips	[ ][ ][•][ ]	Create strips
	Vertices	[ ][ ][•][ ]	Add vertices by left-clicking in the work area
	Delete Strips	[ ][ ][•][ ]	Delete previously created strips
	Delete Vertices	[ ][ ][•][ ]	Delete previously added vertices
	Move	[ ][ ][•][ ]	Move a group of selected vertices
	Round Angle	[ ][ ][•][ ]	Round a selected angle by an arc of the specified radius
	Thicknesses	[ ][ ][•][ ]	Assign thicknesses to the section walls
Settings menu			
	Settings ...	[•][•][•][ ]	Invoke the **Settings** dialog box where you can customize the program
	Grid Settings ...	[•][•][•][ ]	Specify the grid spacing
	Grid	[•][•][•][ ]	Display the grid in the work area
	Coordinate Axes	[•][•][•][ ]	Display the coordinate axes of the section
	Principal Axes	[•][•][•][ ]	Display the principal axes of inertia of the section
	Center of Mass	[•][•][•][ ]	Display the center of mass of the section
	Shear Center	[•][ ][•][ ]	Display the shear center of the section
	Ellipse of Inertia	[•][•][•][ ]	Display the ellipse of inertia of the section
	Core of Section	[•][•][•][ ]	Display the core of the section
	Snap to Points	[ ][•][ ][ ]	Snaps to points when measuring the distances
	Snap to Grid	[•][ ][•][ ]	Snaps the vertices being added to the nodes of the grid

	Snap to Vertices	[•][ ][•][ ]	Snaps to vertices when measuring the distances
	Vertices Numbers	[ ][ ][•][ ]	Display the numbers of vertices
	Strips Numbers	[ ][ ][•][ ]	Display the numbers of strips
	Vertices	[•][ ][ ][ ]	Display vertices
	Vertices Numbers	[•][ ][ ][ ]	Display the numbers of vertices
	Show/Hide Thicknesses	[ ][ ][•][ ]	Display the whole section taking into account the thicknesses
	Show Closed Loops	[ ][ ][•][ ]	Highlight the closed loops of the section
	Sectorial Coordinate Diagrams	[ ][ ][•][ ]	Display the sectorial coordinate diagram
	Values of Sectorial Coordinates	[ ][ ][•][ ]	Display the values of sectorial coordinates
	Workbook	[•][•][•][ ]	Invokes the tabs for switching between windows in a multi-tab mode
View menu			
	Zoom	[•][•][•][ ]	Zooms the section
	In	[•][•][•][ ]	Zooms in the section
	Out	[•][•][•][ ]	Zooms out the magnified section
	Rect	[•][•][•][ ]	Zooms in the part of the section selected by the rectangle
	Undo	[•][•][•][ ]	Returns to the previous scale
	Initial	[•][•][•][ ]	Returns to the initial scale
	Loupe Tools	[•][•][•][ ]	Displays a magnified image of the selected part in the **Loupe Tools** window
	Toolbar	[•][•][•][ ]	Show/hide the toolbar
	Vertices	[ ][ ][•][ ]	Show/Hide Table of Vertices
	Strips	[ ][ ][•][ ]	Show/Hide Table of Strips
	Section	[ ][ ][•][ ]	Show/Hide the **Section** toolbar
	Edit	[ ][ ][•][ ]	Show/Hide the **Edit** toolbar
	View	[ ][ ][•][ ]	Show/Hide the **View** toolbar
	Status Bar	[•][•][•][ ]	Show/hide the status bar
	Table of Vertices	[•][ ][ ][ ]	Show/hide the table of vertices
	Section Element	[ ][•][ ][ ]	Open/close the **Section Element** dialog box

Window menu			
	New Window		Standard commands of the Windows environment for arranging the windows in a multi-tab mode
	Cascade		
	Tile		
	Arrange Icons		
Help menu			
	Help Topics		Standard commands of the Windows environment for obtaining the help information
	Check for Update		
	About ...		

Status Bar

Status Bar (Fig. 12) contains three fields: **Overall dimensions**, coordinates, and **Distance**. The first field displays the specified overall dimensions. The second field displays the coordinates of the current position of the cursor. The third field is used for displaying additional information (a distance between two points of a section in the measuring mode, stress in the current point).

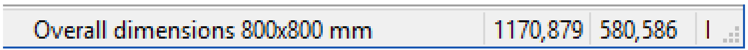


Figure 12. *Status bar*

Toolbar

Pointing and left-clicking on a button in the toolbar invokes the corresponding command. Henceforward, this sequence will be called “clicking the button in the toolbar”.

New Section

This item is used to prepare **Consul**, **Section Builder**, **Tonus** for creating a new section. As a result a new window appears where you can create a new section.

Open a Previously Created Section

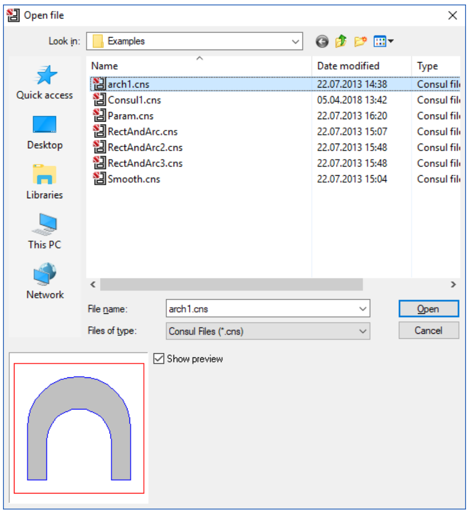


Figure 13. *The* **Open file** *dialog box*

This item enables to open a previously created section. A standard Windows dialog box with a list of files (with the **CNS** or **CON** extensions in **Consul**, the **SEC** extension in **Builder**, or the **TNS** extension in **Tonus**) (Fig. 13) appears once the command is invoked. As in the previous case, the section is opened in a new window.

To preview the sections check the **Show preview** checkbox.

Send

This item enables you to send the file with the information on a section.

Save the Section

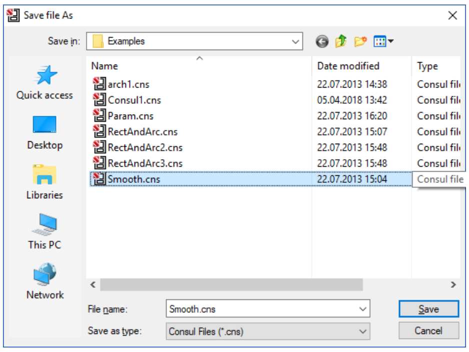


Figure 14. *The* **Save file As** *dialog box*

This item allows you to save the data on a section in a file. If the section has not previously been saved, a standard Windows dialog box appears where you have to enter a file name and select an extension **SEC**, **CNS**, **TNS** or **CON** (Fig. 14).

Undo

This item enables you to undo the previous action. The undo history is unlimited.

Redo

This item enables you to redo the previously undone action.

Rotate the Section

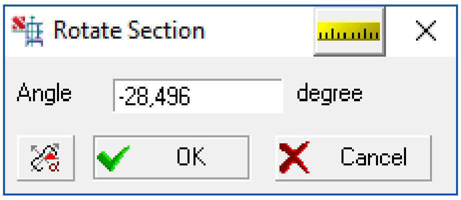


Figure 15. *The* **Rotate Section** *dialog box*

This item enables you to rotate the section by a given angle. The section is rotated about the center of mass of the section. The rotation angle is specified in the **Rotate Section** dialog box (Fig. 15). The button  enables to transfer the angle corresponding to the rotation angle of the principal axes of inertia of the section into the text field.

Create Standard Section

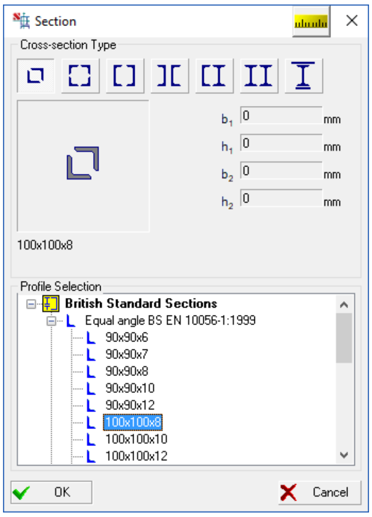


Figure 16. *The* **Section** *dialog box*

The program provides a possibility to create an initial section in the form of a compound section with the help of a set of prototypes. The **Section** dialog box, which appears after clicking the respective button, enables to select a prototype and to set the parameters of the compound section (Fig. 16).

You can select a steel profile catalogue with the desired section from the **Profile Selection** list, which contains only the catalogues included in the **In Use** list in the **Sections** tab of the **Settings** dialog box.

The list of accessible profile groups is defined by the selected cross-section type. For example, if you choose the second section type, only the **Equal Leg Angles** will be accessible.

Import Files

A section can be imported from the AutoCAD system in the **DWG** or **DXF** file formats. The following types of graphic primitives are supported:

3DFACE
SOLID
TRACE
LINE
POLYLINE
LWPOLYLINE
ELLIPSE
CIRCLE
ARC

Moreover, data from other graphic formats such as **3DS**, **IV** etc. can be imported as well.

All the vertices of the section must lie on one plane and all contours must be closed. These conditions are checked during import and if they are not satisfied, the import process is interrupted and the error message appears.

Show Coordinate Axes

This item shows or hides the coordinate axes of the created section.

Show Grid

This item shows or hides the grid. The grid spacing is assigned by clicking the respective button in the **Settings** menu or in the toolbar.

Show Principal Axes of Inertia

This item shows or hides the principal axes of inertia of the created section.

Show the Center of Mass

(red)

This item shows or hides the center of mass of the created section.

Calculate Section Properties

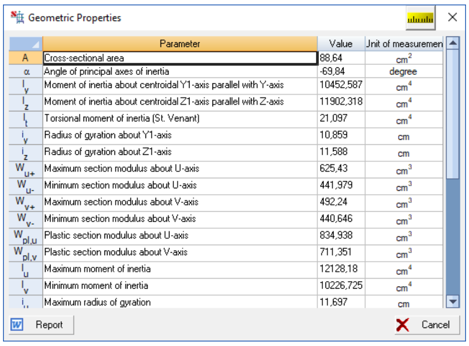


Figure 17. *The* **Geometric Properties** *dialog box*

Once you click this button a calculation of the geometric and stiffness properties of the section is performed and a dialog box with these properties appears (Figure 17). Values of the properties are output with the specified accuracy and in the units of measurement selected for the current section (see the **Units of Measurement**).

Clicking on the button invokes the **Units of Measurement** dialog box (Fig. 18) where you can change the units of measurement, and the **Report** button enables you to generate a report.

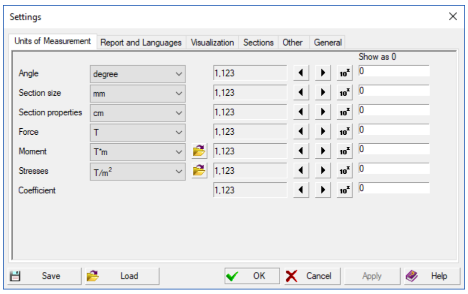


Figure 18. *The* **Setting of units of measurement** *dialog box*

Note that there is the button at the heading of all dialogs where the values having some units of measurements are input or output. This allows you to change the units of measurement directly in the dialog without addressing the Settings.

Display the Stress Fields

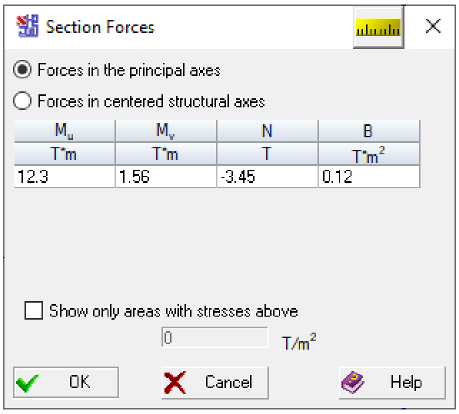


Figure 19. *The* **Section Forces** *dialog box invoked from* **Consul**

When the button is pressed, the program requests information on the internal forces acting in the section. Specify the internal bending moments M_u and M_v acting about the principal axes and the internal axial force N applied to the center of mass in the **Section Forces** dialog box (Fig. 19). Once you close the dialog box the normal stresses fields are displayed in the section (Fig. 20). When calculating the normal stresses in **Tonus**, a bimoment B can be taken into account as well. Its value has to be entered in the respective text field.

Forces can be specified both in the principal axes and in the centered structural axes (axes parallel to the structural axes with the origin at the center of mass).

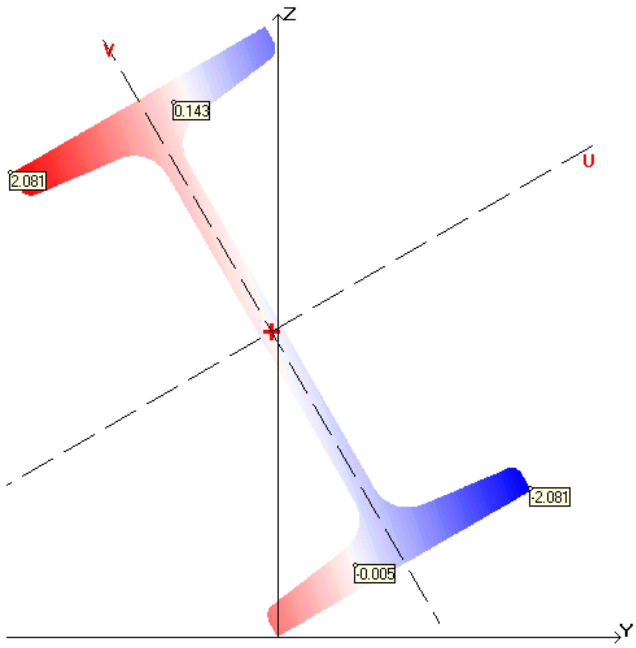


Figure 20. *Normal stresses fields*

If it is necessary to change the values of the internal forces when the normal stress fields are displayed, right-click on any point of the work area, the **Section Forces** dialog box (Fig. 19) will appear where you can enter the new values.

If you need only the fields of the section with absolute stress values exceeding the specified ones, check the **Show only areas with the stresses above…** checkbox and enter the limiting stress value.

When moving the cursor over the section in this mode, the normal stress value at the current position of the cursor is displayed in the status bar.

Stress values in any point of the section can be displayed over the stress fields by left-clicking on the point (minimal and maximal values are always displayed).

If any additional points for displaying the section stresses have been assigned, the following menu appears when you press the right mouse button.

Delete Additional Points
Section Forces

This menu enables to perform one of the two commands of choice: delete the additional points or invoke a dialog box to change the values of the forces in the section.

Consul enables to plot the normal stress diagrams along a specified straight line. To do this, perform the following steps:

- place the cursor over the first point of the straight line;
- press and hold the **Ctrl** key;
- click and hold the left mouse button, and drag the cursor to the second point of the line.

Moreover, **Consul** and **Tonus** enables to plot shear stresses (τ_{yx} or τ_{zx}) and equivalent stresses fields. The type of equivalent stresses fields is selected from the respective drop-down list of the **Stress Fields** dialog box. When calculating the equivalent stresses in **Consul** Huber-Hencky-von Mises theory should be specified in the respective drop-down list as well as in **Tonus** strength theory of Mises or Tresca has to be selected.

Zooming the Section View

A view of the section can be zoomed in. Every time you click the **Zoom In** button — the section view is magnified by 10%. Maximum zoom is 200%. If the section view has been zoomed in, scroll bars appear at the right and bottom edges of the **Work area** allowing you to change the position of the section in the work area. The view can be zoomed out by the **Zoom Out** button. Each time you click on it the magnification is decreased by 10% until you receive the initial view. Press the button to obtain the initial view. Moreover, you can select a part of the section by the marquee zoom or return to the previous scale by clicking on the button .

Loupe Tools

This visualization command allows you to obtain a view of the selected by a rectangular marquee part of a section enlarged to the required scale. The following procedure is recommended:

- click the button in the toolbar, **Loupe Tools** dialog box with the default scale (or the one used the last time) will appear on the screen;
- a rectangular marquee will appear once you start moving the cursor over the work area. The sizes of the marquee correspond to the scale value specified in the **Loupe Tools** dialog box (Fig. 21);
- move the cursor together with the marquee to the part of the section you want to view more closely, so that this area is in the middle of the marquee, and confirm this position by clicking the left mouse button;
- use the slider or the buttons «+» and «-» in the **Loupe Tools** dialog box to set the scale;
- continue working with the object.

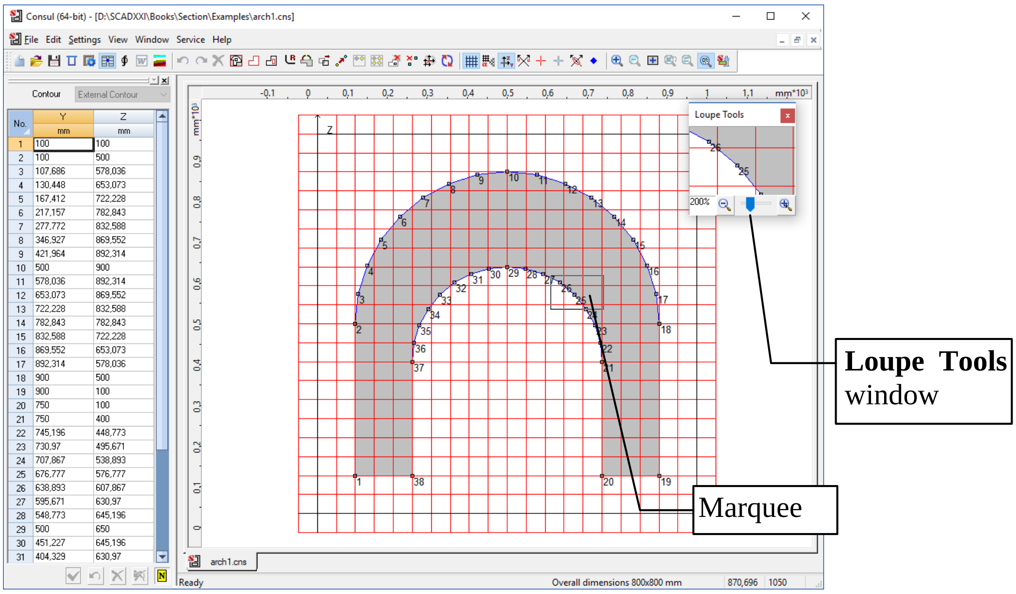


Figure 21. Working with a section view in the **Loupe Tools** mode

Working with the loupe tools does not interrupt any commands, which allows you to continue working with the object after fixing the position of the marquee.

Generating a Report

Once the operation is activated, a report containing properties of the selected section is created. The report is the **RTF** (Rich Text Format) file. After the file is created, an application associated with the **RTF** is automatically invoked (e.g. MS Word or WordPad). If MS Word is used, its version is essential (due to the differences in the data format). The software version installed on the computer is specified during the customization of the program (see **Report and Languages**).

Help

Clicking on the **Help** button invokes the standard Windows function for obtaining the help information on using the application and on its functionality.

Check for Update

Once activated this menu item will check for update on the company’s website and generate the respective message.

About the Program

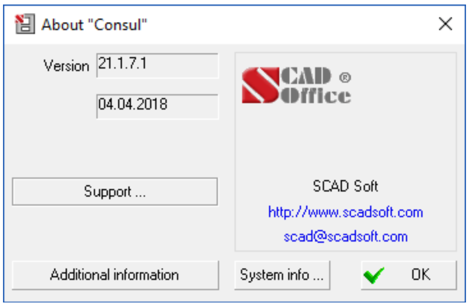


Figure 22. *The* **About** *information window*

Once you click on this button an **About** information window (Fig. 22) is invoked. It contains the information on the version and the developer of the software.

Moreover, there also are the following buttons: **Additional information**, which opens a list of modules comprising the software, and **System info**, which invokes a standard Windows dialog box with the system information.

Consul

Consul window (Fig. 23) contains a menu, a toolbar, a work area and a status bar.

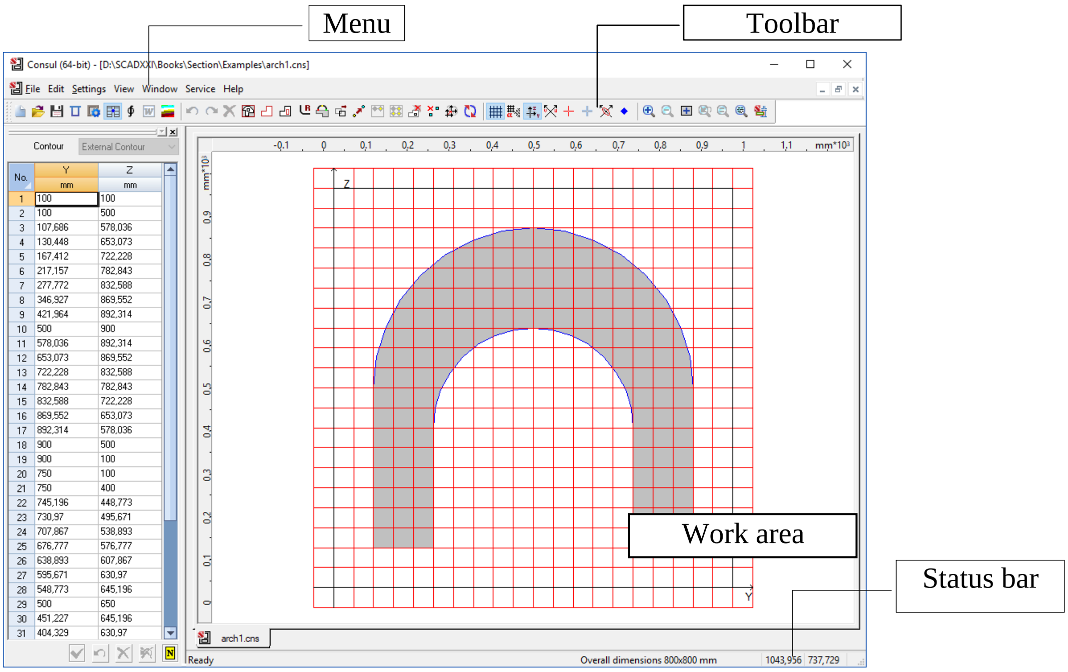


Figure 23. *General view of the* **Consul** *window*

Cursors

All actions are performed in the work area with a cursor. When moving the cursor over the screen or when performing some commands, the shape of the cursor changes. For example, when selecting an item from the menu or the toolbar the cursor takes the form of an arrow, when processing a command the cursor turns into an hourglass (busy cursor). If the cursor is placed over the section contour, it is displayed as a cross with its center coordinates defining its current position. When placed over the node the cursor takes the form of a cross with a target.

A distance between two points of the section can be determined with the cursor. To do this, place the cursor over the first point and left-click. Drag the pointer to the second point while holding the button. The right part of the status bar will display the distance between the points (the accuracy of this indication depends on the precision specified in the **Units of Measurement** tab of the **Settings** dialog box). Coordinates of the current position of the cursor will be displayed in the second field of the status bar.

Creating a Section

It is recommended to follow these steps to create a section:

- specify overall dimensions of the section;
- define parameters of the coordinate grid;
- create the external section contour;
- create the internal contours;
- round the angles (if necessary).

Overall Dimensions

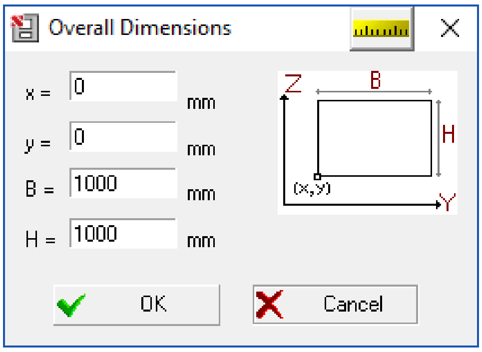


Figure 24. *The* **Overall Dimensions** *dialog box*

A section is created on the coordinate grid the overall dimensions of which are limited by those of the section. Section dimensions are specified in the **Overall Dimensions** dialog box (Fig. 24) in the units of measurement defined in the respective tab of the **Settings** dialog box. Moreover, you can specify the position of the left angle of the rectangle limiting the overall dimensions of the section (*x*, *y*) with respect to the axes of the section.

This rectangle is displayed in the work area (Fig. 25). Values of the section dimensions are displayed in the first field of the **Status Bar**. After creating the external contour of the section the field will display the current overall dimensions of it.

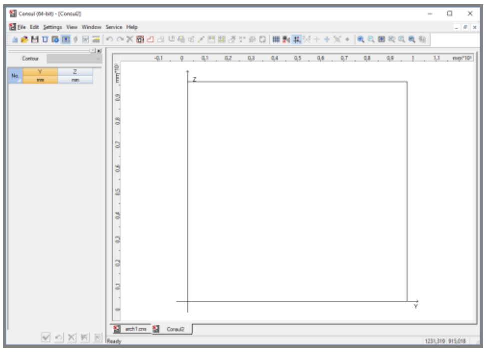


Figure 25. *Overall dimensions displayed in the work area*

Coordinate Grid

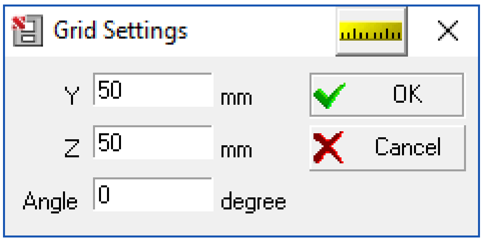


Figure 26. *The* **Grid Settings** *dialog box*

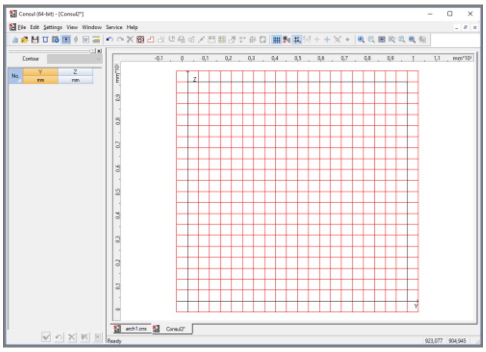


Figure 27. *A grid displayed in the work area*

Parameters of a coordinate grid are specified in the **Grid Settings** dialog box (Fig. 26), which opens once you invoke the respective command. The text fields of this dialog enable you to specify horizontal (along **Y** axis) and vertical (along **Z** axis) grid spacing, and an angle of the grid in degrees with respect to the horizontal axis. The grid is rotated about the origin.

It should be noted that the grid spacing and its angle can be changed as many times as needed during the creation of the section internal contours or editing the external one. This allows you to customize a grid in accordance with dimensions or position of the contours created.

The grid will be displayed once its parameters are entered (Fig. 27). Its visualization is turned on and off by the **Grid** button, , in the toolbar.

External Contour

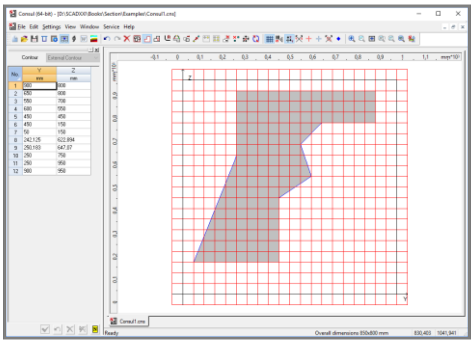


Figure 28. *A section displayed in the work area*

After clicking the respective button the external contour can be created by consecutively adding the vertices of the polygonal contour by the cursor. Each vertex is created by left-clicking. The contour is closed by double-clicking the left mouse button. The last point is connected to the first one and the created section is displayed on the screen (Fig. 28).

The vertices can be placed arbitrarily or snapped to the nearest grid node. If there is no snap, the current coordinates of the cursor will be displayed in the second field of the status bar.

If the **Snap to Grid** option is enabled, the coordinates of the grid node nearest to the cursor will be displayed in the field of the status bar. The current vertex will be snapped to this grid node when left-clicked.

Edit the External Contour

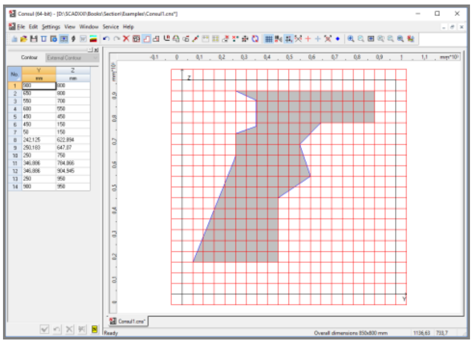


Figure 29. *A section with an edited external contour*

If the contour has already been created, clicking on the **Polygonal External Contour** button enables you to edit the external contour. Place the cursor over any point of the contour to start the editing. After the cursor changes its shape (to a cross for an arbitrary point or to a cross with a target for a vertex), press the left mouse button and “drag” the selected point to a new position. The new vertex is fixed by double-clicking the left mouse button. A section with an edited external contour is shown in Fig. 29.

When moving the vertices the intersection of the sides of the external contour and the intersection of sides of the internal contour with those of the external one are not allowed.

Internal Contours

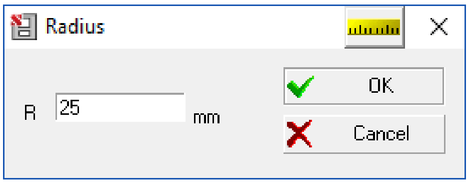


Figure 30. *The* **Radius** *dialog box*

The program provides three types of commands for creating the internal contours:

- creating a contour in the form of a closed polygon;
- creating a contour in the form of a circle with a dynamically assigned radius;
- creating a contour in the form of a circle with a given radius.

The first command can be invoked from the **Edit** menu or from the toolbar, two other commands can be invoked only from the menu (**Circular Hole** and **Circular Hole of Given Radius** respectively).

The sequence of operations for creating and editing a contour in the form of a closed polygon does not differ from that for an external contour of the section.

When creating an internal contour in the form of a circle with a dynamically assigned radius, place the cursor over a point of the section corresponding to the center of the circle, click and hold the left mouse button, and drag the cursor until you reach the required dimensions of the circle. Double click the left mouse button to fix the contour of the hole. If you want to interrupt this operation, click the right mouse button.

If you want to create a circle of a given radius, click on the respective button and specify the radius of the hole in the invoked **Radius** dialog box (Fig. 30). Once you define the snap point of the circle center, the created hole will appear in the section field.

An example of a section with different internal contours is shown in Fig. 31.

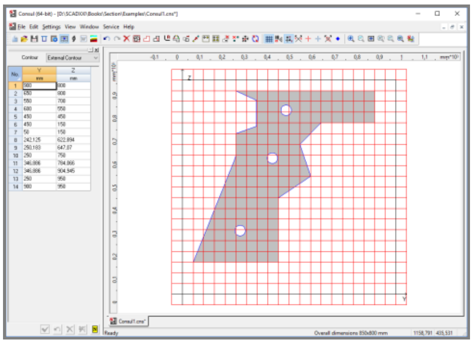


Figure 31. *An example of a section with different internal contours*

When creating polygonal internal contours, their intersection with the external one is not allowed.

Parametric Holes

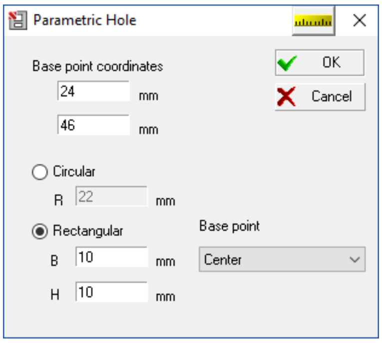


Figure 32. *The* **Parametric Hole** *dialog box*

This command is invoked from the **Edit** menu. It enables you to create a circular or rectangular hole by specifying its base point and dimensions (radius – for a circular hole and sides – for a rectangular one) (Fig. 32). Position of the base point for a rectangular hole is selected from the **Base point** drop-down list. A circular hole is always snapped by its center.

Delete the Internal Contour

To delete an internal contour, invoke the **Delete** command, place the cursor over any point inside the contour you want to delete and click the left mouse button.

Copy the Internal Contour

This command enables to copy one or more internal contours (holes) selected by a rectangular or polygonal marquee. To do this, follow these steps:

- invoke this command;
- select the type of a marquee— rectangular or in the form of an arbitrary polygon;
- select the contours you want to copy by this marquee;
- move the cursor into the marquee, and after the cursor changes its shape, move the marquee together with the selected contours to a new position.

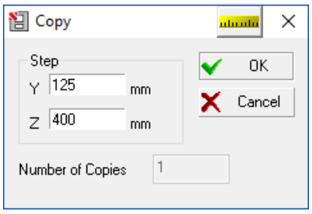


Figure 33. *The* **Copy** *dialog box*

The new position is confirmed by clicking the left mouse button.

If you click the right mouse button after selecting the contours you want to copy by a marquee, the **Copy** dialog box (Fig. 33) will appear where you can specify the precise values of the step.

Create Multiple Copies of the Internal Contour

This command is similar to the previous one (**Copy Internal Contour**). The difference is that after making one copy this process can be continued and a few more copies can be made. Moreover, not only the offset but also the required number of copies can be specified in the **Copy** dialog box, which appears when you click the right mouse button.

Round an Angle

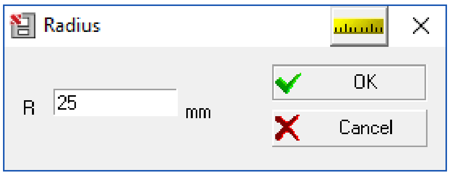


Figure 34. *The* **Radius** *dialog box*

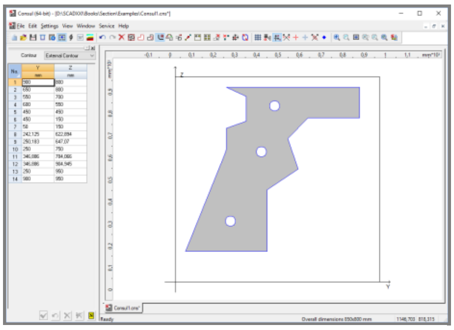


Figure 35. *An example of a section with rounded angles*

An angle can be rounded by inscribing a circular arc of a given radius in it. After you invoke this command, place the cursor over a vertex of the contour (internal or external) and when the cursor takes the form of a cross with a target, click the left mouse button. In the invoked **Radius** dialog box (Fig. 34), specify a radius and click the **OK** button. A section with rounded angles is shown in Fig. 35.

The number of points (nodes) on a circular arc is specified in the **Other** tab of the **Settings** dialog box. The minimum number of nodes on the full circle (including the internal contours) is 4.

When specifying the number of points on a circle, remember that their number greatly affects the calculation time, but at the same time does not affect quality of the result much. The calculation performed by the program is based on the finite elements method. If the specified number of points on the arc is too big, it can lead to the appearance of degenerated finite elements and as a result to the interruption of the calculation.

Create an Arc on the Contour

a) *b)*

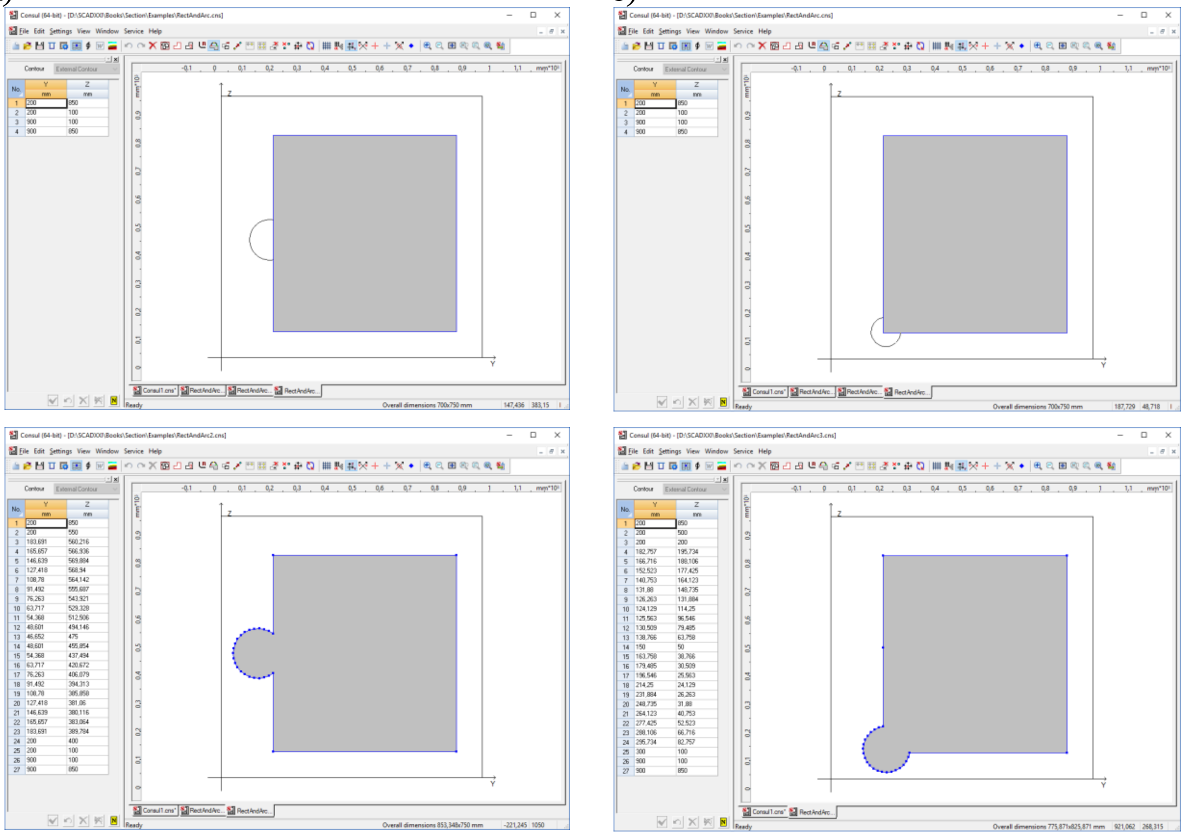


Figure 36. *Create an arc on the contour:*
a) on the side; б) on the corner

This command enables to construct an arc on the internal or external contour of the section. It is constructed through three points, two of which (the beginning and end of the arc) must lie on the contour. The arc can be directed inward or outward from the section. The first and the last point may lie on the adjacent sides of the contour. Number of nodes on the arc depends on the number of points on the full circle specified in the **Settings** dialog box in the **Number of points on the circle** field and is proportional to the length of the arc.

An arc can go beyond the boundary of the section. If this happens, then before constructing the arc you need to change the overall dimensions using the respective command, and then with the help of the **Move Vertices** item move the element within the new limits so that the arc does not intersect the boundary of the section. Perform the following steps to construct an arc:

- place the cursor over the beginning point of the arc and left-click;
- place the cursor over the ending point of the arc and left-click;
- place the cursor over the third point (the arc will be displayed on the screen) and left-click.

Examples of using the **Arc** command are shown in the Fig. 36. An initial arc and the final result are shown for each case.

Move the Contour

This command enables to move the contour to a new position. You can move the whole section or the selected internal contour. The type of the object you want to move is selected in the menu which appears once you invoke this command. The whole section can be moved (shifted) only within the given boundaries. Thus if the section occupies the entire boundary, change the overall dimensions before moving the contour. Follow these steps to perform this operation:

- invoke the command and select the type of the contour you want to move;
- place the cursor inside the contour you want to move and left-click;
- after the cursor changes its shape move the contour to a new position;
- left-click to confirm this new position.

Move Vertices

This command enables to move one vertex or a group of vertices selected by a cursor, rectangular or polygonal marquee. Follow these steps to perform this operation:

- invoke the command and choose a cursor for selecting vertices;
- if you have to move one vertex, select it with a cursor and left-click;
- move the vertex to a new position and left-click to confirm it;
- if you have to move a group of vertices, select them with a rectangular or polygonal marquee;
- move the cursor inside the marquee and when it changes its shape, move the marquee together with the selected vertices to a new position;
- left-click to confirm this new position.

Edit the Coordinates of the Vertices

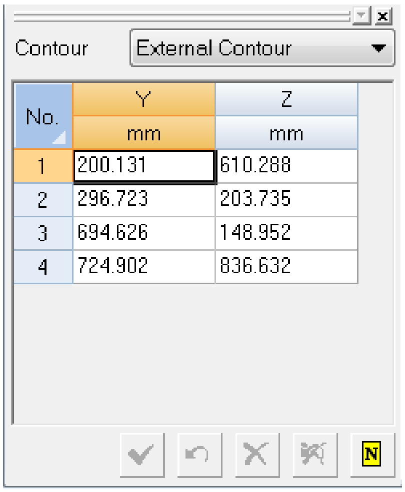


Figure 37. *The* **Coordinates of Vertices** *dialog box*

This command enables to edit the coordinates of the vertices in a tabular form. Click on the **Table of Vertices** button and this table (Fig. 37) will appear on the left from the work area. The dialog box includes a list of contours in the order of their creation and the table with the coordinates of vertices selected from the contour list. Perform the following steps to edit the position of vertices:

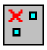
- select a contour from the list;
- press the button to display the numbers of vertices;
- change the coordinates of a vertex in the table of coordinates;
- press the **Apply Modifications** button .

This dialog also contains the following buttons: a button for undoing the performed operation , a button for highlighting the vertices you want to delete and a button for removing these highlights .

To delete the vertices select the respective rows in the table and click on the **Delete Vertices** button. All these vertices will be highlighted in the section and deleted once you press the **Apply Modifications** button.

When moving the vertices the intersection of the sides of the external contour and the intersection of sides of the internal contour with those of the external one are not allowed.

Delete the Vertices



Once you invoke this command, a drop-down menu will appear where you can choose the type of a cursor (marquee) for selecting a group of vertices (or one vertex) you want to delete. A “single” cursor is used to delete one vertex. A rectangular or polygonal marquee can be used to delete several vertices simultaneously. The selected vertices will be deleted when left-clicked.

When deleting the vertices the intersection of the sides of the external contour and the intersection of sides of the internal contour with those of the external one are not allowed.

Cancel the Command

This button enables you to cancel the invoked command and proceed to the measuring mode.

Snap to Vertices

If this item has been enabled in the **Settings** menu, then when measuring the distances, the cursor will be snapped to the nearest vertex, i.e. only the distances between the vertices of the contours are measured.

Shift the Origin

This command is used to move the origin to a point with specified coordinates, or to the center of mass of a section (Fig. 38).

Since the application can calculate moments of inertia with respect not only to the principal axes, but to a custom coordinate system as well, the capability of moving the origin can be useful in geometric analysis. Moreover, the grid is rotated about its origin, therefore moving the origin can be also useful when creating the contours.

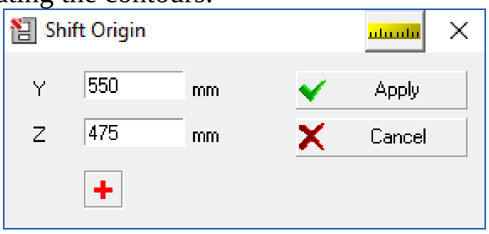


Figure 38. *The* **Shift Origin** *dialog box*

If you need to move the origin to the center of mass, click the red cross button. This will put the coordinates of the center into the respective text fields.

The origin will be moved to the specified point once you click the **OK** button.

Select a Structural Steel Section

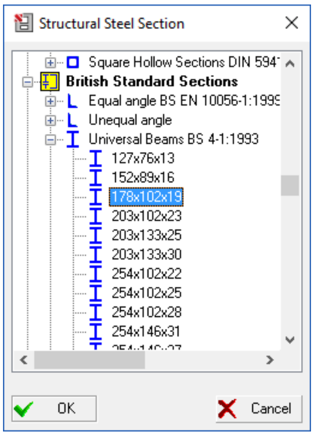


Figure 39. *The* **Structural Steel Section** *dialog box*

This command, which is invoked from the **File** menu, is used to select a section from the database, to modify it if necessary, and to examine its geometric properties. The section can be selected in the **Structural Steel Section** dialog box (Fig. 39).

Show the Shear Center

 (blue)

This item shows or hides the shear center of the created section.

Standard Sections

A set of standard parametric sections can be used to create a section. **Create Standard Section** command is invoked from the **File** menu. The **Standard sections** dialog box (Fig. 40) appears, which contains a list of standard sections, their images with a legend of properties, and fields for entering their numerical values.

Perform the following steps to create a section:

- select a section from the drop-down list;
- enter values in the fields in accordance with the selected model;
- click the **OK** button.

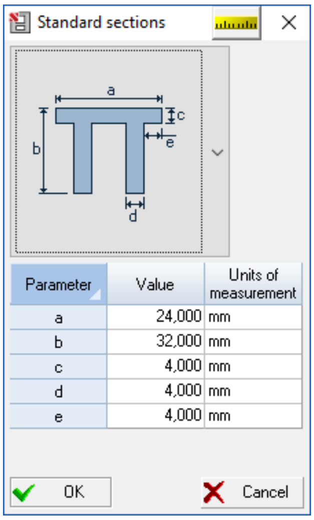


Figure 40. *The* **Standard sections** *dialog box*

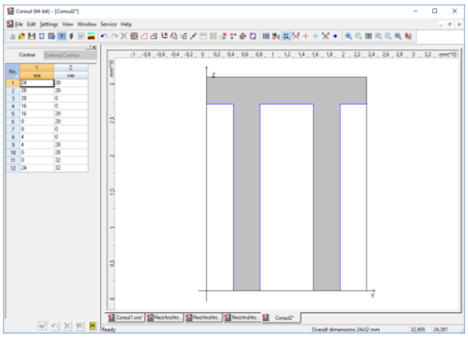
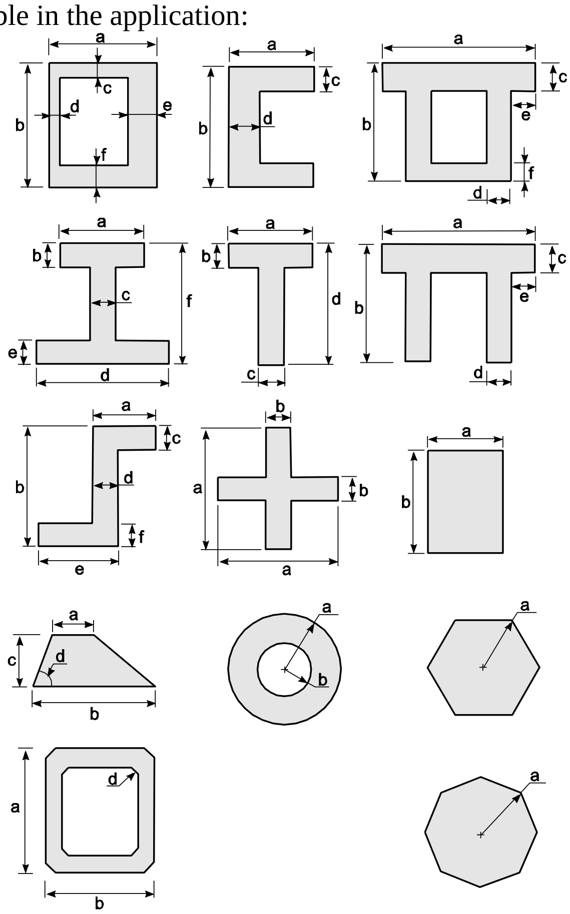


Figure 41. *Resultant section*

The last action will close the dialog box, and the created section will be displayed in the work area of the **Consul** window (Fig. 41).

The section can be modified using the commands from the toolbar. For example, the section contour can be changed, holes can be added, angles can be rounded, etc.

The following set of standard parametric sections is available in the application:



Section Builder

The main elements of the user interface are focused in two windows — **Section Element** (Fig. 42) and **Section Builder** (Fig. 43). The **Section Element** dialog box enables to select a structural steel profile or a plate, change their position, control the assembly process, and contains an assembly history table. The **Section Builder** window enables to edit and save the section similarly to **Consul**.

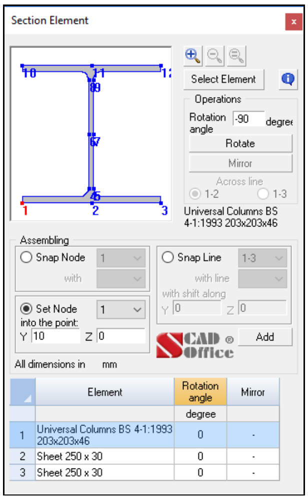


Figure 42. *The* **Section Element** *dialog box*

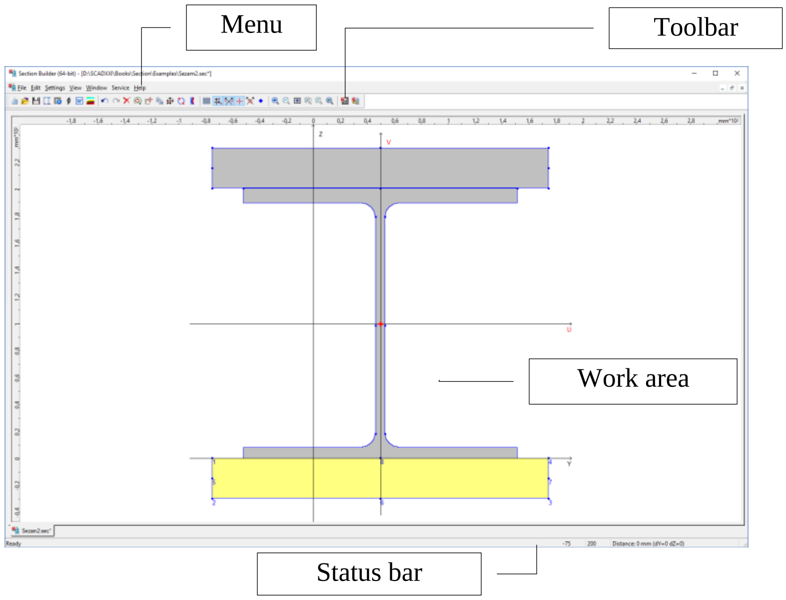


Figure 43. *The* **Section Builder** *window*

Cursors

All actions are performed in the work area with a cursor. When moving the cursor over the screen or when performing some command, the shape of the cursor changes. For example, when selecting an item from the menu or the toolbar, the cursor takes the form of an arrow, when processing a command the cursor turns into an hourglass (busy cursor).

A distance between two points of the section can be determined with the cursor. To do this, place the cursor over the first point and left-click. Drag the pointer to the second point while holding the button. The right part of the status bar will display the distance between the points (the accuracy of this indication depends on the precision specified in the **Units of Measurement** tab of the **Settings** dialog box). Coordinates of the current cursor position will be displayed in the middle part of the status bar.

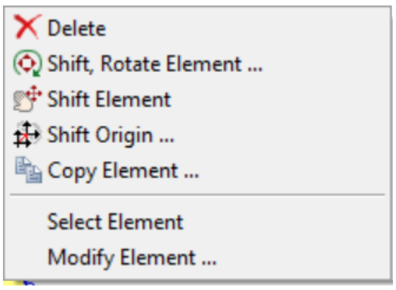


Figure 44. *Menu of the selected element*

Left-click on the element to select it, and right-click to invoke a menu (Fig. 44), where you can select one of the following commands: **Delete** (delete the selected element), **Shift, Rotate Element**, **Shift Element**, **Shift Origin**, **Copy Element**, **Select Element** (a section is selected from the structural steel sections database and opened in the **Section Element** dialog box) and **Modify Element** (**Element Selection** dialog box appears providing access to the structural steel sections database). A description of these commands is provided below. Moreover, double-clicking the left mouse button on the element invokes a window with information on this element.

Section Element Dialog Box

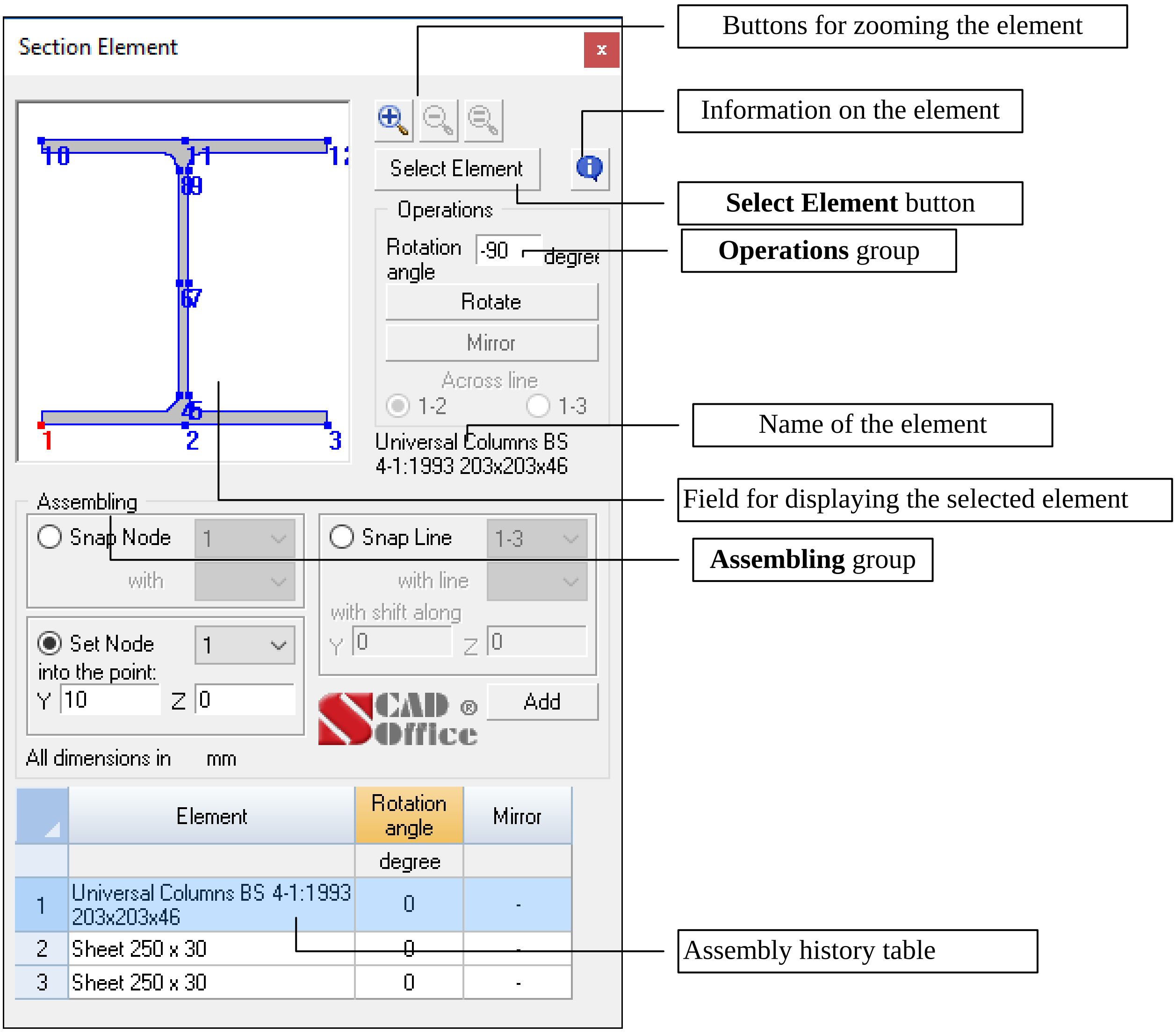


Figure 45. *The* **Section Element** *dialog box*

The **Section Element** dialog box (Fig. 45) enables to select a structural steel profile or a plate from the database, specify their orientation, and control the assembly process. Most controls of this dialog box are gathered into two groups – **Operations** and **Assembling**. Moreover, the dialog box contains **Select Element**, **Zoom In**, **Zoom Out**, **Zoom Initial** buttons, an assembly history table, and a field for displaying the selected element.

Element Selection Dialog Box

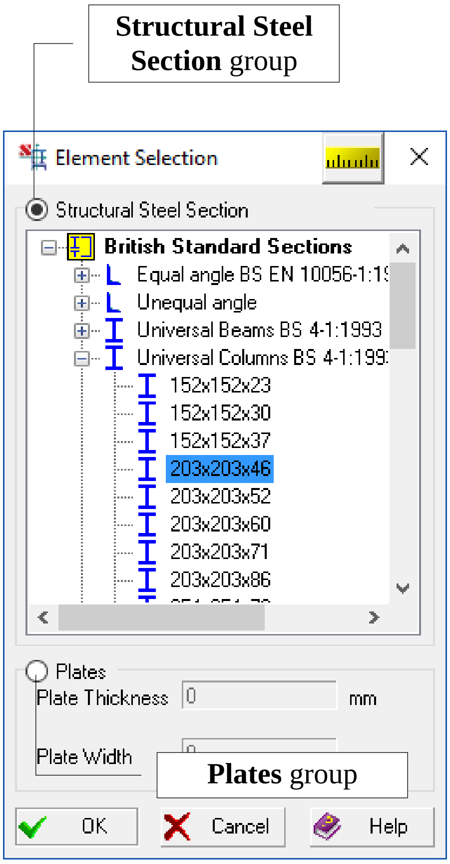


Figure 46. *The* **Element Selection** *dialog box*

The **Element Selection** dialog box (Fig. 46) is invoked by clicking the **Select Element** button. This dialog box is used to select structural steel sections (**Structural Steel Section** group) and to specify the dimensions of plates (**Plates** group).

Perform the following steps to select a structural steel section from an assortment:

- enable the **Structural Steel Section** radio button;
- select a section from the list;
- click the **OK** button.

If you want to use a plate as an element of the section, enable the **Plates** radio button, enter the thickness and width of the plate in the respective text fields and click the **OK** button.

Once the dialog box is closed the name and the scaled image of the selected element will be displayed in the **Section Element** dialog box.

If the nodes of the selected element can not be clearly seen in the image, use the **Zoom In** button. Every time you press this button the image is magnified by 10%. Maximum zoom is 200%. If the image has been zoomed in, scroll bars appear. The **Zoom Out** button decreases the magnified image in the **Section Element** dialog box by 10% at each click until it reaches its initial scale.

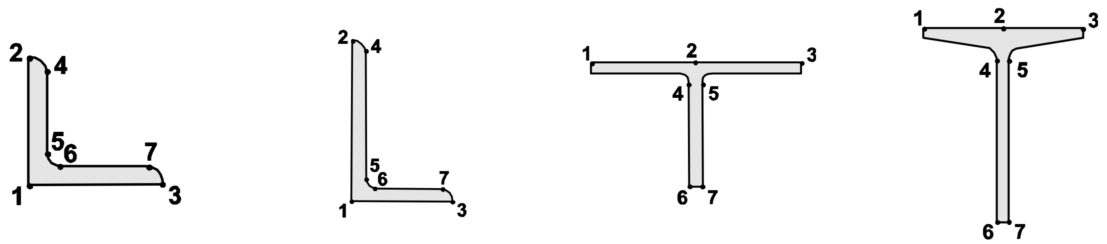
Orientation of Elements

Orientation of the selected element before adding it to the section is performed using the **Rotate** and **Mirror** commands from the **Operations** group. Each element has some nodes used to snap this element to the section.

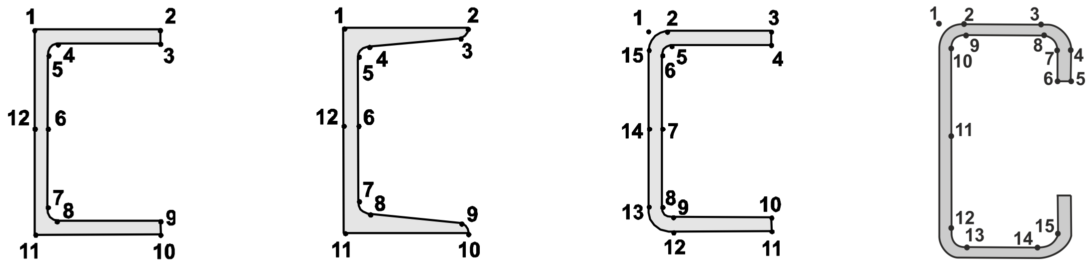
An element will be rotated by an angle specified in the **Rotation Angle** field once you click the **Rotate** button. Positive angle corresponds to the counterclockwise rotation.

While using operation **Shift and/or Rotate an Element** (see below) rotation of the element is performed about ***base*** point.

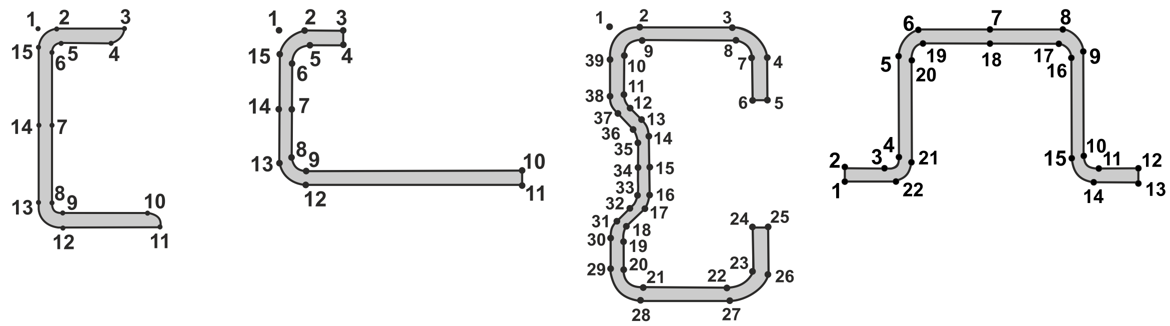
Different sections with nodes and base points are shown in Fig. 47.



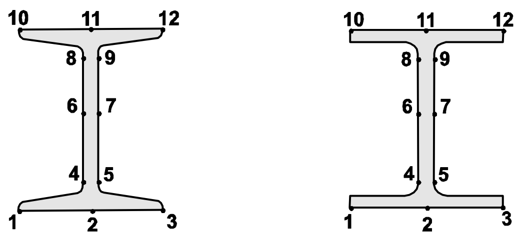
(base node 1)



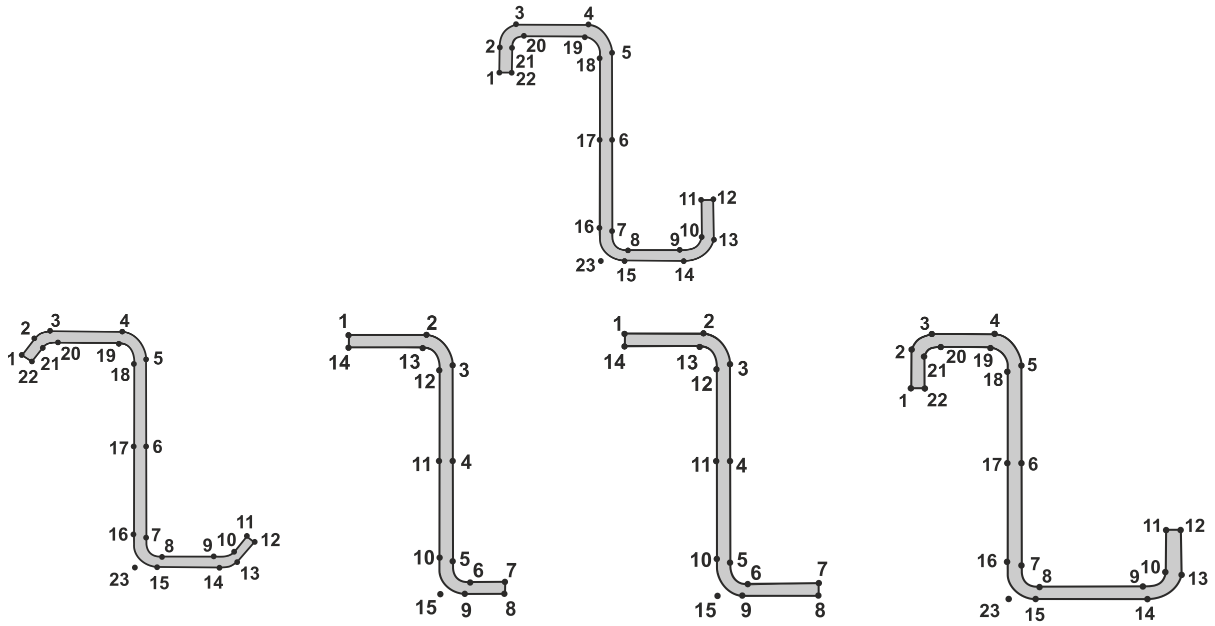
(base node 1)



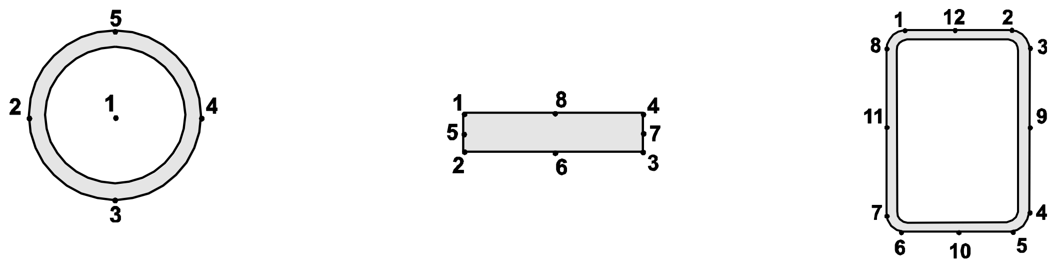
(base node 1)



(base node 1)



(base node is located in the centerof the web)



(base node is located in the center of gravity)

Рис. 47. *Location of nodes and base points in various elements*

Angles and channels can be mirrored using the **Mirror** button. Channels are mirrored about the vertical axis going through the base point 1, and angles can be mirrored about the vertical axis (**1-2** radio button) or the horizontal one (**1-3** radio button).

Information on the Element

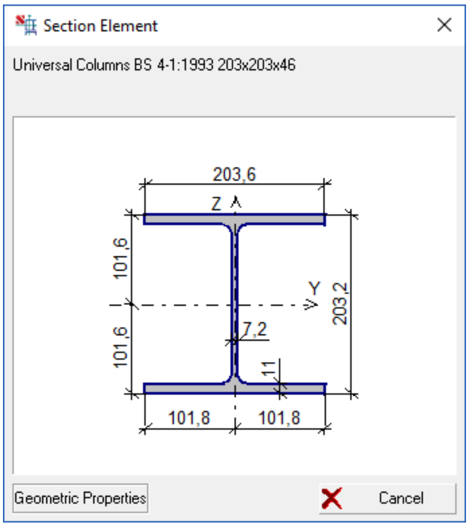
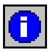


Figure 48. *The* **Section Element** *information window*



The **Element Information** button is used to open a **Section Element** information window (Fig. 48), where the selected element and its dimensions are displayed. Clicking the **Geometric Properties** button invokes the **Geometric Properties** window, which provides the main parameters of the section (area and moments of inertia). Click the **Cancel** button to return to the **Section Element** window.

Assembly History

	Element	Rotation angle	Mirror
		degree	
1	Column I-beam GOST 26020-83 26K2	0	-
2	Sheet 100 x 10	0	-
3	Sheet 100 x 10	45	-

Figure 49. *An assembly history table*

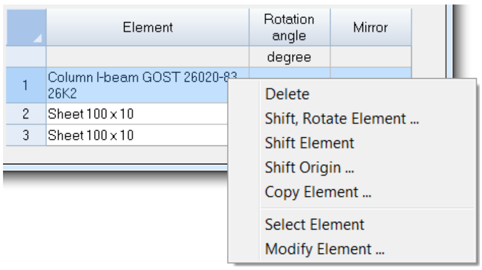


Figure 50. *Invoking commands from the menu*

Lower part of the **Section Element** dialog box contains an assembly history table (Fig. 49), where all the elements included in the compound section are listed in the order they were added to the section. This table also provides information on whether the element has been mirrored and on the angles of rotation about Y-axis of the coordinate system of the section.

Double-clicking on a row of the table highlights it and selects the corresponding element of the section (it is highlighted in the **Section Builder** window).

Right-clicking on the selected row invokes the same menu as that for the selected element.

Operations

Shift the Origin

This command is used to move the origin to a point with specified coordinates, to a node of the selected element or to the center of mass of a section (Fig. 51). Since the application can calculate moments of inertia with respect not only to the principal axes, but to a custom coordinate system as well, the capability of moving the origin can be useful in geometric analysis.

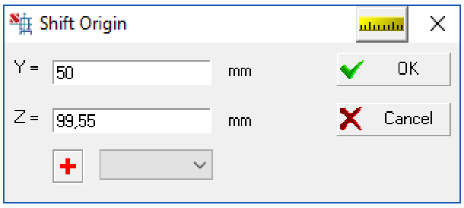


Figure 51. *The* **Shift Origin** *dialog box*

If you need to move the origin to the center of mass or to a particular point of the selected element, click the red cross button or select the number of the point from the drop-down list, respectively. This will put the coordinates into the respective text fields.

The origin will be moved to the specified point once you click the **OK** button.

Delete a Section Element

This item enables to delete an active (selected) element from the section. To do it, left-click on the element you want to delete (it will be highlighted) and press **Delete** or the respective button in the toolbar.

Shift and/or Rotate an Element

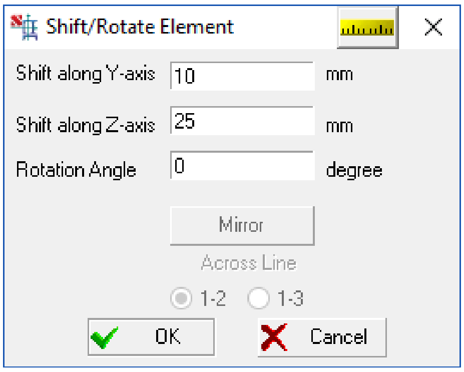


Figure 52. *The* **Shift/Rotate Element** *dialog box*

This command enables to shift, mirror and/or rotate the selected section element. Shift and rotation parameters are specified in the **Shift/Rotate Element** dialog box (Fig. 52). The **Mirror** command makes sense only for angles and channels. Channels are mirrored about the vertical axis. Angles can be mirrored about the horizontal axis (**1-3** radio button) or the vertical one (**1-2** radio button). The element will change its position in the section in accordance with the parameters specified in the dialog box once the dialog box is closed by clicking the **OK** button.

Snap to Points

If the **Snap to Points** checkbox has been checked in the **Settings** menu, then when measuring the distances, the cursor will be snapped to the nearest node, i.e. only the distances between the nodes of the section elements are measured.

Corrosion

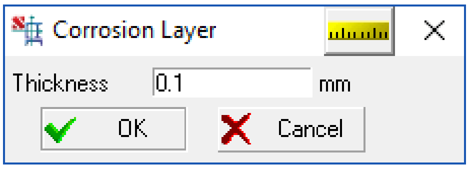


Figure 53. *The* **Corrosion Layer** *dialog box*

This command enables to take corrosion into account in the calculation of the geometric properties of the section. The thickness of the corrosion layer is assumed to be uniform along the perimeter of all section elements. This thickness is specified in the **Corrosion Layer** dialog box (Fig. 53).

If a reinforced section is calculated, it is assumed that only the elements of the main section are subject to corrosion.

Shift an Element

This item enables to shift an element selected by the cursor. To do it, invoke this command, place the cursor inside the element you want to move, click and hold the left mouse button, and drag the element to a new position.

The shifted element is snapped to the section in such a way that one of its nodes (the cursor has to be placed beside this node when moving the element) is merged with a node of the other section element.

Copy an Element

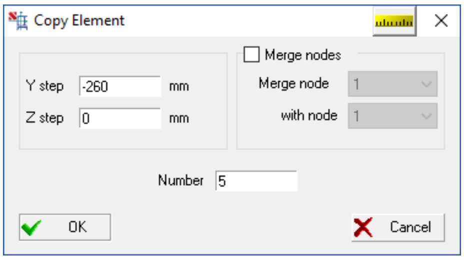


Figure 54. *The* **Copy Element** *dialog box*

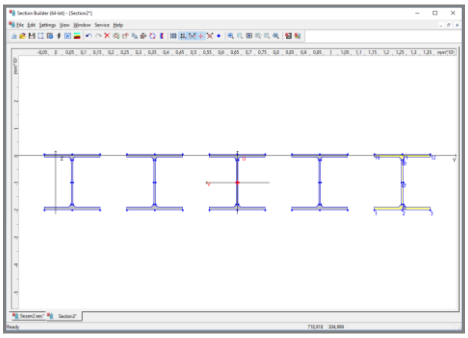


Figure 55. *The result of copying*

This command enables to copy an active (selected) element the given number of times with a specified step in the **Y** and **Z** axes directions. To perform this command select an element you want to copy (it will be highlighted) and click on the respective button in the toolbar. Specify the steps for copying in **Y** and **Z** axes directions and the number of copies in the **Copy Element** dialog box (Fig. 54).

If the copies of an element have to be placed in such a way that a particular node of every element is merged with a given node of the previous copy, then check the **Merge nodes** checkbox and specify the numbers of the merged nodes in the **Copy Element** dialog box. When selecting nodes, the program calculates the offset values (which can be changed if it is necessary to create a certain gap).

The result of the copying is shown in Fig. 55.

Section Assembling

To add an element to the compound section, perform the following steps in the **Section Element** dialog box:

- click the **Select Element** button;
- select a structural steel section or enter the dimensions of a plate in the invoked **Element Selection** dialog box;
- specify the orientation of the element in the section in the **Operations** group;
- select a method of adding the element to the section in the **Assembling** group, and press the **Add** button.

Adding an Element to the Section

Operations for adding an element to the compound section are performed in the **Assembling** group. Assembling means connecting an element selected in the **Section Element** dialog box to one of the previously created elements or snapping it to a section node defined by its coordinates.

Section Builder provides the following methods of assembling:

- joining a new element by one of its nodes to a node of a section element;

- joining a new element by one of its nodes to a section point defined by its coordinates;
- joining an element by merging lines that are going through two nodes of the new element and the selected element of the section.

When using the first two methods, the element is added to the section with an orientation specified in the **Section Element** dialog box. When joining by a line, the orientation of an element in the section is defined by the orientation of the lines used to join the elements. Only the second method can be used for creating the first element.

All these methods are described below.

Creating the First Element

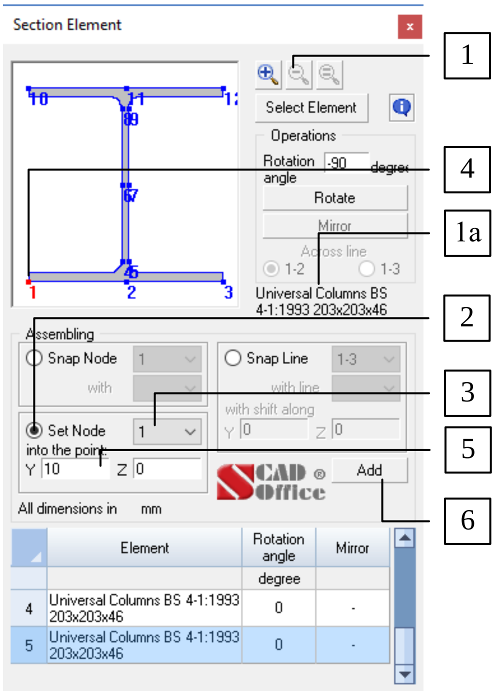


Figure 56. *Sequence of actions for creating the first section element*

Perform the following steps to create the first section element:

- select the first section element in the **Section Element** dialog box (Fig. 56), e.g. I-section 20B1 $\boxed{1a}$ using the **Select Element** button $\boxed{1}$;
- select the **Set Node** radio button $\boxed{2}$;
- select the number of a node which will be set into the point with the specified coordinates from the drop-down list $\boxed{3}$ (e.g. No.1). This node will be highlighted in the section $\boxed{4}$;
- specify the coordinates of the point $\boxed{5}$ the node will be set into (e.g. Y = 0, Z = 0);
- click the **Add** button $\boxed{6}$.

Once the last operation is performed, the created structural steel section will be displayed in the work area of the **Section Builder** window. The assembly history table will simultaneously appear in the bottom of the **Section Element** dialog box. The first row of this table will contain information on this section element (Fig. 57).

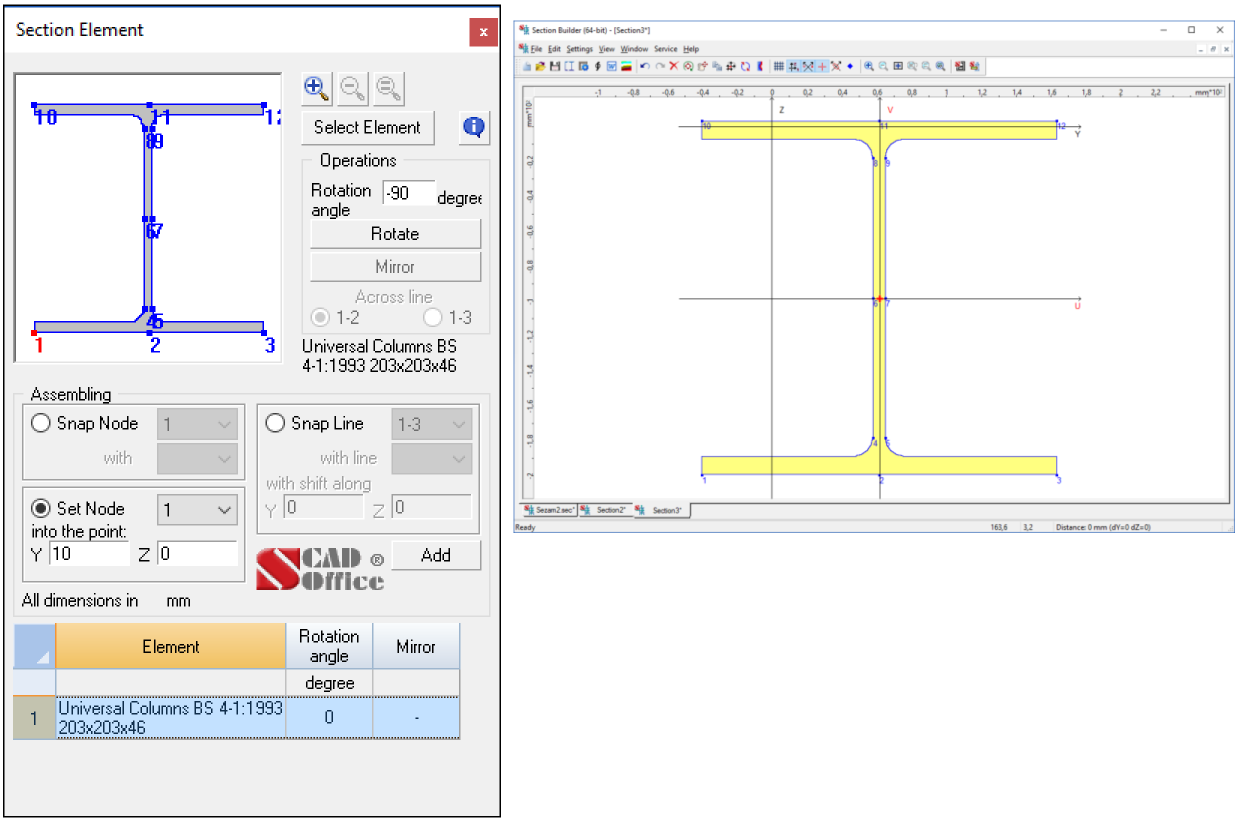


Figure 57. *Result of creating the first section element*

First Method of Assembling

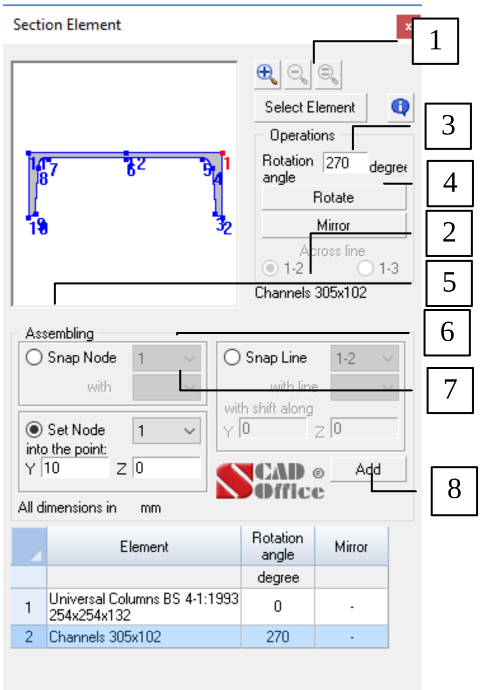


Figure 58, *a)*

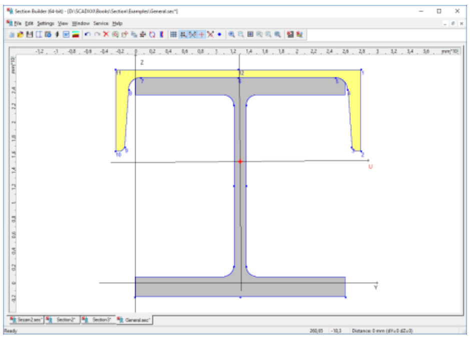


Figure 58, *b)*
Sequence of actions when the first method of assembling is used a) and a section obtained in the result b)

The first method of assembling enables to add a new element to the section by joining a selected node of this element to a selected node of the active section element. An active element is an element of a section a new element is joined to. The active element can be selected by clicking on it in the work area of the **Section Builder** window or by selecting a row in the assembly history table of the **Section Element** dialog box.

Let's join the channel with parallel flanges 14P to the I-section 20B1 created earlier. The assembling is performed in the following way:

- select the element you want to add $\boxed{2}$ in the **Section Element** dialog box (Fig. 58, *a*), using the **Select Element** button $\boxed{1}$;
- specify a rotation angle in the **Operations** group, e.g. 270° $\boxed{3}$;
- click the **Rotate** button $\boxed{4}$;
- select the **Snap Node** radio button $\boxed{5}$ in the **Assembling** group;
- select the number of a node (e.g. 1) which will be merged with a node of an active section element from the drop-down list $\boxed{6}$. This node will be highlighted in the section displayed in the **Section Element** dialog box;
- select an active section element, e.g. I-section, with the cursor in the **Section Builder** window. The element and all its nodes will be highlighted;
- select the number of a node of an active section element (e.g. 11) which will be merged with the node 6 of a new element from the drop-down list $\boxed{7}$ in the **Section Element** dialog box. This node will be highlighted in the assembled section displayed in the **Section Builder** window;
- click the **Add** button $\boxed{8}$.

Second Method of Assembling

The second method of assembling has already been considered in the description of the procedure for the first section element creation. It should also be noted that an element with the orientation (rotation angle, mirroring option) specified in the **Section Element** dialog box can be joined to a point with the given coordinates.

Third Method of Assembling

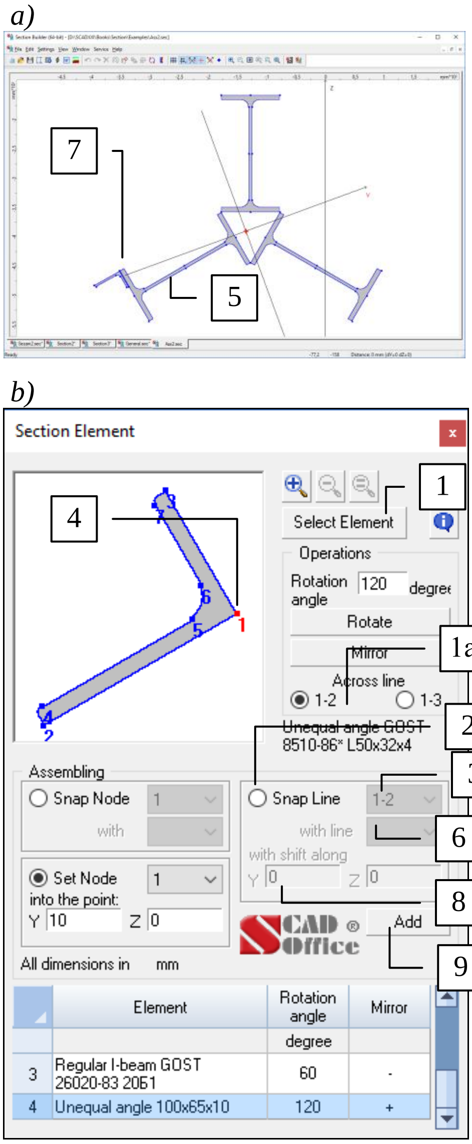


Figure 59. *Joining by a line*
a) initial section,
b) element being added

The third method is characterized by the possibility of connecting an element to the section (an active element of the section) by merging the lines defined by the selected couples of nodes in the added element and in the active section element. The first node of this line of the added element is snapped to the first node of this line of the active element.

The added element can be moved by specifying the shift components ***y*** (along the snap line of the active section element) and ***z*** (perpendicular to this line). The snap lines stay parallel. This method is convenient when inclined elements are added to the section.

Let's add an angle (Fig. 59, *b*) to the section shown in Fig 57, *a*. The assembling is performed in the following order:

- select an element, e.g. an unequal leg angle 50x32x3 1a you want to add to the previously created section using the **Select Element** button 1 in the **Section Element** dialog box (Fig. 59, *b*);
- select the **Snap Line** radio button 2 in the **Assembling** group;
- select the numbers of nodes defining the line of the angle which will be merged with a line of an active section element (e.g. 1-2) from the drop-down list 3. The line going through the specified nodes 4 will be highlighted in the section displayed in the **Section Element** dialog box;
- select an active section element, e.g. an I-beam 5, with the cursor in the **Section Builder** window. The element and all its nodes will be highlighted;
- select the numbers of nodes defining the line of an active section element which will be merged with a line of an angle (e.g. 12-10) from the drop-down list 6 in the **Section Element** dialog box. This line will be highlighted 7 in the assembled section displayed in the **Section Builder** window;
- enter the shift value, e.g. along the flange (*y=0*) 8;
- click the **Add** button 9.

The section obtained in the result is shown in Fig. 60.

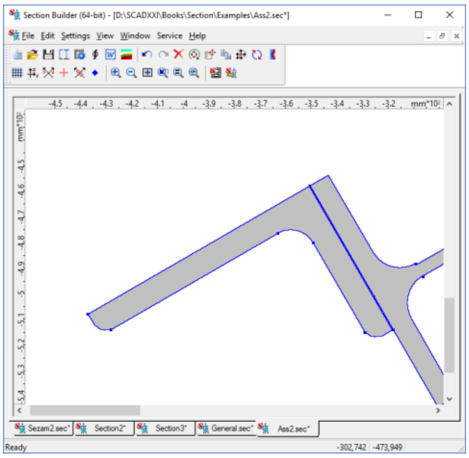


Figure 60. *Section obtained in the result*

The following things should be considered when using this method:

- the new element is added to the section in such a way that the first node of the snap line of this element is merged with the first node of the snap line of the active section element (if there is no shift);
- the shift of the added element is performed along the local coordinate axes **yz** with the origin being at the first node of the snap line of the active section element;
- when the section is being assembled, the control over the intersection of the added element with the existing section is performed and if detected, a respective message is generated.

Intersection of the Section Elements

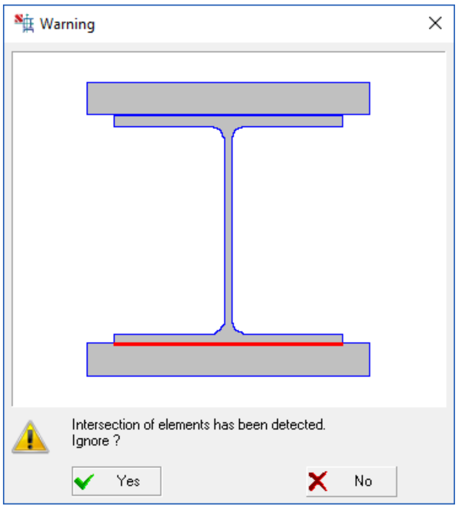


Figure 61. *Message window*

A message warning about the intersection of section elements is noteworthy. The message window (Fig. 61) suggests ignoring this information (**Yes**) or removing the intersecting element from the section (**No**). There is no unambiguous answer. If it is obvious that a mistake has been made in the initial data or when adding a new section element, then the correct answer is **No**. However, in some cases the intersection occurs due to mistakes of approximation when dealing with floating-point numbers (e.g. approximate calculation of the values of trigonometric functions). Such mistakes usually arise at the rotation of an element. In such cases answer **Yes** is recommended. The same answer is also given if the user is aware of the intersection because the final positioning of the element is intended to be performed with the **Shift**, **Rotate** or **Mirror** commands.

Strengthening

When analyzing steel structures with increased sections their two unequal parts should usually be distinguished:

- the main one that existed before the strengthening;
- additional (strengthening), which is attached to the main part in such a way that the combined (strengthened) section works as a single unit.

Section Builder enables to create and analyze both regular and strengthened sections. For this purpose, it is possible to “specify” individual parts as strengthening elements, obtain geometric properties of both the main and strengthened sections, and also analyze normal stress fields in the strengthened section. The toolbar provides the following operations:

 — specify the selected element as a part of the main section or the strengthening element;

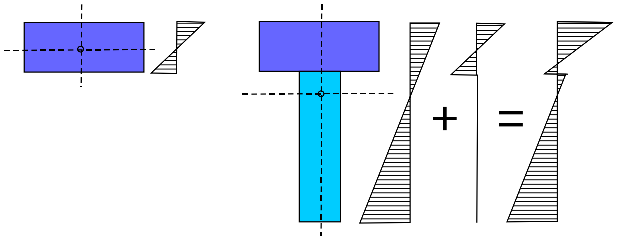
 — display the principal axes, center of mass, ... of the full section;

 — display the principal axes, center of mass, ... of the main section;

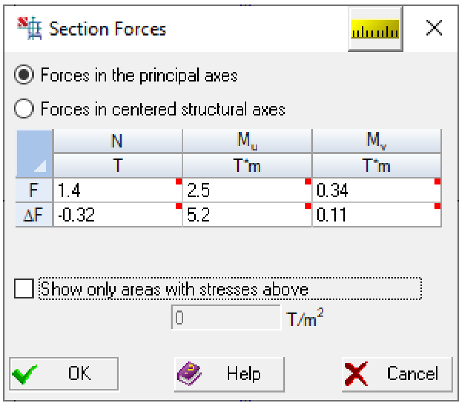
—

Some forces could have acted in the main section before the strengthening. The strengthening element is attached in an unstressed state and the stresses in it arise due to the work as a part of the combined section. The combined section can be subjected to forces additional to those previously specified for the main section.

The stresses previously acting in the main section are added to the stresses in the strengthened section.



If there are strengthening elements, the dialog box for specifying forces and generating normal stress fields looks as follows:



Tonus

Tonus enables to build thin-walled sections and calculate their geometric properties.

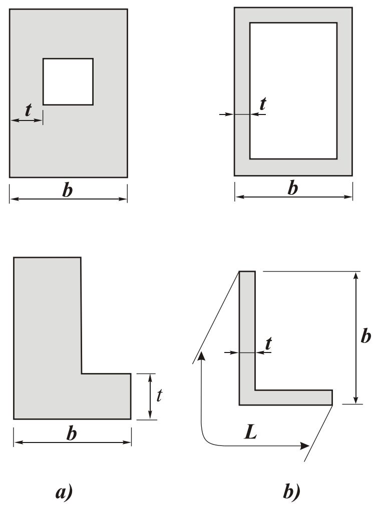


Figure 62.

Thin-walled bars can be found in a great variety of structures used in various fields of engineering. In some cases a thin-walled bar model describes a structure as a whole (such as a multi-storey building with load-bearing walls or a span of a bridge), while in other cases this model can be used to describe important load-bearing components of a framework.

In structural mechanics, a **bar** refers to a body with the maximal overall cross-sectional dimension, b_{max}, much smaller than the length, *l*.

The minimal cross-sectional dimension of a **solid bar**, t_{min}, has the same order of magnitude as b_{max} (Fig. 62, *a*). For **thin-walled bars** $t_{min} << b_{max}$ so, obviously, $t_{min} << L$, where *L* is the length of the cross-section contour of the bar [8] (Fig. 62, *b*). A bar is usually considered to be thin-walled if the following inequalities hold:

$$t / b < 0{,}1; \quad b / l < 0{,}1.$$

A key difference in the behavior of a thin-walled bar under a load from that of a solid bar is that the plane-sections hypothesis can be violated in the case of the thin-walled bar. A typical example is a free torsion of an open-profile bar (a pipe with a longitudinal cut) or a deformation of an I-beam loaded by a bimoment at its end (Fig. 63).

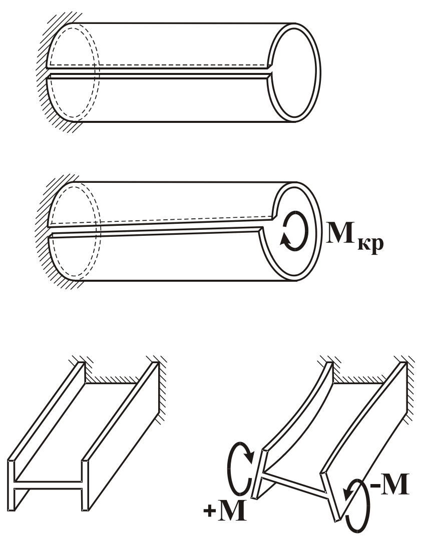


Figure 63.

A deviation from the plane-sections hypothesis is a feature more immanent to **open-profile** thin-walled bars than to **closed-profile** ones.

A theory for analysis of open- and closed-profile bars of this type was developed by V.Z.Vlasov [2] and A.A.Umansky [6, 7] (see also [4]).

Tonus enables you to consider any arbitrary (including mixed open-closed) profiles. It uses a modification of a unified thin-walled bar theory suggested by E.A. Beilin E.A. Beilin [1]. Unlike **Section Builder** and **Consul**, this software implements a different approach to the creation of a cross-section model. The application assumes that a section is thin-walled and is being built of strips; the user specifies the thickness of each strip and the position of its centerline.

Window of the Application

Tonus window (Fig. 64) contains a menu, a toolbar, a work area (with scrollbars when necessary), a table panel, and a status bar.

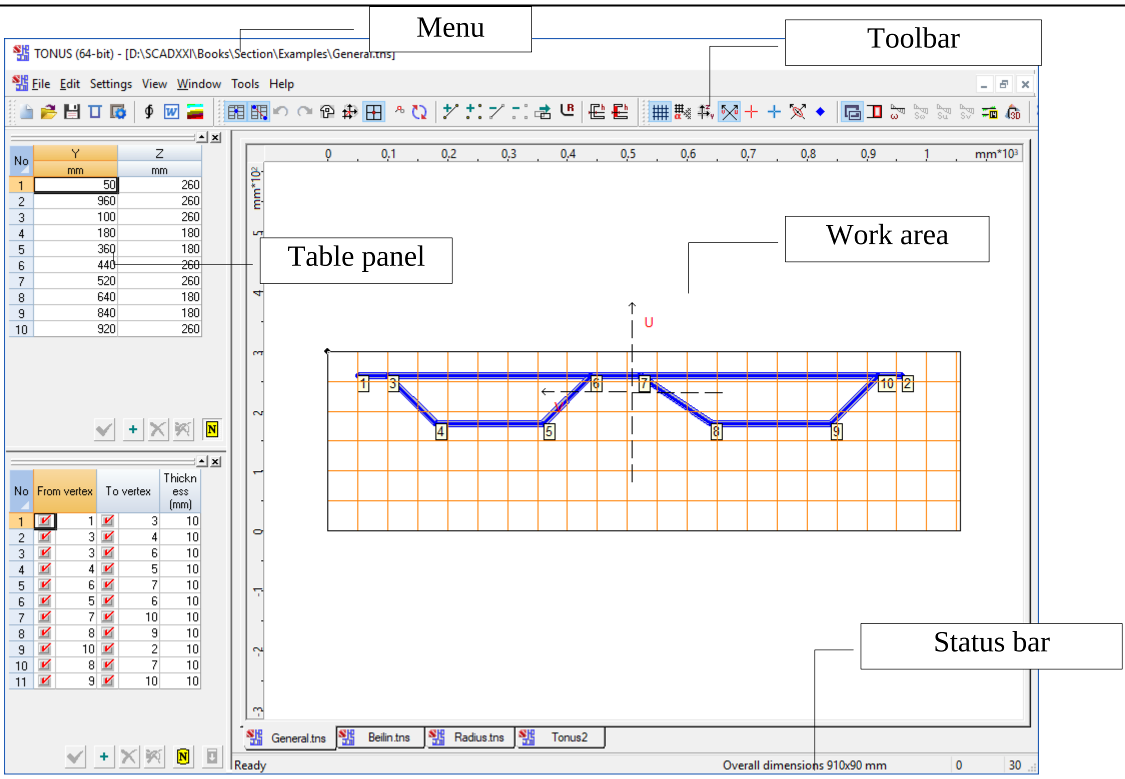


Figure 64. *General view of the* ***Tonus*** *window*

Cursors

All operations are performed in the work area with a cursor. Its shape depends on the current operation. A list of operations with their respective cursor shapes is given below.

— add strips;

— delete strips;

— round angles;

— delete a group of strips;

— move vertices;

0.12 — display stress values in arbitrary points of the section;

— add a vertex;

— delete a vertex;

— delete a group of vertices;

— measure a distance between two points within given overall dimensions of the section.

The cursor can be used to determine a distance between two arbitrary points of a section or the work area. To do it, cancel an operation active at the moment (un-press the button), place the cursor over the first point, and left click. Drag the cursor to the second point while holding the button. The right part of the status bar will display the distance between the points (the accuracy of this indication depends on the precision specified in the **Units of Measurement** tab of the **Settings** dialog box). Coordinates of the current cursor position will be displayed in the second field of the status bar.

Creating a Section

It is recommended to follow these steps to create a section:

- specify sizes (overall dimensions) of the section — ;
- define parameters of the coordinate grid — ;
- assign thicknesses to strips — ;

- add vertices —  and strips — ;
- round angles (if necessary) — .

The vertices and strips can be added both in the graphical mode and in a tabular form. Once a new vertex is added, its coordinates are checked for coincidence with those of previously added vertices. The coincident vertices are those the distance between which is less than or equal to a value specified in the **Precision** field in the **Other** tab of the **Settings** dialog box. If the vertices are coincident, the newer one will be deleted, and the strip will get the older one as its vertex.

When strips are added or vertices are moved, the strips may happen to intersect each another. In this case both the crossed and the crossing strips will be divided into parts automatically, and a new vertex will appear at the point of their intersection. The fact of intersection is analyzed using the given value of precision.

Coordinate Grid

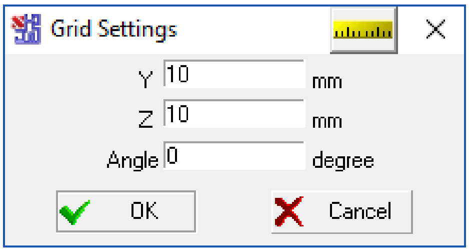


Figure 65. *The* **Grid Settings** *dialog box*

Parameters of a coordinate grid are specified in the **Grid Settings** dialog box (Fig. 65), which opens once you invoke the respective command. The text fields of this dialog enable you to specify horizontal and vertical grid spacing, and an angle of the grid in degrees with respect to the horizontal axis. The grid is rotated about the origin.

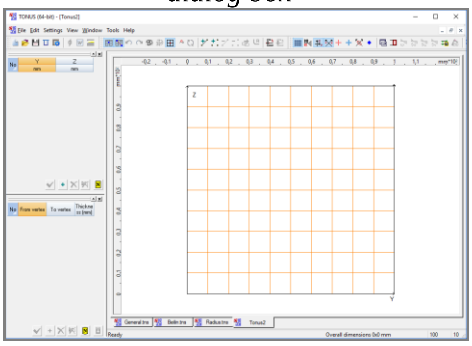


Figure 66. *A grid displayed in the work area*

It should be noted that the grid spacing and its angle can be changed as many times as needed.

The grid will be displayed once its parameters are entered (Fig. 64). Its visualization is turned on and off by the **Grid** button  in the toolbar.

Overall Dimensions

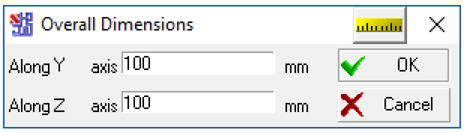


Figure 67. *The* **Overall Dimensions** *dialog box*

A section is created on the coordinate grid the overall dimensions of which are limited by those of the section. The overall dimensions are specified in the **Overall Dimensions** dialog box (Fig. 67) in the units of measurement defined in the respective tab of the **Settings** dialog box.

A rectangle limiting the overall dimensions of the section (Fig. 68) is displayed in the work area. Values of the overall dimensions are displayed in the first field of the **Status bar**. As long as no element is created, the status bar will display the specified dimensions. As you add elements to the section, the field will display the current overall dimensions of it.

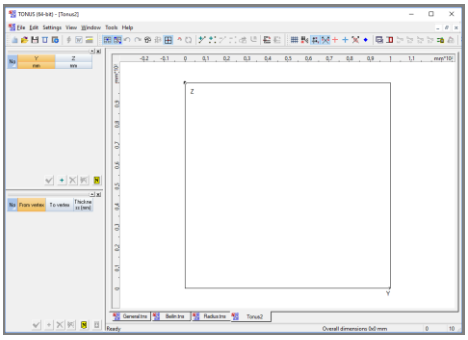


Figure 68. *Overall dimensions displayed in the work area*

Strips

Strips are the line segments. If the **Snap to Grid** mode is active — , the vertices of the segments will snap to the nearest nodes of the coordinate grid automatically as soon as they are added. To add a vertex, place the cursor over the point of the work area (within the given overall dimensions) and left click to confirm the creation of the new vertex. To interrupt the process, click the right mouse button.

Tables with the coordinates of vertices and properties of strips can be displayed to the left from the work area (use the **Table of Vertices** and **Table of Strips** buttons, respectively). As you add a new strip, the tables will be supplemented with information on new objects (vertices and strips).

Delete a Strip

When this action is invoked, you can delete any of the strips comprising the section walls. To do it, place the cursor over the strip and left click. The strip will be also automatically deleted from the table of strips.

Assign Thickness

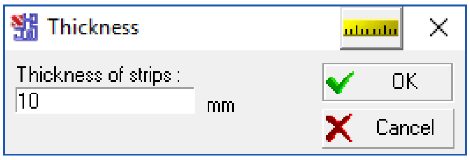


Figure 69. *The* **Thickness** *dialog box*

Clicking this button will open the **Thickness** dialog box (Fig. 69) the text field in which is used to specify a thickness for the section wall. The specified value will be assigned by default to all newly added strips.

Vertices

Use this command to add new vertices without adding any strips. To do it, place the cursor over the point of the work area and left click. If the **Snap to Grid** mode — , is enabled, then the vertices will automatically snap to the nearest nodes of the coordinate grid. The new vertices will be added to the table of vertices.

Delete a Vertex

When this command is invoked, you just need to place the cursor over the vertex and left click to delete it. All the adjacent strips will be deleted together with the vertex. The vertices and strips will be also automatically deleted from the respective tables.

Snap to Grid

When this mode is active, vertices being added will automatically snap to a grid node nearest to the cursor.

Round an Angle

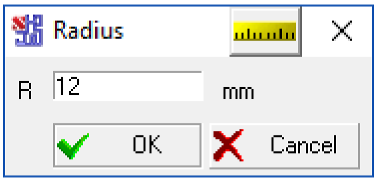
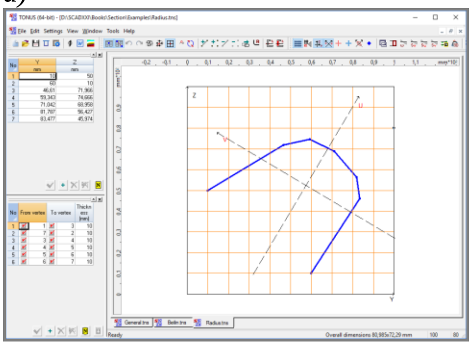


Figure 70. *The* **Radius** *dialog box*

An angle can be rounded by inscribing a circular arc of a given radius in it. After you invoke this command, place the cursor over a corner of the contour, wait for the rounding action cursor to appear , and left click. In the invoked **Radius** dialog box (Fig. 70) specify a radius and click the **OK** button. A section in the form of a contour with rounded corners is shown in Fig. 71, *a*, and the same section with the **Show Thicknesses** mode enabled is shown in Fig. 71, *b*.

The number of points (vertices) on a circular arc is specified in the **Other** tab of the **Settings** dialog box.

a)



b)

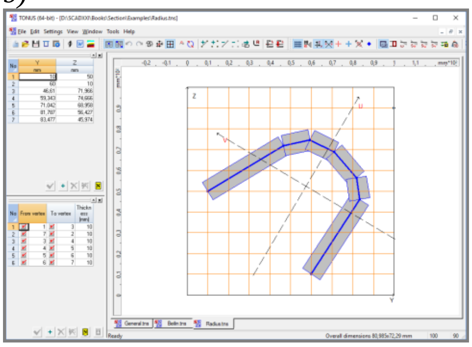


Figure 71. *An example of a section with rounded angles*

Move a Group of Selected Vertices

This item is used to move a group of vertices selected with a rectangular marquee. To do it, perform the following steps:

- invoke the command;
- select the vertices you want to move with the rectangular marquee;
- drag the marquee together with the selected vertices into a new position.

Left-click to confirm the new position of the vertices.

If moving the vertices causes any strips to intersect, the intersection points will become new vertices and the strips will be divided.

Shift the Origin

This command is used to move the origin to a point with specified coordinates, to a vertex, to the center of shear or to the center of mass of a section (Fig. 72). Since the application can calculate moments of inertia with respect not only to the principal axes, but to a custom coordinate system as well, the capability of moving the origin can be useful in geometric analysis.

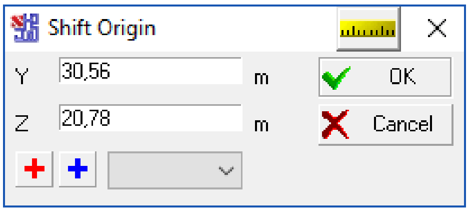


Figure 72. *The* **Shift Origin** *dialog box*

If you need to move the origin to the center of mass, to the center of shear or to a particular vertex, click the red cross button, blue cross button or select the number of the vertex from the drop-down list, respectively. This will put the coordinates into the respective text fields.

The origin will be moved to the specified point once you click the **OK** button.

Table of Vertices

To add, delete, or edit the coordinates of existing vertices, you can use a table on the table panel, which opens when you click the respective button in the toolbar. There is a number of buttons used to control the table editing process under the table (Fig. 73).

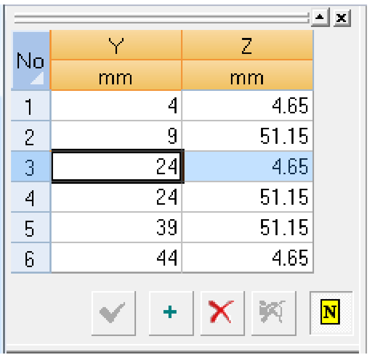


Figure 73. *A table of vertices*

The table can be filled either automatically, when you use graphic tools to add vertices and strips, or directly by entering coordinates of new vertices in the table. In the latter case you should click the + button before specifying a vertex; this will add a new row to the table where you can enter the coordinates for the new vertex.

The results of editing will be displayed in the work area only after you click the **Apply** button .

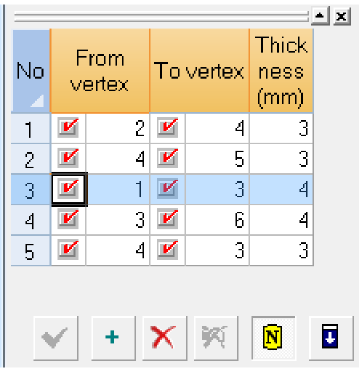
To delete vertices, select the respective rows in the table and then click the button . The vertices in the section will be highlighted, but deleted only when you click the button . To remove the highlighting from the selected vertices, click the button .

To select one or more successive rows, place the pointer over the number of a row, click and hold the left mouse button, and drag the cursor to the last row you want to delete.

Use the **Show/Hide Vertices Numbers** button to have the vertices numbered in the section view.

Table of Strips

The table of strips is very similar to the table of vertices (Fig. 74). Each row of the table contains information on one strip. The information includes the numbers of vertices at the beginning and end of a strip, accompanied by connection checkboxes, and thickness of the strip.



No	From vertex	To vertex	Thickness (mm)
1	2	4	3
2	4	5	3
3	1	3	4
4	3	6	4
5	4	3	3

Figure 74. *A table of strips*

The table can be filled either automatically, when you use graphic tools to add strips, or directly, by entering coordinates of new strips in the table. In the latter case you should click the + button before specifying a strip; this will add a new row to the table where you can enter data for the new strip. If a strip is rigidly attached to other strips at its vertex, its respective connection checkbox will be checked (when you add strips with graphic tools, the checkboxes are checked by default). Unchecked checkbox means that there is no connection between the considered strip and other strips coming into the same vertex.

By default the thickness of every new strip is assigned a value specified using the **Thicknesses** button — . The thickness can be modified when adding new strips or by editing in the table.

To change the thickness of several strips, select the respective rows in the table and click the **Enter thicknesses** button . In the invoked **Thickness** dialog box specify a new value and click the **Apply** button.

Use the **Delete** button to delete the selected strips (table rows).

To select one or more successive rows, place the cursor over a number of a row, click and hold the left mouse button, and drag the cursor to the last row you want to delete.

The results of editing the table will be displayed in the work area only after you click the **Apply** button.

Use the **Show/Hide Strips Numbers** button to have the strips numbered in the section view.

Shear Center

(blue)

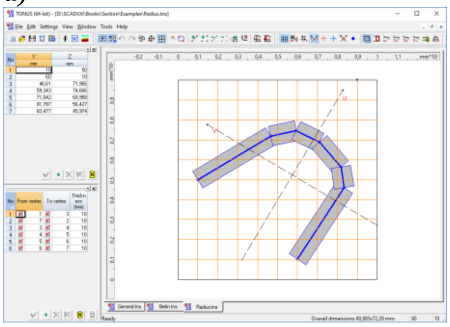
This button enables to display the shear center of a section.

It should be noted that there is one special case when all strips of the section lie on one line. The section is non-warping (in particular the sectorial moment of inertia is equal to zero), moreover, *any* point on the straight line on which lie the center lines of the strips can be taken as the shear center.

Show Thicknesses

Depending on whether this button is pressed or depressed, the work area will display either a whole section (if the button is pressed) or just a contour of it, i.e., the center lines of the strips (Figs. 75, *a* and 75, *b* respectively).

a)



b)

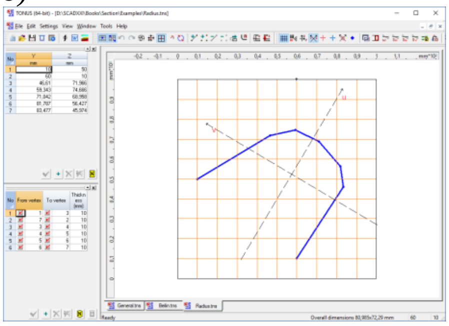


Figure 75. *A section displayed in the work area*

Snap to Vertices

If this item has been enabled, then when measuring the distances, the cursor will be snapped to the nearest vertex, i.e. only the distances between the vertices of the contours are measured.

Sectorial Coordinate Diagrams

If the option is selected, the program displays the sectorial area diagrams. The operation invokes the dialog box (Fig. 76) with a 3D display of sectorial area diagrams.

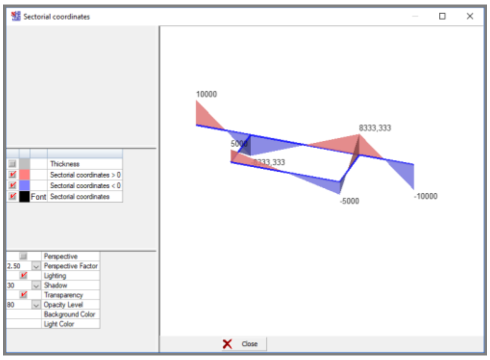


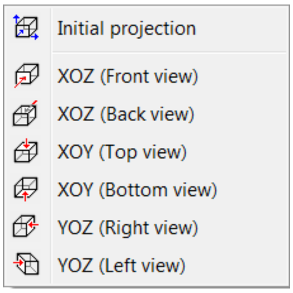
Figure 76. *The* **Sectorial Areas** *dialog box*

Controls in the left side of the window enable to:

- change the colors used for drawing (as well as the fonts for the digitization);

- set the transparency and/or lighting mode;
- display geometric perspective and select the distortion factor;
- change the background color and the color of the lighting.

In order to change the color or font, double click on the respective cell and select the parameters. Right-clicking invokes the context menu where you can select a projection:



The following operations with the mouse can be performed in the program:

- scrolling the wheel changes the scale of the image;
- clicking and holding the middle mouse button (wheel) while dragging the cursor moves the image;
- clicking and holding the middle mouse button (wheel) together with *Shift* or *Ctrl* key while dragging the cursor rotates the surface.

Static Moment Diagrams

These options enable to display the diagrams of static moments S_u, S_v and static sectorial moments S_ω.

Shear and Equivalent Stresses Diagrams

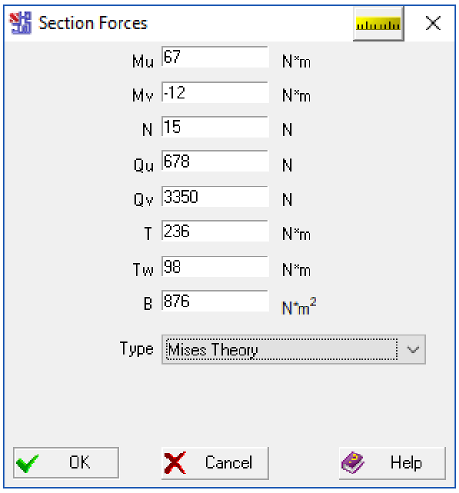
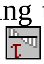


Figure 77. *Dialog box* **Section Forces** *invoked from* **Tonus**

After clicking one of these buttons the program asks for information on the internal forces acting in the section. The **Section Forces** dialog box (Fig. 77) allows to input bending moments M_u and M_v acting about the principal axes and the internal axial force N applied to the center of mass, the shear forces Q_u and Q_v, assumed to be applied to the mass center of the section, as well as the Saint Venant torsion moment T and the warping torsion moment T_ω. After closing the dialog box, the shear  or equivalent  stresses diagrams are displayed in the section. When calculating the equivalent stresses strength theory of Mises or Tresca should be selected in the respective drop-down list.

Values of Sectorial Coordinates, Static Moments, Stresses

If this item is enabled, the application displays the values of sectorial coordinates. These values are displayed in respective nodes. When displaying the static moment and stress diagrams, this option enables to digitize the diagrams.

Table of Diagrams

If one of the options for displaying diagrams (of static moments, stresses, ...) is active, the diagram values (in the first vertex of the strip, in the center, and in the last vertex of the strip) are output in a special table (Fig. 78).

No	Vertices	S_ω, cm^4
1	1	0
	Center	-491,47
	2	-339,32
2	2	-339,32
	Center	-120,97
	3	-294,15
3	3	-294,15
	Center	-550,66
	4	-776,54
4	4	-776,54
	Center	-693,03
	5	0

Figure 78. *Table of Diagrams*

Standard Sections

A set of standard parametric sections can be used to create a section. **Create Standard Section** command is invoked from the **File** menu. The **Standard sections** dialog box (Fig. 79) appears, which contains a list of standard sections, their images with a legend of properties, and fields for entering their numerical values.

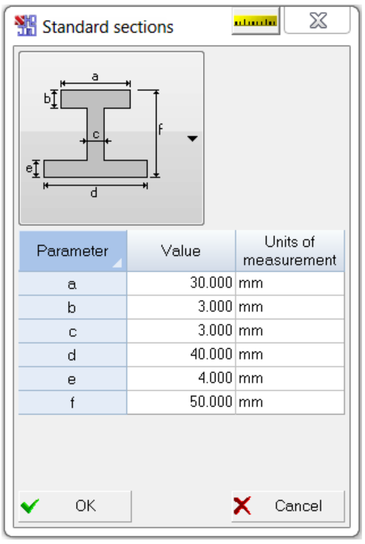


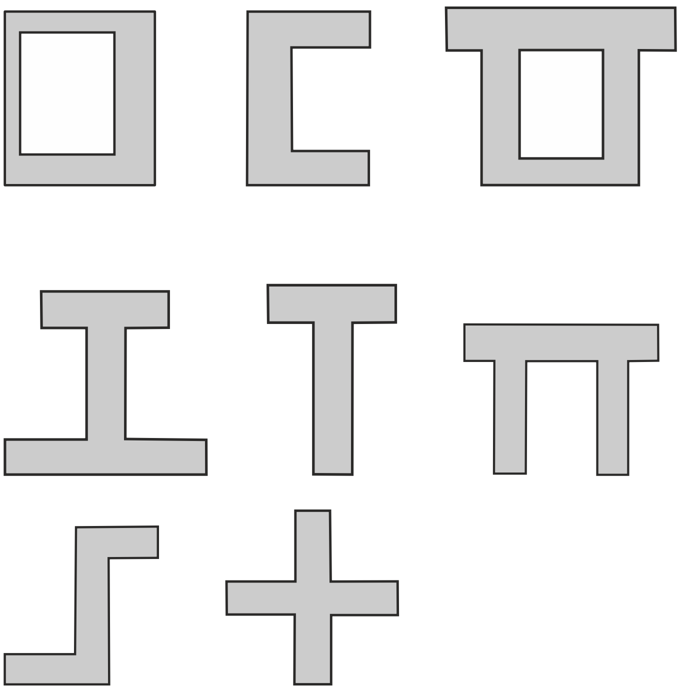
Figure 79. *The* **Standard Sections** *dialog box*

Perform the following steps to create a section:

- select a section from the drop-down list;
- enter values in the fields in accordance with the selected model;
- click the **OK** button.

The last action will close the dialog box, and the created section will be displayed in the work area of the **Tonus** window (Fig. 80).

The following set of standard parametric sections is available in the application:



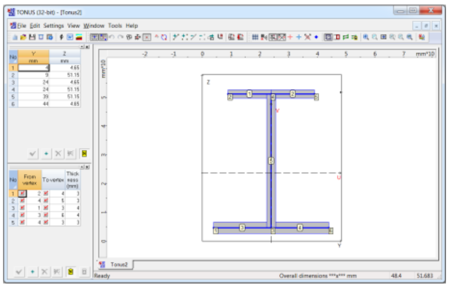
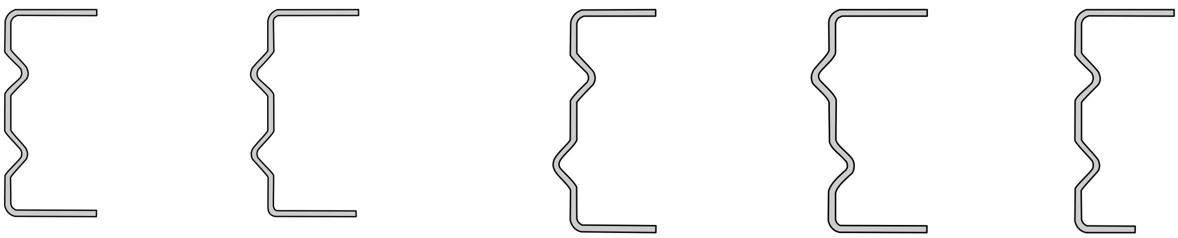
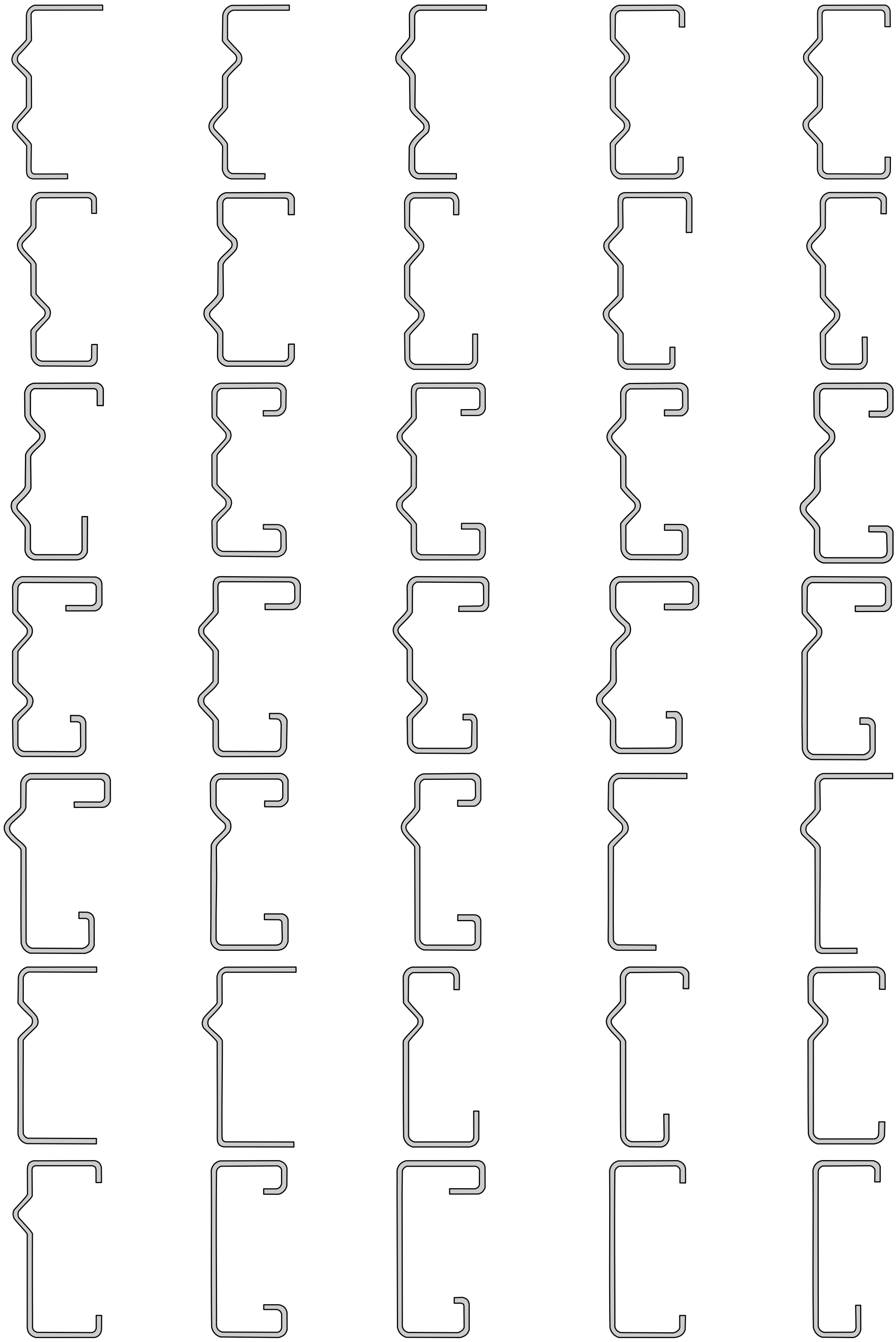
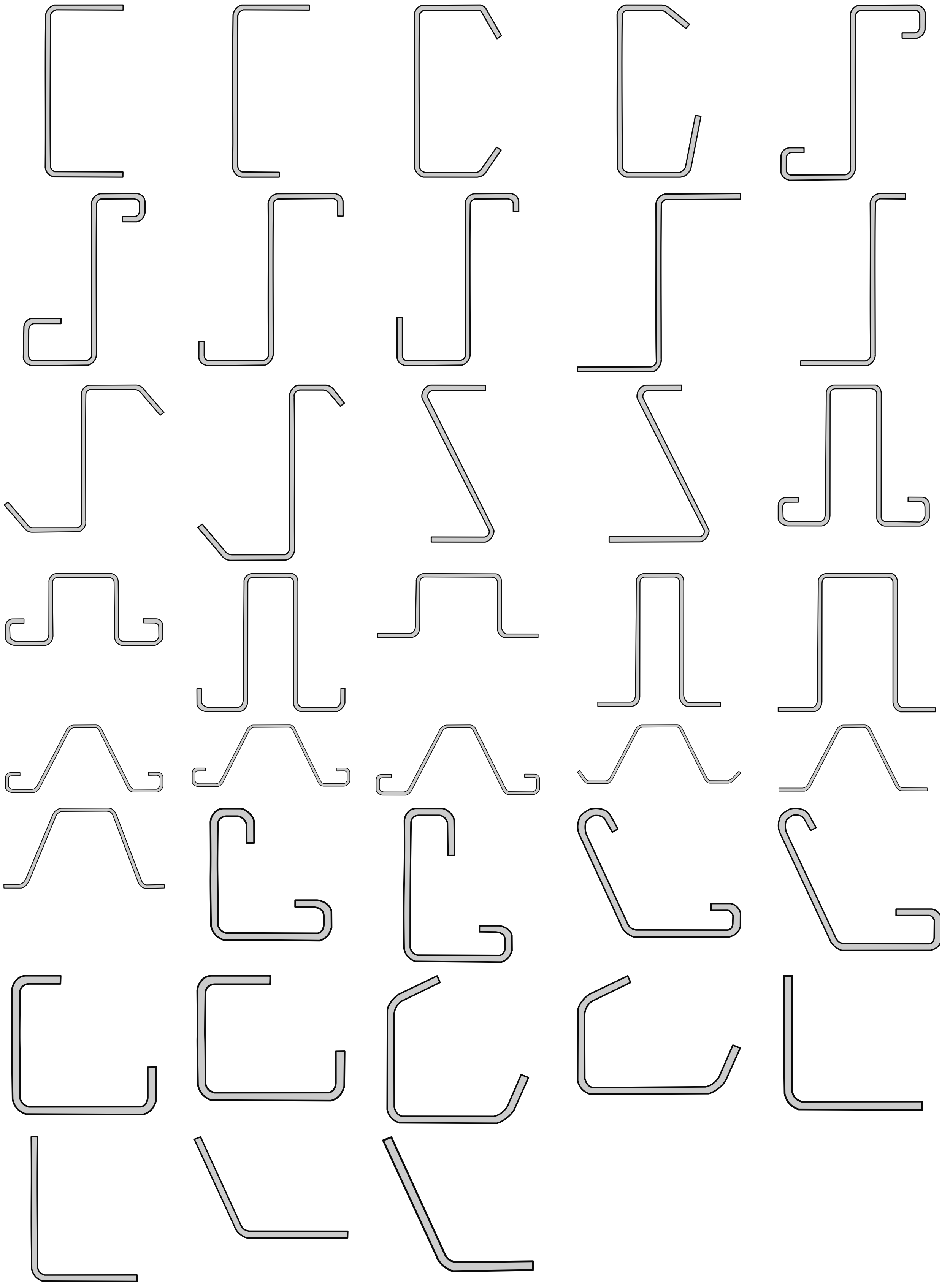


Figure 80. *A section created in* **Tonus**







Sezam

General Information

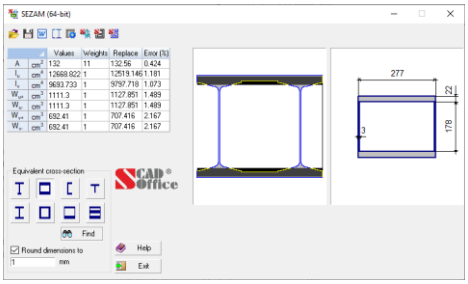


Figure 81. *The main window of* **Sezam**

An arbitrary section can only be checked for strength according to the formulas given in the strength of materials manual. However, when you have to consider the elastoplastic stage of work, check for the web buckling, check for the out-of-plane buckling, or to make some other checks according to design codes, it appears that all the codes are oriented only toward certain types of cross-sections.

Engineers usually use the following approach – the strength is checked for a real cross-section and all the other checks are carried out for a "similar" section, the geometric properties of which are selected according to the consideration of equivalence.

The equivalence is understood as the proximity of the cross-sectional geometric properties (an area, moments of inertia, moments of resistance, etc.). Sometimes in the process of reduction some additional considerations are used which can help to specify the very concept of equivalence. For example, only the equality of the moments of inertia has to be achieved, if it is only the buckling that has to be checked.

Sezam enables to find such a section (in this version only a hollow section, a channel, a Tee section, or an I-beam), which approximates an arbitrary section set by the user according to its geometric properties the best. An initial section can be set:

- as a file created by **Consul**;
- as a file created by **Section Builder**;
- as a file created by **Tonus**;
- by the set of geometric properties;
- as a compound section from the set of prototypes given in the program (e.g. two channels, two I-beams, etc.).

At any method of the section setting only geometric properties are used for the calculation in the program. The following properties are approximated for a section:

- area ($\boldsymbol{A}$);
- principal moments of inertia ($\boldsymbol{I_u}, \boldsymbol{I_v}$);
- moments of resistance ($\boldsymbol{W_{u+}}, \boldsymbol{W_{u-}}, \boldsymbol{W_{v+}}, \boldsymbol{W_{v-}}$).

Apart from the parameters mentioned above, it is necessary to set weight coefficients for each of the properties (all the weights are equal to 1 by default).

The task is to select such geometric dimensions of a hollow section, a channel, a Tee section, or an I-beam at which the functional is minimized.

$$k_1\left(1-\frac{A}{A^0}\right)^2+k_2\left(1-\frac{I_u}{I_u^0}\right)^2+k_3\left(1-\frac{I_v}{I_v^0}\right)^2+k_4\left(1-\frac{W_{u+}}{W_{u+}^0}\right)^2+k_5\left(1-\frac{W_{u-}}{W_{u-}^0}\right)^2+$$
$$+k_6\left(1-\frac{W_{v+}}{W_{v+}^0}\right)^2+k_7\left(1-\frac{W_{v-}}{W_{v-}^0}\right)^2, \qquad (1)$$

where A^0, I_u^0, I_v^0, W_{u+}^0, W_{u-}^0, W_{v+}^0, W_{v-}^0 are respective geometric properties of the equivalent section (a hollow section, a channel, a Tee section, or an I-beam).

Coefficients k_i (i = 1, …, 7) indicate the importance assigned to each geometric property; in particular, by setting one of the coefficients equal to zero it is possible to reject the approximation of a corresponding geometric property.

Selection Results

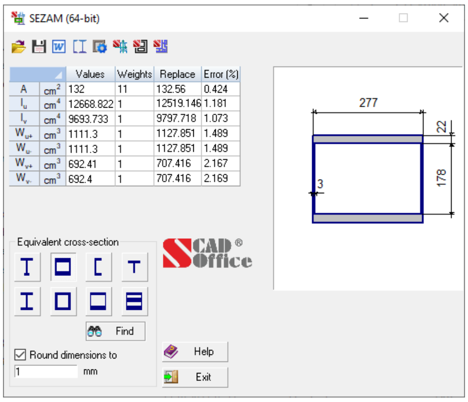


Figure 82. *The main window of* **Sezam** *with the results of selection*

Once the **Find** button is activated, the program finds the equivalent section in accordance with a selected prototype (I-beams with equal and unequal flanges, rectangular and square hollow sections, a Tee section, or a channel) and with the selected weight coefficients. The selected section and its dimensions are shown in the window (Fig. 82). The geometric properties of the equivalent section and the difference of initial and resultant section values (in percent) for each geometric property are shown simultaneously.

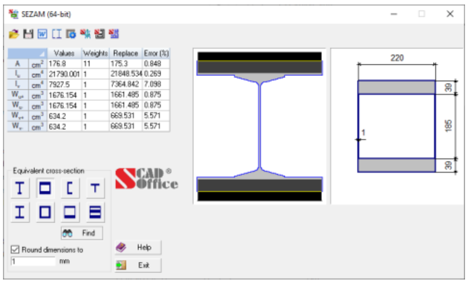


Figure 83. *The main window of* **Sezam** *with the results of selection*

(*the initial section is on the left, and the equivalent one is on the right*)

If a section has been selected as a file created by **Consul**, **Tonus** or **Section Builder**, the initial and equivalent sections are shown simultaneously in the window (Fig. 83), which allows to qualitatively assess their correspondence.

Invoking Section Builder

This item allows to invoke **Section Builder** and to open a selected equivalent section automatically. **Section Builder** enables to calculate additional geometric properties and to modify the section itself if necessary.

Invoking Consul

This item allows to invoke **Consul** and to open a selected equivalent section automatically. **Consul** enables to calculate additional geometric properties and to modify the section itself if necessary.

Invoking Tonus

This item allows to invoke **Tonus** and to open a selected equivalent section automatically. **Tonus** enables to calculate additional geometric properties and to modify the section itself if necessary.

Appendixes

1. Definitions of Geometric Properties

Moments of Inertia

To calculate some geometric properties (e.g. an area, moments of inertia, position of the gravity center), we actually calculate moments of an area (**Ω**) covered by a section, i.e. the calculation of values of the form:

$$\nu_{pq} = \int_{\Omega} y^p z^q \, dydz \, .$$

For example, when $p = q = 0$ we obtain the area of the section, A.

It is often necessary to calculate moments normalized by the area (A), i.e. values of the form:

$$\alpha_{pq} = \nu_{pq} / A \, .$$

Values α_{01} and α_{10} determine the section gravity center.

When $p + q \geq 2$ the central moments are of interest:

$$\mu_{pq} = \int_{\Omega} (y - \alpha_{10})^p (z - \alpha_{01})^q \, dydz \, .$$

Values μ_{20}, μ_{02}, μ_{11} are central moments of inertia about **Z**, **Y** axes and a centrifugal moment of inertia, respectively.

Principal Moments of Inertia, Angle of Principal Axes

Principal moments of inertia are calculated by the following formula:

$$I_{u/v} = \frac{(I_y + I_z)}{2} \pm \sqrt{\left(\frac{I_y - I_z}{2}\right)^2 + I_{yz}^2} \; .$$

Angle of the principal axes of inertia:

$$\alpha = \mathrm{arctg}\left(\frac{I_{yz}}{I_y - I_{u/v}}\right) \; .$$

In the last formula, you should substitute I_u to its right part to determine an angle of the axis of the maximal moment of inertia; and I_v. – to determine an angle of the axis of the minimal moment of inertia.

> ***Note***: **Consul** enables you to work not only with areas limited by polygons, but also with those limited by curves (when using **Round Corner** and **Circular Hole** items). In the latter case the application will replace the curve by a polyline to perform the calculation.

Radii of Gyration

$$i_y = \sqrt{\frac{I_y}{A}} \; ; \quad i_z = \sqrt{\frac{I_z}{A}} \; ; \quad i_u = \sqrt{\frac{I_u}{A}} \; ; \quad i_v = \sqrt{\frac{I_v}{A}} \; .$$

Section Moduli

Axial Section Moduli

$$W_{u+} = \frac{I_u}{v_{\max}} \; ; \quad W_{u-} = \frac{I_u}{v_{\min}} \; ; \quad W_{v+} = \frac{I_v}{u_{\max}} \; ; \quad W_{v-} = \frac{I_v}{u_{\min}} \; ,$$

where u_{max}, u_{min}, v_{max}, v_{min} are maximal distances from points of the section exterior boundary to the **U, V** axes (on one and another side) respectively.

Polar Section Modulus

$$W_\rho = \frac{I_y + I_z}{\rho_{max}},$$

where ρ_{max} is the maximal distance from points of the section to its center of mass.

Value $I_y + I_z$ is called the ***polar moment of inertia***.

Core Sizes

$$a_{u+} = \frac{W_{u+}}{A}; \quad a_{u-} = \frac{W_{u-}}{A}; \quad a_{v+} = \frac{W_{v+}}{A}; \quad a_{v-} = \frac{W_{v-}}{A}.$$

Torsional Stiffness

Let's consider a function $\varphi(y, z)$ in the $\mathbf{\Omega}$ area (a stress function or Prandtl function) which satisfies the equation $\Delta\varphi + 2 = 0$ and also $\varphi = 0$ on the boundary of $\mathbf{\Omega}$ in the case when $\mathbf{\Omega}$ is simply connected. In case of a multiply connected area (with holes) it is assumed that $\varphi = 0$ on the exterior boundary of the area $\mathbf{\Omega}$, and the stress function is constant on every interior boundary (L_i, i=1, … n), the constants U_i (i=1, … n) being such that the following relationships hold:

$$\oint_{L_i} \frac{\partial\varphi}{\partial n} ds = -2\Omega_i$$

where $\mathbf{\Omega}_i$ is an area limited by the contour L_i.

Value $I_t = 2\left(\int_\Omega \varphi(y,z)dy \quad dz + \sum_{i=1}^{n} U_i\Omega_i\right)$ is called the torsional moment of inertia.

Shear Center

Consider a section of a cantilever beam with a concentrated force perpendicular to the longitudinal axis of the bar applied at some point of its free end. If this force does not cause torsion of the bar, then this point is called the *shear center*.

The coordinates of the shear center (in the principal centroidal axes) can be determined according to the following formulas:

$$y = \frac{1}{J_y}\int_\Omega \omega(y,z)z \quad dy \quad dz;$$

$$z = -\frac{1}{J_z}\int_\Omega \omega(y,z)y \quad dy \quad dz,$$

where $\omega(y,z)$ is Saint-Venant torsion function, or a displacement function. This function is harmonic in the $\mathbf{\Omega}$ area ($\mathbf{\Delta\omega} = 0$) and satisfies the following condition on the boundary:

$$\frac{\partial\omega}{\partial n} = z \quad \cos \quad ny - y \quad \cos \quad nz$$

Moreover,

$$\oint \frac{\partial\omega}{\partial n} ds = 0.$$

It should be noted that the definition of the shear center used in **Consul** is based on the equality to zero of the torsional moment when the shear forces are applied at the shear center. This definition of the shear center is different from that given, for example in [13], where the shear center is defined by the condition of equality to zero of the mean value of torsion (in the latter case the position of the shear center depends on the Poisson's ratio on the contrary to our definition, where this dependence does not arise).

Section Shear Areas

There are several definitions of the shear area. Classic definition (used in **Section Builder**) is as follows. Suppose Fig. 84 depicts a section, and its **Y**, **Z** axes are the principal ones.

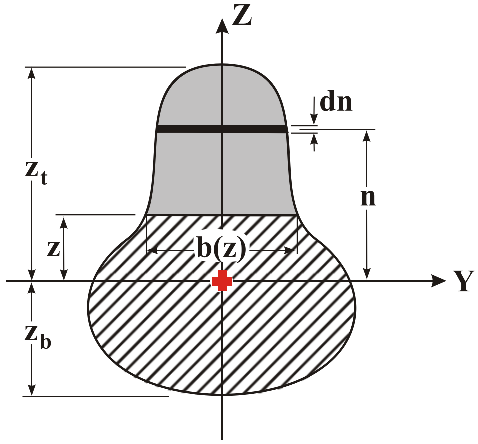


Figure 84. To defining of the section shear area

Let

$$Q(z) = \int_{z}^{z_t} n\, b(n)\, dn\,.$$

A shear area with respect to the **Y** axis is the following value:

$$\frac{I_y^2}{\int_{z_b}^{z_t} \frac{Q(z)^2}{b(z)}\, dz}$$

A shear area with respect to the **Z** axis can be determined in a similar way.

In **Tonus** the shear areas are determined according to the recommendations given in the Engineering Guide [10, § 5.3.2] by the formulas of the following type:

$$A_{vy} = \sum_j A_j \cos^2\alpha_j\,, A_{vz} = \sum_j A_j \sin^2\alpha_j\,,$$

where A_j is the area of the j segment of the section, α_j is the inclination angle of the j segment of the section to the principal axis of inertia.

In **Consul** the shear areas are determined by the formuls of kA type, where A is the cross-sectional area, k is the coefficient equal to the ratio of the mean value of the tangential stress to the tangential stress obtained from the accurate solution of the equations of the elasticity theory (for details, see articles [11], [12]).

Plastic Section Moduli

Let **Ω** be the section area. Let **Ω**$_2$ be a part of the **Ω** area lying on one side of the principal **U** axis. A ***plastic section modulus*** for bending with respect to the **U** axis is the value:

$$W_{\mathrm{pl},u} = 2\int_{\Omega_2} v\, d\omega\,.$$

A plastic modulus $W_{\mathrm{pl},v}$ with respect to the **V** principal axis can be determined in a similar way.

Sectorial Properties

A sectorial moment of inertia of a solid section:

$$I_\omega = \int_\Omega \omega^2(y,z)\ dy\ \ dz,$$

where $\omega(y,z)$ is Saint-Venant torsion function. In the case of a thin-walled section the sectorial moment is determined according to the V.Z.Vlasov theory (see [2, 1]).

It should be noted that the sectorial properties are usually used in the thin-walled bar theory developed by V.Z.Vlasov [2]. However, G.Y. Janelidze [3] has shown that the above formulas are applicable to all sections and conform to the concepts of the bimoment and the sectorial static moment of the Vlasov theory with the accuracy of $1+O(h/\rho)$, where h is the thickness of a thin-walled section and, ρ is the radius of curvature.

Moreover, G.Y.Janelidze [3] proved that the formulas for the coordinates of the shear center and sectorial moment of inertia can be obtained by passage to limit (thickness of the section strips $\rightarrow 0$) from the equations of the elasticity theory. The consequence of these results is the fact that the value of inaccuracy of the V.Z.Vlasov formulas at final thickness of the strips is $O(h^2)$ for the coordinates of the shear center and $O(h^3)$ for the value of the sectorial moment of inertia.

Normal Stresses

You have to specify components of the forces in a section, i.e. the N component of an integral force vector and the M_u, M_v components of an integral moment with respect to the section center of mass. In the case of thin-walled sections (in **Tonus**) bimoment B is also taken into account.

The value of normal stress in a point is equal to

$$\sigma = \frac{N}{A} - \frac{M_u\ v}{I_u} - \frac{M_v\ u}{I_v} + \frac{B\omega}{I_\omega},$$

where $N,\ M_u,\ M_v, B$ are a normal force, moments (in the principal axes) and a bimoment acting in the section respectively;

u, v are coordinates of a point in the section principal axes;

ω is a sectorial area.

2. File Formats

Consul

The application is capable of importing sections created by other software. In particular, **Consul** can import files of the **CON** format (which can be created, for example, by **SCAD** [5]).

CON files are text files of the following structure:

◊ a section is defined as a set of polygons;

◊ the first polygon is an external contour, and all the following ones (if any) define holes (internal contours);

◊ each polygon (external and internal) must be defined as follows:
- the first line is an integer number *n* defining the number of vertices in a polygon;
- it is followed by *n* lines, each one containing three floating-point numbers — coordinates of a vertex in the section plane and a radius of the rounded corner at this vertex (the last number may be absent when there is no rounding).

All dimensions are specified in meters. The numbers in a line are separated by spaces. The decimal separator is a period.

Example: A section shown in Fig. 85 is described in the **CON** format as follows:

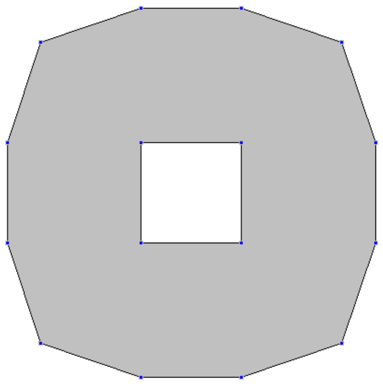


Figure 85

```
12
  -1.000   3.000
   0.000   0.000
   3.000  -1.000
   6.000  -1.000
   9.000   0.000
  10.000   3.000
  10.000   6.000
   9.000   9.000
   6.000  10.000
   3.000  10.000
   0.000   9.000
  -1.000   6.000
4
   3.000   3.000
   6.000   3.000
   6.000   6.000
   3.000   6.000
```

Tonus

TNS files are text files. A section is defined by a set of vertices and segments.

The first line in a file specifies two numbers of the section dimensions. The next line contains an integer, *n*, that defines the number of vertices. They are followed by *n* lines with coordinates of the vertices. Each line consists of two floating-point numbers separated by spaces. They are in turn followed by a line which contains an integer, *m*, defining the number of segments. This line must be followed by *m* lines with segment descriptions. Each line that describes a segment contains five numbers. First two numbers are integers; they are respective numbers of start and end vertices (the vertices are numbered starting from 0). The second couple of integers (each can be either 0 or 1) defines whether the respective ends of a segment are connected to their vertices. The last number in the line is the thickness of a segment.

All dimensions are specified in meters. The numbers in a line are separated by spaces. The decimal separator is a period.

Example: A section shown in Fig. 86 is described in the **TNS** format as follows:

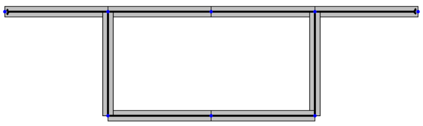


Figure 86

```
100.0 100.0
9
25.0 75.0
35.0 75.0
45.0 75.0
55.0 75.0
65.0 75.0
55.0 65.0
45.0 65.0
35.0 65.0
45.0 75.0
9
0 1 0 1 1.0
1 2 1 1 1.0
2 3 1 1 1.0
3 4 1 0 1.0
3 5 1 1 1.0
5 6 1 1 1.0
6 7 1 1 1.0
7 1 1 1 1.0
8 2 1 1 1.0
```

3. Service Functions

As you work with the program, you may need to perform some relevant auxiliary calculations. The **Service** menu contains items for invoking additional calculators: a standard MS Windows one (if it has been installed together with the system), a formula calculator, and a converter of units of measurement.

Formula Calculator

This calculator (Fig. 87) is used to perform calculations by formulas that can be specified in a text field.

The following rules should be observed when entering a formula:

- names of functions must be entered in lowercase Roman letters;
- the fractional and the integer parts of a number must be separated by a period or another separator assigned by the user during the customization of the operating system (see **Settings | Regional Settings | Number**);
- arithmetic operations must be specified with the symbols +, –, *, /, ^ (raising to a power); for example, 2.5*2.5*2.5 can be written also as 2.5^3.

The following mathematical functions can be used in the formulas:

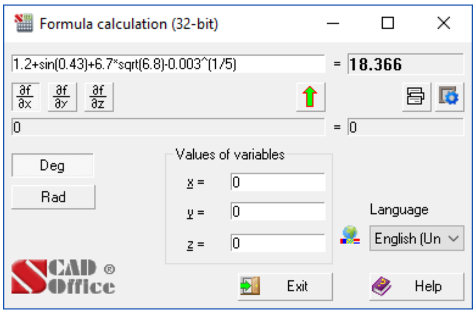


Figure 87. *The dialog box of the calculator*

floor — the greatest integer not greater than the argument;
tan — tangent;
sin — sine;
cos — cosine;
asin — arc sine;
acos — arc cosine;
atan — arc tangent;
exp — exponent;
ceil — the least integer greater than the argument;
tanh — hyperbolic tangent;
sinh — hyperbolic sine;
cosh — hyperbolic cosine;
log — natural logarithm;
log10 — decimal logarithm;
abs — absolute value;
sqrt — square root.

Depending on the state of the **Degrees/Radians** switch buttons, arguments of the trigonometric functions (**sin, cos, tan**) and results of inverse trigonometric functions (**asin, acos, atan**) can be presented in degrees or radians, respectively.

Only parentheses are allowed for grouping arguments together; these can be nested as deeply as desired.

Example.

The following formula

$$1,2+\sin(0,43)+6,7\sqrt{6,8}-\sqrt[5]{0,003}$$

must be written as follows:

1.2+sin(0.43)+6.7*sqrt(6.8)–0.003^(1/5).

There is an additional option of using three independent variables **x, y, z** in formulas. Values for the variables will be specified in respective text fields. This makes it possible to perform a series of similar calculations with different parameters. For example, the following formula:

$$1,2+\sin(x)+6,7\sqrt{6,8}-\sqrt[5]{y}$$

must be written in this mode as follows:

1.2+sin(x)+6.7*sqrt(6.8)–y^(1/5).

Furthermore, if you have entered a formula depending on the variables *x*, *y*, *z*, the field at the bottom will display a symbolic expression of its partial derivative with respect to one of the variables (*x*, *y*, or *z*) for which the respective marker $\frac{\partial f}{\partial x}$, $\frac{\partial f}{\partial y}$, or $\frac{\partial f}{\partial z}$ is enabled at the moment.

Button allows to save the current state of the text field with a formula and the respective values of variables and to open data saved earlier. After pressing the button the drop-down menu appears. Selecting its first position (**Save**) will save the entered data. The other lines display the formulas entered earlier, which can be selected by the mouse-pointer.

Converting Units of Measurement

This converter can be started from both the **SCAD Office** program group with the icon , and from the **Service** menu. The application converts between data specified in different units of measurement (Fig. 88). In order to do this, select a tab of respective measures (**Length**, **Area** etc.).

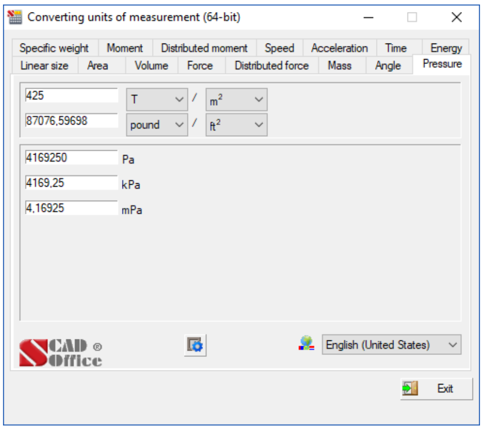


Figure 88. *The* **Converting Units Of Measurement** *dialog box*

The order of converting operations depends on whether the units of measurement are simple (i.e. length, area or time) or compound (i.e. pressure, speed or mass).

If you have to convert simple units of measurement, you just have to enter a number into one of the text fields. As a result you will receive values in all other units of measurement. If the units are compound, you have to select the original units of measurement in the drop-down lists of one line and the units you wish to convert to in the other one. Enter the number in the text field of the first line and you will receive the result in the second one.

Section Viewer

Section Viewer can be started from the **SCAD Office** folder on the desktop and used to browse through rolled steel profile assortments. The program window (Fig. 89) includes a list of assortments and a table of profile properties.

To activate a table that contains a list of profiles of a particular type, open the list of profiles of the desired assortment and choose a group of the respective profile type in the list.

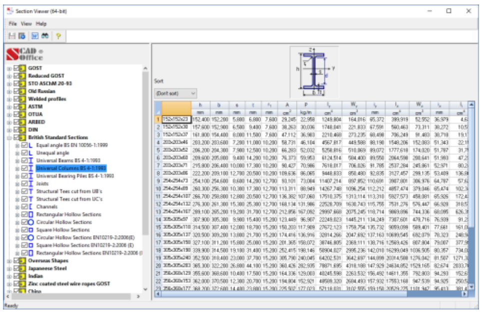


Figure 89. *The main window of* **Section Viewer**

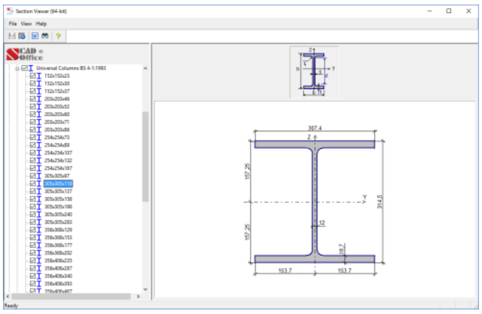


Figure 90. *The profile image*

To view the section with its dimensions, open the profile group list and choose the respective profile (Fig. 90).

The sections tables can be sorted in the ascending order of values of different properties. The properties are selected from the **Sort** drop-down list. The order of the sections in the list by default corresponds to the accepted one in the standard (or catalogue).

If needed, the selected profile table can be exported as an RTF format file to an editor associated with this format (the **Report** button).

Moreover, there is a checkbox beside each profile, which can be either checked or unchecked. If the **Save** command is activated (using the menu or the toolbar) after changing the state of one or more checkboxes, the profiles for which the respective checkboxes have been unchecked won't be involved in the profile selection procedure performed by an application that works with steel profiles.

The customization of the view/print mode (the **Settings** button,) is performed according to the same rules as other applications described above.

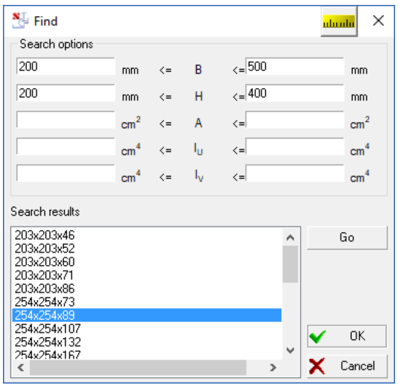


Figure 91. *The* **Find** *dialog box*

When activating the search function (**Find** button —), the user can introduce limitations for the profile dimensions and its geometrical properties (area and principal moments of inertia). Clicking the **OK** button will display a list of profiles which meet the specified limitations (Fig. 91).

4. List of Assortments of Rolled Profiles Provided with the Software Package

List of GOST sections
Equal leg angle GOST 8509-93
Unequal leg angle GOST 8510-86*
Channel with parallel flanges GOST 8240-89
Channels with sloped inner flange surfaces GOST 8240-89
Channel GOST 5267.1-90
Channel with parallel flanges GOST 8240-97
Channels with sloped inner flange surfaces GOST 8240-97
Economical channels with parallel flanges GOST 8240-97
Special channels GOST 8240-97
Light channels with parallel flanges GOST 8240-97
Special steel channels GOST 19425-74*
Column I-beam GOST 26020-83
I-beam with sloped inner flange surfaces GOST 8239-89
Additional series I-beam GOST 26020-83
Regular I-beam GOST 26020-83
Wide flange beam GOST 26020-83
Special I-beam GOST 19425-74*
Column T-bar TU 14-2-685-86
T-bar TU 14-2-685-86
Longitudinally electric welded Circular Hollow Sections GOST 10704-91
Circular Hollow Sections GOST 10704-91 (reduced list)
Seamless hot finished steel Circular Hollow Sections GOST 8732-78
Circular Hollow Sections GOST P 54157-2010
Roll-formed channels with equal flanges GOST 8278-83 (steels C239-C245)
Roll-formed channels with equal flanges GOST 8278-83 (steels C255-C275)
Square Hollow Sections TU 36-2287-80
Rectangular Hollow Sections TU 67-2287-80
Square Hollow Sections GOST 12336-66
Square Hollow Sections GOST P 54157-2010
Rectangular Hollow Sections GOST 12336-66
Rectangular Hollow Sections GOST P 54157-2010
Square Steel Hollow Sections GOST 8639-68
Rectangular Steel Hollow Sections GOST 8645-68
Square Hollow Sections GOST 25577-83*
Rectangular Hollow Sections GOST 25577-83*
Square Hollow Sections GOST 30245-94
Rectangular Hollow Sections GOST 30245-94
Steel roll-formed closed welded square section GOST 30245-2003
Steel roll-formed closed welded rectangular section GOST 30245-2003
Square Steel Hollow Sections GOST 8639-82
Calibrated round steel GOST 7417-75
Round Hot-rolled Steel Bars GOST 2590-88
Square Hot-rolled Steel Bars GOST 2591-88
Steel roll-formed closed welded square section GOST 30245-2012
Steel roll-formed closed welded rectangular section GOST 30245-2012
Roll-formed equal leg angle GOST 19771-93 (tab.1)
Roll-formed equal leg angle GOST 19771-93 (tab.2)
Roll-formed unequal leg angle GOST 19771-93 (tab.1)
Roll-formed unequal leg angle GOST 19771-93 (tab.2)

Round steel bars per GOST 2590-2006
Square Hot-rolled Steel Bars per GOST 2591-2006
Circular Hollow Sections TU 1381-103-05757848-2013
Wide flanged I-beam TU 0925-016-00186269-2016
Wide flang I-beam TU 0925-036-00186269-2016
Column I-beam TU 0925-016-00186269-2016
Regular I-beam TU 0925-016-00186269-2016
Regular I-beam TU 0925-016-00186269-2016
Column I-beam TU 0925-036-00186269-2016
Regular I-beam TU 0925-036-00186269-2016
Pile I-beam TU 0925-036-00186269-2016
Narrow I-beam TU 0925-016-00186269-2016
Narrow flange I-beam TU 24107-016-00186269-2017
Regular I-beam TU 24107-016-00186269-2017
Medium flange I-beam TU 24107-016-00186269-2017
Wide flange I-beam TU 24107-016-00186269-2017
Column I-beam TU 24107-016-00186269-2017
Regular I-beam TU 24107-036-00186269-2017
Column I-beam TU 24107-036-00186269-2017
Wide flange I-beam TU 24107-036-00186269-2017
Pile I-beam TU 24107-036-00186269-2017
Additional series I-beam GOST R 57837-2017
Additional series column I-beam GOST R 57837-2017
Wide flange I-beam GOST R 57837-2017
Regular I-beam GOST R 57837-2017
Column I-beam GOST R 57837-2017
Pile I-beam GOST R 57837-2017
Circular Hollow Sections GOST 32931-2015
Square Hollow Sections GOST 32931-2015
Rectangular Hollow Sections GOST 32931-2015
Circular Hollow Welded Sections GOST R 58064-2018
Additional series I-beam GOST R 57837-2017 change No.1
Additional series column I-beam GOST R 57837-2017 change No.1
Wide flange I-beam GOST R 57837-2017 change No.1
Hot-rolled list steel GOST 19903-2015
Cold-rolled steel sheets GOST 19904-90
Hot-rolled list steel GOST 19903-74
Hot-rolled steel strip GOST 103-76
Hot-rolled steel strips GOST 103-2006
Universal hot-rolled steel wide strips GOST 82-70
Hot-rolled list steel GOST 19903-74 (roll)
Hot-rolled list steel GOST 19903-2015 (roll)
List of the reduced GOST sections
Equal leg angle GOST 8509-93
Unequal leg angle GOST 8510-86*
Channel with parallel flanges GOST 8240-89
Channels with sloped inner flange surfaces GOST 8240-89
Column I-beam GOST 26020-83
I-beam with sloped inner flange surfaces GOST 8239-89
Additional series I-beam GOST 26020-83
Regular I-beam GOST 26020-83
Wide-flange I-beam GOST 26020-83
Column T-bar TU 14-2-685-86
T-bar TU 14-2-685-86

Longitudinally electric welded Circular Hollow Sections GOST 10704-91
Roll-formed channels with equal flanges GOST 8278-83 (steels C239-C245)
Roll-formed channels with equal flanges GOST 8278-83 (steels C255-C275)
Square Hollow Sections TU 36-2287-80
Rectangular Hollow Sections TU 67-2287-80
List of STO ASChM 20-93 sections
Regular I-beam STO ASChM 20-93
Wide flange beam STO ASChM 20-93
Column I-beam STO ASChM 20-93
I-beam R40-93
Special I-beam STO ASChM 20-93
List of sections of old assortments
Equal leg angle OST 14-1926
Equal leg angle OST 14-1932
Unequal leg angle OST 15-1926
Unequal leg angle OST 15-1932
I-beam OST 16-1926
I-beam OST 16-1932
Channels with sloped inner flange surfaces OST 17-1926
Channels with sloped inner flange surfaces OST 17-1933
Equal leg angle OST 10014-39
Unequal leg angle OST 10015-39
I-beam OST 10016-39
Channel OST 10017-39
IPB Shapes DIN 1025
IPB1 Shapes DIN 1025
IPBv Shapes DIN 1025
IPE Shapes DIN 1025
IPEo Shapes DIN 1025
IPEv Shapes DIN 1025
List of British Standard Sections
Equal leg angle BS EN 10056-1:1999
Unequal leg angle
Universal Beams BS 4-1:1993
Universal Columns BS 4-1:1993
Universal Bearing Piles BS 4-1:1993
Joists
Structural Tees cut from UB’s
Structural Tees cut from UC’s
Channels
Rectangular Hollow Sections
Circular Hollow Sections
Square Hollow Sections
Circular Hollow Sections EN10219-2:2006(E)
Square Hollow Sections EN10219-2:2006 (E)
Rectangular Hollow Sections EN10219-2:2006 (E)
List of British Overseas Shapes
ASTM W Shapes (Universal beams and columns)
IPE Shapes (European universal beams)
HE Shapes (European universal beams and columns)
Rectangular Hollow Sections
Circular Hollow Sections

Square Hollow Sections
List of OTUA sections
Equal leg angle NF A 45-009
Unequal leg angle NF A 45-010
IPN Shapes NF A 45-209
PA Shapes NF A 45-205
IPE-A Shapes NF A 45-205
IPE Shapes NF A 45-205
IPE-R Shapes NF A 45-205
HEA-A Shapes NF A
HEA Shapes NF A 45-201
HEB Shapes NF A 45-201
HEM, HEC Shapes NF A 45-201
Structural Tees cut from PA NF A 45-205
Structural Tees cut from IPE-A NF A 45-205
Structural Tees cut from IPE NF A 45-205
Structural Tees cut from IPE-R NF A 45-205
Structural Tees cut from HEA-A NF A 45-211
Structural Tees cut from HEA NF A 45-201
Structural Tees cut from HEB NF A 45-201
Structural Tees cut from HEM, HEC NF A 45-201
Channels UPN NF A 45-202
Channels UPN-A NF A 45-202
Channels UAP NF A 45-255
Channels UAP-A NF A 45-255
Circular Hollow Sections
Rectangular Hollow Sections
Square Hollow Sections
List of DIN sections
Equal leg angle DIN 1028
Unequal leg angle DIN 1029
Beam DIN 1025
IP DIN 1025
IP DIN 1025 (9%)
Channels DIN 1026
Circular Hollow Sections DIN 2448
Rectangular Hollow Sections DIN 59410
Square Hollow Sections DIN 59410
List of ARBED sections
Equal leg angle Euronorm 56-77
Unequal leg angle Euronorm 57-78
European I-beams (IPE)
European standard beams (IPN) NF A 45-209
European wide flange beams (HE)
European wide flange beams (HL)
Wide flange columns (HD)
Wide flange bearing piles (HP)
American wide flange beams (W)
British universal beams (UB) BS 4-1:1993
British universal columns (UC) BS 4-1:1993
Channels with parallel flanges NF A 45-255
European standard channels NF A 45-202

List of ASTM sections
Equal leg angle
Unequal leg angle
H-Piles ASTM A6/A6M-98
Miscellaneous Shapes
American Standard Shapes
Wide Flange Shapes ASTM A6/A6M-98
Miscellaneous Tees
American Standard Tees
Wide Flange Tees
American Standard Channels
Miscellaneous Channels
Pipe
Extra Strong Pipe
Double-Extra Strong Pipe
Tube Steel (Square)
Tube Steel (Rectangular)
List of welded profiles
Welded I-beam TU U 01412851.001-95
Welded I-beam instead of GOST 26020-83 (TU 0925-001-97638531-2016)
Welded I-beam instead of STO ASChM 20-93 (TU 0925-001-97638531-2016)
Column I-beam instead of GOST 26020-83 (TU 0925-001-97638531-2016)
Welded I-beam instaed of STO ASChM 20-93 (TU 0925-001-97638531-2016)
Broad-flanged beam instead of GOST 26020-83 (TU 0925-001-97638531-2016)
Broad-flanged beam instead of STO ASChM 20-93 (TU 0925-001-97638531-2016)
Welded I-beam TU 0925-001-97638531-2016
Welded I-beam instead of STO ASChM 20-93 (TU 0925-002-62017235-2016)
Wide flange I-beam instead of STO ASChM 20-93 (TU 0925-002-62017235-2016)
Welded I-beam instead of STO ASChM 20-93 (TU 0925-002-62017235-2016)
Welded I-beam GK Euroangar_01_2020
Additional series welded I-beam GOST R 58966-2020
Additional series column welded I-beam GOST R 58966-2020
Wide flange welded I-beam GOST R 58966-2020
Regular welded I-beam GOST R 58966-2020
Column welded I-beam GOST R 58966-2020
Pipe welded I-beam GOST R 58966-2020
Cold-formed profiles
Profile LP TU 1121-009-46216359-2010
Profile LC TU 1121-009-46216359-2010
Profile U TU 1122-002-10836231-2014
Profile C TU 1122-02-10836231-2014
Profile U TU 1120-001-37820873-2012
Profile C TU 1120-001-37820873-2012
Profile PC TU 1120-001-82861223-2009
Profile PC TU 25.11.23-001-97638531-2017
Steel roll-formed C-shaped equal flange sections GOST 8282-83
Steel roll-formed Z-shaped sections GOST 13229-78 tab.3
Steel roll-formed Z-shaped sections GOST 13229-78 tab.4
Steel roll-formed Z-shaped sections GOST 13229-78 tab.1
Steel roll-formed Z-shaped sections GOST 13229-78 tab.2
Steel roll-formed unequal channels GOST 8281-80 tab.1
Steel roll-formed unequal channels GOST 8281-80 tab.2

Roll-formed steel hat equal flange sections GOST 8283-93 tab.1
Roll-formed steel hat equal flange sections GOST 8283-93 tab.2
Profile PC1 TU 25.11.23-001-97638531-2017
Profile PP TU 5285-004-4281025-04
Profile PS TU 5285-004-4281025-04
Profile PGS TU 5285-004-4281025-04
Profile PGS_E TU 5285-004-4281025-04
Profile Z TU 5285-004-4281025-04
Roll-formed equal leg angle TU 25.11.23-001-00206227-2020
Roll-formed unequal leg angle TU 25.11.23-001-00206227-2020
Profile PP TU 25.11.23-001-00206227-2020
Profile PGS TU 25.11.23-001-00206227-2020
Profile PGS_E TU 25.11.23-001-00206227-2020
Profile PS TU 25.11.23-001-00206227-2020
Profile Z TU 25.11.23-001-00206227-2020
Steel roll-formed C-shaped equal flange sections GOST 8282-20-22
Profile PSh TU 25.11.23-001-00206227-2020
Profile PSh TU 5285-004-42481025-04
Cold-formed zinc-coated steel profiles
Profile PC TU 1121-001-13830080
Profile PN TU 1121-001-13830080
Profile TC TU 1121-001-13830080
Profile TN TU 1121-001-13830080
Profile AC TU 1122-002-82866678-2013
Profile E TU 1121-001-99651760-2015 (steel 250/C255)
Profile E TU 1121-001-99651760-2015 (steel 350/C345)
Profile AE TU 1122-002-82866678-2013
Profile AZ TU 1122-002-82866678-2013 tab.2
Profile AZ TU 1122-002-82866678-2013 tab.3
Profile (steel 250) CTO 12447545-0012-2012
Profile (steel 350) CTO 12447545-0012-2012
Steel roll-formed Z-shaped sections (steel 250) CTO 12447545-0012-2012
Steel roll-formed Z-shaped sections (steel 350) CTO 12447545-0012-2012
List of Indian sections
Rolled steel equal leg angle
Unequal leg angle
Rolled Steel Beams ISHB
Rolled Steel Beams ISJB
Rolled Steel Beams ISLB
Rolled Steel Beams ISMB
Rolled Steel Beams ISWB
Rolled Steel Channels ISJC
Rolled Steel Channels ISLC
Rolled Steel Channels ISMC
Circular Hollow Sections
List of Japanese sections
Equal leg angle JIS G3192:1990
Unequal leg angle
I-sections JIS G3192:1990
Middle Flange Shapes
Wide Flange Shapes
Channel JIS G3192:1990
Short Flange Tee

Middle Flange Tee
Wide Flange Tee
Circular Hollow Sections
Rectangular Hollow Sections
Square Hollow Sections
List of zinc coated steel wire ropes GOST
Load-bearing closed wire rope with two layers of Z-shaped wire and a core of TK type GOST 18901-73*
Double strand wire rope of LK-RO type. TU 14-4-902-78
Load-bearing closed wire rope with one layer of Z-shaped wire and a core of TK type GOST 3090-73*
Load-bearing closed wire rope with a layer of wedge and Z-shaped wire and a core of TK type GOST 7675-73*
Cables GOST 7676-73*
Closed spiral strand zinc coated steel wire ropes TU 14-4-1216-82
Single strand wire rope of LK-O type GOST 3062-80*
Single strand wire rope of TK-type GOST 3063-80*
Single strand wire rope of T12 type GOST 3064-80*
Double strand wire rope of LK-O type GOST 3066-80*
Double strand wire rope of LK-3 type GOST 7667-80*
Double strand wire rope of DK-RO type GOST 7669-80*
Double strand wire rope of LK-R type GOST 14954-80*
List of GOST rebars
Rebars of Class A-I GOST 5781-82*
Rebars of Class A-II GOST 5781-82*
Rebars of Class A-III GOST 5781-82*
Rebars of Class A-IV GOST 5781-82*
Rebars of Class A-V GOST 5781-82*
Rebars of Class A-VI GOST 5781-82*
Rebars of Class At-VII GOST 10884-81
Rebars of Class Bp-I GOST 6727-80
Rebars of Class Bp -II GOST 7348-81
Rebars of Class B-II GOST 7348-81
Rebars of Class A400C STO ASChM 7-93
Rebars of Class A500C STO ASChM 7-93
Cables of Class K-7 GOST 13840-68
Cables of Class K-19 TU 14-4-22-71
List of Belarus rebars
Rebars of Classes S400, S500 TU RB 190266671.001-2002
Rebars of Classes S400, S500 TU RB 04778771.001-97
Rebars of Class S800 TU RB 04778771.001-97
Rebars of Class S500 STB1341-2002
List of ENV 10080:1996 rebars
Rebars of Class B500A ENV 10080:1996
Rebars of Class B500B ENV 10080:1996
Rebars of Class B450C ENV 10080:1996
Ukrainian cold-formed profiles
Profile C manufacture by Light House-Ukraine
Profile U manufactured by Light House-Ukraine
Profile C manufactured by Stalex
Profile Cw manufactured by Stalex
Profile U manufactured by Stalex
Steel roll-formed Z-manufacture by Stalex
Steel roll-formed Zw-manufacture by Stalex
Profile C manufacture by Pruszynski
Steel roll-formed Z-manufacture by Pruszynski

RUUKKI cold-formed profiles
Roll-formed steel hat equal flange sections RUUKKI
Profile C manufacture by Pruszynski RUUKKI
Profile E manufacture by Pruszynski RUUKKI
Profile Z manufacture by Pruszynski RUUKKI
Pruszynski cold-formed profiles
Profile C manufacture by Pruszynski
Steel E-manufacture by Pruszynski
Steel roll-formed Z-manufacture by Pruszynski
Ukrainian profiles
Equal leg angle DSTU 2551:2018 (short)
Hot-rolled steel equal-leg angle DSTU 2251:2018
Channel DSTU 3436-96 (short)
Channel DSTU 3436-96
Economical channels parallel flanges DSTU 3436-96 (GOST 8240-97)
Light channels with parallel flanges DSTU 3436-96 (GOST 8240-97)
Channels with parallel flanges DSTU 3436-96 (GOST 8240-97)
Channels with sloped inner flange surfaces DSTU 3436-96 (GOST 8240-97)
I-beam special DSTU 8768:18 (short)
I-beam DSTU 8768:18 (short)
Hot-rolled steel flange beams DSTU 8768:2018
Welded I-beam TU U 01412851.001-95
Welded I-beam instead of GOST 26020-83 (TU 0925-001-97638531-2016)
Column I-beam instead of GOST 26020-83 (TU 0925-001-97638531-2016)
Wide flange I-beam instead of GOST 26020-83 (TU 0925-001-97638531-2016)
Circular Hollow Sections GOST 10704-91 (short)
Longitudinally electric welded Circular Hollow Sections GOST 10704-91
Circular Welded Hollow Sections GOST 10219-2:2009
Square Hollow Sections EN 10219:2006 (short)
Square Steel Hollow Sections GOST 8639-82
Square Hollow Sections GOST 8639-82 (short)
Rectangular Hollow Sections GOST 8645-68 (short)
Square Welded Hollow Sections DSTU EN 10219-2:2009
Rectangular Steel Hollow Sections GOST 8645-68
Rectangular Welded Hollow Sections EN10219:2006
Rectangular Hollow Sections EN10219:2006
Hot-rolled steel sheets DSTU 8540:2015 (roll) (short)
Hot-rolled steel sheets DSTU 8540:2015 (short)
Cold-rolled steel sheets DSTU 8971:2019 (short)
SEAMLESS HOT-DEFORMED STEEL PIPES DSTU 8938:2019
Shaped Steel Pipes Square DSTU 8940:2019
Shaped Steel Pipes Rectangle DSTU 8940:2019
List of polish sections
Equal leg angle PN-EN 10056-1:2000
Equal leg angle PN-84/H-93401
I-beam PN-91/H-93419
Structural Tees cut from HEA PN-H 93452:2005
Wide flange I-beam PN-H-93452:2005
Structural Tees cut from HEC PN-H 93452:2005
Channel PN/H-93403
Square Hollow Sections PN-EN 10219-2:2000
Thermal roll-formed steel profiles
Profile TPGC CTO 42481025 006-2007

Profile TPP CTO 42481025 006-2007
List of chinese sections
Equal leg angle GB/T 706-2008
Unequal leg angle GB/T 706-2008
Unequal leg angle type II GB/T 706-2008
I-beam with sloped inner flange surfaces GB/T 706-2008
Channel with sloped inner flange surfaces GB/T 706-2008
Circular HoLLow Sections GB/T 6728-2002
Square Hollow Sections GB/T GB/T 6728-2002
Rectangular Hollow Sections GB/T 6728-2002
Hot-rolled section Equal Leg Angle steel GB/T 706-2016
Hot-rolled section Unequal Leg Angle steel GB/T 706-2016
Hot-rolled H section steel GB/T 11263-2017
Hot-rolled cut T section steel GB/T 11263-2017
Hot-rolled section I-steel GB/T 706-2016
Hot-rolled section U-steel GB/T 706-2016
Extruded of aluminium alloys
Aluminium-alloy extruded profiles rectangular GOST 13616-97
Magnezium-alloy extruded profiles rectangular GOST 13616-97
Aluminium-alloy extruded profiles oblique-angled fiting GOST 13618-97
Magnezium-alloy extruded profiles oblique-angled fiting GOST 13618-97
Aluminium-alloy extruded profiles Z-section GOST 13619-97
Magnezium-alloy extruded profiles Z-section GOST 13619-97
Aluminium-alloy extruded profiles zee-section GOST 13620-90
Magnezium-alloy extruded profiles zee-section GOST 13620-90
Aluminium-alloy extruded profiles H-beam section GOST 13621-90
Magnezium-alloy extruded profiles H-beam section GOST 13621-90
Aluminium-alloy extruded profiles T-section GOST 13622-91
Magnezium-alloy extruded profiles T-section GOST 13622-91
Aluminium-alloy extruded profiles channel-section GOST 13623-90
Magnezium-alloy extruded profiles channel-section GOST 13623-90
Aluminium-alloy extruded profiles flanged channel-section GOST 13624-90
Magnezium-alloy extruded profiles flanged channel-section GOST 13624-90
Aluminium-alloy extruded profiles equishelf angle-section GOST 13737-90
Magnezium-alloy extruded profiles equishelf angle-section GOST 13737-90
Aluminium-alloy extruded profiles unequishelf angle-section GOST 13738-91
Magnezium-alloy extruded profiles unequishelf angle-section GOST 13738-91
Aluminium-alloy extruded profiles trapezoidal flanged-section GOST 17576-97
Magnezium-alloy extruded profiles trapezoidal flanged-section GOST 17576-97
Aluminium-alloy extruded profiles unequishelf H-beam GOST 29303-92
Magnezium-alloy extruded profiles unequishelf H-beam GOST 29303-92
Aluminium-alloy extruded round tube GOST 18475-82
Aluminium-alloy extruded square tube GOST 18475-82
Aluminium-alloy extruded rectungle tube GOST 18475-82
Aluminium-alloy extruded round tube GOST P 56281-2014
Aluminium-alloy extruded round tube GOST 18482-2018
Aluminium-alloy welded round tube GOST 23697-79
Aluminium-alloy pressed bars round of normal accuracy GOST 21488-97
Aluminium-alloy pressed bars round of improved accuracy GOST 21488-97
Aluminium-alloy pressed bars of high accuracy round GOST 21488-97
Aluminium-alloy pressed bars square of normal accuracy GOST 21488-97
Aluminium-alloy pressed bars square of improved accuracy GOST 21488-97
Aluminium-alloy pressed bars square of high accuracy GOST 21488-97

5. Verification Tests

This section contains verification tests for examining the accuracy of the results obtained in **Consul** and **Tonus**. The numerical results are compared with known theoretical solutions (exact or approximate).

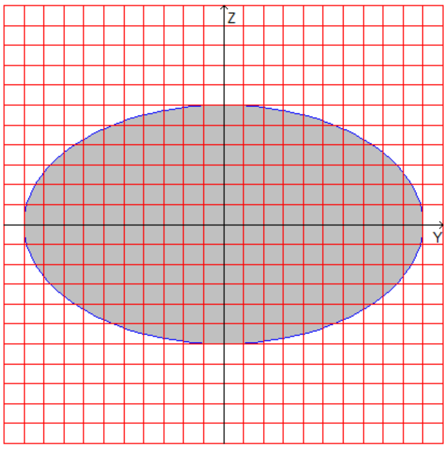
Initial data with the design models, and also references to publications which are sources of the decisions, are given in all verification tests. There are analytical formulas for the calculation of the results by theoretical solutions for most of the verification tests. The results of the analysis are displayed in tabular and graphical form.

Differences between the results obtained in **Consul** and **Tonus** and theoretical results are given as percent relative deviations of the solution. Calculation of deviations was not performed in the areas close to the zero solutions.

The problem of determining such parameters as area, moments of inertia, etc., is rather simple, so the verification of these characteristics is given only for one form of the section (ellipse). The problem of determining torsional and shear parameters is rather difficult; therefore the check of these values is performed in most tests.

5.1 Consul

Geometric Properties of an Ellipse



Aim: To check the accuracy of the geometric properties calculation for a solid elliptical cross-section of a rod.

Name of a file with the initial data: **Ellipse_Solid.cns**

Formulation: Check the accuracy of the geometric properties calculation for a solid elliptical cross-section of a rod.

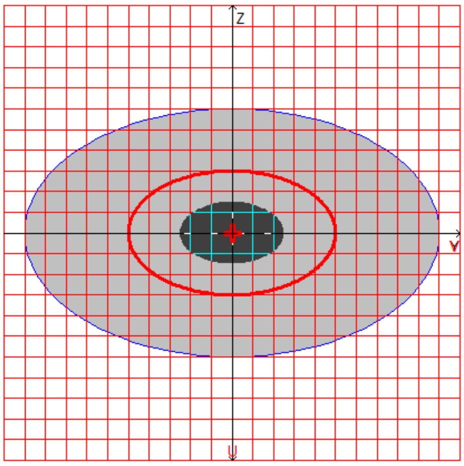
References: S.P. Demidov, *Theory of Elasticity*, M., Vysshaya Shkola, 1979.
A.I. Lurie, *Theory of Elasticity*, M., Nauka, 1970.

Initial data:

$\nu = 0.30$	- Poisson’s ratio;
a = 50 cm	- length of the semi-major axis of the elliptical cross-section (along Y axis);
b = 30 cm	- length of the semi-minor axis of the elliptical cross-section (along Z axis).

Design model: The design model is created by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour imported from the AutoCad graphic editor. The model of an external contour is a polygon inscribed in an ellipse with given properties and built in polar coordinates with an angle step of 3°. The number of vertices of a polygon in a model is 120.

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	CONSUL	Deviation, %
Cross-sectional area, A cm^2	4712.389	4709.319	0.07
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	3724.143	3702.975	0.57
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	4147.170	4161.672	0.35
Angle of the principal axes of inertia α rad	1.5708	1.5708	0.00
Moment of inertia about the centroidal Y_1 axis parallel to the coordinate Y axis, I_y cm^4	1060287.521	1059491.143	0.08
Moment of inertia about the centroidal Z_1 axis parallel to the coordinate Z axis, I_z cm^4	2945243.113	2939784.432	0.19
Torsional moment of inertia, I_t cm^4	3118492.708	3064969.367	1.72
Sectorial moment of inertia, I_w cm^6	97835065.337	95561910.155	2.32
Radius of gyration about Y_1 axis, i_y cm	15.000	14.980	0.13
Radius of gyration about Z_1 axis, i_z cm	25.000	24.991	0.04
Maximum section modulus about U-axis, W_{u+} cm^3	58904.862	58795.689	0.19
Minimum section modulus about U-axis, W_{u-} cm^3	58904.862	58795.689	0.19
Maximum section modulus about V-axis, W_{v+} cm^3	35342.917	35316.371	0.08
Minimum section modulus about V-axis, W_{v-} cm^3	35342.917	35316.371	0.08
Plastic section modulus about U-axis, $W_{pl,u}$ cm^3	100000.000	99796.050	0.20
Plastic section modulus about V-axis, $W_{pl,v}$ cm^3	60000.000	59820.326	0.30
Maximum moment of inertia, I_u cm^4	2945243.113	2939784.432	0.19
Minimum moment of inertia, I_v cm^4	1060287.521	1059491.143	0.08
Maximum radius of gyration, i_u cm	25.000	24.985	0.06
Minimum radius of gyration, i_v cm	15.000	14.999	0.01
Core size along positive Y(U)-axis, a_{u+} cm	7.500	7.494	0.08
Core size along negative Y(U)-axis, a_{u-} cm	7.500	7.480	0.27
Core size along positive Z(V)-axis, a_{v+} cm	12.500	12.491	0.07
Core size along negative Z(V)-axis, a_{v-} cm	12.500	12.491	0.07
Y-coordinate of the center of mass, y_m cm	0.000	0.000	—
Z-coordinate of the center of mass, z_m cm	0.000	0.000	—
Y-coordinate of the shear center, y_b cm	0.000	0.013	—
Z-coordinate of the shear center, z_b cm	0.000	0.040	—
Perimeter, P cm	255.180	255.180	0.00
Internal perimeter, P_i cm	0.000	0.000	—
External perimeter, P_e cm	255.180	255.180	0.00

Parameter	Theory	CONSUL	Deviation, %
Polar moment of inertia, I_p cm^4	4005530.633	3993669.583	0.30
Polar radius of gyration, i_p cm	29.155	29.136	0.07
Polar section modulus, W_p cm^3	80110.800	79872.926	0.30

***Notes*:** Geometric properties of the solid elliptical cross-section of the rod can be determined analytically by the following formulas:

$$A = \pi \cdot a \cdot b;$$

$$A_{v,y} = \frac{3 \cdot (1+\nu)^2 \cdot \left(a^2 + 3 \cdot b^2\right)^2 \cdot b^2}{(1+\nu)^2 \cdot \left(22 \cdot a^2 + 30 \cdot b^2\right) \cdot b^4 + \left(2 \cdot \nu^2 \cdot a^2 + \left(4 + 8 \cdot \nu + 10 \cdot \nu^2\right) \cdot b^2\right) \cdot a^4} \cdot \pi \cdot a \cdot b;$$

$$A_{v,z} = \frac{3 \cdot (1+\nu)^2 \cdot \left(3 \cdot a^2 + b^2\right)^2 \cdot a^2}{(1+\nu)^2 \cdot \left(30 \cdot a^2 + 22 \cdot b^2\right) \cdot a^4 + \left(\left(4 + 8 \cdot \nu + 10 \cdot \nu^2\right) \cdot a^2 + 2 \cdot \nu^2 \cdot b^2\right) \cdot b^4} \cdot \pi \cdot a \cdot b;$$

$$\alpha = 0; \qquad I_y = I_v = I_1 = \frac{\pi \cdot a \cdot b^3}{4}; \qquad I_z = I_u = I_2 = \frac{\pi \cdot a^3 \cdot b}{4};$$

$$I_t = \frac{\pi \cdot a^3 \cdot b^3}{a^2 + b^2}; \qquad I_w = \frac{\pi \cdot a^3 \cdot b^3}{24} \cdot \left(\frac{a^2 - b^2}{a^2 + b^2}\right)^2;$$

$$i_y = i_v = \frac{b}{2}; \qquad i_z = i_u = \frac{a}{2};$$

$$W_{u+} = W_{u-} = \frac{\pi \cdot a^2 \cdot b}{4}; \qquad W_{v+} = W_{v-} = \frac{\pi \cdot a \cdot b^2}{4};$$

$$W_{pl,u} = \frac{4 \cdot a^2 \cdot b}{3}; \qquad W_{pl,v} = \frac{4 \cdot a \cdot b^2}{3};$$

$$a_{u+} = a_{u-} = \frac{b}{4}; \qquad a_{v+} = a_{v-} = \frac{a}{4};$$

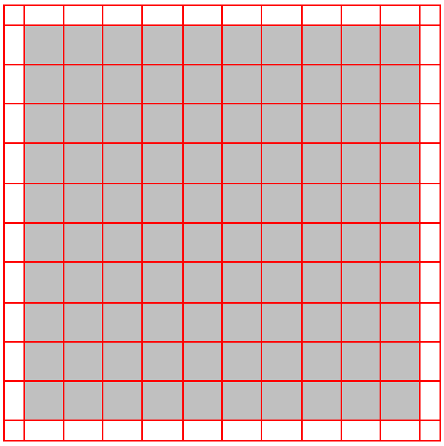
$$y_m = y_b = z_m = z_b = 0;$$

$P = P_e = 4 \cdot a \cdot E\left(\dfrac{\sqrt{a^2 - b^2}}{a}\right)$, where: $E(x) -$ Legendre complete elliptic integral of the second kind;

$$P \approx 4 \cdot (a+b) - \frac{2 \cdot (4-\pi) \cdot a \cdot b}{\sqrt[\frac{3\cdot\pi-8}{8-2\cdot\pi}]{\dfrac{a^{\frac{3\cdot\pi-8}{8-2\cdot\pi}} + b^{\frac{3\cdot\pi-8}{8-2\cdot\pi}}}{2}}}; \qquad P \approx \pi \cdot (a+b); \qquad P_i = 0;$$

$$I_{12} = 0; \qquad I_p = \frac{\pi \cdot a \cdot b \cdot \left(a^2 + b^2\right)}{4}; \qquad i_p = \frac{\sqrt{a^2 + b^2}}{2}; \qquad W_p = \frac{\pi \cdot b \cdot \left(a^2 + b^2\right)}{4}.$$

Geometric Properties of a Square



Aim: To check the accuracy of the geometric properties calculation for a square cross-section of a rod.

Name of a file with the initial data: **Square.cns**

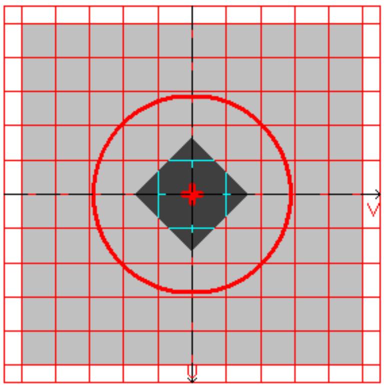
Formulation: Check the accuracy of the shear and torsional geometric properties calculation for a square cross-section of a rod.

References: S.P. Timoshenko, J. Goodier, *Theory of Elasticity*, M., Nauka, 1975.
F. Gruttmann, W. Wagner, *Shear correction factors in Timoshenko's beam theory for arbitrary shaped cross-sections* // Comput. Mech. — 2001. — 27; No. 3 — 199–207.

Initial data:
$\nu = 0.25$ - Poisson's ratio;
a = 40 cm - side length of a square.

Design model: The design model is created by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour. The external contour is a square. The number of vertices of the contour in a model is 4.

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	CONSUL	Deviation, %
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	1327,36	1332,135	0,359
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	1327,36	1332,135	0,359
Torsional moment of inertia, I_t cm^4	360000	357205,548	0,77
Y-coordinate of the shear center, y_b cm	20	20	0
Z-coordinate of the shear center, z_b cm	20	20	0

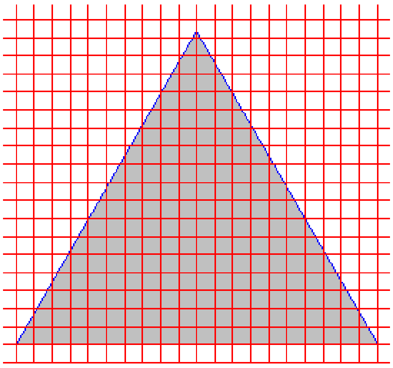
Notes: Geometric properties can be determined analytically by the following formulas:

$$I_t = \frac{a^4}{3}\left[1 - \frac{192}{\pi^5}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^5}\tanh\left(\frac{\pi(2n-1)}{2}\right)\right] \approx 2,25\left(\frac{a}{2}\right)^4;$$

$$y_b = a/2;$$

$$z_b = a/2;$$

Geometric Properties of an Equilateral Triangle



Aim: To check the accuracy of the geometric properties calculation for a rod cross-section in the form of an equilateral triangle.

Name of a file with the initial data: **Triangle.cns**

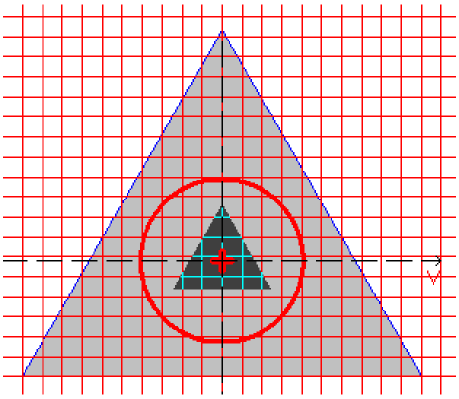
Formulation: Check the accuracy of the torsional geometric properties calculation for a rod cross-section in the form of an equilateral triangle.

References: W.C. Young, R.G. Budynas, *Roark's Formulas for Stress and Strain*, New York , McGraw-Hill, New York, 2002.

Initial data:
$\nu = 0.3$ - Poisson's ratio;
a = 40 cm - side length of an equilateral triangle.

Design model: The design model is created by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour. The external contour is an equilateral triangle. The number of vertices of the contour in a model is 3.

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	CONSUL	Deviation, %
Torsional moment of inertia, I_t cm^4	55425,625	54477,143	1.71
Y-coordinate of the shear center, y_b cm	20	19,999	0,005
Z-coordinate of the shear center, z_b cm	11,547	11,589	0,36

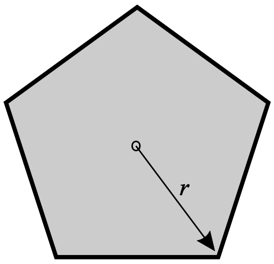
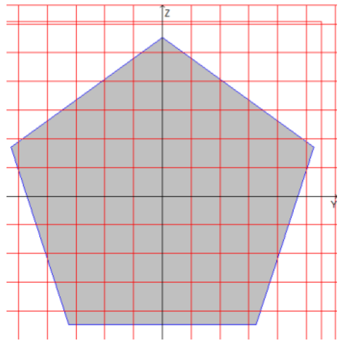
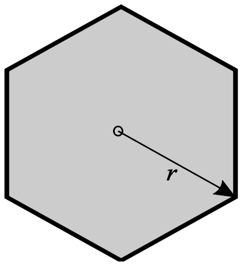
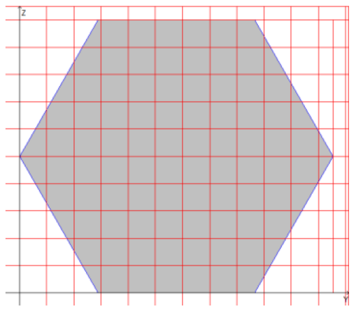
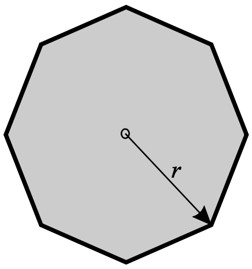
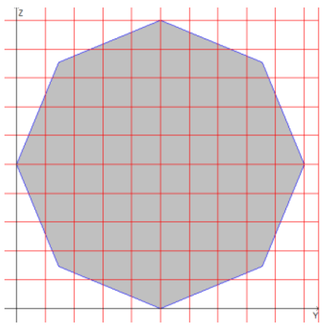
***Notes*:** Geometric properties can be determined analytically by the following formulas:

$$I_t = \frac{\sqrt{3}}{80} a^4;$$

$$y_b = a/2;$$

$$z_b = \frac{a}{2\sqrt{3}}.$$

Geometric Properties of Regular Polygons

pentagon		
hexagon		
octagon		

Aim: To check the accuracy of the torsional moment of inertia calculation for a rod cross-section in the form of a regular polygon.

Names of files with the initial data: **Pentagon.cns**
Hexagon.cns
Octagon.cns

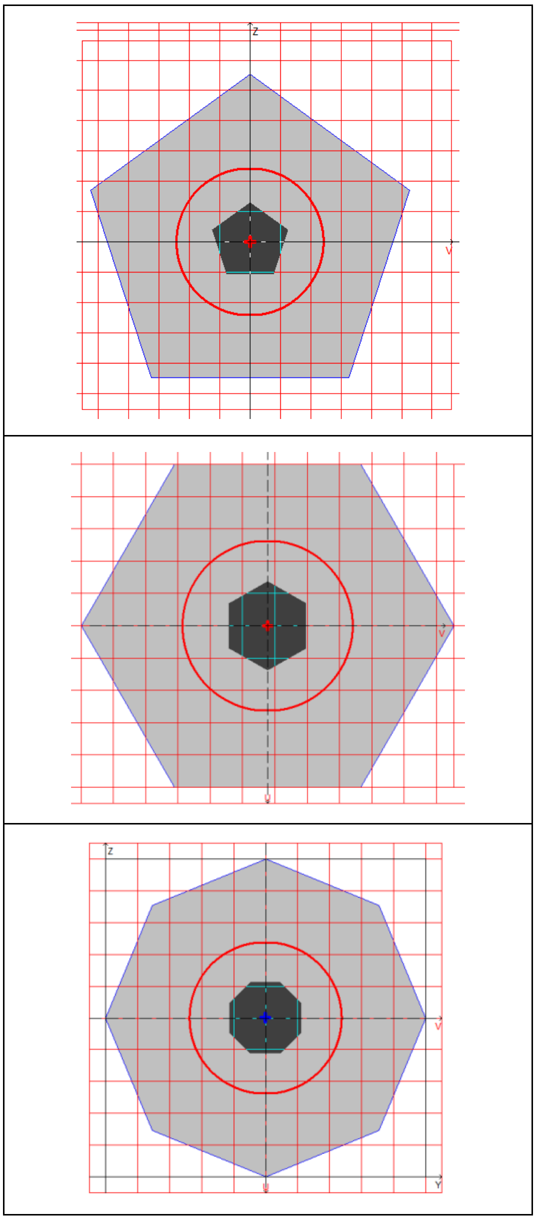
Formulation: Check the accuracy of the torsional geometric properties calculation for a rod cross-section in the form of a regular pentagon, hexagon and octagon.

References: W.C. Hassenpflug, *Torsion of uniform bars with polygon cross-section*, Computers & Mathematics with Applications, 2003, 46, No. 2-3, 313–392.
A. Kovář, *Moment tuhosti v kroucení pravidelného pětiúhelníka*, Aplikace matematiky, 1957, 2, No. 1, 58-65.

Initial data:
$\nu = 0.3$ - Poisson's ratio;
$r = 10$ cm - radius of a circumscribed circle.

Design model: The design model is created by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour. The external contour is a regular polygon. The number of vertices of the contour in a model is 5 (6, 8).

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

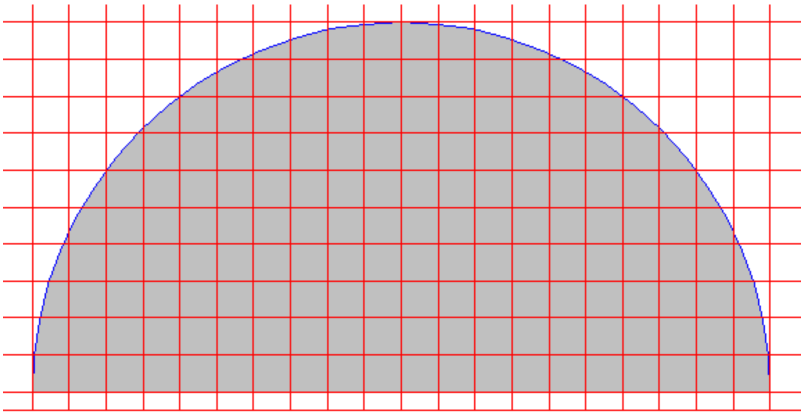
Comparison of results:

	Parameter	Theory	CONSUL	Deviation, %
pentagon	Torsional moment of inertia, I_t cm^4	8478,1	8312,915	1,98
hexagon		10384	10215,966	1,61
octagon		12556,6	12453,297	0,822

***Notes*:** Geometric properties can be determined analytically by the following formulas:

pentagon	$I_t \approx 0{,}84781r^4$;
hexagon	$I_t \approx 1{,}03877r^4$;
octagon	$I_t \approx 1{,}25566r^4$;

Geometric Properties of a Semicircle



Aim: To check the accuracy of the geometric properties calculation for a rod cross-section in the form of a semicircle.

Name of a file with the initial data: **Disk2.cns**

Formulation: Check the accuracy of the torsional geometric properties calculation for a rod cross-section in the form of a semicircle.

References: W.C. Young, R.G. Budynas, *Roark's Formulas for Stress and Strain*, New York , McGraw-Hill, New York, 2002.

E.W. Weisstein, *Torsional Rigidity*, From MathWorld — A Wolfram Web Resource. http://mathworld.wolfram.com/TorsionalRigidity.html

G.R. Cowper, *The Shear Coefficient in Timoshenko's Beam*, ASME Journal of Applied Mechanics, 1966, **33**, 335-341.

V.V. Novojilov, *Theory of Elasticity*, Moscow, State Union Publishing House of the Shipbuilding Industry, 1958, (§ VI.21).

A. Marinetti, *On the Accuracy of Shear Factors for Elastic Uniform Beams: Evaluation Using the Boundary Element Method*, In "Materiali e Metodi Innovativi nell'Ingegneria Strutturale" Aracne Editrice, ISBN 978-88-548-2451-5, (2009).

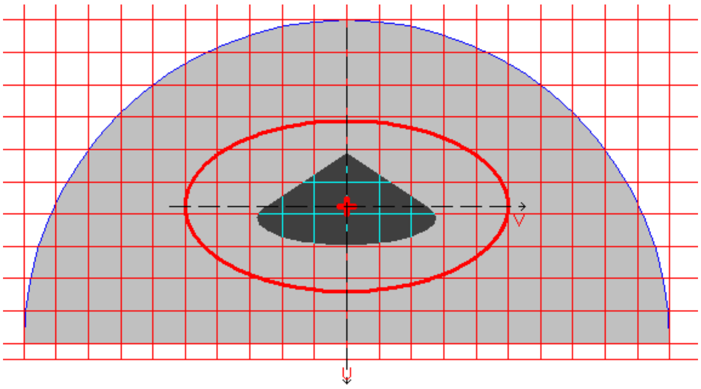
Initial data:

$\nu = 0.1$ - Poisson's ratio;

d = 10 cm - diameter of a circle.

Design model: The design model is created by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour. The external contour is a polygon approximating a semicircle. The number of vertices of the contour in a model is 33.

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	CONSUL	Deviation, %
Cross-sectional area, A cm^2	39,269	39,207	0.16
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	30,239	29,071	3,862
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	34,691	33,29	4,03
Torsional moment of inertia, I_t cm^4	182,25	183,05	0,438
Y-coordinate of the shear center, y_b cm	5	5	0
Z-coordinate of the shear center Z, z_b cm	2,55497	2,555	0,00117

***Notes*:** Geometric properties can be determined analytically by the following formulas:

$$A_{v,y} \approx A\frac{1+\nu}{1,305+1,273\nu};$$

$$A_{v,z} \approx A\frac{(1+\nu)^2}{\frac{7}{6}+\left(2+\frac{64}{45\pi^2}\right)\cdot\nu+\left[\frac{2}{3}+\frac{64}{15\pi^2}-\sum_{m=1}^{\infty}\frac{1}{(2n-1)^2(2n+3)^2}\right]\cdot\nu^2};$$

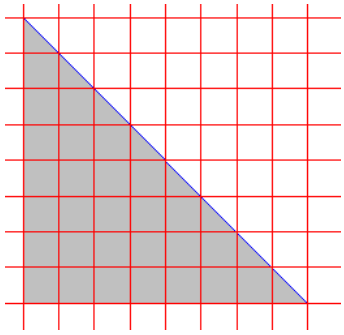
$$I_t=\left(\frac{\pi}{2}-\frac{4}{\pi}\right)\left(\frac{d}{2}\right)^4;$$

$$y_b=d/2;$$

$$z_b \approx \left(\frac{4}{15\pi}\cdot\frac{3+3,05\nu}{1+\nu}\right)d\,.$$

Differences in the position of the shear center are partially explained by the difference in the definition of the shear center (see *Definitions of Geometric Properties*).

Geometric Properties of an Isosceles Right Triangle



Aim: To check the accuracy of the geometric properties calculation for a rod cross-section in the form of an isosceles right triangle.

Name of a file with the initial data: **Triangle90.cns**

Formulation: Check the accuracy of the torsional geometric properties calculation for a rod cross-section in the form of an isosceles right triangle.

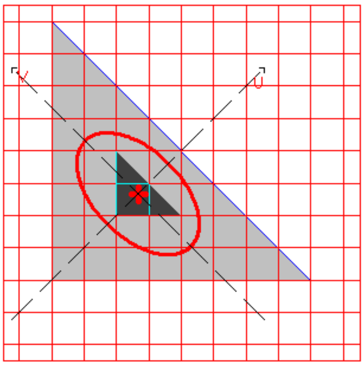
References: B.G. Galerkin, *Torsion of a Triangular Prism*, Izv. Akad. Nauk. VI series, 13:1 (1919), 111–118

G. Polya, G. Szego, *Isoperimetric Inequalities in Mathematical Physics*, — M., Fizmatgiz, 1962.

Initial data:
a = 40 cm - leg length of the triangle.

Design model: The design model is formed by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour. The external contour is an isosceles right triangle. The number of vertices of the contour in a model is 3.

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

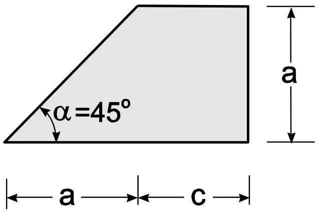
Comparison of results:

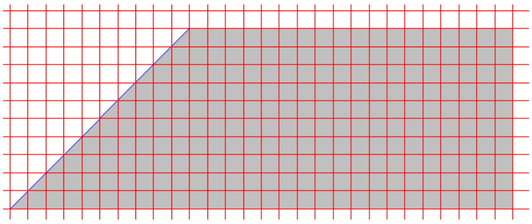
Parameter	Theory	CONSUL	Deviation, %
Torsional moment of inertia, I_t cm^4	66816	66251,348	0,845

***Notes*:** Geometric properties can be determined analytically by the following formulas:

$$I_t = a^4\left[\frac{1}{12} - \frac{16}{\pi^5}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^5}\coth\left(\frac{\pi(2n-1)}{2}\right)\right] \approx 0.0261 \cdot a^4.$$

Geometric Properties of a Trapezoid with an Acute Angle of 45°





Aim: To check the accuracy of the geometric properties calculation for a rod cross-section in the form of a trapezoid with an acute angle of 45°.

Name of a file with the initial data: **Trapec45.cns**

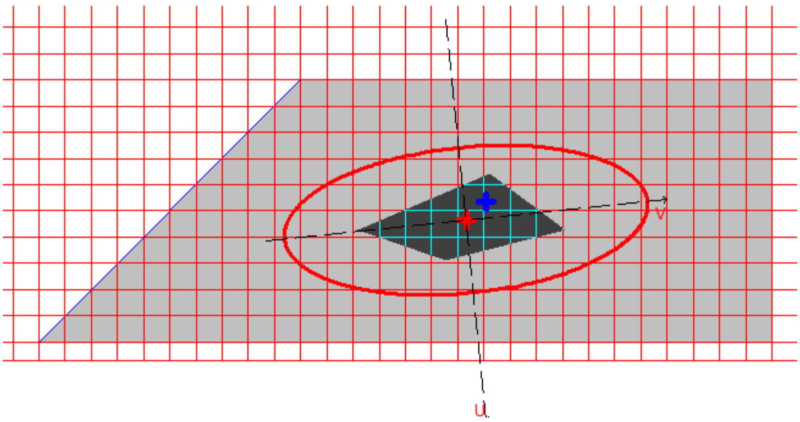
Formulation: Check the accuracy of the torsional geometric properties calculation for a rod cross-section in the form of a trapezoid with an acute angle of 45°.

References: N.H. Arutiunian, B.L. Abramian, *Torsion of Elastic Bodies*, M., Fizmatgiz, 1963 (§ II.4)

Initial data:
a = 50 cm - side length of a trapezoid;
c = 90 cm - side length of a trapezoid.

Design model: The design model is formed by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour. The external contour is a trapezoid with an acute angle of 45°. The number of vertices of the contour in a model is 4.

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

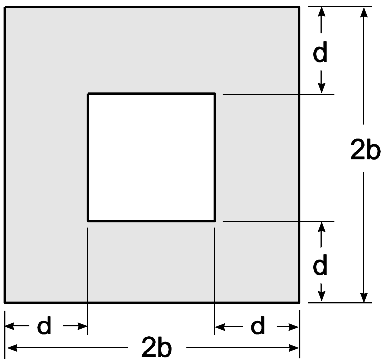
Comparison of results:

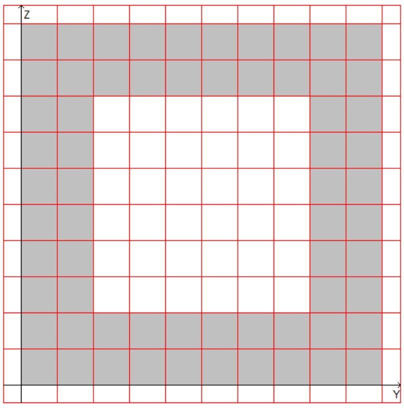
Parameter	Theory	CONSUL	Deviation, %
Torsional moment of inertia, I_t cm^4	3277083,333	3258832,976	0,556

***Notes*:** Geometric properties can be determined analytically by the following formulas:

$$I_t \approx a^4 \left(\frac{1}{3} \frac{a+c}{a} - 0.409 \right).$$

Geometric Properties of a Square with a Central Square Hole





Aim: To check the accuracy of the torsional moment of inertia calculation for the cross-section of a rod with a hole.

Name of a file with the initial data: **SquareWithHole.cns**

Formulation: Check the accuracy of the torsional geometric properties calculation for a rod cross-section in the form of a square with a central square hole.

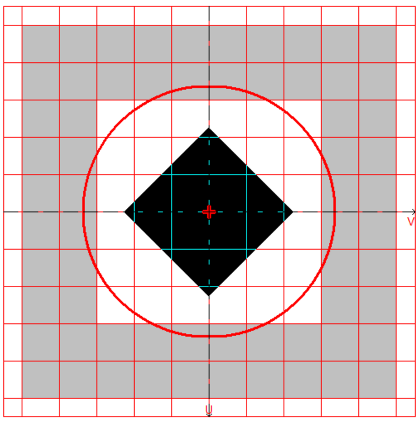
References: N.H. Arutiunian, B.L. Abramian, *Torsion of Elastic Bodies*, M., Fizmatgiz,, 1963 (see § III.1.7).

Initial data:

$\nu = 0.3$ - Poisson's ratio;
b = 100 cm - geometric dimansions.
d = 40 cm

Design model: The design model is formed by triangulation (the number of triangles ≈ 3000) on the basis of a model of the external contour. The external contour is a square, the internal one is a central square. The number of vertices of the contour in a model is 8.

Results Obtained in Consul



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

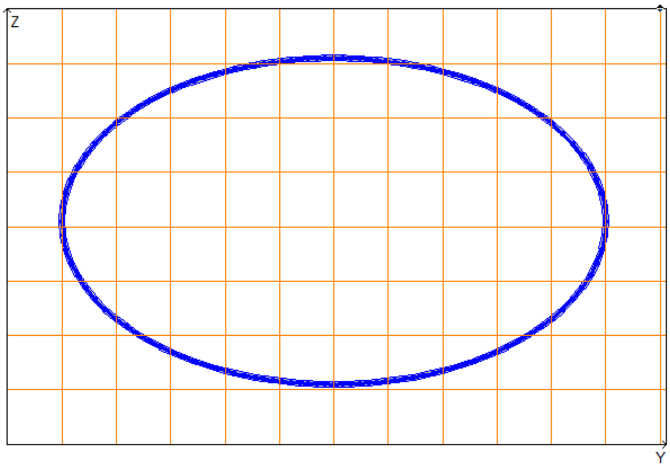
Comparison of results:

Parameter	Theory	CONSUL	Deviation, %
Torsional moment of inertia, I_t cm^4	189095936	188022747,341	0,56

***Notes*:** Geometric properties can be determined analytically by the following formulas:

$$I_t \approx 8\left[\left(\frac{b}{d}\right)^3 - 1,2704\left(\frac{b}{d}\right)^2 + 0,661\left(\frac{b}{d}\right) - 0,1043\right]d^4.$$

5.2 Tonus



Aim: To check the accuracy of the geometric properties calculation for a closed elliptical shell of the rod cross-section.

Name of a file with the initial data: **Ellipse_Shell.tns**

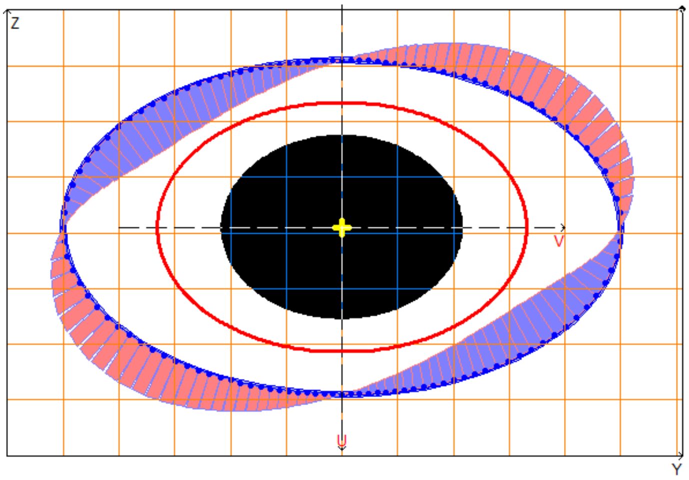
Formulation: Check the accuracy of the geometric properties calculation for a closed elliptical shell of the rod cross-section.

References: A.A. Umansky, *Reference book for designers of industrial, apartment and civil buildings (theoretical calculation)*. Book 1, Moscow, Publishing House On Construction, 1972.
A.V. Aleksandrov, V.D. Potapov, B.P. Derzhavin, *Strength of Materials*, Moscow, Vysshaya shkola, 1995.

Initial data:
a = 50 cm - length of the semi-major axis of an elliptical shell of the cross-section (along Y axis);
b = 30 cm - length of the semi-minor axis of an elliptical shell of the cross-section (along Z axis);
t = 1.0 cm - thickness of the shell of the cross-section.

Design model: The design model is created on the basis of a model of the central contour imported from the AutoCad graphic editor. The model of the contour is a polygon inscribed in an ellipse with given properties and built in polar coordinates with an angle step φ = 3°. The number of vertices of a polygon in a model is 120.

Results Obtained in Tonus



Design model, principal axes, center of mass, ellipse of inertia, core of the section, sectorial coordinate diagrams

Comparison of results:

Parameter	Theory	TONUS	Deviation, %
Cross-sectional area, A cm^2	255.180	255.215	0.01
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	81.383	80.890	0.61
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	173.738	174.325	0.34
Angle of the principal axes of inertia, α rad	1.5708	1.5708	0.00
Moment of inertia about the centroidal Y_1 axis parallel to the coordinate Y axis, I_y cm^4	128657.250	128839.668	0.14
Moment of inertia about the centroidal Z_1 axis parallel to the coordinate Z axis, I_z cm^4	280418.750	279824.429	0.21
Torsional moment of inertia, I_t cm^4	348176.760	347677.226	0.14
Sectorial moment of inertia, I_w cm^6	4265014.702	4260080.440	0.12
Radius of gyration about Y_1 axis, i_y cm	22.457	22.468	0.05
Radius of gyration about Z_1 axis, i_z cm	33.154	33.112	0.13
Maximum section modulus about U-axis, W_{u+} cm^3	5608.375	5541.222	1.20
Minimum section modulus about U-axis, W_{u-} cm^3	5608.375	5541.222	1.20
Maximum section modulus about V-axis, W_{v+} cm^3	4288.575	4224.254	1.50
Minimum section modulus about V-axis, W_{v-} cm^3	4288.575	4224.254	1.50
Plastic section modulus about U-axis, $W_{pl,u}$ cm^3	7471.878	7467.234	0.06
Plastic section modulus about V-axis, $W_{pl,v}$ cm^3	5277.357	5275.030	0.04
Maximum moment of inertia, I_u cm^4	280418.750	279824.429	0.21
Minimum moment of inertia, I_v cm^4	128657.250	128839.668	0.14
Maximum radius of gyration, i_u cm	33.154	33.112	0.13
Minimum radius of gyration, i_v cm	22.457	22.468	0.05
Core size along positive Y(U)-axis, a_{u+} cm	16.810	16.552	1.53
Core size along negative Y(U)-axis, a_{u-} cm	16.810	16.552	1.53
Core size along positive Z(V)-axis, a_{v+} cm	21.983	21.712	1.23
Core size along negative Z(V)-axis, a_{v-} cm	21.983	21.712	1.23
Y-coordinate of the center of mass, y_m cm	0.000	0.000	—
Z-coordinate of the center of mass, z_m cm	0.000	0.000	—
Y-coordinate of the shear center, y_b cm	0.000	0.013	—
Z-coordinate of the shear center, z_b cm	0.000	0.040	—
Perimeter, P cm	510.360	510.430	0.01

Parameter	Theory	TONUS	Deviation, %
Internal perimeter, P_i cm	255.180	255.215	0.01
External perimeter, P_e cm	255.180	255.215	0.01
Polar moment of inertia, I_p cm^4	409076.000	408664.097	0.10
Polar radius of gyration, i_p cm	40.043	40.016	0.07
Polar section modulus, W_p cm^3	8181.520	8092.567	1.09

Values of sectorial coordinates ω in the first quarter of the Cartesian coordinate system UV, cm^2

φ, °	Theory	TONUS	Deviation, %
0	0.000	0.000	0.00
3	-33.798	-33.931	0.39
6	-66.041	-66.277	0.36
9	-95.381	-95.675	0.31
12	-120.827	-121.132	0.25
15	-141.807	-142.088	0.20
18	-158.147	-158.383	0.15
21	-169.998	-170.171	0.11
24	-177.691	-177.821	0.07
27	-181.736	-181.819	0.05
30	-182.648	-182.691	0.02
33	-180.947	-180.957	0.01
36	-177.108	-177.094	0.01
39	-171.555	-171.521	0.02
42	-164.646	-164.598	0.03
45	-156.680	-156.624	0.04
48	-147.904	-147.842	0.04
51	-138.514	-138.448	0.05
54	-128.666	-128.599	0.05
57	-118.482	-118.417	0.05
60	-108.058	-107.995	0.06
63	-97.466	-97.407	0.06
66	-86.761	-86.706	0.06
69	-75.982	-75.933	0.06
72	-65.158	-65.115	0.07
75	-54.310	-54.273	0.07
78	-43.450	-43.420	0.07
81	-32.586	-32.564	0.07
84	-21.722	-21.707	0.07
87	-10.861	-10.853	0.07
90	0.000	0.000	0.00

Notes**:** Geometric properties of the closed elliptical shell of the rod cross-section can be determined analytically by the following formulas:

$$A = 4 \cdot t \cdot a \cdot E\left(\frac{\sqrt{a^2 - b^2}}{a}\right);$$

$$A_{v,y} = 4 \cdot t \cdot \frac{a \cdot b^2}{a^2 - b^2} \cdot \left[F\left(\frac{\sqrt{a^2 - b^2}}{a}\right) - E\left(\frac{\sqrt{a^2 - b^2}}{a}\right)\right];$$

$$A_{v,z} = 4 \cdot t \cdot \frac{a}{a^2 - b^2} \cdot \left[a^2 \cdot E\left(\frac{\sqrt{a^2 - b^2}}{a} \right) - b^2 \cdot F\left(\frac{\sqrt{a^2 - b^2}}{a} \right) \right];$$

$$\alpha = 0;$$

$$I_y = I_v = I_1 = \frac{4}{3} \cdot t \cdot \frac{a \cdot b^2}{a^2 - b^2} \cdot \left[\left(2 \cdot a^2 - b^2 \right) \cdot E\left(\frac{\sqrt{a^2 - b^2}}{a} \right) - b^2 \cdot F\left(\frac{\sqrt{a^2 - b^2}}{a} \right) \right];$$

$$I_z = I_u = I_2 = \frac{4}{3} \cdot t \cdot \frac{a^3}{a^2 - b^2} \cdot \left[\left(a^2 - 2 \cdot b^2 \right) \cdot E\left(\frac{\sqrt{a^2 - b^2}}{a} \right) + b^2 \cdot F\left(\frac{\sqrt{a^2 - b^2}}{a} \right) \right];$$

$$I_t = \frac{\pi^2 \cdot t \cdot a \cdot b^2}{E\left(\frac{\sqrt{a^2 - b^2}}{a} \right)};$$

$$\omega = a \cdot b \cdot \left[\arcsin\left(\frac{v}{a} \right) - \frac{\pi}{2} \cdot \frac{E\left(\arcsin\left(\frac{v}{a} \right); \frac{\sqrt{a^2 - b^2}}{a} \right)}{E\left(\frac{\sqrt{a^2 - b^2}}{a} \right)} \right];$$

$$v = \frac{a \cdot b \cdot cos(\varphi)}{\sqrt{a^2 \cdot sin^2(\varphi) - b^2 \cdot cos^2(\varphi)}};$$

$$I_\omega \approx \frac{\pi^2 \cdot t \cdot a^3 \cdot b^2}{E\left(\frac{\sqrt{a^2 - b^2}}{a} \right)} \cdot \left[0.007812500 \cdot \frac{\left(a^2 - b^2\right)^2}{a^4} + 0.003906250 \cdot \frac{\left(a^2 - b^2\right)^3}{a^6} + \right.$$

$$+0.002326965 \cdot \frac{\left(a^2 - b^2\right)^4}{a^8} + 0.001537323 \cdot \frac{\left(a^2 - b^2\right)^5}{a^{10}} + 0.001087957 \cdot \frac{\left(a^2 - b^2\right)^6}{a^{12}} + \quad ;$$

$$+0.000808729 \cdot \frac{\left(a^2 - b^2\right)^7}{a^{14}} + 0.000254599 \cdot \frac{\left(a^2 - b^2\right)^8}{a^{16}} + 0.000113341 \cdot \frac{\left(a^2 - b^2\right)^9}{a^{18}} +$$

$$\left. +0.000053772 \cdot \frac{\left(a^2 - b^2\right)^{10}}{a^{20}} + 0.000024374 \cdot \frac{\left(a^2 - b^2\right)^{11}}{a^{22}} + 0.000008701 \cdot \frac{\left(a^2 - b^2\right)^{12}}{a^{24}} \right]$$

$$i_y = i_v = \sqrt{\frac{b^2}{3\cdot\left(a^2-b^2\right)}\cdot\left\{2\cdot a^2-b^2\cdot\left[1+\frac{F\left(\frac{\sqrt{a^2-b^2}}{a}\right)}{E\left(\frac{\sqrt{a^2-b^2}}{a}\right)}\right]\right\}};$$

$$i_z = i_u = \sqrt{\frac{a^2}{3\cdot\left(a^2-b^2\right)}\cdot\left\{a^2-2\cdot b^2\cdot\left[1-\frac{F\left(\frac{\sqrt{a^2-b^2}}{a}\right)}{2\cdot E\left(\frac{\sqrt{a^2-b^2}}{a}\right)}\right]\right\}};$$

$$W_{u+} = W_{u-} = \frac{4}{3}\cdot t\cdot\frac{a^2}{a^2-b^2}\cdot\left[\left(a^2-2\cdot b^2\right)\cdot E\left(\frac{\sqrt{a^2-b^2}}{a}\right)+b^2\cdot F\left(\frac{\sqrt{a^2-b^2}}{a}\right)\right];$$

$$W_{v+} = W_{v-} = \frac{4}{3}\cdot t\cdot\frac{a\cdot b}{a^2-b^2}\cdot\left[\left(2\cdot a^2-b^2\right)\cdot E\left(\frac{\sqrt{a^2-b^2}}{a}\right)-b^2\cdot F\left(\frac{\sqrt{a^2-b^2}}{a}\right)\right];$$

$$W_{pl,u} = 2\cdot t\cdot a\cdot\left[a+\frac{b^2}{\sqrt{a^2-b^2}}\cdot ln\left|\frac{\sqrt{a^2-b^2}+a}{b}\right|\right];$$

$$W_{pl,v} = 2\cdot t\cdot b\cdot\left[b+\frac{a^2}{\sqrt{a^2-b^2}}\cdot arcsin\left(\frac{\sqrt{a^2-b^2}}{b}\right)\right];$$

$$a_{u+} = a_{u-} = \frac{1}{3}\cdot\frac{b}{a^2-b^2}\cdot\left\{2\cdot a^2-b^2\cdot\left[1+\frac{F\left(\frac{\sqrt{a^2-b^2}}{a}\right)}{E\left(\frac{\sqrt{a^2-b^2}}{a}\right)}\right]\right\};$$

$$a_{v+} = a_{v-} = \frac{1}{3}\cdot\frac{a}{a^2-b^2}\cdot\left\{a^2-2\cdot b^2\cdot\left[1-\frac{F\left(\frac{\sqrt{a^2-b^2}}{a}\right)}{2\cdot E\left(\frac{\sqrt{a^2-b^2}}{a}\right)}\right]\right\};$$

$$y_m = y_b = z_m = z_b = 0;$$

$$P_e = P_i = 4 \cdot a \cdot E\left(\frac{\sqrt{a^2 - b^2}}{a}\right); \qquad P = P_e + P_i;$$

$$I_{12} = 0;$$

$$I_p = \frac{4}{3} \cdot t \cdot a \cdot \left[\left(a^2 + b^2\right) \cdot E\left(\frac{\sqrt{a^2 - b^2}}{a}\right) + b^2 \cdot F\left(\frac{\sqrt{a^2 - b^2}}{a}\right)\right];$$

$$i_p = \sqrt{\frac{1}{3} \cdot \left\{a^2 + b^2 \cdot \left[1 + \frac{F\left(\frac{\sqrt{a^2 - b^2}}{a}\right)}{E\left(\frac{\sqrt{a^2 - b^2}}{a}\right)}\right]\right\}};$$

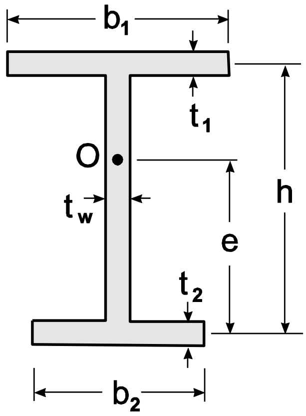
$$W_p = \frac{4}{3} \cdot t \cdot \left[\left(a^2 + b^2\right) \cdot E\left(\frac{\sqrt{a^2 - b^2}}{a}\right) + b^2 \cdot F\left(\frac{\sqrt{a^2 - b^2}}{a}\right)\right],$$

where: $F(x) -$ Legendre complete elliptic integral of the first kind,

$E(x) -$ Legendre complete elliptic integral of the second kind,

$E(k; x) -$ Legendre incomplete elliptic integral of the second kind.

Sectorial Properties of an I-beam with Unequal Flanges



Aim: To check the accuracy of the geometric properties calculation for a thin-walled I-beam with unequal flanges.

Name of a file with the initial data: **ISection.tns**

Formulation: Check the accuracy of the geometric properties calculation for a rod cross-section in the form of a thin-walled I-beam with unequal flanges.

References: W.C. Young, R.G. Budynas, *Roark's Formulas for Stress and Strain*, New York , McGraw-Hill, New York, 2002.

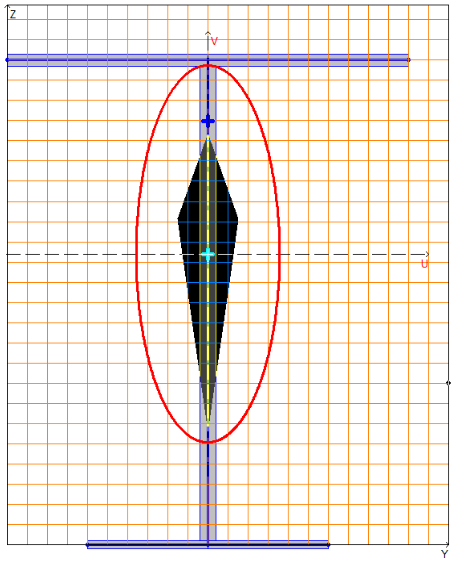
A.A. Umansky, *Reference book for designers of industrial, apartment and civil buildings (theoretical calculation)*. Book 1, Moscow, Publishing House On Construction, 1972.

Initial data:

Geometric dimensions of the section:

b_1 = 100 cm,
b_2 = 60 cm,
h = 120 cm,
t_1 = 3 cm,
t_2 = 2 cm,
t_w = 4 cm.

Results Obtained in Tonus:



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	TONUS	Deviation, %
Cross-sectional area, A cm^2	900	900	0
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	420	420	0
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	480	480	0
Torsional moment of inertia, I_t cm^4	3620	3620	0
Sectorial moment of inertia, I_w cm^6	453146853,147	453146853,147	0
Y-coordinate of the shear center, y_b cm	50	50	0
Z-coordinate of the shear center, z_b cm	104,895	104,895	0

Notes: Geometric properties can be determined analytically by the following formulas:

$$A = t_1 b_1 + t_2 b_2 + t_w h;$$

$$A_{v,y} = t_1 b_1 + t_2 b_2;$$

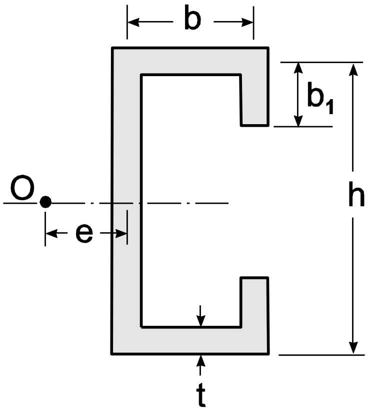
$$A_{v,z} = t_w h;$$

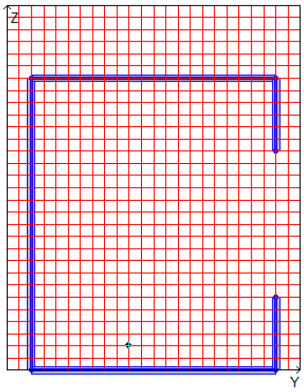
$$I_t = \frac{1}{3}\left(t_1^3 b_1 + t_2^3 b_2 + t_w^3 h\right);$$

$$I_\omega = \frac{h^2 t_1 t_2 b_1^3 b_2^3}{12\left(t_1 b_1^3 + t_2 b_2^3\right)};$$

$$e = \frac{t_1 b_1^3 h}{t_1 b_1^3 + t_2 b_2^3}.$$

Sectorial Properties of a C-shaped Thin-walled Section





Aim: To check the accuracy of the geometric properties calculation for a C-shaped thin-walled section.

Name of a file with the initial data: **CSection.tns**

Formulation: Check the accuracy of the geometric properties calculation for a thin-walled C-shaped rod cross-section.

References: W.C. Young, R.G. Budynas, *Roark's Formulas for Stress and Strain*, New York, McGraw-Hill, New York, 2002.

Initial data:

Geometric dimensions of a section:

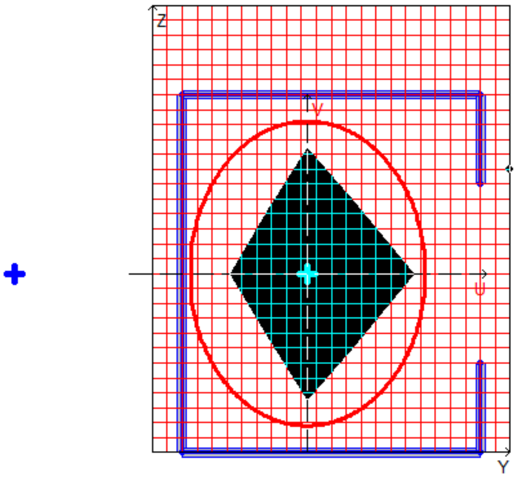
$b = 100$ cm,

$b_1 = 30$ cm,

$h = 120$ cm,

$t = 3$ cm.

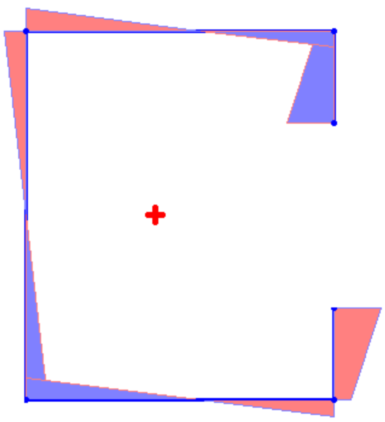
Results Obtained in Tonus:



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	TONUS	Deviation, %
Cross-sectional area, A cm^2	1140	1140	0
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	600	600	0
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	540	540	0
Torsional moment of inertia, I_t cm^4	3420	3420	0
Sectorial moment of inertia, I_w cm^6	8024714070,28	8024727272,72	0.00016
Y-coordinate of the shear center, y_b cm	-46,364	-46,364	0
Z-coordinate of the shear center, z_b cm	60	60	0



Sectorial Coordinate Diagrams

***Notes*:** Geometric properties can be determined analytically by the following formulas:

$$A = (2b + 2b_1 + h)t;$$

$$A_{v,y} = 2bt;$$

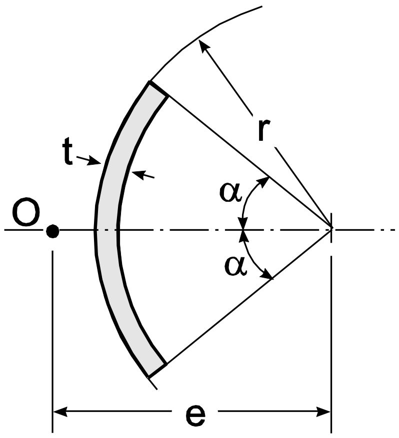
$$A_{v,z} = t(h + 2b_1);$$

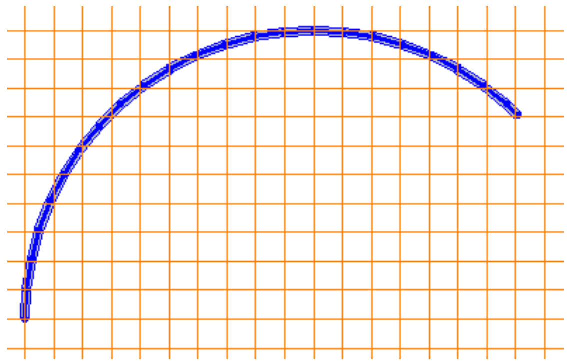
$$I_t = \frac{t^3}{3}\left(h + 2b + 2b_1\right);$$

$$e = b\,\frac{3h^2b + 6h^2b_1 - 8b_1^3}{h^3 + 6h^2b + 6h^2b_1 + 8b_1^3 - 12hb_1^2};$$

$$I_\omega = t\left[\frac{h^2b^2}{2}\left(b_1 + \frac{b}{3} - e - \frac{2eb_1}{b} + \frac{2b_1^2}{h}\right) + \frac{h^2e^2}{2}\left(b + b_1 + \frac{h}{6} - \frac{2b_1^2}{h}\right) + \frac{2b_1^3}{3}(b+e)^2\right].$$

Sectorial Properties of a Thin-walled Ring Sector





Aim: To check the accuracy of the geometric properties calculation for a thin-walled ring sector.

Name of a file with the initial data: **ArcSection.tns**

Formulation: Check the accuracy of the geometric properties calculation for a thin-walled rod cross-section in the form of a ring sector.

References: W.C. Young, R.G. Budynas, *Roark's Formulas for Stress and Strain*, New York , McGraw-Hill, New York, 2002.

Initial data:

Geometric dimensions of the section:

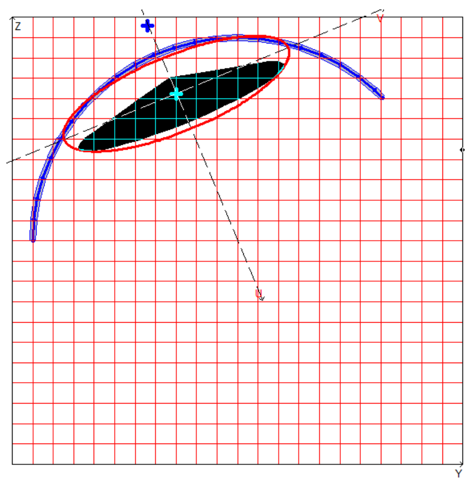
r = 100 cm,

t = 3 cm,

α= 67,5°.

Design model: The design model is created on the basis of a model of the central contour. The model of the contour is a polygon inscribed in an arc of a circle with specified properties. The number of vertices of a polygon in a model is 24.

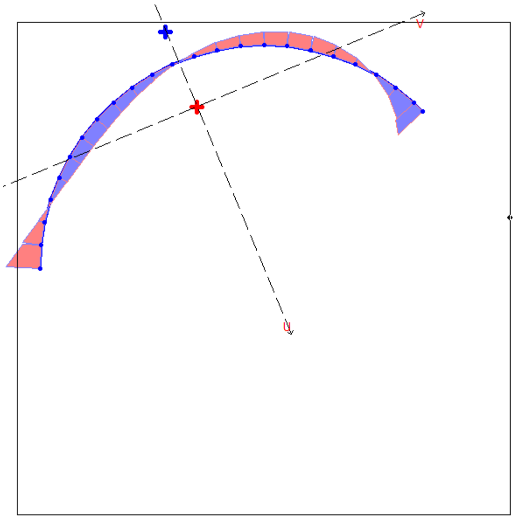
Results Obtained in Tonus:



Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	TONUS	Deviation, %
Cross-sectional area, A cm^2	706,858	707,159	0,043
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	247,313	247,879	0,229
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	459,487	459,279	0,045
Torsional moment of inertia, I_t cm^4	2126,858	2121,476	0,253
Sectorial moment of inertia, I_w cm^6	135771063,361	136173663,259	0,297
Y-coordinate of the shear center, y_b cm	66,229	66,232	0,005
Z-coordinate of the shear center, z_b cm	215,963	215,981	0,008



Sectorial Coordinate Diagrams

***Notes*:** Geometric properties can be determined analytically by the following formulas:

$$A = r\alpha;$$

$$A_{v,y} = 2rt\left(\frac{\alpha}{2} - \frac{\sin(2\alpha)}{4}\right);$$

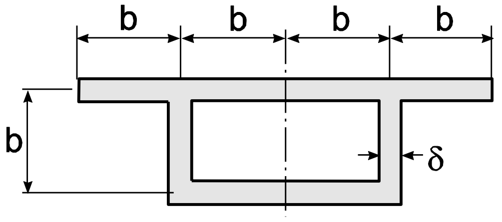
$$A_{v,z} = 2rt\left(\frac{\alpha}{2} + \frac{\sin(2\alpha)}{4}\right);$$

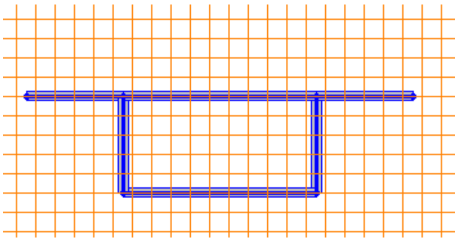
$$I_t = \frac{2}{3}t^3 r\alpha;$$

$$I_\omega = \frac{2tr^5}{3}\left[\alpha^3 - 6\frac{(\sin\alpha - \alpha\cos\alpha)^2}{\alpha - \sin\alpha\cos\alpha}\right];$$

$$e = 2r\frac{\sin\alpha - \alpha\cos\alpha}{\alpha - \sin\alpha\cos\alpha}.$$

Sectorial Properties of a Open-Closed Thin-walled Section





Aim: To check the accuracy of the geometric properties calculation for a open-closed thin-walled section.

***Name of a file with the initial data:* Beilin.tns**

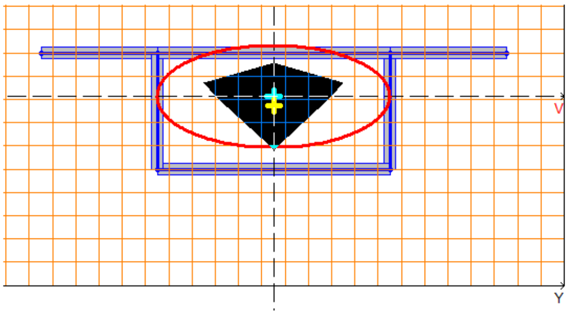
Formulation: Check the accuracy of the geometric properties calculation for a thin-walled open-closed cross-section.

References: E.A. Beilin, *Version of the Unified Torsion Theory for Bars with Open, Closed, and Partially Closed Profiles*. In: Researches on Mechanics of Structures and Materials. Topical collected works of universities, Leningrad Civil Engineering Institute, 1991, pp. 57-74.

Initial data:

δ = 1 cm – thickness of strips;
b = 10 cm – height of the section.

Results Obtained in Tonus:

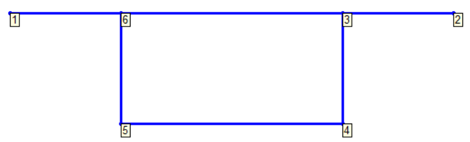


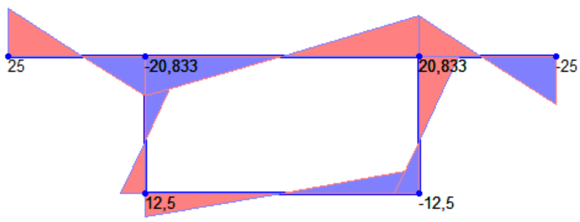
Design model, coordinate and principal axes, center of mass, ellipse of inertia, core of the section

Comparison of results:

Parameter	Theory	TONUS	Deviation, %
Cross-sectional area, A cm^2	80	80	0
Conventional shear area along the principal U-axis, $A_{v,y}$ cm^2	20	20	0
Conventional shear area along the principal V-axis, $A_{v,z}$ cm^2	60	60	0
Torsional moment of inertia, I_t cm^4	2693,333	2693,333	0
Sectorial moment of inertia, I_w cm^6	9722,222	9722,222	0
Y-coordinate of the shear center, y_b cm	25	25	0
Z-coordinate of the shear center, z_b cm	15,417	15,417	0

Comparison of the sectorial coordinates:

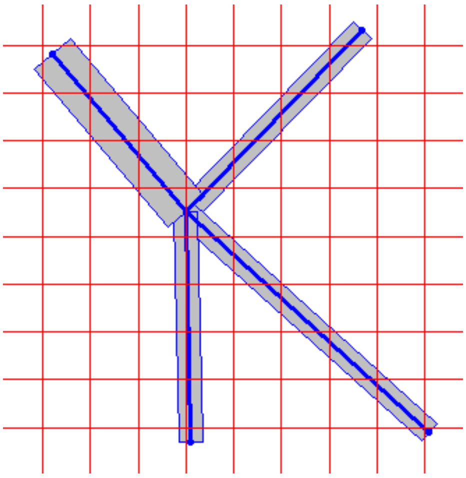




Numbers of Vertices	*Sectorial Coordinate Diagrams*

Number of a point	Sectorial coordinate		
	Theory	TONUS	Deviation, %
1	25	25	0
2	-25	-25	0
3	20.833	20.833	0
4	-12.5	-12.5	0
5	12.5	12.5	0
6	-20.833	-20.833	0

Non-warping Section of an Open Type



Aim: To check the identification of the non-warping section of an open type.

Name of a file with the initial data: **Starlike.tns**

Formulation: Check the accuracy of identification of a non-warping thin-walled rod cross-section in the form of a petal.

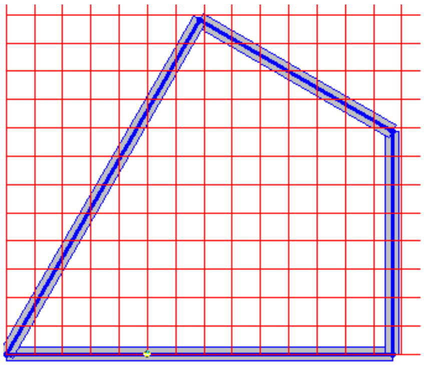
References: V. Slivker, *Mechanics of Structural Elements: Theory and Applications*, Springer, 2007 (§ 6.2.8).

Design model: Cross-section has a form of a thin-walled petal consisting of four strips.

Comparison of results:

Parameter	Theory	TONUS
Sectorial moment of inertia, I_ω cm^6	0	0

Non-warping Closed Section



Aim: To check the identification of the non-warping section of a closed type.

Name of a file with the initial data: **Slivker386.tns**

Formulation: Check the accuracy of identification of a non-warping thin-walled closed cross-section of a rod.

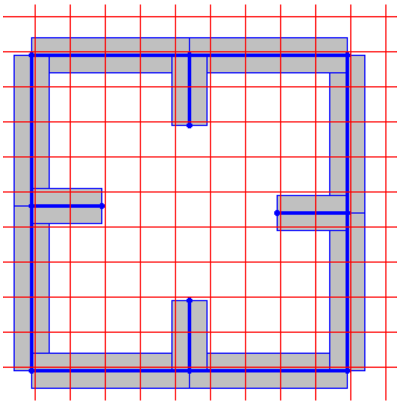
References: V. Slivker, *Mechanics of Structural Elements: Theory and Applications*, Springer, 2007 (§ 7.1.6).

Design model: Cross-section has a form of a thin-walled rhombus with a constant wall thickness.

Comparison of results:

Parameter	Theory	TONUS
Sectorial moment of inertia, I_ω cm^6	0	0

Non-warping Open-Closed Thin-Walled Section



Aim: To check the identification of the non-warping open-closed thin-walled section.

Name of a file with the initial data: **Combined.tns**

Formulation: Check the accuracy of identification of a non-warping thin-walled open-closed symmetric cross-section of a rod.

References: V. Slivker, *Mechanics of Structural Elements: Theory and Applications*, Springer, 2007 (§ 8.1.3).

Design model: Cross-section has a form of a thin-walled box with additional strips.

Comparison of results:

Parameter	Theory	TONUS
Sectorial moment of inertia, I_{ω} cm^6	0	0

Sectorial Areas, Static Moments, and Tangential Stresses for an Open Thin-Walled Section

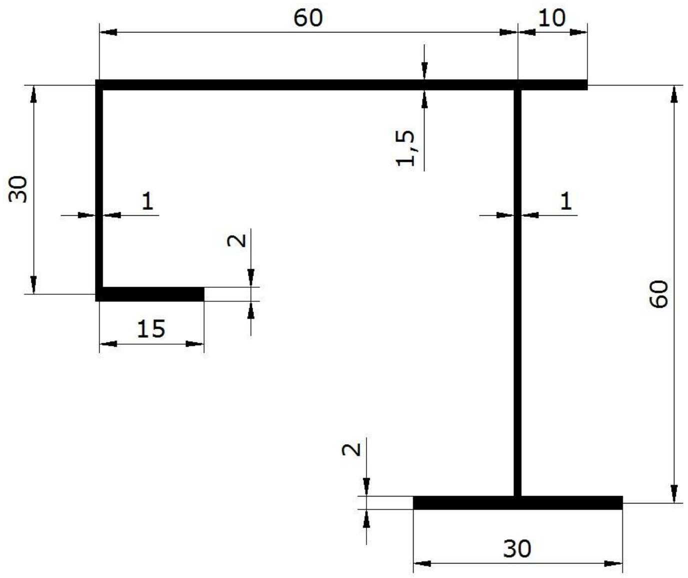
Aim: To check the accuracy of the determination of sectorial areas ω, a sectorial static moment S_{ω}, and tangential stresses τ_{ω}, caused by constrained torsion for an open thin-walled section.

Name of a file with the initial data: **Prokic_open.tns**

Formulation: Check the accuracy of the calculation of the sectorial areas, static moments, and tangential stresses for an open thin-walled section.

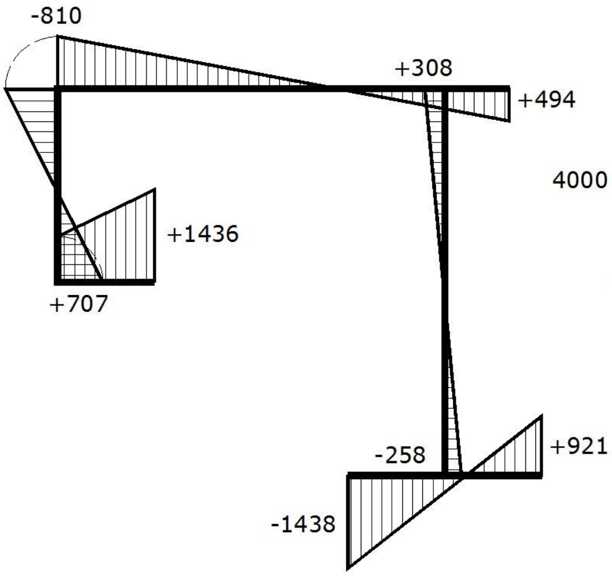
References: Prokić A. *Computer program for determination of geometrical properties of thin-walled beams with open-closed section* // Computers and Structures, Vol. 74 (2000). – pp. 705 – 715.

Initial data:



Open thin-walled section with sizes, cm

Results from the source:



Sectorial area diagram ω, cm^2

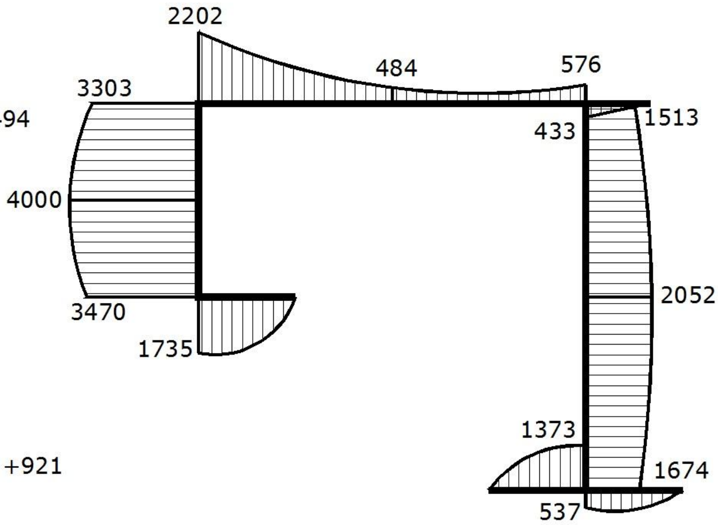
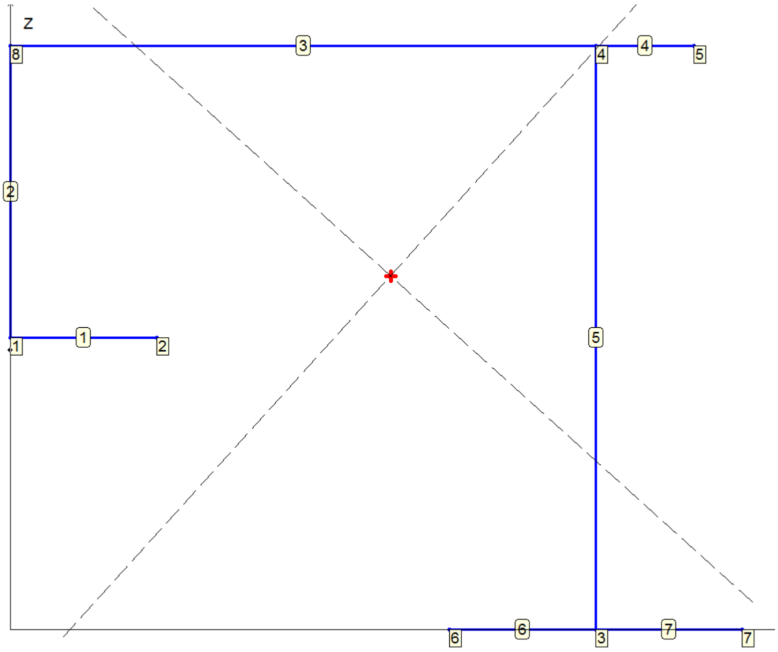
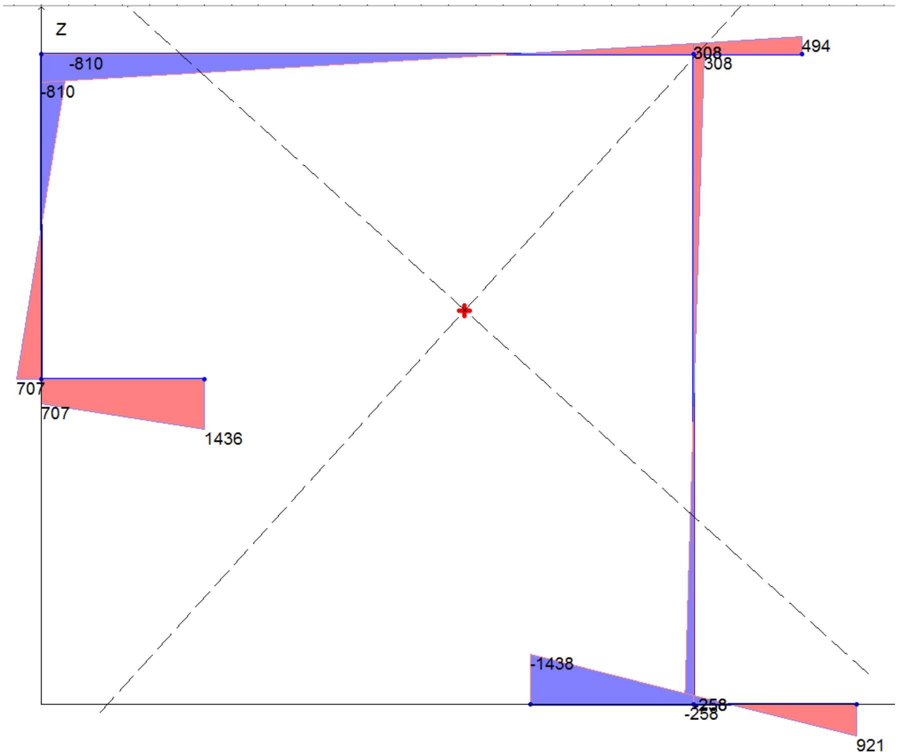


Diagram of tangential stresses related to the constrained torque,
$\tau_\omega/M_\omega \times 10^7$, $1/cm^3$

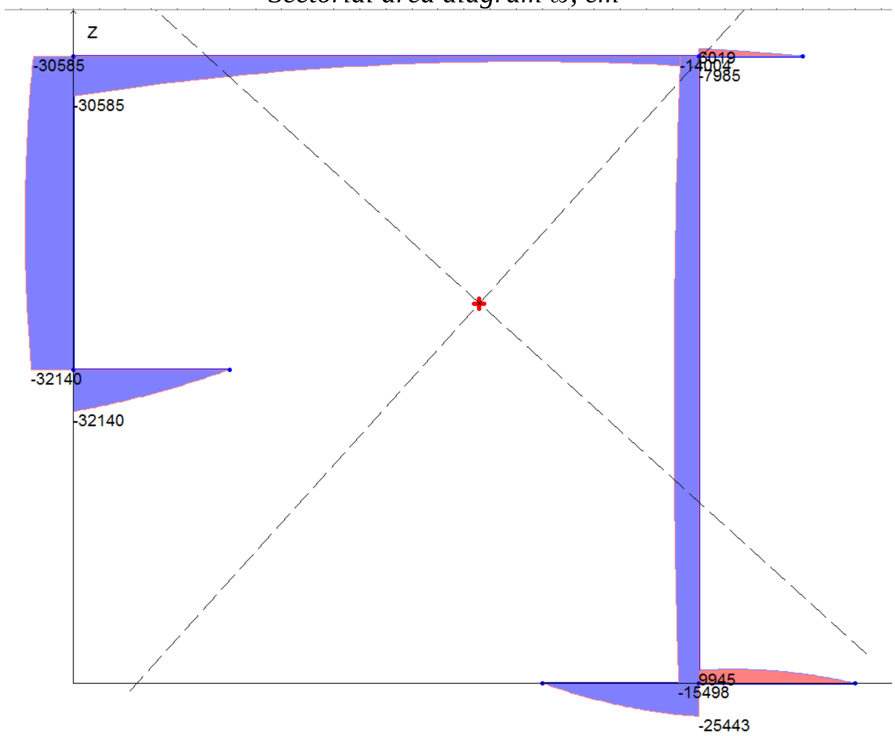
Results obtained in Tonus:



Numbering of vertices and strips, position of the mass center and shear center



Sectorial area diagram ω, cm²



Sectorial static moment diagram S_ω, cm⁴

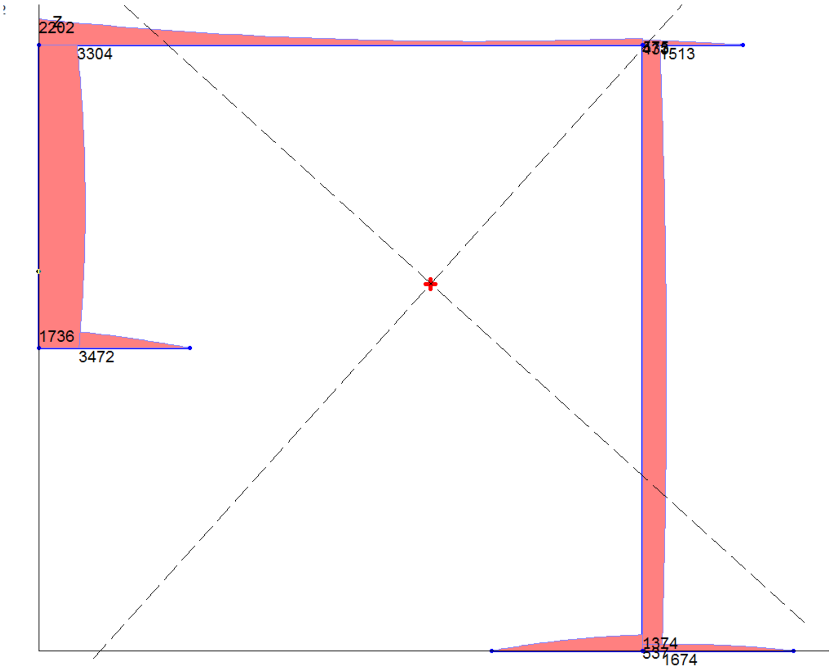


Diagram of the tangential stress module τ_ω
for the value of the constrained torque M_ω = 10^7, kNcm

Comparison of results:

Element number	Vertex number	Sectorial static moment, cm^4			Tangential stress, kN/cm^2 (at $M_\omega = 10^7$, *kNcm*)		
		Source*	TONUS	Deviation, %	Source	TONUS	Deviation, %
1	1	32126	32140	0,04	1735	1736	0,06
1	2	0	0	0	0	0	0
2	1	32126	32140	0,04	3470	3472	0,06
2	8	30580	30585	0,02	3303	3304	0,06
3	8	30580	30585	0,02	2202	2202	0
3	4	7999	7985	0,18	576	575	0,17
4	4	6013	6019	0,1	433	432	0,23
4	5	0	0	0	0	0	0
5	4	14008	14004	0,03	1513	1513	0
5	3	15498	15498	0	1674	1674	0
6	6	0	0	0	0	0	0
6	3	25423	25443	0,08	1373	1374	0,07
7	3	9943	9945	0,02	537	537	0
7	7	0	0	0	0	0	0

Note:
*The value of the static sectorial moment S_ω was calculated using the value τ_ω/M_ω, obtained from the source as ($I_\omega = 92582119$ cm^6): $S_\omega = \tau_\omega I_\omega t / M_\omega$.

Vertex number	Sectorial area, cm^2		
	Source	TONUS	Deviation, %
1	707	707	0
2	1436	1436	0
3	-258	-258	0
4	308	308	0
5	494	494	0
6	-1438	-1438	0
7	921	921	0
8	-810	-810	0

Sectorial Areas, Static Moments, and Tangential Stresses for an Open-Closed Thin-Walled Section

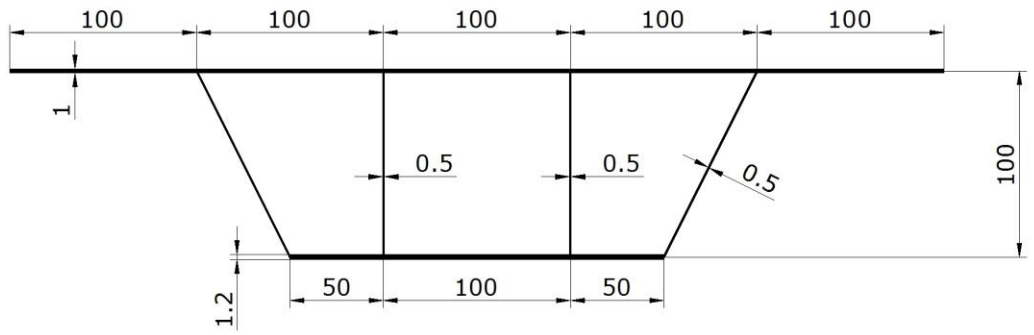
Aim: To check the accuracy of the determination of sectorial areas ω, static moments with respect to the principal axes of inertia of the section S_u, S_v, a sectorial static moment S_ω, tangential stresses τ_u, τ_v, caused by shear forces, and tangential stresses τ_ω, caused by constrained torsion for an open-closed thin-walled section.

Name of a file with the initial data: **Prokic_openclosed.tns**

Formulation: Check the accuracy of the calculation of the sectorial areas, static moments, and tangential stresses for an open-closed thin-walled cross-section.

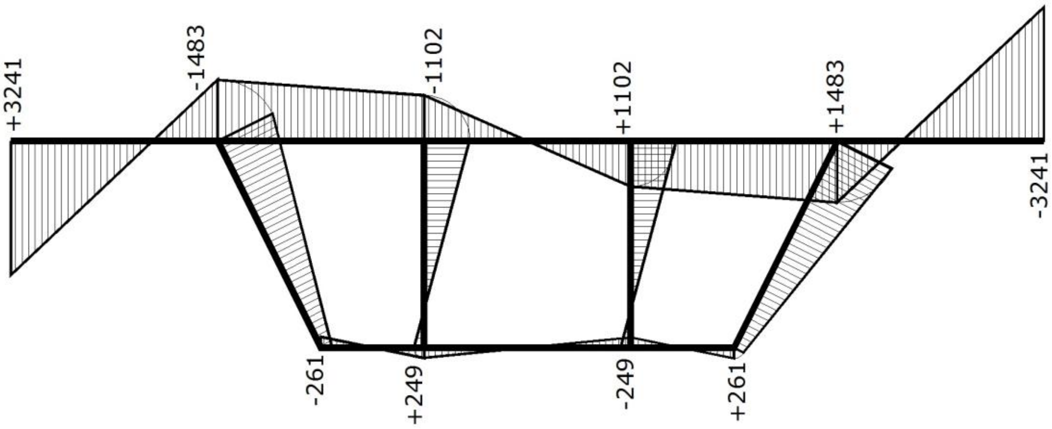
References: Prokić A. *Computer program for determination of geometrical properties of thin-walled beams with open-closed section* // Computers and Structures, Vol. 74 (2000). – pp. 705 – 715.

Initial data:



Open-closed thin-walled section with sizes, cm

Results from the source:



Sectorial area diagram ω, cm²

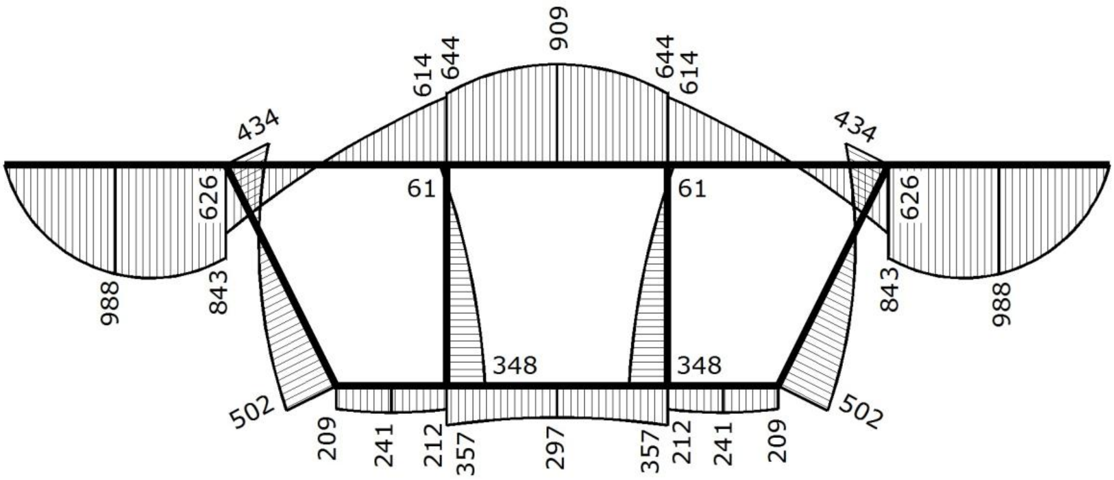


Diagram of tangential stresses related to the constrained torque,
$\tau_\omega/M_\omega \times 10^7$, $1/cm^3$

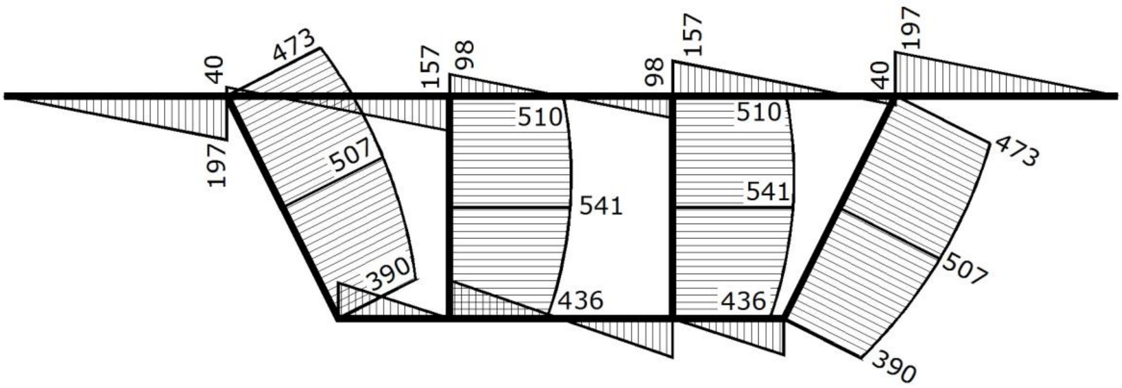
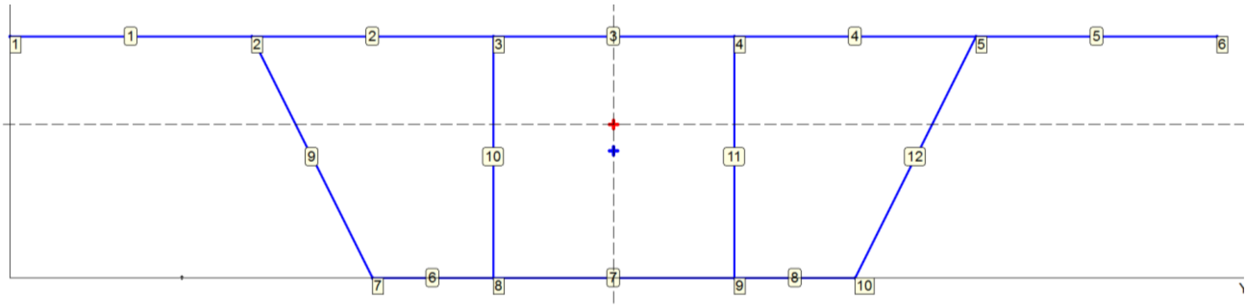
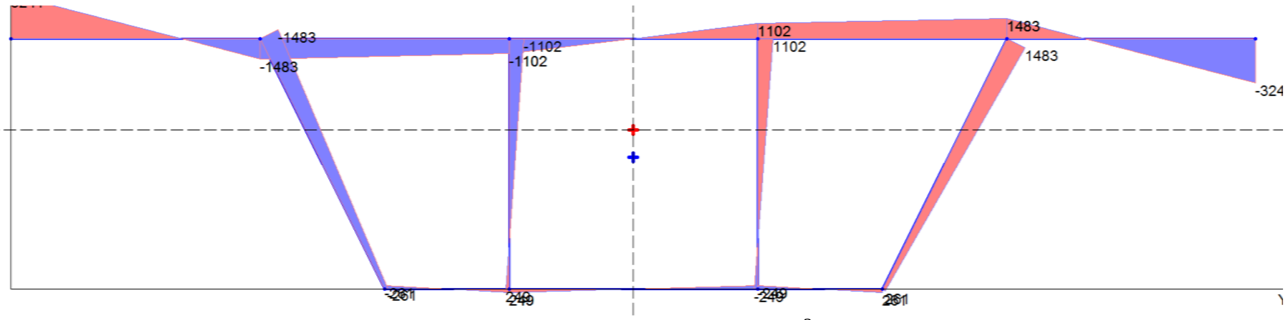


Diagram of tangential stresses related to the shear force,
$\tau_u/Q_u \times 10^5$, $1/cm^2$

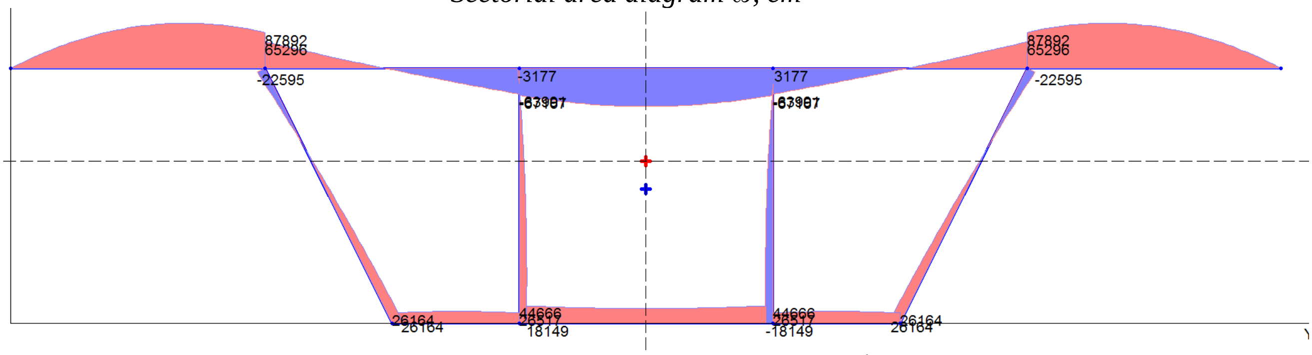
Results obtained in Tonus:



Numbering of vertices and strips, position of the mass center and shear center



Sectorial area diagram ω, cm^2



Sectorial static moment diagram S_ω, cm^4

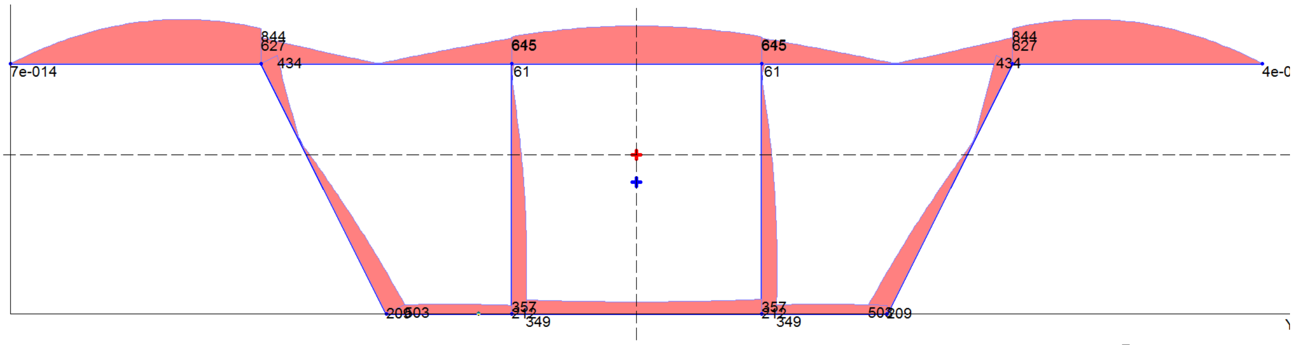
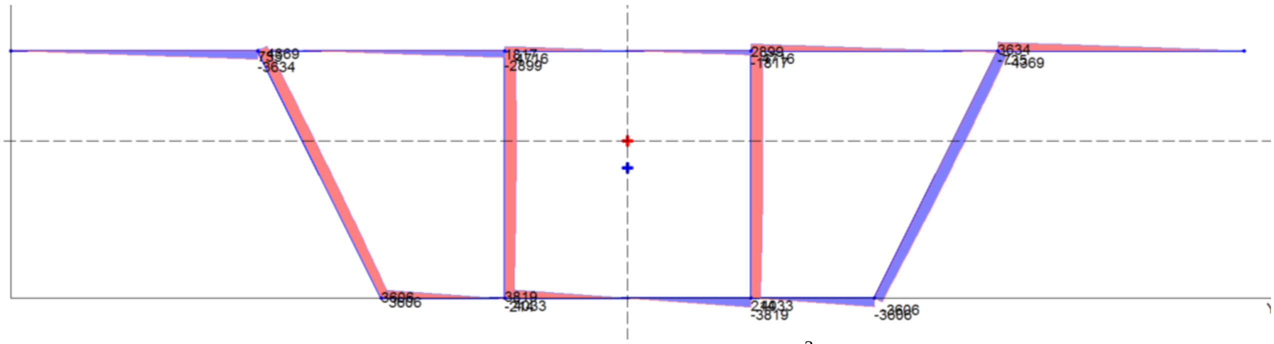


Diagram of the tangential stress module τ_ω for the value of the constrained torque $M_\omega = 10^7$, kNcm



Static moment diagram S_v, cm^3

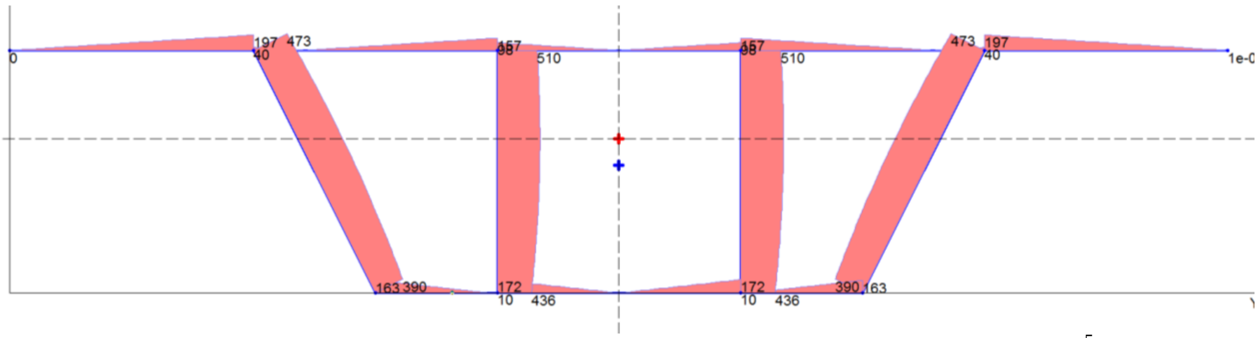


Diagram of the tangential stress module τ_u for the value of the shear force $Q_u = 10^5$, kN

Comparison of results:

Element number	Vertex number	Sectorial static moment S_ω, cm^4			Static moment S_v, cm^3		
		Source*	TONUS	Deviation, %	Source**	TONUS	Deviation, %
1	1	0	0	0	0	0	0
1	2	87776	87892	0,13	3643	3634	0,25
2	2	65181	65296	0,18	740	741	0,14
2	3	63932	64036	0,16	2903	2899	0,14
3	3	67055	67159	0,16	1812	1817	0,28
6	7	26114	26164	0,19	3595	3606	0,3
6	8	26489	26517	0,11	–	10	–
7	8	44606	44666	0,13	3816	3819	0,08
9	2	22595	22595	0	4373	4369	0,09
9	7	26135	26164	0,11	3606	3606	0
10	3	3176	3177	0,03	4715	4716	0,02
10	8	18117	18149	0,15	4031	4033	0,05

Notes:
* The value of the static sectorial moment S_ω was calculated using the value τ_ω/M_ω, obtained from the source as ($I_\omega = 1041229484$ cm^6): $S_\omega = \tau_\omega I_\omega t / M_\omega$;
** The value of the static moment S_v was calculated using the value τ_u/Q_u, obtained from the source as ($I_v = 1849016$ cm^4): $S_v = \tau_u I_v t / Q_u$.

Element number	Vertex number	Tangential stress τ_ω, kN/cm^2 (at $M_\omega = 10^7$, *kNcm*)			Tangential stress τ_u, kN/cm^2 (at $Q_u = 10^5$, *kN*)		
		Source	TONUS	Deviation, %	Source	TONUS	Deviation, %
1	1	0	0	0	0	0	0
1	2	843	844	0,12	197	197	0
2	2	626	627	0,16	40	40	0

2	3	614	615	0,16	157	157	0
3	3	644	645	0,16	98	98	0
6	7	209	209	0	162	163	0,6
6	8	212	212	0	–	10	0
7	8	357	357	0	172	172	0
9	2	434	434	0	473	473	0
9	7	502	503	0,20	390	390	0
10	3	61	61	0	510	510	0
10	8	348	349	0,29	436	436	0

Vertex number	**Sectorial area, cm^2**		
	Source	**TONUS**	**Deviation, %**
1	+3241	+3241	0
2	–1483	–1483	0
3	–1102	–1102	0
7	–261	–261	0
8	+249	+249	0

References

1. E.A. Beilin, *Version of the Unified Torsion Theory for Bars with Open, Closed, and Partially Closed Profiles*. In: Researches on Mechanics of Structures and Materials. Topical collected works of universities, Leningrad Civil Engineering Institute, 1991, pp. 57-74.
2. V.Z. Vlasov, *Selected works*, Vol. 2, Moscow: USSR Academy of Science Publishing House, 1963.
3. G.Y. Janelidze, *To the Theory of Thin and Thin-walled bars.* In: Applied Mathematics and Mechanics, 1949., **XIII**; No. 6, pp. 597–608.
4. G.Y. Janelidze, Y.G. Panovko, *Statics of Elastic Thin-walled Bars*, Moscow: OGIZ, 1948, 208 p.
5. V.S. Karpilovsky, E.Z. Kriksunov, A.V. Perelmuter, M.A. Perelmuter, *SCAD Office. SCAD Computing System*. — M.: ASV Publishers, 2011.— 596 p.
6. A.A. Umansky, *Bending and Torsion of Thin-walled Aircraft Structures*, Moscow: Oboronizdat Publishing House, 1939, 112 p.
7. A.A. Umansky, *Analysis of Thin-walled Curvilinear Beams*. In: Proceedings of Sci.-Tech. Conference of Zhukovski Higher Air Force School, issue 2, 1944.
8. A.P. Filin. *Applied Mechanics of Deformable Solids: Strength of Materials with Elements of Continuum Theory and Structural Mechanics*, Vol. 2, Moscow: Nauka, 1978, 616 p.
9. V.S. Karpilovsky, E.Z. Kriksunov, A.A. Malyarenko, M.A. Mikitarenko, A.V. Perelmuter, M.A. Perelmuter, V.G. Fedorovsky. *SCAD Office. Implementation of SNiP Codes in Computer-Aided Design Applications*. — M.: ASV Publishers, 2010. — 288 p.
10. A.A. Umansky, *Reference book for designers (theoretical calculation)*. Book 1, Moscow, Publishing House On Construction, 1972. — 600 p.
11. F. Gruttmann, W. Wagner, *Shear correction factors in Timoshenko's beam theory for arbitrary shaped cross-sections* // Comput. Mech. — 2001. — **27**; No. 3 — 199–207.
12. S.Y. Fialko, D.E. Lumelskiy, On Numerical Solution of the Problem on Torsion and Bending of Prismatic Bars of Arbitrary Cross-section // Mathematical methods and physical mechanical fields— 2012. — **55**, No. 2 — pp.156-169.
13. V.V. Novojilov, *Theory of Elasticity*, Moscow, State Union Publishing House of the Shipbuilding Industry, 1958, 370 p.
14. A.Prokić, *Computer program for determination of geometrical properties of thin-walled beams with open-closed section* // Computers and Structures, Vol. 74 (2000). – pp. 705–715