MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

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Methodological guidelines
for practical classes,
independent and calculator-graphical works
on the subject

"MECHANICS of MATERIALS"
(Tension – Compression)

(for the second year full-time Bachelor degree students
specialty 192 – Construction and civil engineering)

Kharkiv
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Methodological Guidelines for practical classes, independent and calculator-graphical works on the Subject "Mechanics of Materials" (Tension – Compression) (for the second year full-time Bachelor degree students of the specialty 192 – Construction and civil engineering) / O. M. Beketov National University of Urban Economy in Kharkiv ; com.: N. V. Sereda, A. O. Garbuz, T. A. Suprun. – Kharkiv : O. M. Beketov NUUE, 2018. – 22 p.

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CONTENTS

INTRODUCTION

Mechanic of materials is one of the most important disciplines studied by students in a higher technical educational university.

Using the laws of theoretical mechanics and the corresponding mathematical apparatus, the mechanic of materials considers the problems of strength, stiffness and durability of machines and structures.

These guidelines should be used in independent work of students at training for practical classes and making of calculation and solving graphic problem. They contain theoretical materials and source data for the problem. Output data are taken on the instruction of the teacher.

Before proceeding to the problem, you should introduce yourself with the theoretical material outlined in these guidelines and the list literature.

UNITS OF MEASUREMENT

The work adopted the international system of SI units. Using manuals of mechanical characteristics with the technical system of units, the following dependencies should be applied:

1 kgf = 10 N; 1 tf = 10 kN, 1 kN = 10^3 N;
1 tf/m = 10 kN/m;
1 kgf/cm^2 = 0,1 MPa, 1 MPa = 10^6 Pa = 0,1 kN/cm^2 = 10^3 kN/m^2;
1 tf · m = 10 kN · m.

1 FORMATION OF CALCULATION AND GRAPHICAL WORK

1. Work is executed on sheets of standard A4 format.
2. The cover is made of dense paper for drawing. On the title page there should be the name and number of the calculation and graphic problem, name of the discipline, last name, first name of the student, his variant, the name of the faculty, the group, the surname and initials of the teacher.
3. The solution of each problem should begin with the indication of its number, names, writing down complete problem task, numerical output data and draw calculation scheme.
4. The solution to the problem should be accompanied by short explanations, drawings and sketches.
5. Drawings and graphs are executed necessarily on a certain scale. In the drawings one must indicate the letter designation and numerical values of all values used in the calculations.
6. When solving the problem, you must first obtain the result in algebraic form, and then substitute the corresponding numerical values. The results obtained in numerical form should be indicated and units of measurement must be specified.

2 OUTPUT DATA AND PROBLEM TO WORK

PROBLEM 1 *Calculation of statically determined systems at tension-compression*.

For a given system (Fig. 1) determine the forces in the rods; choose the cross-sections of the rods, if they are made of steel [σ] = 160 MPa. Output data are taken from *Table* 1.

The order of the problem:

1. Draw a calculation scheme.

2. When determining the longitudinal forces in the rods cross-sectional method should be used. Let's imagine the rod cut; reject one part, replace the action of the rejected part with internal forces, make the equation equilibrium for the left part to which external and internal forces operate. Longitudinal force is considered *positive* when it *stretches* the rod, and *negative* when *compressing* it.

3. The cross-section size of the rod is chosen from the strength conditions of tensile - compression $A > \dfrac{N}{[\sigma]}$.

Table 1

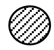
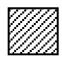
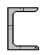
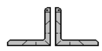
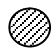
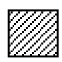
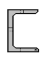
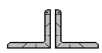
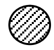
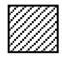
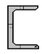
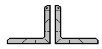
N variant	*a*, m	*b*, m	*c*, m	*d*, m	*q*, kN/m	*F*, kN	*M*, kN·м	Cross-section
1	2	3	4	5	6	70	8	9
1	2	2	3	2	5	200	30	
2	1	2,5	2	2,5	10	300	40	
3	1,5	3	3	2	20	400	10	
4	2,5	2,5	2	3	30	100	20	
5	3	3	2,5	1	10	250	30	
6	1,5	2	1,5	2,5	20	350	40	
7	1	3	2,5	1	5	150	50	
8	2	2,5	1	1,5	10	200	30	
9	3	2	1,5	2	20	300	20	
10	2,5	3	1	3	5	100	40	

Table continuation 1

1	2	3	4	5	6	7	8	9
11	3	2	2	2	5	200	20	
12	2	2,5	1	2,5	10	300	30	
13	3	2	1,5	3	20	400	40	
14	2	3	2,5	2,5	30	100	10	
15	2,5	1	3	3	10	250	25	

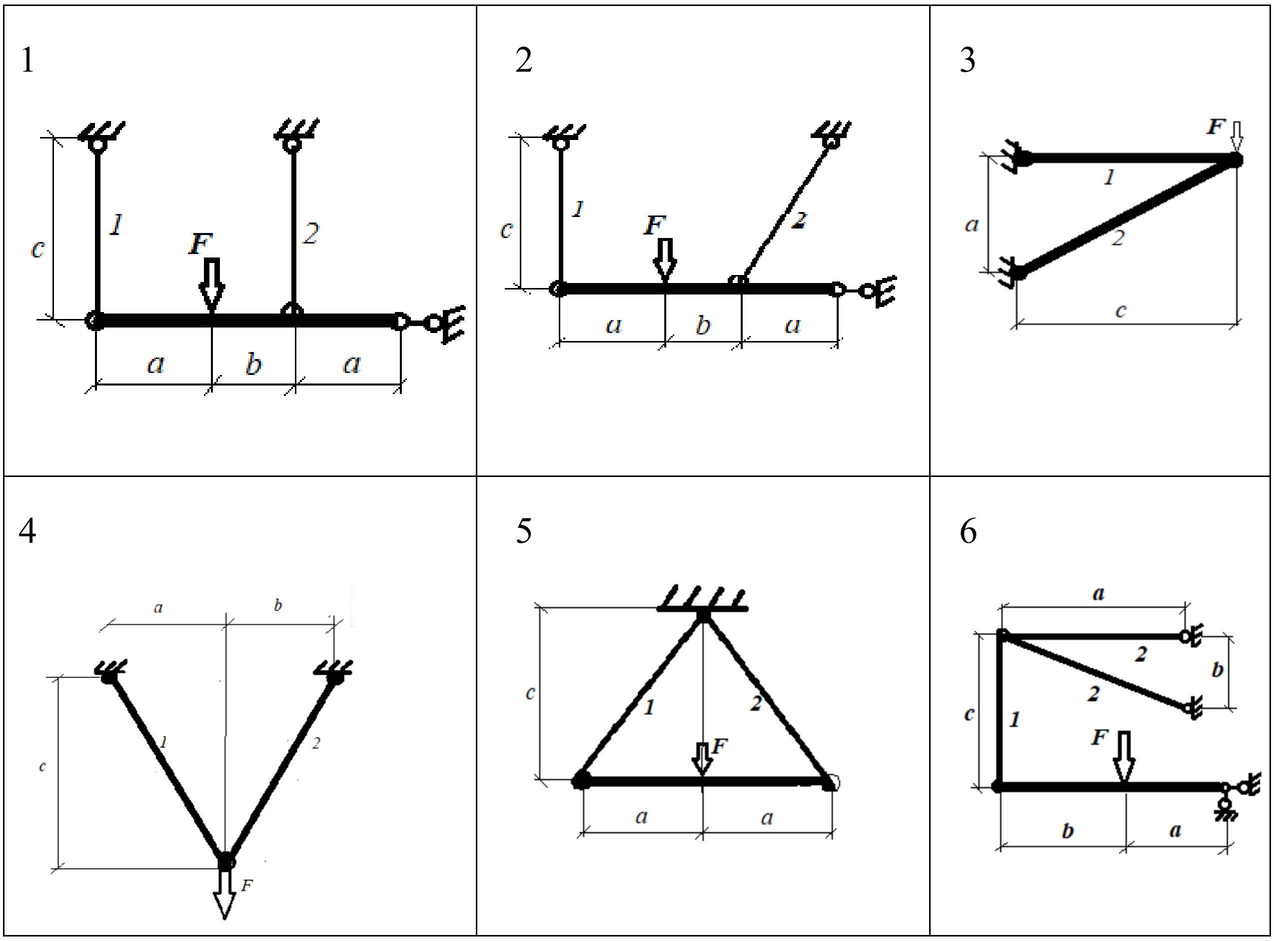


Figure 1 – Schemes of systems to problem number 1

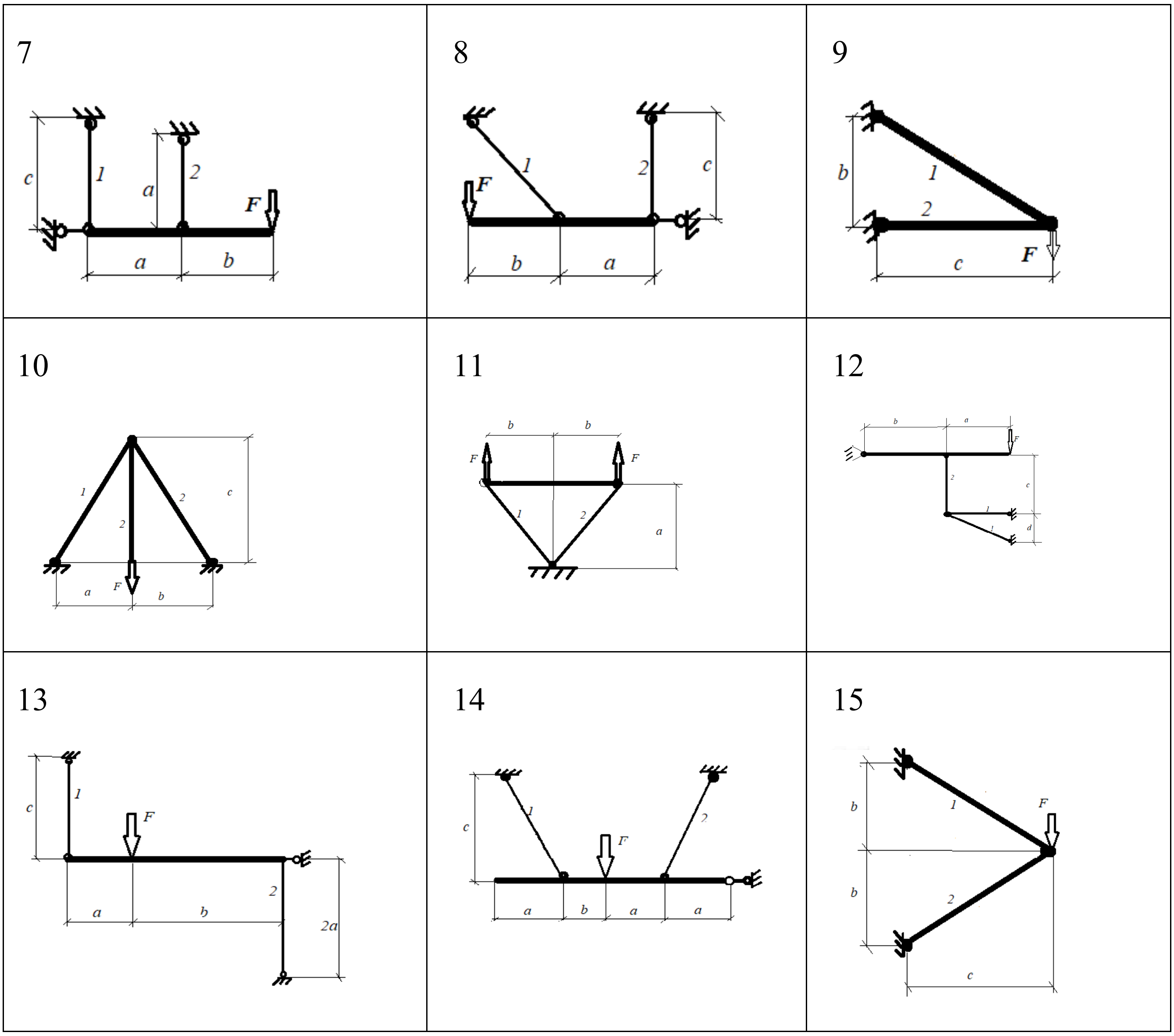


Figure 1 (continuation) – Schemes of systems to problem number 1

PROBLEM 2 Calculation of statically determined systems having deformation of tension and compression.

For a given rod (Figure 2), taking into account its own weight, determine forces and stress on each parts; draw a diagram of longitudinal forces, normal stresses; find deformation (displacement) of section I-I. Output data should be taken from tables 2, 3.

The order of the problem:

1. Draw a calculation scheme.
2. In determining the longitudinal forces in the sections of the stepped rod you need to use the cross-sectional method. Make imaginary part cross sections.

Rejecting one of the parts of the rod and replacing it with the internal action forces, we form an equilibrium equation for the left part to which we applied external and internal forces.

The *longitudinal force* is *positive* when it is *stretched* the rod, and *negative* when it is *compressed*.

3. Normal stresses in each section are determined the ratio of longitudinal forces to its area

$$\sigma = \frac{N}{A}.$$

4.Displacement of the section I-I is determined relatively to the fixed section, it depends on the deformation of that part of the rod, which lies between the section I-I and the fixing constrain.

Extension or reduction of this part by external force are found by the formula:

$$\Delta L = \frac{FL}{EA}.$$

Extension or reduction of this part of the rod from its own weight are found by the formula:

$$\Delta L = \frac{GL}{2EA},$$

where G – weight of the part;

L – length of the part; E – modulus of elasticity; A – cross-section.

The weight of the part of the rod from the section I-I to the free end is considered as an external load acting in the cross-section and causing strain of the rod from cross-section to support.

Table 2

Number variant	A_1, cm^2	A_2, cm^2	A_3, cm^2	L_1, m	L_2, m	L_3, m	F_1, *kN*	F_2, *kN*	F_3, *kN*
1	2	3	4	5	6	7	8	9	10
1	8	12	12	3	3	2	4	7	8
2	10	15	8	2	2,5	3	3	5	6
3	15	16	10	4	2	3,5	5	3	5
4	20	10	12	5	4	2	7	4	6
5	25	18	20	3,5	3	4	6	4	5
6	30	20	10	2,5	4	3,5	5	3	4
7	10	12	8	4,5	2,5	3	9	2	7
8	15	16	15	3	2	4	10	8	6
9	20	15	10	5	3,5	2,5	9	10	8
10	25	10	20	4	3	2	10	7	9
11	8	8	12	3	3	3	4	4	7
12	10	10	15	2	2	2,5	3	3	5
13	15	15	16	4	4	2	5	5	3
14	20	20	10	5	5	4	7	7	4
15	25	25	18	3,5	3,5	3	6	6	4

Table 3 – Mechanical characteristics of materials

Material	Steel-3	Copper	Brass	Bronze	Concrete	Oak
E, MPa	$2{,}1\cdot10^5$	$1{,}1\cdot10^5$	$0{,}9\cdot10^5$	$0{,}89\cdot10^5$	$0{,}18\cdot10^5$	$0{,}1\cdot10^5$
ρ*, kN/m*^{3}	78	89,4	85	85	24	5,3

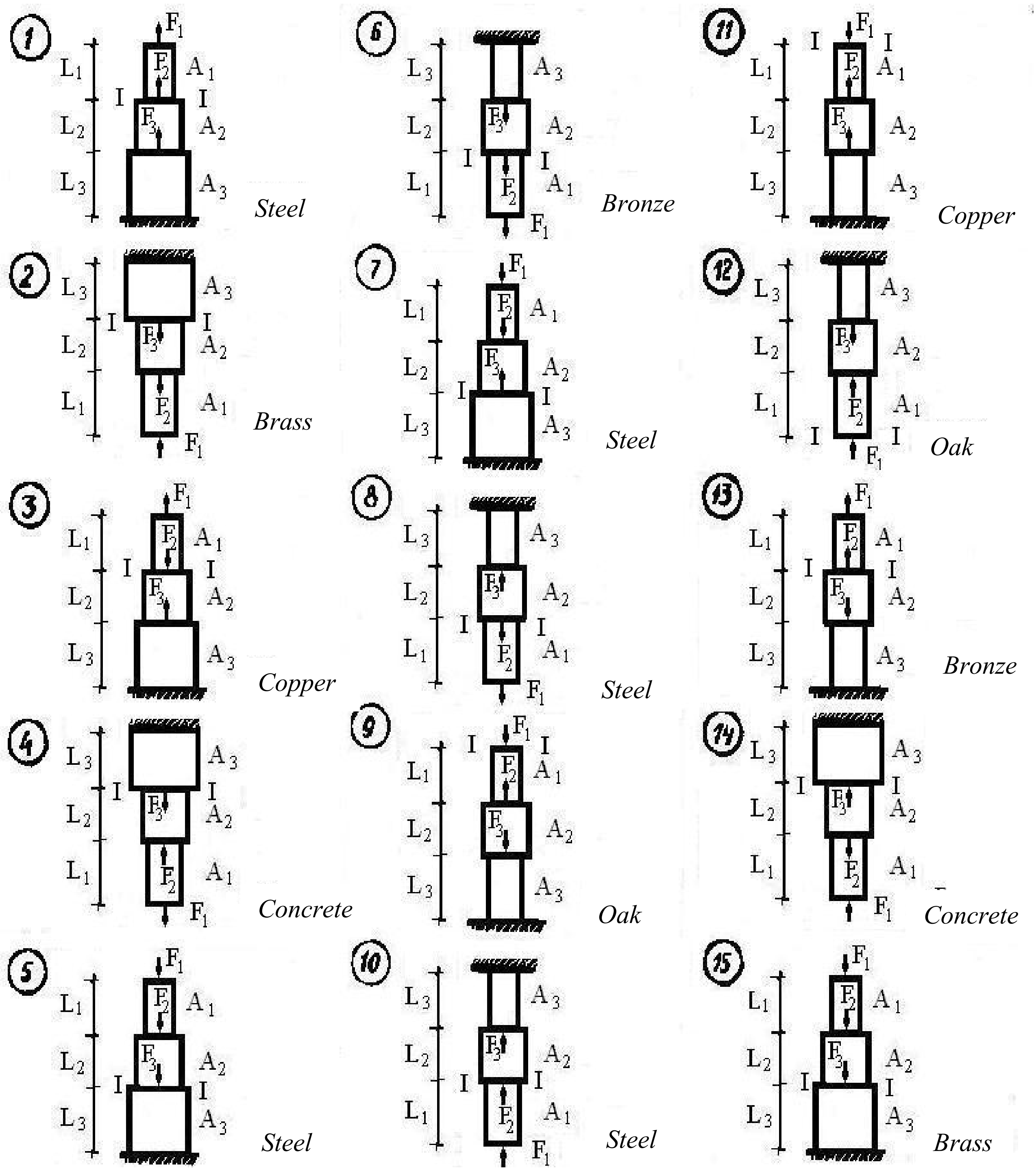


Figure 2 – Schemes of systems to problem number 2

PROBLEM 3 *Calculation of statically undetermined systems having deformation of tension and compression*

Stiffness beam (Fig. 3) rests on a fixed support and jointed to two rods. We need to find the forces and stresses in steel rods (in fractions of force *F*); find load $\boldsymbol{F_{all}}$ when the maximum stress is $[\sigma] = 160$ MPa.

Output data to be taken from *table 4*.

The order of the problem:

1. Draw a calculation scheme.

2. By writing the equation of static equilibrium of the system, find the index the static undetermined of the problem, that is, the number of unnecessary unknowns equate to the number of real static equations. The missing condition must be the equation of compatibility of strains (displacements) of a rod. This equation together with the static equations (after determination of displacements through forces on *Hooke's law*) determines the forces in the rods in fractions of force *F*.

3. On the strength condition of it is necessary to determine the stresses in the rods in fractions of external load ***F*** and limit the received stresses to allowable. Find the allowable loads for each rod and, analyzing them, determine the allowable load for the whole system.

Table 4

№ варіанта	A_1, см^2	A_2, см^2	*a*, м	*b*, м	*c*, м	*d*, м
1	2	3	4	5	6	7
1	20	30	1	4	3	4
2	10	20	2	3	2	3
3	15	10	3	2	1	2
4	10	15	4	1	4	1
5	20	5	5	3	2	1
6	15	10	4	2	1	2
7	20	15	3	4	3	3
8	10	20	2	1	2	4
9	10	10	1	4	2	1
10	15	20	3	3	3	3
11	5	20	5	3	1	3
12	10	10	4	5	3	2
13	15	15	3	4	3	4
14	20	10	2	3	2	1
15	10	20	1	2	4	4

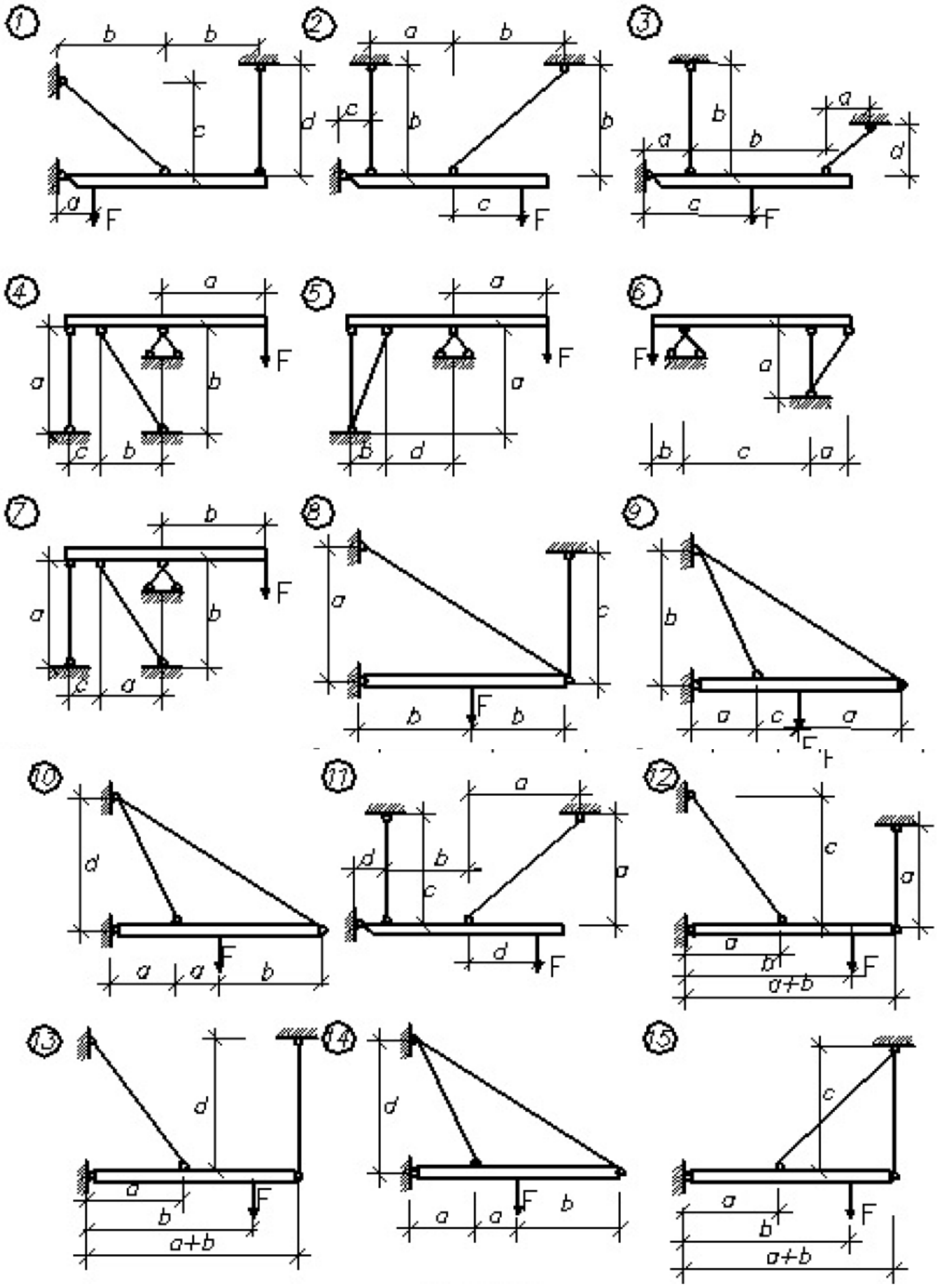


Figure 3 – Schemes of systems to problem number 3

3 EXAMPLES OF CALCULATIONS

Problem №. 1

Output data:

Cross-section ①	Cross-section ②	*a*, m	*b*, m	*c*, M	[σ], kN/cm^2	*F*, kN
		2	4	3	16	40

Solution:

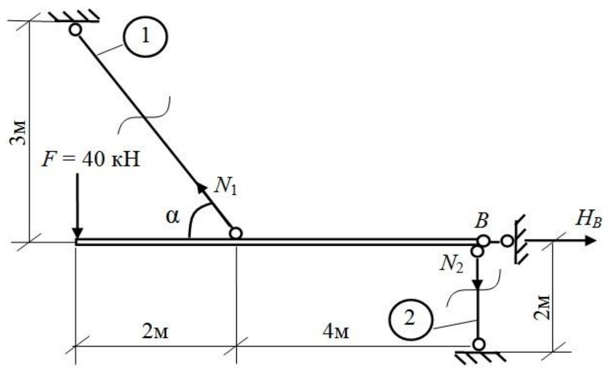


Figure 4

$$\sin\alpha = \frac{3}{\sqrt{3^2+2^2}} = \frac{3}{\sqrt{15}} = 0{,}775;$$

$$\cos\alpha = \frac{2}{\sqrt{15}} = 0{,}517.$$

1. Equations of equilibrium:

$$\left.\begin{array}{ll} \sum x = 0, & -N_1\cos\alpha + H_B = 0 \\ \sum y = 0, & N_1\sin\alpha - N_2 - F = 0 \\ \sum M_B = 0, & N_1\sin\alpha\cdot 4 + F\cdot 6 = 0 \end{array}\right\} \quad (1)$$

$$N_1 = \frac{F\cdot 6}{\sin\alpha\cdot 4} = \frac{40\cdot 6}{0{,}775\cdot 4} = 77{,}4\ kN.$$

$$N_2 = N_1\cdot\sin\alpha - F = 77{,}4\cdot 0{,}775 - 40 = 19{,}98\ kN.$$

II. The strength conditions of tensile-compression:

$$\sigma = \frac{N}{A} \le [\sigma] \rightarrow A \ge \frac{N}{[\sigma]}. \qquad (2)$$

$$A_1 \ge \frac{N_1}{[\sigma]} = \frac{77{,}4}{16} = 4{,}84\ cm^2;\ A_1' = \frac{A_1}{2} = 2{,}42\ cm^2;$$

$A_1' = 2{,}43\ cm^2$;  № 3,2.

$$A_2 \ge \frac{N_2}{[\sigma]} = \frac{19{,}98}{16} = 1{,}25\ cm^2;\ a_2 = \sqrt{A_2} = \sqrt{1{,}25} = 1{,}118\ cm^2.$$

Problem №. 2

Output data: $A_1 = 10cm^2 = 10^{-3}m^2$; $A_2 = A_3 = 20cm^2 = 2\cdot10^{-3}m^2$; $\rho = 78\frac{kN}{m^2}$;
$E = 2\cdot10^5 MPa$

For a given stepped rod, made of steel, to draw diagrams of longitudinal forces and normal stresses. Determine the displacement of the section B-B

Solution:

Cross-section I-I: $0 \le x_1 \le 4\ m$,

$$\sum F_x = 0 \rightarrow N_1 = F_1 + \rho\cdot A_1\cdot x_1;$$

$$N_{1x_1=0} = F_1 = 5\ kN;\quad N_{1x_1=4} = 5 + 78\cdot10^{-3}\cdot4 = 5{,}312\ kN;$$

$$\sigma_{1x_1=0} = \frac{N_1}{A_1} = \frac{5}{10^{-3}} = 5\cdot10^3\frac{kN}{m^2};\quad \sigma_{1x_1=l} = \frac{5{,}312}{10^{-3}} = 5{,}312\cdot10^3\frac{kN}{m^2}.$$

Cross-section II-II: $4\ m \le x_2 \le 9\ m$

$$\sum F_x = 0 \rightarrow N_2 = F_1 + \rho\cdot A_1\cdot l_1 + F_2 + \rho\cdot A_2\cdot(x_2 - 4),$$

$$N_{2x_2=4} = 5{,}312 + 3 = 8{,}312\ kN,\ N_{2x_2=9} = 8{,}312 + 78\cdot2\cdot10^{-3}(9-4) = 9{,}092\ kN,$$

$$\sigma_{2x_2=4} = \frac{N_2}{A_2} = \frac{8{,}312}{2\cdot10^{-3}} = 4{,}156\cdot10^3\frac{kN}{m^2},$$

$$\sigma_{2x_2=9} = \frac{9{,}092}{2\cdot10^{-3}} = 4{,}546\cdot10^3\frac{kN}{m^2}.$$

Cross-section III-III: $9m \le x_3 \le 12m$

$$\sum F_x = 0 \rightarrow N_3 = F_1 + \rho\cdot A_1\cdot l_1 + F_2 + \rho\cdot A_2\cdot l_2 - F_3 + \rho\cdot A_3\cdot(x_3 - 9),$$

$$N_{3x_3=9} = 9{,}092 - 10 = -908\ kN;$$

$$N_{3x_3=12} = -0{,}908 - 78\cdot2\cdot10^{-3}(12-9) = -0{,}44\ kN,$$

$$\sigma_{3x_3=9} = \frac{N_3}{A_3} = \frac{0{,}908}{2\cdot10^{-3}} = -0{,}454\cdot10^3\frac{kN}{m^2},$$

$$\sigma_{3x_3=12} = \frac{N_3}{A_3} = \frac{-0{,}44}{2\cdot10^{-3}} = -0{,}22\cdot10^3\frac{kN}{m^2}.$$

Draw diagrams “N” and “σ” (figure 5).
Total displacement of section *B-B*:

$$\Delta l_{B-B} = \Delta l_3 = \frac{l_3}{E\cdot A_3}\left(F_1 + \rho\cdot A_1\cdot l_1 + F_2 + \rho\cdot A_2\cdot l_2 - F_3 + \frac{1}{2}\rho\cdot A_3\cdot l_3\right) =$$

$$= \frac{3}{2\cdot10^5\cdot10^3\cdot2\cdot10^{-3}}(5 + 78\cdot10^{-3}\cdot4 + 3 + 78\cdot10^{-3}\cdot5 - 10 +$$

$$+\frac{1}{2}\cdot78\cdot2\cdot10^{-3}\cdot3) = -\frac{3\cdot0.674}{2\cdot10^5\cdot10^3\cdot2\cdot10^{-3}} = -0.5055\cdot10^{-5}\ m$$

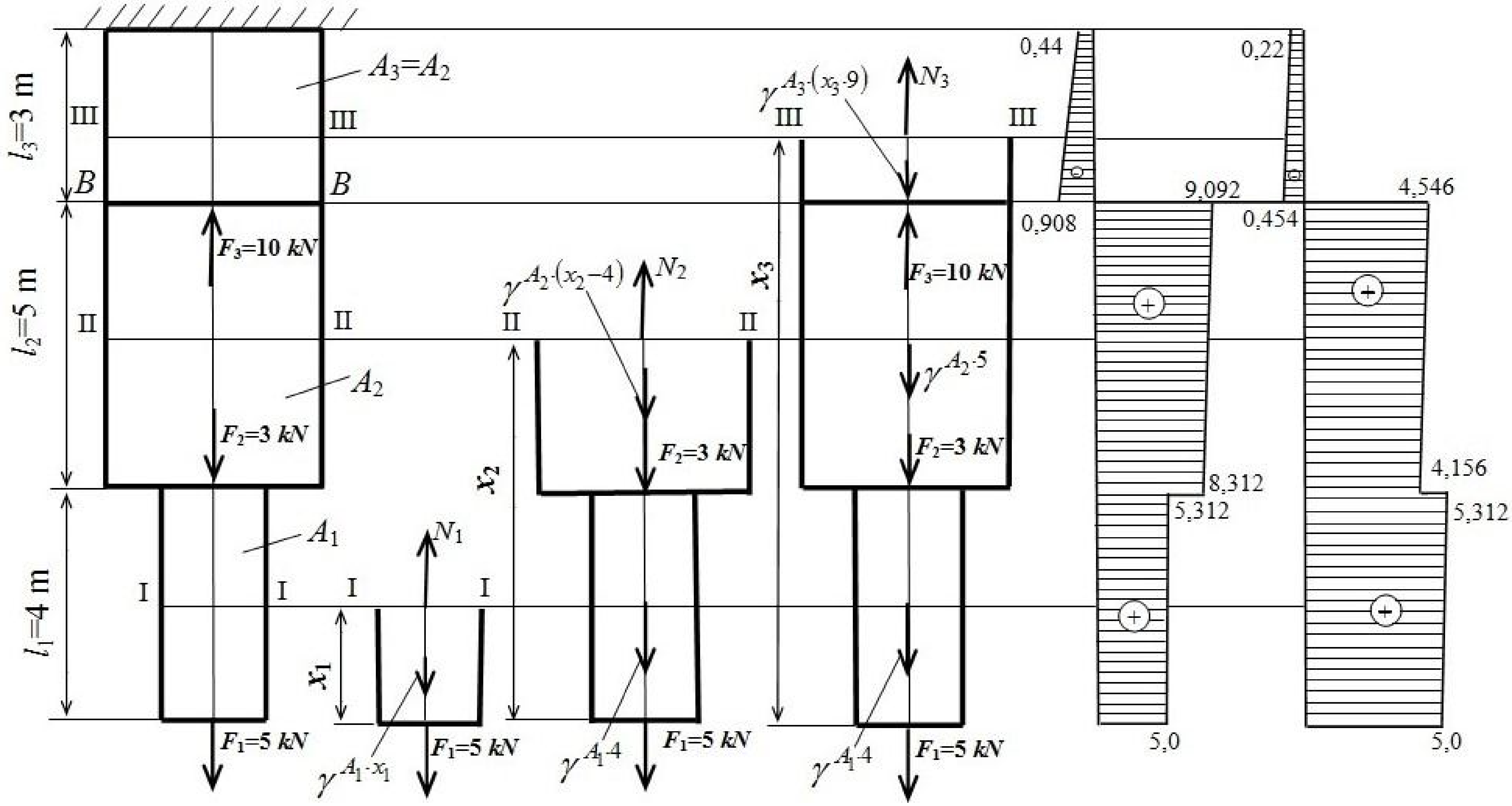


Figure 5. Diagram “N”. Diagram “σ”

Problem №. 3 Stiffness beam BC rests on the pinned joint support and jointed to the two rods BD and CK (Fig. 6, a). Determine the forces and stresses in the rods (in fractions of force F), find allowed load F, using strength conditions of tension - compression. Output data [σ] = 160 MPa, $\alpha = 45^0$, l_1= 2 m, l_2= 2,82 m, a = 2 m, b = 3 m, c = 1 m, $A_1 = 20\ cm^2 = 1\cdot10^{-3}\ m^2$, $A_2 = 20\ cm^2 = 2\cdot10^{-3} m^2$.

Solution: We cut the rods of KC and BD. The action of the rejected parts of the system we will replace with the forces in the rods N_1 and N_2, directed along these rods. The reaction of the support A has a horizontal component H_A and a vertical R_A, because this support prevents the vertical and horizontal displacement of the point A. Thus, we have four unknowns, and there can be made up only three equations of equilibrium for the plate systems. Consequently, this system is once statically indetermined and for solving the problem there must be added one equation. On the condition of the problem it is necessary to determine the forces of N_1 and N_2 steel rods BD and KC, and the H_A and R_A reactions are unnecessary. Therefore, it is enough to use one of the three possible equations of equilibrium, which would not include H_A and R_A reactions. This equation is the sum of moments of all forces relative to the pin-joint A:

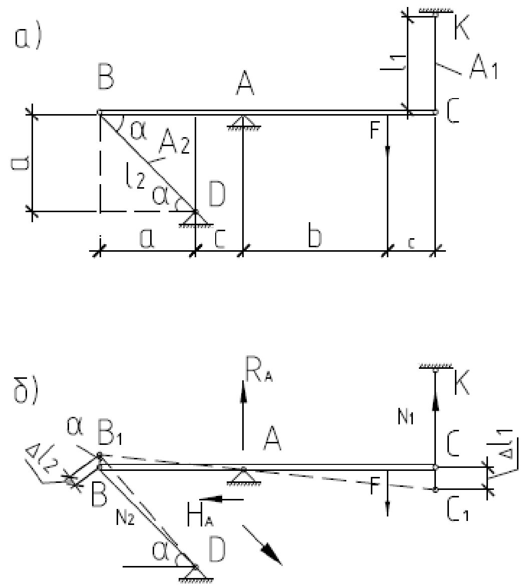


Figure 6.

$$\sum M_A = 0; \quad N_2 \cdot \sin\alpha(a+c) - Fb + N_1(b+c) = 0$$

To compile the added equation we consider the strain of the system. In Figure 6, the shaded line denotes the axis of the beam after the strain systems. This axis is straight line (the beam is stiffness), without strains, but it can rotate around point A. The pins B and C after the deformation move into positions B_1 and C_1 respectively, i. e., they move vertically. From the similarity of the triangles BB_1A and CC_1A we find:

$$\frac{BB_1}{BA} = \frac{CC_1}{AC}$$

Lengthening $\Delta L_1 = CC_1, \Delta L_2 = BB_1 \cdot \cos\alpha$, where $BB_1 = \frac{\Delta L_2}{\cos\alpha}$. (5)

Let's substitute an expression (5) into (4): $\frac{\Delta L_2}{\cos\alpha(a+c)} = \frac{\Delta L_1}{b+c}$. (6)

For the Hooke's law $\Delta L_1 = \frac{N_1 L_1}{EA_1}; \quad \Delta L_2 = \frac{N_2 L_2}{EA_2};$ (7)

and on the basis of equality (6) we have: $\frac{N_2 L_2}{EA_2 \cos\alpha(a+c)} = \frac{N_1 L_1}{EA_1(b+c)};$

or, $N_2 L_2 A_1 (b+c) - N_1 L_1 A_2 \cos\alpha(a+c) = 0$. (8)

Solving the equation of strains compatibility (8), from the equilibrium equation (3) find the value of longitudinal forces N_1 and N_2 written in terms of the load F:

$$N_2 = N_1 \frac{L_1 A_2 \cos\alpha(a+c)}{L_2 A_1 (b+c)}; \tag{9}$$

$$N_1 \left(\frac{L_1 A_2 \cos\alpha(a+c)}{L_2 A_1 (b+c)} \right) \sin\alpha(a+c) + N_1(b+c) = F \cdot b; \tag{10}$$

$$N_1 = \frac{F \cdot b}{K \sin\alpha(a+c) + (b+c)};$$

where

$$K = \frac{L_1 A_2 \cos\alpha(a+c)}{L_2 A_1 (b+c)}; \quad K = \frac{2 \cdot 2 \cdot 10^{-3} \frac{\sqrt{2}}{2}(2+1)}{2{,}82 \cdot 10^{-3}(3+1)} = 0{,}75;$$

Substituting (10) into (9) we get an expression:

$$N_2 = \frac{KFb}{K \sin\alpha(a+c) + (b+c)} \quad . \tag{12}$$

We substitute numerical values for the formulas obtained (10), (12):

$$N_1 = \frac{F \cdot 3}{\left(0{,}75\frac{\sqrt{2}}{2}(2+1) + (3+1)\right)} = F \cdot 0{,}418;$$

$$N_2 = \frac{0{,}75 \cdot F \cdot 3}{\left(0{,}75\frac{\sqrt{2}}{2}(2+1) + (3+1)\right)} = F \cdot 0{,}313.$$

Let’s write straits in fractions of force F:

$$\sigma_1 = \frac{N_1}{A_1} = \frac{0{,}418}{10^{-3}} \cdot F = 0{,}418 \cdot 10^3 F \; \left[\text{кН/м}^2\right], \; [kN/m^2];$$

$$\sigma_2 = \frac{N_2}{A_2} = \frac{0{,}313}{2 \cdot 10^{-3}} \cdot F = 0{,}156 \cdot 10^3 F \; \left[\text{кН/м}^2\right]. \; [kN/m^2].$$

Since the first rod is more loaded ($\sigma_1 > \sigma_2$) and using the condition of strength, determine the allowed load:

$$\sigma_1 = 0{,}418 \cdot 10^{-3} F \le [\sigma];$$

$$F_{доп} = \frac{160 \cdot 10^3}{418} = 0{,}382 \cdot 10^3 \text{ кН}.$$

CRITERIA FOR THE EVALUATION OF CALCULATION WORK

According to the Calculation and Graphic Work (CGW) a student gets maximum mark, if completed within the time limit (3 weeks from the moment of giving a problem), using computer technology, is executed carefully, contains an analysis of the given results.

In the case of executing CGW without the use of a computer or a delay for 2 weeks (using a computer) student gets 90% from the maximum mark. When executing CGW with a delay of more than for 2 weeks, the student gets 80% of the maximum mark, with a delay of more than month - 60% of the maximum mark.

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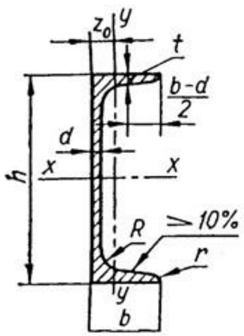
APPENDIX A

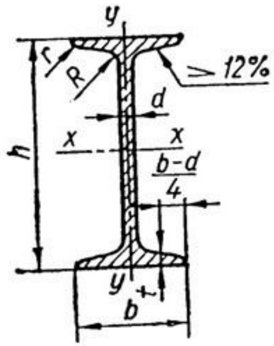


Designations:

h – height;
b – flange width;
d – web thickness;
t – flange thickness;
J – moment of gyration;
W – weight per unit length;
i – radius of gyration;
S – static moment of semi cut;
z_0 – distance to centroid in x direction.

Profile number	Dimensions, mm				cross-sectional area, F cm^2	J_x, cm^4	W_x, cm^3	i_x, cm	S_x, cm^3	J_y, cm^4	W_y,cm^3	i_y, cm	z_0, cm	Mass 1 m, kg
	h	b	d	t										
5	50	32	4,4	7,0	6,16	22,8	9,1	1,92	5,59	5,61	2,75	0,954	1,16	4,84
6,5	65	36	4,4	7,2	7,51	48,6	15,0	2,54	9,0	8,7	3,68	1,08	1,24	5,90
8	80	40	4,5	7,4	8,98	89,4	22,4	3,16	13,3	12,8	4,75	1,19	1,31	7,05
10	100	46	4,5	7,6	10,9	174	34,8	3,99	20,4	20,4	6,46	1,37	1,44	8,59
12	120	52	4,8	7,8	13,3	304	50,6	4,78	29,6	31,2	8,52	1,53	1,54	10,4
14	140	58	4,9	8,1	15,6	491	70,2	5,60	40,8	45,4	11,0	1,70	1,67	12,3
14a	140	62	4,9	8,7	17,0	545	77,8	5,66	45,1	57,5	13,3	1,84	1,87	13,3
16	160	64	5,0	8,4	18,1	747	93,4	6,42	54,1	63,6	13,8	1,87	1,80	14,2
16a	160	68	5,0	9,0	19,5	823	103	6,49	59,4	78,8	16,4	2,01	2,00	15,3
18	180	70	5,1	8,7	20,7	1090	121	7,24	69,8	86	17,0	2,04	1,94	16,3
18a	180	74	5,1	9,3	22,2	1190	132	7,32	76,1	105	20,0	2,18	2,13	17,4
20	200	76	5,2	9,0	23,4	1520	152	8,07	87,8	113	20,5	2,20	2,07	18,4
20a	200	80	5,2	9,7	25,2	1670	167	8,15	95,9	139	24,2	2,35	2,28	19,8
22	220	82	5,4	9,5	26,7	2110	192	8,89	110	151	25,1	2,37	2,21	21,0
22a	220	87	5,4	10,2	28,8	2330	212	8,99	121	187	30,0	2,55	2,46	22,6
24	240	90	5,6	10,0	30,6	2900	242	9,73	139	208	31,6	2,60	2,42	24,0
24a	240	95	5,6	10,7	32,9	3180	265	9,84	151	254	37,2	2,78	2,67	25,8
27	270	95	6,0	10,5	35,2	4160	308	10,9	178	262	37,3	2,73	2,47	27,7
30	300	100	6,5	11,0	40,5	5810	387	12,0	224	327	43,6	2,84	2,52	31,8
33	330	105	7,0	11,7	46,5	7980	484	13,1	281	410	51,8	2,97	2,59	36,5
36	360	110	7,5	12,6	53,4	10 820	601	14,2	350	513	61,7	3,10	2,68	41,9
40	400	115	8,0	13,5	61,5	15 220	761	15,7	444	642	73,4	3,23	2,75	48,3

APPENDIX B

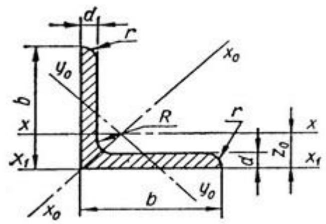


Designations:

h – height;
b – flange width;
d – web thickness;
t – flange thickness;
J – moment of gyration;
W – weight per unit length;
i – radius of gyration;
S – static moment of semi cut.

Profile number	Dimensions, mm				cross-sectional area, F cm^2	J_x, cm^4	W_x, cm^3	i_x, cm	S_x, cm^3	J_y, cm^4	W_y, cm^3	i_y, cm	Mass 1 m, kg
	a	b	d	t									
10	100	55	4,5	7,2	12,0	198	39,7	4,06	23,0	17,9	6,49	1,22	9,46
12	120	64	4,8	7,3	14,7	350	58,4	4,88	33,7	27,9	8,72	1,38	11,5
14	140	73	4,9	7,5	17,4	572	81,7	5,73	46,8	41,9	11,5	1,55	13,7
16	160	81	5,0	7,8	20,2	873	109	6,57	62,3	58,6	14,5	1,70	15,9
18	180	90	5,1	8,1	23,4	1290	143	7,42	81,4	82,6	18,4	1,88	18,4
18a	180	100	5,1	8,3	25,4	1430	159	7,51	89,8	114	22,8	2,12	19,9
20	200	100	5,2	8,4	26,8	1840	184	8,28	104	115	23,1	2,07	21,0
20a	200	110	5,2	8,6	28,9	2030	203	8,37	114	155	28,2	2,32	22,7
22	220	110	5,4	8,7	30,6	2550	232	9,13	131	157	28,6	2,27	24,0
22a	220	120	5,4	8,9	32,8	2790	254	9,22	143	206	34,3	2,50	25,8
24	240	115	5,6	9,5	34,8	3460	289	9,97	163	198	34,5	2,37	27,3
24a	240	125	5,6	9,8	37,5	3800	317	10,1	178	260	41,6	2,63	29,4
27	270	125	6,0	9,8	40,2	5010	371	11,2	210	260	41,5	2,54	31,5
27a	270	135	6,0	10,2	43,2	5500	407	11,3	229	337	50,0	2,80	33,9
30	300	135	6,5	10,2	46,5	7080	472	12,3	268	337	49,9	2,69	36,5
30a	300	145	6,5	10,7	49,9	7780	518	12,5	292	436	60,1	2,95	39,2
33	330	140	7,0	11,2	53,8	9840	597	13,5	339	419	59,9	2,79	42,2
36	360	145	7,5	12,3	61,9	13 380	743	14,7	423	516	71,1	2,89	48,6
40	400	155	8,3	13,0	72,6	19 062	953	16,2	545	667	86,1	3,03	57,0
45	450	160	9	14,2	84,7	27 696	1231	18,1	708	808	101	3,09	66,5
50	500	170	10	15,2	100	39 727	1589	19,9	919	1043	123	3,23	78,5
55	550	180	11	16,5	118	55 962	2035	21,8	1181	1356	151	3,39	92,6
60	600	190	12	17,8	138	76 806	2560	23,6	1491	1725	182	3,54	108

APPENDIX C



Designations:
b – leg length;
d – thickness;
J – moment of gyration;
i – radius of gyration;
z_0 – distance to center of gravity to the outer edge shelves.

Profile number	Dimensions, mm		cross-sectional area, F cm^2	J_x, cm^4	i_x, cm	J_{x0max}, cm^4	i_{x0max}, cm	J_{y0min}, cm^4	i_{y0min}, cm	J_{x1}, cm^4	z_0, cm	Mass 1 m, kg
	b	d										
5	50	3	2,96	7,11	1,55	11,3	1,95	2,95	1,00	12,4	1,33	2,32
		4	3,89	9,21	1,54	14,6	1,94	3,80	0,99	16,6	1,38	3,05
		5	4,80	11,20	1,53	17,8	1,92	4,63	0,98	20,9	1,42	3,77
5,6	56	4	4,38	13,1	1,73	20,8	2,18	5,41	1,11	23,3	1,52	3,44
		5	5,41	16,0	1,72	25,4	2,16	6,59	1,10	29,2	1,57	4,25
6,3	63	4	4,96	18,9	1,95	29,9	2,45	7,81	1,25	33,1	1,69	3,90
		5	6,13	23,1	1,94	36,6	2,44	9,52	1,25	41,5	1,74	4,81
		6	7,28	27,1	1,93	42,9	2,43	11,20	1,24	50,0	1,78	5,72
6,5	65	6	7,52	29,85	1,99	47,38	2,51	13,32	1,28	17,53	1,83	5,91
			9,84	38,13	1,97	60,42	1,27	15,85	2,48	28,29	1,90	7,73
7	70	4,5	6,20	29,0	2,16	46,0	2,72	12,0	1,39	51,0	1,88	4,87
		5	6,68	31,9	2,16	50,7	2,72	13,2	1,39	56,7	1,90	5,38
		6	8,15	37,6	2,15	59,6	2,71	15,5	1,38	68,4	1,94	6,39
		7	9,42	43,0	2,14	68,2	2,69	17,8	1,37	80,1	1,99	7,39
		8	10,70	48,2	2,13	76,4	2,68	20,0	1,37	91,9	2,02	8,37
7,5	75	5	7,39	39,5	2,31	62,6	2,91	16,4	1,49	69,6	2,02	5,80
		6	8,78	46,6	2,30	73,9	2,90	19,3	1,48	83,9	2,06	6,89
		7	10,1	53,3	2,29	84,6	2,89	22,1	1,48	98,3	2,10	7,96
		8	11,5	59,8	2,28	94,6	2,87	24,8	1,47	113	2,15	9,02
		9	12,8	66,1	2,27	105	2,86	27,5	1,46	127	2,18	10,10
8	80	5,5	8,63	52,7	2,47	83,6	3,11	21,8	1,59	93,2	2,17	6,78
		6	9,38	57,0	2,47	90,4	3,11	23,5	1,58	102	2,19	7,36
		7	10,8	65,3	2,45	101	3,09	27,0	1,58	119	2,23	8,51
		8	12,3	73,4	2,34	116	3,08	30,3	1,57	137	2,27	9,65
9	90	6	10,6	82,1	2,78	130	3,50	34,0	1,79	145	2,43	8,33
		7	12,3	94,3	2,77	150	3,49	38,9	1,78	169	2,47	9,64
		8	13,9	106	2,76	168	3,48	43,8	1,77	194	2,51	10,9
		9	15,6	118	2,75	186	3,96	48,6	1,77	219	2,55	12,2

APPENDIX D

Profile number	Dimensions, mm		cross-sectional area, F cm^2	J_x, cm^4	i_x, cm	J_{x0max}, cm^4	i_{x0max}, cm	J_{y0min}, cm^4	i_{y0min}, cm	J_{x1}, cm^4	z_0, cm	Mass 1 m, kg
	b	d										
10	100	6,5	12,8	122	3,09	193	3,88	50,7	1,99	214	2,68	10,1
		7	13,8	131	3,08	207	3,88	54,2	1,98	231	2,71	10,8
		8	15,6	147	3,07	233	3,87	60,9	1,98	265	2,75	12,2
		10	19,2	179	2,05	284	3,84	74,1	1,96	333	2,83	15,1
		12	22,8	209	3,03	331	3,81	86,9	1,95	402	2,91	17,9
		14	26,3	237	3,00	375	3,78	99,3	1,94	472	2,99	20,6
		16	29,7	264	2,98	416	3,74	112,0	1,94	542	3,06	23,3
11	110	7	15,7	176	3,40	279	4,29	72,7	2,19	308	2,96	11,9
		8	17,2	198	3,39	315	4,28	81,8	2,18	353	3,00	13,5
12,5	125	8	19,7	294	3,37	467	4,87	122	2,49	516	3,36	15,5
		9	22,0	327	3,86	520	4,86	135	2,48	582	3,40	17,3
		10	24,3	360	3,85	571	4,84	149	2,47	649	3,45	19,1
		12	28,9	422	3,82	670	4,82	174	2,46	782	3,53	22,7
		14	33,4	482	3,80	764	4,78	200	2,45	916	3,61	26,2
		16	37,8	539	3,78	853	4,75	224	2,44	1051	3,68	29,6
14	140	9	24,7	466	4,34	739	5,47	192	2,79	818	3,78	19,4
		10	27,3	512	4,33	814	5,46	211	2,78	911	3,82	21,5
		12	32,5	602	4,31	957	5,43	248	2,76	1097	3,90	25,5
16	160	10	31,4	774	4,96	1229	6,25	319	3,19	1356	4,30	24,7
		11	34,4	844	4,95	1341	6,24	348	3,18	1494	4,35	27,0
		12	37,4	913	4,94	1450	6,23	376	3,17	1633	4,39	29,4
		14	43,3	1046	4,92	1662	6,20	431	3,16	1911	4,47	34,0
		16	49,1	1175	4,89	1866	6,17	485	3,14	2191	4,55	38,5
		18	54,8	1299	4,87	2061	6,13	537	3,13	2472	4,63	43,0
		20	60,4	1419	4,85	2248	6,10	589	3,12	2756	4,70	47,4
18	180	11	38,8	1216	5,60	1933	7,06	500	3,59	2128	4,85	30,5
		12	42,2	1317	5,59	2093	7,04	540	3,58	2324	4,89	33,1

Виробничо-практичне видання

Методичні рекомендації
для практичних занять, самостійної
та розрахунково-графічних робіт
із навчальної дисципліни

«ОПІР МАТЕРІАЛІВ»
(РОЗТЯГ – СТИСК)

(*для студентів-бакалаврів 2 курсу денної форми навчання*
за спеціальністю 192 – Промислове та цивільне будівництво)
(*Англійською мовою*)

Укладачі: **СЕРЕДА** Наталя Василівна
ГАРБУЗ Алла Олегівна
СУПРУН Тетяна Олександрівна

Відповідальний за випуск *О. О. Чупринін*
За авторською редакцією
Комп'ютерне верстання *І. В. Волосожарова*

План 2018, поз. 209 М

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