MINISTRY OF EDUCATION AND SCIENCE
KYIV NATIONAL UNIVERSITY OF CONSTRUCTION AND ARCHITECTURE

STRENGTH OF MATERIALS

Geometric characteristics of cross sections

Methodical recommendations for the performance of calculation and graphic

work No. 1.

Methodical recommendations, tasks and

examples for performing

calculation and graphic works

for students pursuing the first (Bachelor’s) level of higher education in specialties

G19 Building and civil engineering.

Educational program: Heating, Gas Supply and Ventilation Engineering (HV);

Water Supply and Drainage (WSD)

Kyiv 2026

УДК 539.3
О-61

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Approved at the meeting of the Department of Strength of Materials, Minutes No. 3 dated December 22, 2025

Strength of Materials: Geometric Characteristics of Cross-Sections:
Methodical Guidelines, Assignments, and Examples of Performing Calculation and Graphic Works [electronic resource] / compilers: O.O. Koshevyi, O.P. Koshevyi – Kyiv: KNUCA, 2026. – 22 p.

The methodical guidelines contain variants of individual assignments and detailed plans for performing calculation and graphic works in the course *“Strength of Materials”*, as well as examples of solving each task. The section *“Geometric Characteristics of Cross-Sections”* is considered.

For students pursuing the first (Bachelor’s) level of higher education, in specialties **G19 (192) Building and Civil Engineering**. Educational programs: Heat and Gas Supply and Ventilation (HV); Water Supply and Drainage (WSD).

Опір матеріалів: Геометричні характеристика поперечних перерізів
О-61 вказівки, завдання та приклади виконання розрахункових і графічних робіт [електронний ресурс] / уклад.: О.О. Кошевий, О.П. Кошевий. – Київ: КНУБА, 2026. – 25 с.

Містять варіанти індивідуальних завдань та детальні плани виконання розрахункових і графічних робіт з курсу «Опір матеріалів», а також приклади розв’язання кожного завдання. Розглянуто розділ «Геометричні характеристики поперечних перерізів».

Призначено для здобувачів першого (Бакалаврського) рівня вищої освіти за програмою **G19 «Будівництво та цивільна інженерія»,** що навчаються англійською мовою. Освітні програми: «Теплогазопостачання і вентиляція» (ТГВ); «Водопостачання та водовідведення» (ВВ).

GENERAL PROVISIONS

The methodological guidelines are intended to assist students in completing the calculation and graphic work for the course “Strength of Materials” in the section: “Geometric Characteristics of Cross-Sections.” The student according to an individual assignment, the conditions of which are determined by the lecturer, must complete the calculation and graphic work. The initial data (calculation schemes and numerical values) are selected by the student from the appendices (see Appendices 1, 2, 3) according to their personal code in the form of a three-digit number. Explanations and calculations must be performed on a computer using MS Word. For each assignment, a plan and recommendations for step-by-step calculations are provided.

The calculation and graphic work is prepared on A4 sheets, bound on the left side.

The title page of the work is formatted according to the provided sample.

The calculation and graphic work is prepared on A4 sheets, bound on the left side. The title page of the work is formatted according to the following sample:

Ministry of Education and Science of Ukraine

Kyiv National University of Construction and Architecture

Department of Strength of Materials

Calculation and Graphic Work No.__

“_______________________________”

/Topic/

Prepared by:

Student

/Specialty, Year,

Group/

____

/Surname, Initials/

Supervisor:

/Surname, Initials/

Kyiv – 20__

Explanations and calculations must be performed on one side of the sheet using a pen, while drawings must be completed in pencil. Computer-aided drafting is permitted.

For each assignment, a plan and recommendations for step-by-step calculations are provided. An example of completing the calculation and graphic work (CGW) is given for illustration. When performing each stage of the calculation, the student must first write down the calculation formulas, substitute the numerical values, and record the result of the computation in the appropriate units of measurement (SI system).

The calculation and graphic work is considered completed only after its defense.

PURPOSE OF THE WORK:

To familiarize students with the basic concepts and geometric characteristics of cross-sections of load-bearing structural elements; with the main approaches and principles for determining internal forces arising in structures; to provide practical skills in performing engineering calculations for determining geometric characteristics required for strength, stiffness, and stability analysis; to teach methods for processing and verifying the obtained calculation results.

Section I: Geometric Characteristics of the Cross-Section of a Bar

Problem Statement. Determine the principal central moments of inertia and section moduli of a cross-section of complex shape. Construct the inertia ellipse and, using it, find the central moments of inertia relative to the given system of central axes.

Given: Diagram of the cross-section with profile numbers and dimensions of the rectangular element.

Plan of the Assignment:

1. Determination of the position of the centroid of the given composite cross-section in the adopted system of coordinate axes (auxiliary system).
2. Determination of axial and centrifugal moments of inertia of the composite section relative to the central axes parallel to the initial axes.
3. Determination of the position of the principal central axes of the section and calculation of the values of the principal central moments of inertia of the composite section.
4. Determination of the section moduli.
5. Construction of the inertia ellipse and determination, using it, of the central moments of inertia relative to the central axes adopted in step 2 or specified by the instructor.

Graphical Requirements:

1. Draw the given cross-section to scale, indicate the necessary dimensions, the positions of the centroids of the elements, and the central axes of each element of the composite section.
2. Indicate the position of the centroid of the given composite cross-section and the central axes parallel to the auxiliary axes adopted for determining the centroid coordinates. Specify the distances between the central axes of the entire section and the central axes of the individual elements.

3. Indicate the position of the principal central axes of inertia and the distances to them from the most remote points of the cross-section.

4. Construct the inertia ellipse, draw tangents to it parallel to the central axes (see step 2), and indicate the distances from the points of tangency to the central axes.

Instructions for Completing the Exercise:

1. Divide the composite cross-section into a number of elementary sections whose geometric characteristics are available in handbooks or can be easily calculated. Elementary sections include I-beams, channels, equal and unequal angles, rectangles, and others.

Select auxiliary axes relative to which the centroid of the section is determined.

As auxiliary axes, it is advisable to adopt the axes of symmetry of the elementary sections included in the composite section.

The coordinates of the centroid of the given composite cross-section in the chosen auxiliary system are found as the ratio of the static moment of area to the area of the section.

The static moment of area of the composite section equals the algebraic sum of the static moments of the areas of the simple figures that compose it.

If the area of the section and the coordinate of its centroid relative to the chosen axis are known, the static moment is determined without integration, as the product of the area and the coordinate.

The static moment of area may be positive, negative, or equal to zero.

The sign of the static moment is determined by the sign of the centroid coordinate of the elementary section relative to the chosen axis.

The static moment of a composite section relative to its central axes must equal zero.

The correctness of determining the centroid position of a composite section can also be checked graphically.

If a complex figure is divided into several simple figures, its centroid lies inside the polygon obtained by sequentially connecting the centroids of the simple figures, traversing them in one direction.

2. All moments of inertia of section areas are measured in m^4, cm^4, or mm^4.

Attention must be paid to the fact that the central axes of rolled profiles indicated in the section tables may, according to the problem statement, be rotated by 90°, i.e., the x-axis of the profile may correspond to the y_c-axis in the adopted coordinate system, and conversely, the y-axis of the profile may correspond to the x_c-axis.

The centrifugal moment of inertia may be positive, negative, or equal to zero. Its sign depends on the signs of the coordinates of the individual elements relative to the central axes of the composite section. If one of the coordinate axes is an axis of symmetry of the section, the centrifugal moment of inertia equals zero.

Recall that the centrifugal moments of inertia of I-beams and channels relative to their central axes equal zero.

The moments of inertia of rolled profiles (equal and unequal angles, I-beams, and channels) are given for each profile number in the corresponding section tables. When using these values, special attention must be paid to the correspondence of the chosen axes with the axes relative to which the moments of inertia are tabulated. In most section tables, the values of moments of inertia are given in the old system of units (cm^4). To convert them to the international SI system, the tabulated value must be multiplied by the factor 10^{-8}.

In the section tables for equal and unequal angles, the values of centrifugal moments of inertia relative to the central axes parallel to the flanges are not provided. In each specific case, they must be determined using the following formulas:

$$I_{xy} = \pm(I_{max} - I_x)$$

Or

$$I_{x_0 y_0} = \pm 0{,}5(I_{max} - I_{min})$$

– For Unequal angles

$$I_{x_0 y_0} = \pm\sqrt{(I_{max} - I_x)\left(I_{max} - I_y\right)}$$

Depending on the orientation of the angle section relative to the selected centroidal axes parallel to its legs, the product of inertia may be positive or negative. The sign of the product of inertia should be determined according to the scheme provided below.

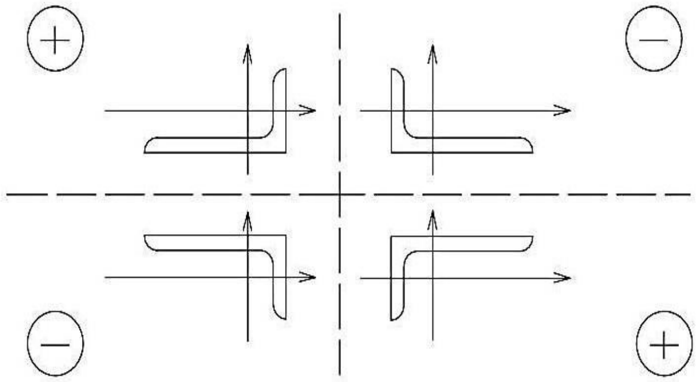


Fig. 1.1

Any complex figure can be decomposed into a set of simple ones, whose moments of inertia with respect to the chosen system of coordinate axes are determined quite easily.

The axial moment of inertia of a complex figure with respect to a selected axis equals the sum of the axial moments of inertia of its constituent simple figures with respect to the same axis.

The product of inertia of a complex figure with respect to the chosen coordinate axes equals the algebraic sum of the products of inertia of its constituent simple figures with respect to those same axes.

When adding the products of inertia of the simple figures that form the complex figure, attention must be paid to the signs of the products of inertia, in the same way as when summing the static moments of areas.

If the location of the centroid of the complex figure and the values of the centroidal moments of inertia of its constituent figures (axial and product of inertia) are known, then the values of the moments of inertia with respect to the centroidal axes parallel to the auxiliary ones (see item 2) are equal to:

$$I_{x_c} = \sum_{1}^{n} \left(I_{x_i} + a_{y_i}^2 \cdot A_i \right);$$

$$I_{y_c} = \sum_{1}^{n} \left(I_{y_i} + b_{x_i}^2 \cdot A_i \right);$$

$$I_{x_c y_c} = \sum_{1}^{n} \left(I_{x_i y_i} + a_{y_i}^2 b_{x_i}^2 \cdot A_i \right);$$

where $a_{y_i}^2$ and $b_{x_i}^2$ are the squared distances between the axes

A_i – the area of the cross-section

3. Through the centroid, an infinite number of coordinate axes can be drawn, among which mutually perpendicular axes can be found for which the product of inertia equals zero. These axes are called the principal centroidal axes of inertia, and the moments of inertia with respect to them are referred to as the principal centroidal moments of inertia.

The values of the principal centroidal moments of inertia are determined by the following formulas:

$$I_u = I_{x_c} \cos^2 a_\alpha + I_{y_c} \sin^2 a_\alpha - I_{x_c y_c} \sin 2a_\alpha;$$

$$I_v = I_{x_c} \sin^2 a_\alpha + I_{y_c} \cos^2 a_\alpha - I_{x_c y_c} \sin 2a_\alpha.$$

or

$$I_u = I_{x_c} - I_{x_c y_c} \operatorname{tg} 2a_\alpha \, ;$$

$$I_v = I_{y_c} - I_{x_c y_c} \operatorname{tg} 2a_\alpha .$$

The distinction of the principal central moments of inertia is that one of them is maximum, and the other is minimum of all possible central moments of inertia. The maximum and minimum values of the principal central moments of inertia can be determined by formulas, without taking into account the angle of inclination α.

$$I_{u,v} = I_{max,min} = \left(I_{x_c} + I_{y_c}\right)0{,}5 \pm \sqrt{0{,}25\left(I_{x_c} - I_{y_c}\right)^2 + I_{x_c y_c}^2}.$$

The inclination angle of the principal central axes of inertia with respect to the central axes system is determined using the formula:

$$\operatorname{tg} 2a_0 = \frac{2I_{x_c y_c}}{I_{y_c} + I_{x_c}}$$

The angle of inclination (α_0) can be positive or negative.

A positive value of the angle α_0 indicates that the principal central axes are rotated relative to the given central axes counter-clockwise; a negative value indicates clockwise rotation.

Verification of the accuracy of the moment of inertia determination is performed using the invariance of central moments of inertia under axis rotation. The following condition must be fulfilled:

$$I_u + I_v = I_{x_c} + I_{y_c}.$$

Performing this verification, it is worth remembering that the central moments of inertia I_{x_c} and I_{y_c} must have intermediate values compared to the principal central moments of inertia I_u and I_v. That is, the maximum principal central moment of inertia must be greater than the larger of the central moments of inertia, and the minimum must be less than the smaller central one.

4. The section modulus (moment of resistance) is equal to the quotient obtained by dividing the principal central moment of inertia by the distance from the principal central axis to the farthest point of the cross-section. The location of the farthest points is determined by tangents to the cross-section contour that are parallel to the principal central axes of inertia.

The distance to the farthest points is determined graphically on the drawing or analytically, using coordinate transformation formulas for the rotation of the central axes by an angle equal to the inclination angle of the principal central axes of inertia a_0

$$h_u = h_x cosa_0 - h_y sina_0.$$

$$h_v = h_x sina_0 - h_y cosa_0.$$

Here, h_u and h_v are the distances of the points farthest from the U and V axes, respectively; and h_x and h_y are the coordinates of these points in the system of central axes of the cross-section, adopted in Item 2 during the determination of central moments of inertia.

5. The Ellipse of Inertia is an ellipse whose semi-axes are equal to the principal central radii of gyration.

The radii of gyration with respect to the U and V axes are the quantities:

$$i_u = \sqrt{\frac{I_u}{A}}$$

$$i_v = \sqrt{\frac{I_v}{A}}$$

where I_u and I_v are the principal central moments of inertia, and A is the cross-sectional area.

The principle of constructing the ellipse of inertia is as follows: having analytically determined the principal moments of inertia and the principal central axes of inertia, the following rule must be observed.

The principal radius of gyration i_u (the semi-axis of the ellipse of inertia) is plotted along the axis V, and i_v is plotted along the axis U.

Then, using the equation of the ellipse of inertia

$$\frac{V^2}{i_u^2} + \frac{U^2}{i_2^2} = 1.$$

where U and V are the coordinates of the points of the ellipse; by specifying one of the coordinates, the second coordinate is determined.

To construct the ellipse of inertia, it is necessary to determine the coordinates of at least three points of the ellipse in one of the quadrants. Knowing the coordinates of the points of the ellipse, along with the points defined by its semi-axes, one can graphically construct one quarter of the ellipse with sufficient accuracy using these five points. Since an ellipse is a figure with two axes of symmetry, the obtained data is sufficient to construct the entire ellipse of inertia.

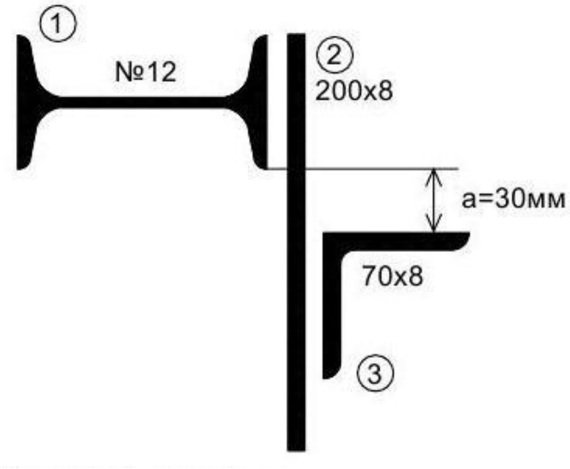
Using the ellipse of inertia, one can graphically determine the radius of gyration with respect to any central axis forming an angle α with the principal central axis, and determine the moment of inertia

$$I_\alpha = i_a^2 \cdot A.$$

To find the radius of gyration i_α, construct a tangent to the ellipse parallel to the axis that is inclined to the principal central axis of inertia at an angle α. The distance from the center of the ellipse to this tangent represents the radius of gyration i_α, the magnitude of which is determined taking into account the scale used for the ellipse construction. The inclination angle α is specified by the instructor.

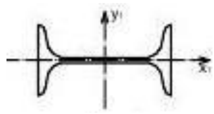
Moments of inertia determined using the ellipse of inertia may differ slightly from those obtained analytically; this is attributed to potential graphical construction errors.

Example:



Cross-sectional scheme

Initial data: Double-T beam No. 12



$A_1 = 14{,}7$ cm^2

$I_{x1} = 27{,}9$ cm^4

$I_{y1} = 350$ cm^4

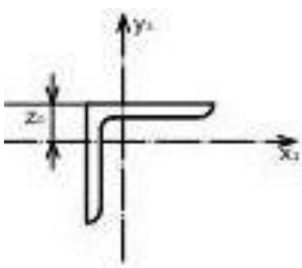
Rectangle: 20x0,8 cm

$A_2 = 16$ cm^2

$I_{x_2} = \frac{0{,}8 \cdot 20^3}{12} = 533{,}3$ cm^4

$I_{y_2} = \frac{20 \cdot 0{,}8^3}{12} = 0{,}85$ cm^4

Equal-leg L-section 7x0,8 cm



$z_0 = 2{,}02$ см; $A_3 = 10{,}7$ см^2; $I_{y_3} = I_{x_3} = 48{,}2$ cm^4.

$I_{max} = 76{,}4$ см^4; $I_{x_3 y_3} = +(76{,}4 - 48{,}2) = 28{,}2$ cm^4.

I. Determination of the centroid position (Fig.1.2) relative to the $x_3 y_3$ axes

$$a_{13} = 8{,}22 \text{ cm}; \quad b_{13} = -8{,}82 \text{ cm}.$$

$$a_{23} = 8{,}22 - 6{,}8 = 1{,}42 \text{ cm}; \quad b_{23} = -(2{,}02 - 0{,}4) = -2{,}42 \text{ cm}.$$

$$a_{33} = 0\text{ cm};\ b_{33} = 0\text{ cm}.$$

$$y_{3c} = \frac{\sum A_i a_{i3}}{\sum A_i} = \frac{8{,}22 \cdot 14{,}7 + 1{,}42 \cdot 16{,}0}{41{,}4} = \frac{143{,}5}{41{,}4} = 3{,}47\text{ cm}.$$

$$x_{3c} = \frac{\sum A_i b_{i3}}{\sum A_i} = \frac{-8{,}82 \cdot 14{,}7 + 1{,}42 \cdot 16{,}0}{41{,}4} = \frac{168{,}4}{41{,}4} = 4{,}07\text{ cm}.$$

Coordinates of the centroids of individual elements of the composite cross-section in the $x_c y_c$ coordinate system:

$$a_{y1} = 4{,}74\text{ cm};\quad b_{x1} = -4{,}75\text{ cm}.$$

$$a_{y2} = -6{,}80 + 4{,}74 = -2{,}06\text{ cm};\quad b_{x2} = 6{,}40 - 4{,}75 = 1{,}65\text{ cm}.$$

$$a_{y3} = -3{,}47\text{ cm};\quad b_{x3} = 4{,}07\text{ cm}.$$

Verification of the determination of the centroid coordinates of the cross-section:

$$S_{x_c} = 0; \qquad\qquad S_{y_c} = 0;$$

$$S_{x_c} = \frac{\sum A_i a_i}{\sum A_i} = \frac{14{,}7 \cdot 4{,}74 - 16{,}0 \cdot 2{,}06 - 10{,}7 \cdot 3{,}47}{41{,}4} = \frac{69{,}8 - 69{,}9}{41{,}4} \approx 0$$

$$S_{y_c} = \frac{\sum A_i b_i}{\sum A_i} = \frac{-14{,}7 \cdot 4{,}75 - 16{,}0 \cdot 1{,}65 - 10{,}7 \cdot 4{,}07}{41{,}4} = \frac{-69{,}8 + 69{,}9}{41{,}4} \approx 0$$

Determination of I_{x_c}, I_{y_c} and $I_{x_c y_c}$ (Fig. 1.2)

$$I_{x_c} = \sum_1^3 \left(I_{x_i} + a_{yi}^2 A_i\right) = 27{,}9 + 4{,}74^2 \cdot 14{,}7 + 533{,}3 + 2{,}06^2 \cdot 16 + 48{,}2 +$$
$$+3{,}47^2 \cdot 10{,}7 = 28 + 333 + 533 + 67 + 48 + 129 = 1138\text{ cm}^4.$$

$$I_{y_c} = \sum_1^3 \left(I_{y_i} + b_{xi}^2 A_i\right) = 350 + 4{,}75^2 \cdot 14{,}7 + 0{,}85 + 1{,}65^2 \cdot 16 + 48{,}2 +$$

$$+4{,}07^2 \cdot 10{,}7 = 350 + 333 + 1 + 44 + 48 + 177 = 953 \text{ cm}^4.$$

$$I_{x_c} I_{y_c} = \sum_1^3 \left(I_{x_i y_i} + a_{yi} b_{xi} A_i\right) = 0 - 4{,}74 \cdot 4{,}75 \cdot 14{,}7 + 0 - 2{,}06 \cdot 1{,}65 \cdot 16 +$$

$$+28{,}2 - 3{,}47 \cdot 4{,}07 \cdot 10{,}7 = -333 - 54 + 28 = -500 \text{ cm}^4.$$

Determination of the inclination angle a_0 of the principal central axes and determination of the principal central moments of inertia I_u and I_v:

$$\tan 2a_0 = \frac{2I_{x_i y_i}}{I_{y_i} - I_{x_i}} = -\frac{2 \cdot 500}{953 - 1138} = \frac{1000}{185} = 5{,}405.$$

$$2a_0 = 79^\circ 30'; \quad a_0 = 39^\circ 45'.$$

$$\sin a_0 = 0{,}639; \cos a_0 = 0{,}769; \sin 2a_0 = 0{,}983; \tan a_0 = 0{,}832.$$

1. Method of determination:

$$I_u = 1138 \cdot 0{,}769^2 + 953 \cdot 0{,}639^2 + 500 \cdot 0{,}983 = 672 + 389 + 492 = 1553 \text{ cm}^4.$$

$$I_v = 1138 + 0{,}639^2 + 953 \cdot 0{,}769^2 - 500 \cdot 0{,}983 = 465 + 565 - 492 = 538 \text{ cm}^4.$$

2. Method of determination:

$$I_u = 1138 + 500 \cdot 0{,}832 = 1138 + 416 = 1554 \text{ cm}^4.$$

$$I_v = 953 - 500 \cdot 0{,}832 = 953 - 416 = 537 \text{ cm}^4.$$

3. Method of determination:

$$I_{u,v} = 0{,}5(1138 + 953) \pm \sqrt{0{,}25(1138 - 953)^2 + 500} =$$

$$= 1045 \pm \sqrt{8556 + 250000} = 1045 \pm 509.$$

$$I_u = 1045 + 509 = 1554 \text{ cm}^4, I_v = 1045 - 509 = 536 \text{ cm}^4.$$

Verification of the invariance of the sum of central moments of inertia

$$I_u + I_v = I_{x_c} + I_{y_c}$$

$$I_{x_c} + I_{y_c} = 1138 + 953 = 2091 \text{ cm}^4.$$

$$(1) I_u + I_v = 1553 + 538 = 2091 \text{cm}^4.$$

$$(2) I_u + I_v = 1553 + 537 = 2090 \text{ cm}^4.$$

$$(3) I_u + I_v = 1553 + 536 = 2089 \text{ cm}^4.$$

Determination of the section moduli of the cross-section (Fig. 1.3):

$$h_u = (4{,}74 + 3{,}2) \cdot 0{,}769 - (-4{,}75 - 6{,}0) \cdot 0{,}639 = 6{,}1 + 5{,}8 = 11{,}9 \text{ cm}.$$

$$h_v = (4{,}74 - 3{,}2) \cdot 0{,}639 + (-4{,}75 - 6{,}0) \cdot 0{,}769 = 1{,}0 - 8{,}3 = -7{,}3 \text{ cm}.$$

$$W_u = \frac{I_u}{h_u} = \frac{1553}{11{,}9} = 130 \text{ cm}^3.$$

$$W_v = \frac{I_v}{h_v} = \frac{538}{7{,}3} = 74 \text{ cm}^3.$$

Construction of the ellipse of inertia (Fig. 1.3):

$$i_u = \sqrt{\frac{I_u}{A}} = \sqrt{\frac{1553}{41{,}4}} = \sqrt{37{,}5} = 6{,}1 \text{ cm}.$$

$$i_v = \sqrt{\frac{I_v}{A}} = \sqrt{\frac{538}{41{,}4}} = \sqrt{13{,}0} = 3{,}6 \text{ cm}.$$

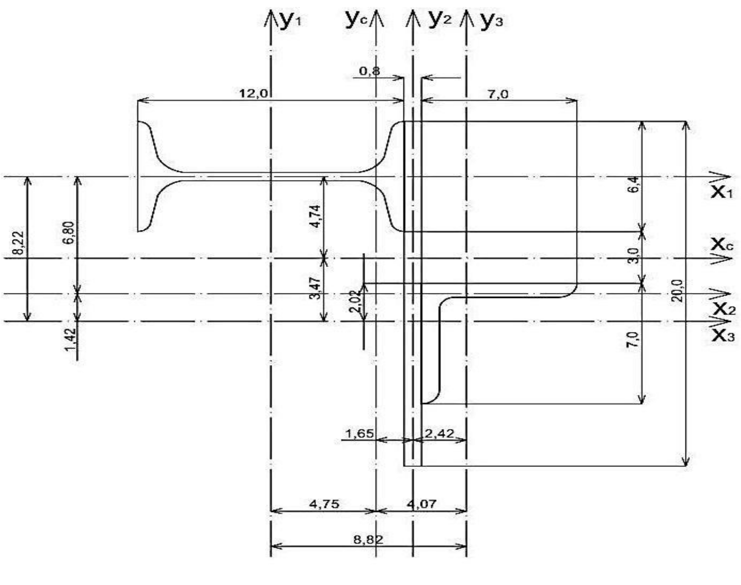


Fig. 1.2

Determination of the point coordinates for one quarter of the ellipse of inertia:

$$V = i_u \sqrt{1 - \frac{U^2}{i_v^2}}.$$

U	$1 - \frac{U^2}{i_v^2}$	$\sqrt{1 - \frac{U^2}{i_v^2}}$	V
i_v	0	0	0
0,75	0,44	0,66	4,0
0,5	0,75	0,86	5,2
0,25	0,94	0,97	5,9
0	1	1	6,1

Based on this data, the ellipse of inertia is constructed on the drawing (Fig.1.3)

Determination of the central moments of inertia I_{y_c} and I_{x_c} using the ellipse of inertia.

Graphical determination of the radius of gyration

$$i_{x_c} = 6{,}1 \text{ cm}.$$

$$i_{y_c} = 3{,}6 \text{ cm}.$$

Determining moments of inertia

$$I_{x_c} = i_{x_c}^2 \cdot A = 37{,}2 \cdot 41{,}4 = 1540 \text{ cm}^4$$

$$I_{y_c} = i_{y_c}^2 \cdot A = 13{,}0 \cdot 41{,}4 = 548 \text{ cm}^4$$

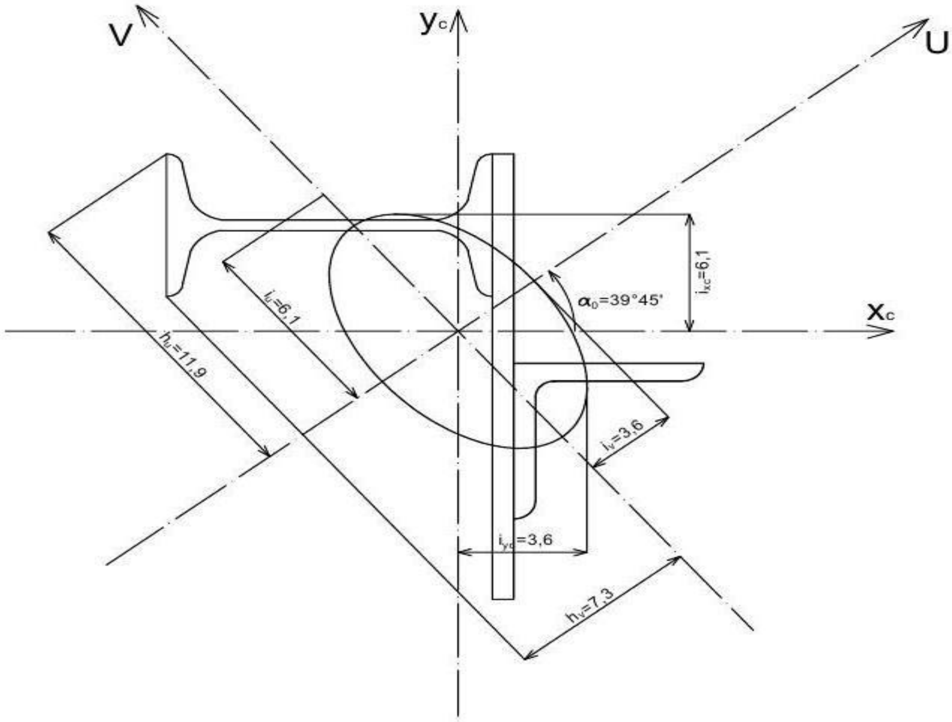


Fig. 1.3

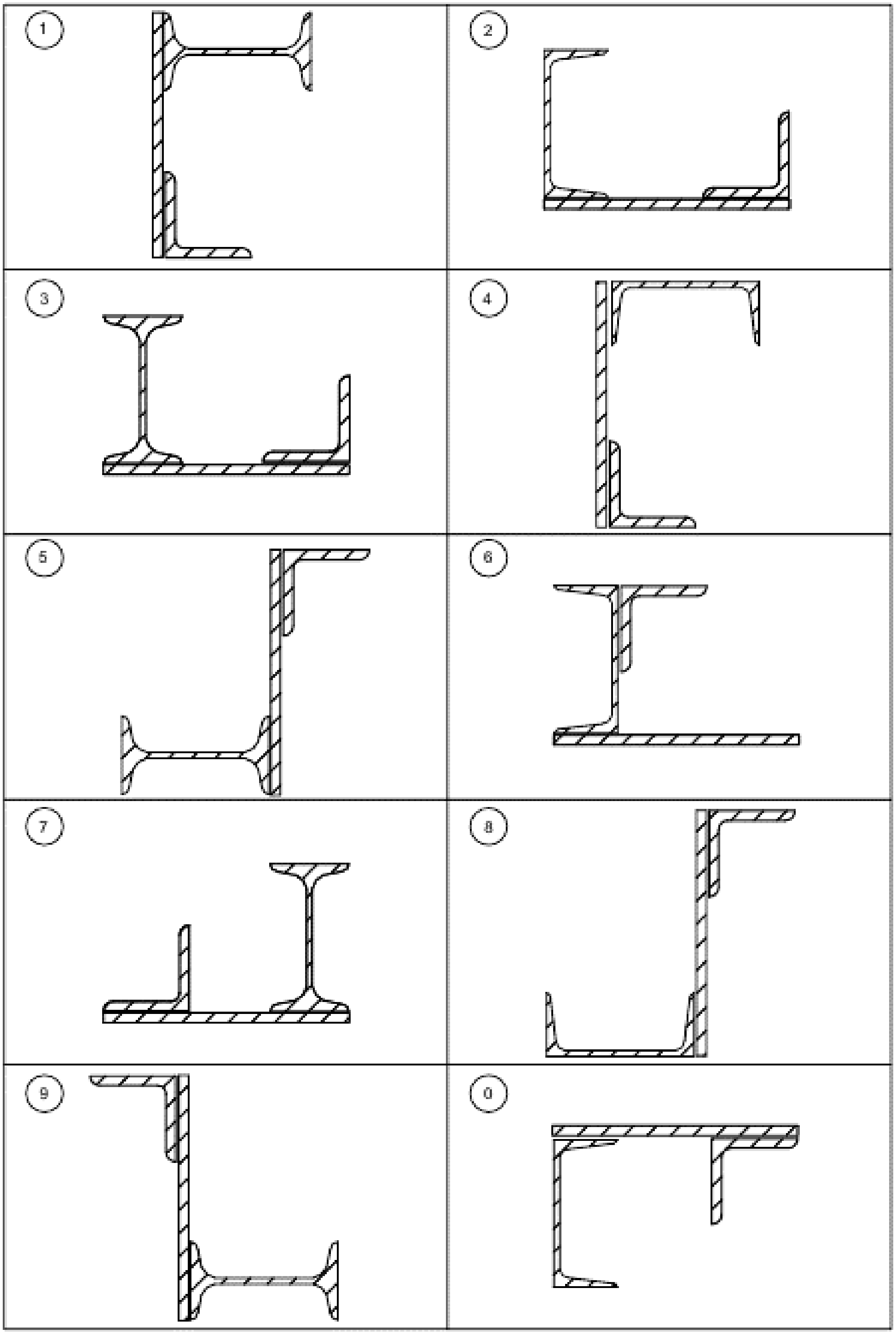


Fig. D-1.1

Table D-1

№	Numerical values corresponding to the cipher digits				
	First digit	Second digit		Third digit	
	Scheme No.	Beam No.	Channel No.	Angle dimensions	Plate dimensions
0	1	60	14	250x20	200x10
1	2	55	16	220x14	200x12
2	3	50	18	200x20	220x14
3	4	40	20	180x12	220x16
4	5	36	22	140x10	300x18
5	6	30	24	125x10	300x20
6	7	24	27	110x8	350x18
7	8	22	30	180x10	400x16
8	9	20	36	90x8	420x14
9	0	10	40	80x8	440x8

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Educational and Methodological Publication

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Water Supply and Water Supply and Drainage (WSD)

Compilers: **KOSHEVYI** Oleksandr Oleksandrovych
KOSHEVYI Oleksandr Petrovych

Комп'ютерне верстання *А. П. Селівестрової*

Ум. друк. арк. 1,86 Обл.-вид. арк. 2,0
Електронний документ. Вид № 66/V-26.

Виконавець і виготовлювач

Київський національний університет будівництва і архітектури
Проспект Повітряних Сил, 31, Київ, Україна, 03037

Свідоцтво про внесення до Державного реєстру суб'єктів
видавничої справи ДК № 808 від 13.02.2002 р