MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

O. M. BEKETOV NATIONAL UNIVERSITY
of URBAN ECONOMY in KHARKIV

Methodical recommendations
for prepare for lectures and practical classes,
self-dependent and test works
on the Subject

«STRENGTH of MATERIALS. STRUCTURAL MECHANICS»

(for full-time foreigner students first (bachelor's) level of higher education specialty
191 – Architecture and town planning)

Kharkiv
O. M. Beketov NUUE
2023

Methodical recommendations for prepare for lectures and practical classes, self-dependent and test works on the Subject «Strength of materials. Structural mechanics» (for full-time foreigner students first (bachelor's) level of higher education specialty 191 – Architecture and town planning) / O. M. Beкetov National University of Urban Economy in Kharkiv; com. A. A. Chuprynin, A. O. Garbuz, M. A. Zasiadko. – Kharkiv: O. M. Beketov NUUE, 2023. – 20 p.

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CONTENTS

INTRODUCTION

Strength of Materials and Structural mechanics is one of the most important disciplines which makes the foundations of the future specialist of the civil engineering in the field of structural calculation and their elements for strength, stiffness and durability of machines and structures.

The course of Strength of Materials and Structural mechanics is studied by students after learning the courses of higher mathematics.

For the design of structures, it is necessary to learn the theoretical and practical methods of their calculation, which ensure the reliability of the structure, and its cost-effectiveness. In the conditions of exploitation of structures there is a constant problem of their calculation for high loads. Such calculations and knowledge can be obtained by studying the course Strength of Materials and Structural mechanics.

When acquiring a course on Strength of Materials and Structural mechanics, the most effective method is the students independent solving problems and control tasks. It contain theoretical statements and variants of problems for control work and an example of its application.

Each student is given out a problem to perform the calculation and graphical work, and in order to eliminate possible questions when performing home control work, practical classes are held to analyses the basic positions of homework.

After receiving a note on the supervisory work, the student must correct the mistakes indicated by the teacher, make the necessary corrections, even if the work has been approved.

If the work is not approved, correct the same or in a separate drawing and resubmit the work for reconsideration. Independence in the execution of calculated and graphical work is of paramount importance for mastering program material. Detailed instructions for completing and design of the problem are given below.

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

The initial data for the problem should be taken from tables 1–3 and drawings 1–3. Specific numerical tasks for each control work the student chooses himself from the tables in accordance with his personal cipher on the last three digits of the number of the gradebook. For example, record book № 81135 educational cipher, educational cipher, 135: 1 – being first, 3 – second, 5 – third digit of code.

To perform task 1, you must use the rod scheme from figure 1 and the numerical data of table 1. In the problem it is necessary to construct diagrams of longitudinal forces and normal stresses.

To perform task 2 it is necessary to consider the system in figure 2 with the numerical data of table 2. The task requires: to determine the forces in the rods, to pick up the cross sections of the rods from the strength conditions.

To perform task 3 it is necessary to consider the system in figure 3 with the numerical data of table 3. The task requires: to plot the transverse forces and bending moments, to pick up the I-beam section, assuming that it is made of steel and has $[\sigma] = 16\ kN/sm^2$.

Table 1 – Initial data for task 1

Initial number cipher's	ℓ_1 m	ℓ_2 m	ℓ_3 m	A_1, sm^2	A_2, sm^2	A_3, sm^2	Second number cipher's	F_1, kN	F_2, kN	F_3, kN	Third number cipher's	Number scheme
1	1,1	0,9	0,7	3	4	2	1	11	62	10	1	1
2	1,2	0,8	1,5	5	3	4	2	12	32	18	2	2
3	1,3	0,6	0,9	5	3	4	3	13	40	10	3	3
4	1,4	1,2	0,8	6	4	2	4	14	60	20	4	4
5	1,5	1,3	1,1	1	3	5	5	15	25	10	5	5
6	1,6	0,9	0,6	3	4	2	6	16	20	20	6	6
7	1,7	0,8	0,9	2	5	3	7	17	70	38	7	7
8	1,8	0,8	1,5	4	3	5	8	18	22	80	8	8
9	1,9	1,5	0,9	5	3	4	9	19	60	18	9	9
0	2,0	1,0	1,3	6	4	2	0	20	25	20	0	10

Table 2 – Initial data for task 2

Initial number cipher's	ℓ, m	h, m	a, m	α°	Second number cipher's	F, kN	Third number cipher's	Number scheme
1	1,1	3	2	30	1	60	1	1
2	1,2	2	3	30	2	40	2	2
3	1,3	3	4	45	3	120	3	3
4	1,4	1	1	30	4	80	4	4
5	1,5	3	5	45	5	60	5	5
6	1,6	2	2	45	6	40	6	6
7	1,7	3	3	45	7	120	7	7
8	1,8	2	4	30	8	80	8	8
9	1,9	3	1	45	9	90	9	9
0	2,0	1	5	30	0	40	0	10

Table 3 – Initial data for task 3

Initial number cipher's	a, m	b, m	c, m	ℓ, m	Second number cipher's	F, kN	M, kN·m	q, kN/m	Third number cipher's	Number scheme
1	1,1	2,5	2,0	6,5	1	11	25	10	1	1
2	1,2	1,5	2,5	7,5	2	12	20	15	2	2
3	1,3	2,0	1,5	8,0	3	13	30	20	3	3
4	1,4	3,5	1,0	9,5	4	14	10	25	4	4
5	1,5	1,5	1,5	7,5	5	15	25	30	5	5
6	1,6	3,0	1,5	8,5	6	16	20	10	6	6
7	1,7	4,0	2,0	9,5	7	17	70	15	7	7
8	1,8	1,0	1,0	6,0	8	18	25	20	8	8
9	1,9	2,0	1,0	7,0	9	19	65	25	9	9
0	2,0	4,5	2,0	9,0	0	20	25	30	0	10

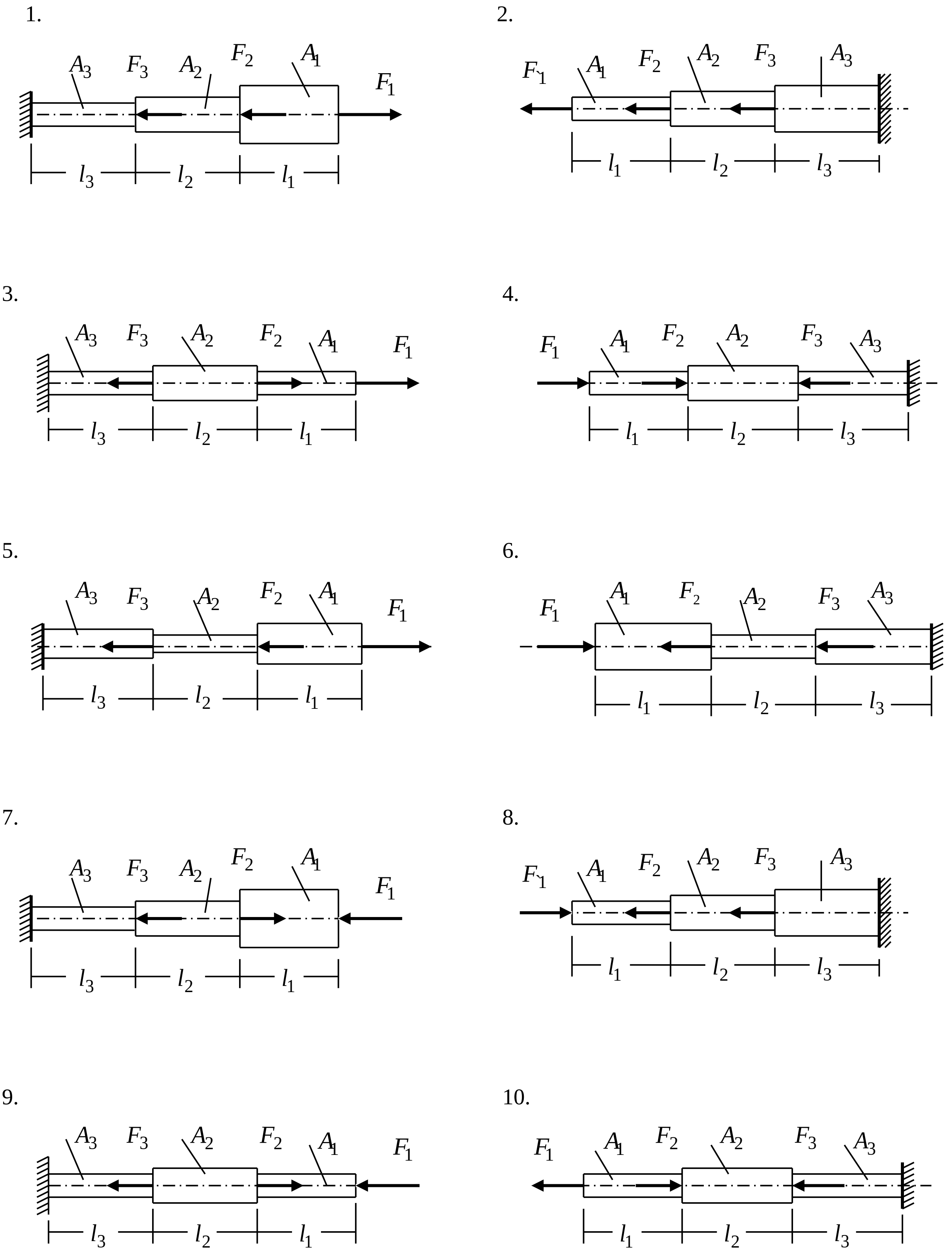


Figure 1 – Scheme for task 1

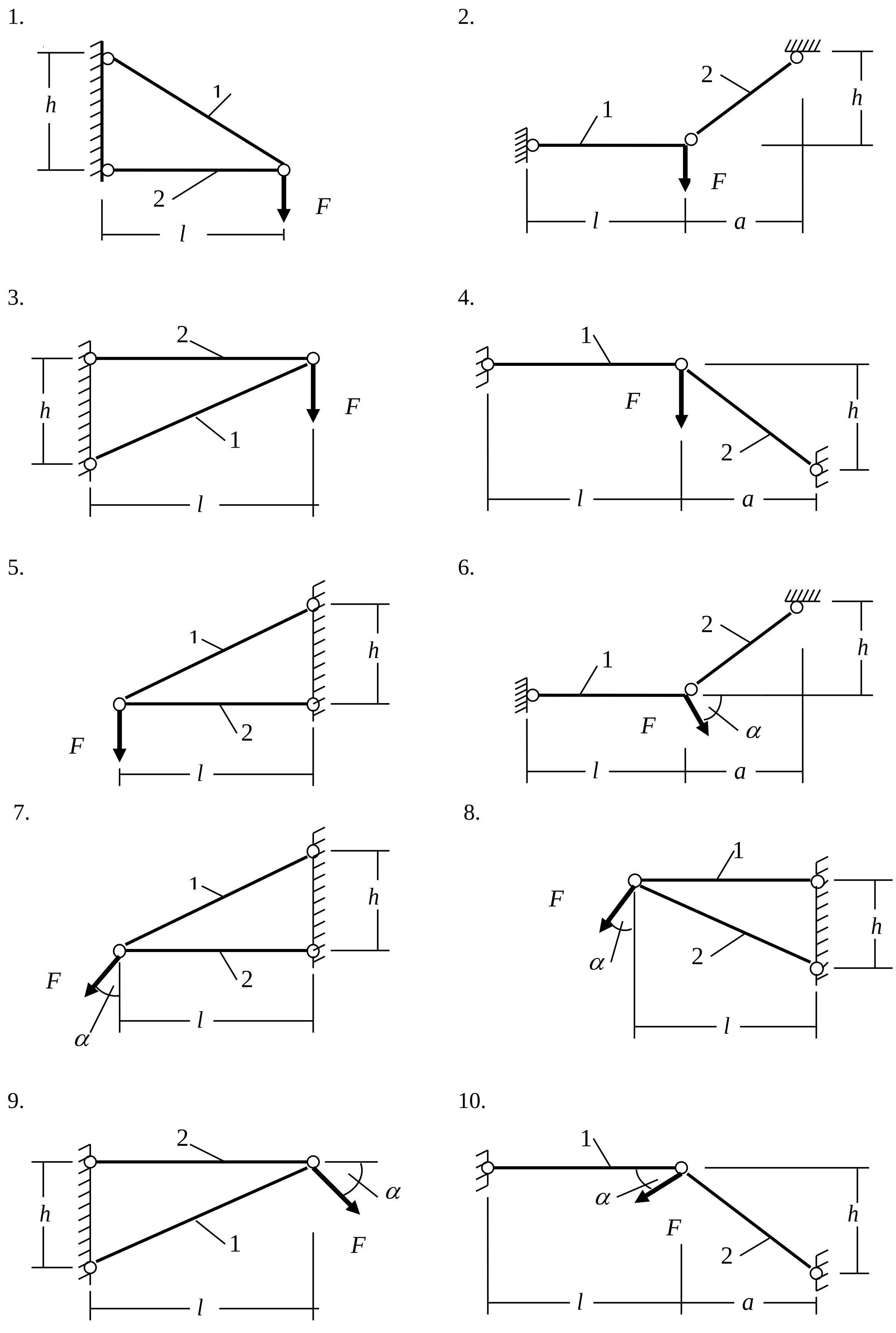


Figure 2 – Scheme for task 2

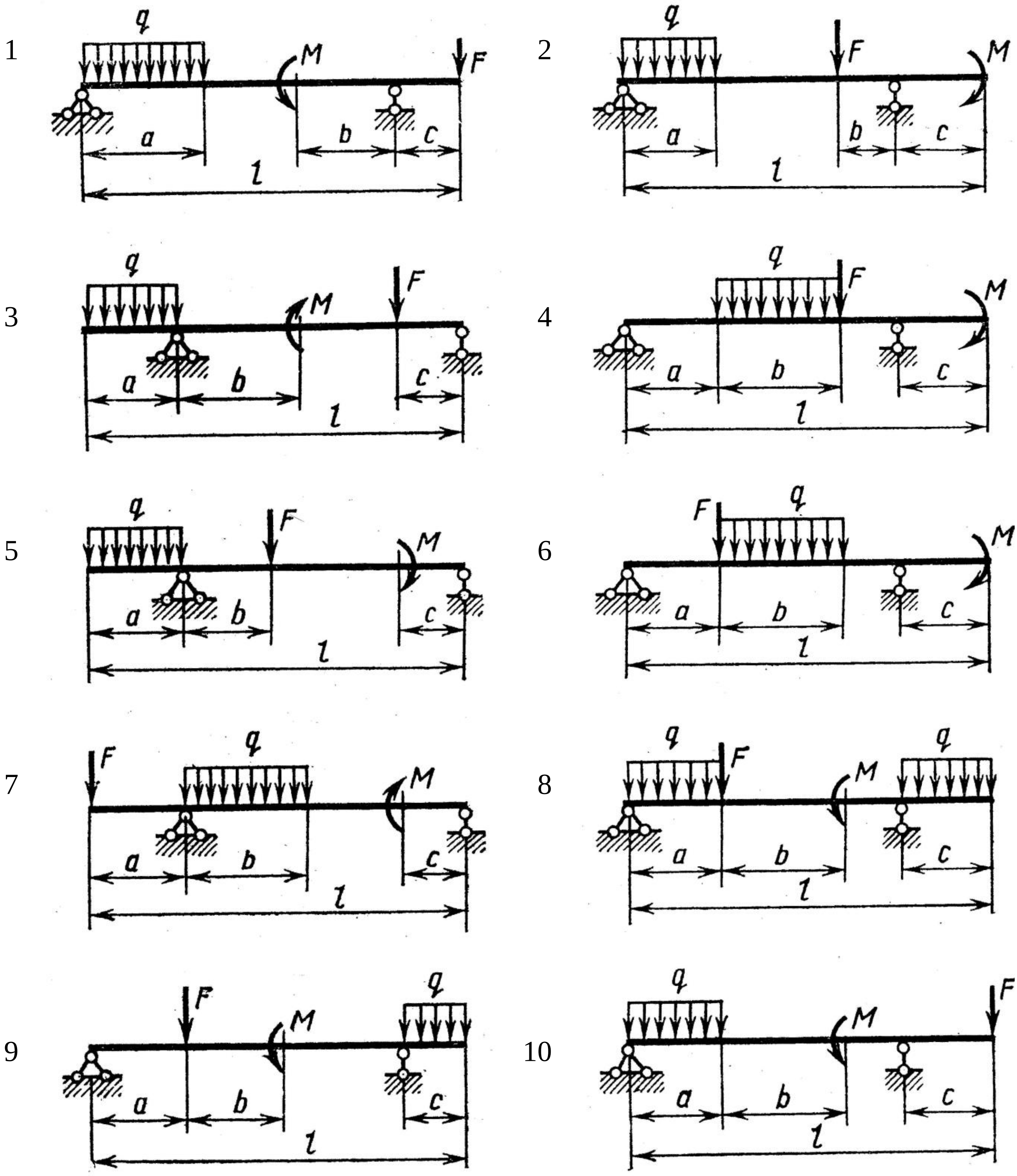


Figure 3 – Scheme for task 3

3 EXAMPLES OF CALCULATIONS

Problem № 1

Output data.

Plot a plot of normal stresses, determine the elongation of the rod, check the strength of the rod, which is shown in Figure 4, and if $F_I = 40кН$; $F_{II} = 20кН$; $F_{III} = 70кН$; $l_I = 1,0\ м$; $l_{II} = 0,8м$; $l_{III} = 0,8м$; $A_{II} = 3см^2$; $A_{III} = 4см^2$; $[\sigma] = 140МПа$.

Solution.

We divide the rod into sections, starting from its free end. We apply the cross section method and determine the longitudinal forces N in the cross sections in each section:

$$N_I = -F_1 = -40кНl;\ N_{II} = N_{III} = -F_1 + F_2 = -20кН;$$
$$N_{IY} = -F_1 + F_2 + F_3 = 50кН.$$

Plotting normal stresses. Values of normal stresses on each section of the rod:

$$\sigma_I = \frac{N_I}{A_1} = \frac{-40}{5} = -8кН / см^2;$$

$$\sigma_{II} = \frac{N_{II}}{A_2} = \frac{-20}{3} - 6,67кН / см^2;$$

$$\sigma_{III} = \frac{N_{III}}{A^3} = \frac{-20}{4} = -5кН / см^2;$$

$$\sigma_{IV} = \frac{N_{IV}}{A_3} = \frac{50}{4} = 12,5кН / см^2.$$

To check the strength of the rod, we compare the highest normal stresses with the permissible normal stresses ([σ]):

$$\sigma_{max} = \sigma_{IV} = 12,5\frac{кН}{см^2} < [\sigma] = 14\frac{кН}{см^2}.$$

The strength condition is met-the rod is strong.

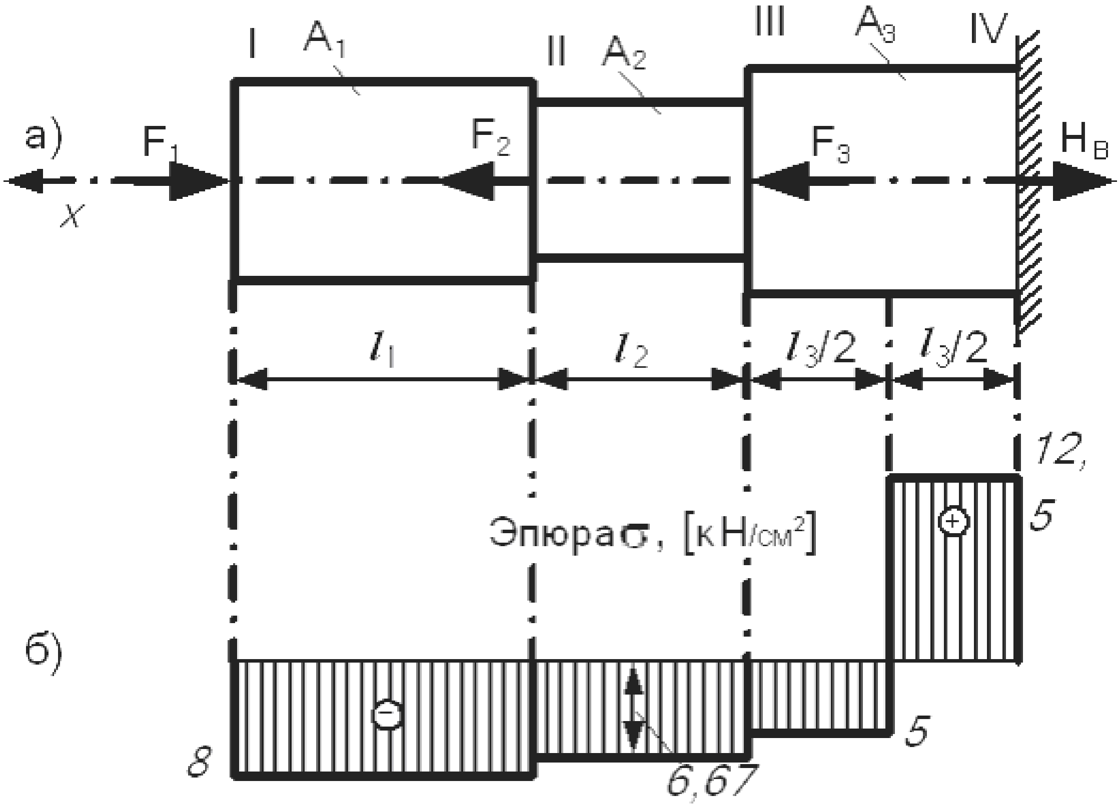


Figure 4 –Problem 1

Problem № 2

Output data.

For a system of two pivotally connected rods loaded, as shown in Figure 5, determine the forces in the rods and their elongation. From the strength conditions, select the cross-sections of the rods, if $E = 1{,}8 \cdot 10^5 \text{МПа}$, $[\sigma] = 140\text{МПа}$, $F = 75\text{кН}$, $l = 3\text{м}$, $a = 2\text{м}$, $h = 1{,}5\text{м}$.

Solution.

Cut out Node a (fig. 5) and make up two equilibrium equations:

$$\Sigma F_x=0;\quad N_2 \sin\alpha - N_1 = 0,\ \Sigma F_y=0;\quad N_2 \cos\alpha - F = 0.$$

From here $N_2 = \dfrac{F}{\cos\alpha}$; $\quad N_1 = N_2\, \sin\alpha = \dfrac{F \sin\alpha}{\cos\alpha}$.

The values of trigonometric functions are determined by the rod connection scheme:

$$sin\ \alpha = \frac{a}{l_2} = \frac{2}{2,5} = 0,8;\ cos\ \alpha = \frac{h}{l_2} = \frac{1,5}{2,5} = 0,6;$$

where $l_2 = \sqrt{a^2 + h^2} = \sqrt{2^2 + 1,5^2} = 2,5м$ – rod length 2.

Then $N_2 = \frac{75}{0,6} = 125кН$, $N_1 = \frac{75 \cdot 0,8}{0,6} = 100кН$.

Positive values of forces N_1 and N_2 indicate that rods 1 and 2 stretch.

From the strength conditions, we determine the required cross-sectional area for each rod:

$$A_1 = \frac{N_1}{[\sigma]} = \frac{100}{14} = 7,14см^2;\ A_2 = \frac{N_2}{[\sigma]} = \frac{125}{14} = 8,93см^2.$$

Recall that $[\sigma] = 140МПа = 14кН/см^2$.

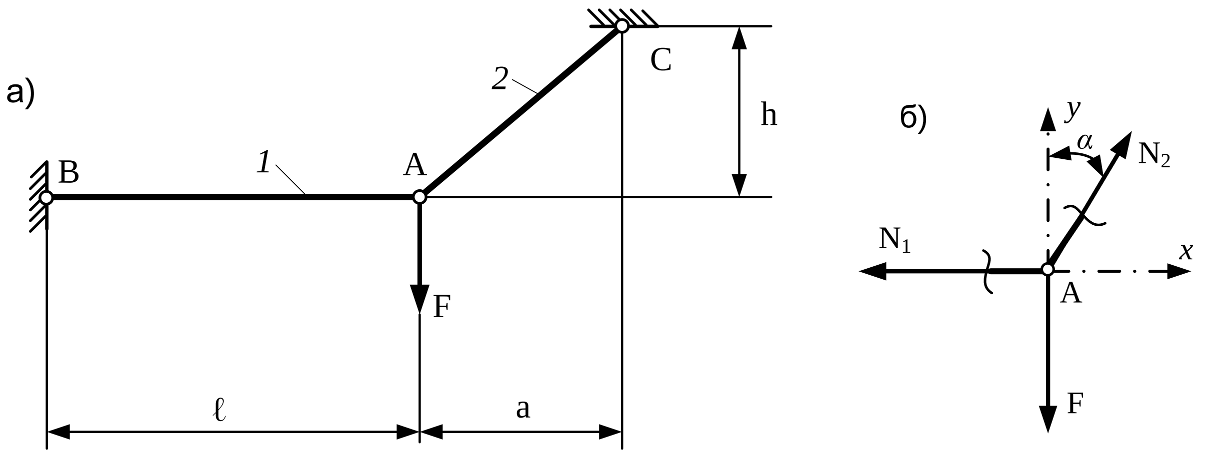


Figure 5 – Problem 2

Problem № 3

Output data.

For the simple beam shown in Figure 6: to determine constrained reactions and to draw a diagram ***Q*** and ***M***, and choose the cross-section shape.

Solution:

1. We write equations of equilibrium for determination reactions of constrain:

$$\sum F_x = 0 \;\Rightarrow\; H_A = 0$$

$$\sum M_A = 0;\;\; F \cdot 3{,}0 - q \cdot 5{,}0 \cdot 2{,}5 - M + R_B \cdot 5{,}0 = 0,$$

$$\sum M_B = 0;\;\; F \cdot 8{,}0 - R_A \cdot 5{,}0 + q \cdot 5{,}0 \cdot 2{,}5 - M = 0,$$

$$R_A = \frac{20 \cdot 8{,}0 + 20 \cdot 5{,}0 \cdot 2{,}5 - 30}{5{,}0} = 76\ kN,$$

$$R_B = \frac{-20 \cdot 3{,}0 + 20 \cdot 5{,}0 \cdot 2{,}5 + 30}{5{,}0} = 44\ Kn.$$

It is necessary to change reactions direction to the opposite if they get the negative sign and then to consider it as positive.

Checking:

$$\sum F_y = -F + R_A - q \cdot 0{,}5 + R_B = -20 + 76 - 20 \cdot 0{,}5 + 44 = 0$$

e. i., the constrained reactions are determine correctly.

2. To determine the internal force factors ***Q*** and ***M*** we divide the beam into three sections and consider the sections 1-1, 2-2, 3-3. Reject the right side of the beam for sections 1-1 and 2-2 (left – for section 3-3) and consider the equilibrium of the left (right) part of these beams.

Section 1-1 (segment 1) $0 \le x_1 \le 3{,}0\ m$

Condition of equilibrium for left side of beam:

$\sum F_y = 0; \quad Q_1 = -F = -20\ kN.$

From this solution, we can conclude that the shear force in this segment is constant, so its graphic line will be a straight line parallel to the ***z***-axis.

Bending moment in the first section equals the sum moment of left forces about to section 1-1:

$$M_1 = -F \cdot x_1$$

$$\text{if } x_1 = 0 \qquad M_1 = 0,$$

$$x_1 = 3\ m \quad M_1 = -20 \cdot 3{,}0 = -60\ kNm.$$

From the given equality, it follows that the moments change according to the linear law.

Section 2-2 (segment 2) $3{,}0 \leq x_2 \leq 8{,}0\ m$

Shear forces ***Q*** are described equation in this segment

$$Q_2 = -F + R_A - q(x_2 - 3{,}0)$$

and varies according to the linear law:

if $x_2 = 3{,}0\ m$ $\qquad Q_2 = -F + R_A = -20 + 76 = 56\ \ kN,$

$x_2 = 8{,}0\ m$ $\qquad Q_2 = -F + R_A - q \cdot 5{,}0 = -20 + 76 - 20 \cdot 5{,}0 = -44\ \ kN.$

Bending moment ***M*** about section 2-2 determine by

$$M_2 = -F \cdot x_2 + R_A(x_2 - 3{,}0) - q\frac{(x_2 - 3{,}0)^2}{2}$$

and varies according to the square parabola law:

if $x_2 = 3{,}0\ m$ $\qquad M_2 = -F \cdot 3{,}0 = -20 \cdot 3{,}0 = -60\ \ kNm,$

$x_2 = 8{,}0\ m$ $\qquad M_2 = -F \cdot 8 + R_A \cdot 5 - q\frac{5^2}{2} = -20 \cdot 8 + 76 \cdot 5 - 20\frac{5^2}{2} = -30\ \ kNm.$

*M*aximum bending moment M is in the section, in which s*hear force* $\boldsymbol{Q_2} = 0$:

$$Q_2 = -F + R_A - q(x_2 - 3{,}0) = -20 + 76 - 20(x_2 - 3{,}0) = 0$$

We receive $x_2 = 5{,}8\ m$.

The maximum bending moment ***M*** is in the section at a distance of 5.8 m from the left end of the beam and

$$M_{2max} = -F \cdot 5{,}8 + R_A(5{,}8 - 3{,}0) - q\frac{(5{,}8 - 3{,}0)^2}{2} =$$

$$= -20 \cdot 5{,}8 + 76 \cdot 2{,}8 - 20\frac{2{,}8^2}{2} = 18{,}4\ \ kNm.$$

Section 3-3 (segment 3) $0 \leq x_3 \leq 1{,}0\ m$

$$Q_3 = 0.$$

$$M_3 = -M = -30\ kNm.$$

The bending moment on this section is *constant* and has a *negative* sign (causing the stretching of the upper fibers of the beam).

Based on the got values of ***Q*** and ***M*** on the boundaries of the sections, we draw the diagrams.

3. The cross-section of the beam is designated by the *maximum* modulus value of the bending moment, which is equal to 60 kN m.

Steel beam of *I-beam* shape. Considering [σ] = 160 MPa. Determine

$$W_x = \frac{M_{max}}{[\sigma]} = \frac{60 \cdot 10^2}{16} = 375 \text{ cm}^3.$$

According to *Assortment* ДСТУ 8239-89 take I-27a (Appendices A) $W_z = 407$ cm^3.

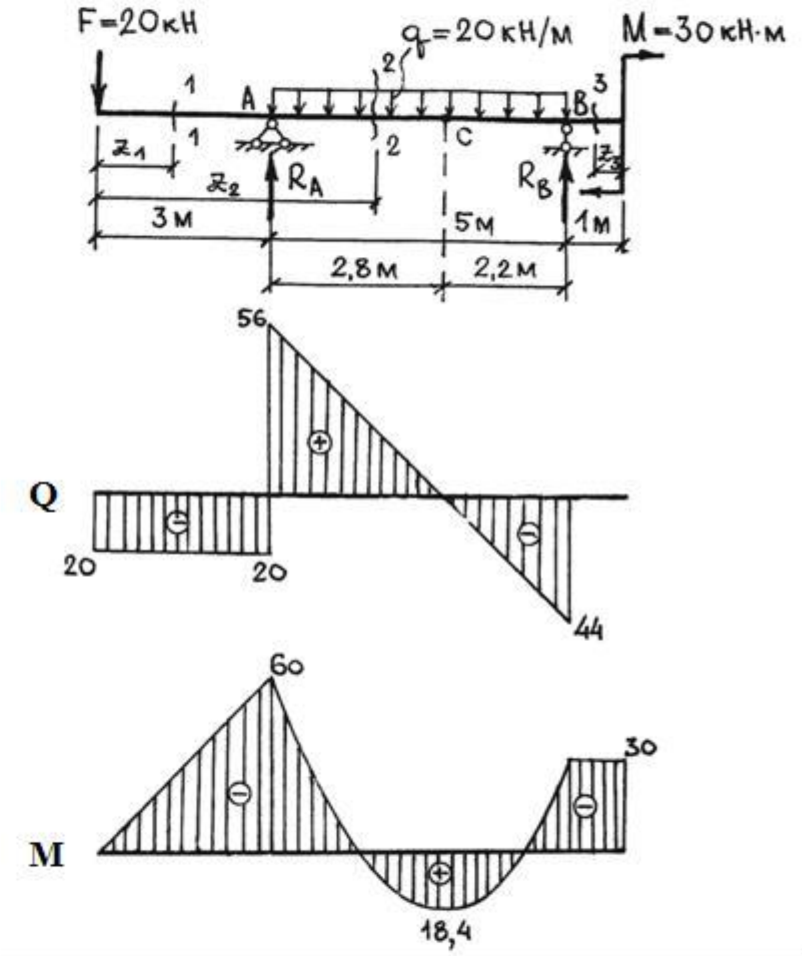


Figure 6 – Diagrams Q and M for beam Problem 3

4 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.

REFERENCES

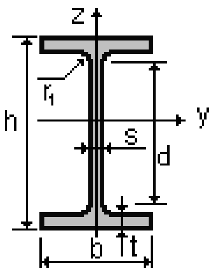
1. Methodological Guidelines for practical classes, independent and calculator-graphical works on the Subject «Mechanics of Materials» (Tension – Compression) (for the second year full-time Bachelor degree students of the specialty 192 – Construction and civil engineering) [Electronic resource] / O. M. Beкеtov National University of Urban Economy in Kharkiv ; comp. : N. V. Sereda, A. O. Garbuz, T. A. Suprun. – Electronic text data. – Kharkiv : O. M. Beketov NUUE, 2018. – 24 p. – Regime of access: https://eprints.kname.edu.ua/50048/, free (date of the application: 07.09.2023). – Header from the screen.

2. Methodological Guidelines for practical classes, independent and calculator-graphical works on the Subject «Mechanics of Materials» (Bending calculation. Drawing the diagrams) (for the second year full-time Bachelor degree students of the specialty 192 – Construction and civil engineering) [Electronic resource] / O. M. Beketov National University of Urban Economy in Kharkiv ; comp. : N. V. Sereda, A. O. Garbuz, T. A. Suprun. – Electronic text data. – Kharkiv : O. M. Beketov NUUE, 2019. – 30 p. – Regime of access: https://eprints.kname.edu.ua/52671/, free (date of the application: 07.09.2023). – Header from the screen.

3. Methodological Guidelines for practical classes, self-dependent and calculator-graphical works on the Subject «Strength of Materials» (Calculation of statically indeterminate frame by force method) (for the second year full-time students of the specialty 192 – Construction and civil engineering) [Electronic resource] / O. M. Beкеtov National University of Urban Economy in Kharkiv ; comp. : N. V. Sereda, A. O. Garbuz, O. O. Chuprynin, T. A. Suprun. – Electronic text data. – Kharkiv : O. M. Beketov NUUE, 2020. – 24 p. – Regime of access: https://eprints.kname.edu.ua/56460/, free (date of the application: 07.09.2023). – Header from the screen.

APPLICATION A

I-beam section



Number	h	b	s	t	r_1	r_2	A	P	I_y	W_y	i_y	S_y
	см	см	см	см	см	см	см^2	Т/м	см^4	**см^3**	см	см^3
10	10,0	5,5	0,450	0,720	0,700	0,250	12,0	0,009	198,0	**39,700**	4,060	23,000
12	12,0	6,4	0,480	0,730	0,750	0,300	14,7	0,012	350,0	**58,400**	4,880	33,700
14	14,0	7,3	0,490	0,750	0,800	0,300	17,4	0,014	572,0	**81,700**	5,730	46,800
16	16,0	8,1	0,500	0,780	0,850	0,350	20,2	0,016	873,0	**109,000**	6,570	62,300
18	18,0	9,0	0,510	0,810	0,900	0,350	23,4	0,018	1 290	**143,000**	7,420	81,400
20	20,0	10,0	0,520	0,840	0,950	0,400	26,8	0,021	1 840	**184,000**	8,280	104,000
22	22,0	11,0	0,540	0,870	1,000	0,400	30,6	0,024	2 550	**232,000**	9,130	131,000
24	24,0	11,5	0,560	0,950	1,050	0,400	34,8	0,027	3 460	**289,000**	9,970	163,000
27	27,0	12,5	0,600	0,980	1,100	0,450	40,2	0,032	5 010	**371,000**	11,200	210,000
30	30,0	13,5	0,650	1,020	1,200	0,500	46,5	0,037	7 080	**472,000**	12,300	268,000
33	33,0	14,0	0,700	1,120	1,300	0,500	53,8	0,042	9 840	**597,000**	13,500	339,000
36	36,0	14,5	0,750	1,230	1,400	0,600	61,9	0,049	13 380	**743,000**	14,700	423,000
40	40,0	15,5	0,830	1,300	1,500	0,600	72,600	0,057	19 062	**953,000**	16,200	545,000
45	45,0	16,0	0,900	1,420	1,600	0,700	84,700	0,067	27 696	**1 231,0**	18,100	708,000
50	50,0	17,0	1,000	1,520	1,700	0,700	100,00	0,078	39 727	**1 589,0**	19,900	919,000
55	55,0	18,0	1,100	1,650	1,800	0,700	118,00	0,093	55 962	**2 035,0**	21,800	1 181,0
60	60,0	19,0	1,200	1,780	2,000	0,800	138,00	0,108	76 806	**2 560,0**	23,600	1 491,0

Електронне навчальне видання

Методичні рекомендації
для підготовки до лекцій і практичних занять, виконання контрольних завдань і самостійної роботи
з навчальної дисципліни

«ОПІР МАТЕРІАЛІВ. БУДІВЕЛЬНА МЕХАНІКА»

*(для здобувачів 2 курсу денної форми навчання
зі спеціальності 191 – Архітектура та містобудування)*

(Англ. мовою)

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