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"

(BENDING CALCULATION. DRAWING the DIAGRAMS)

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

Kharkiv
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2019

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) / 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, 2019. – 30 p.

Compiler : N. V. Sereda,
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Recommended by the Department of Theoretical and Structural Mechanics, record № 6 of 29.01.2019.

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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.

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 BASIC INFORMATION OF THE TEORY

Cantilevered beam is fixed at one end and free at the other. The shear and moment diagrams provide detailed information about the *variation* of the shear and moment along the beam's axis.

Beam Sign Convention

The *positive directions* are as follows: the *distributed load* acts *upward* on the beam, the internal *shear force* causes a *clockwise* rotation of the beam segment on which it acts.

the internal *moment* causes *compression* in the *top fibers* of the segment such that it bends the segment so that it "holds water". Loadings that are opposite to these are considered negative.

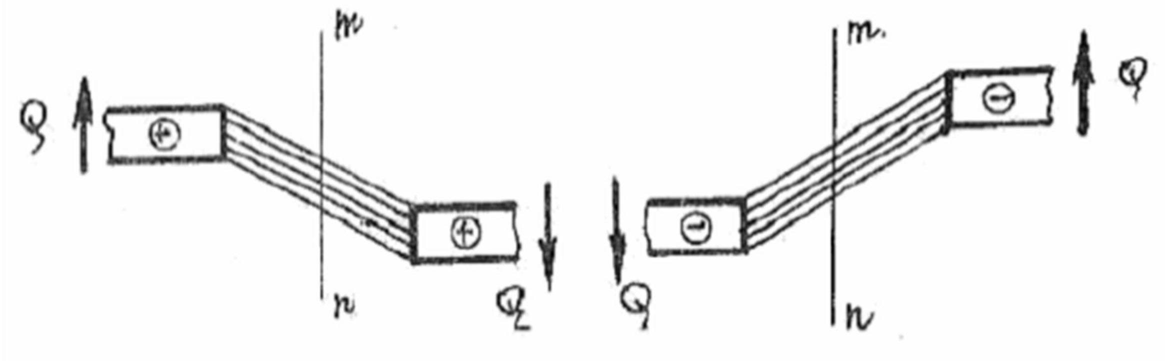

Figure 1 – *The sign conventions of Shear Forces Q*

The **sign conventions** for these loads are as follows: *Distributed loads and concentrated loads are positive when they act downward on the beam and negative when they act upward*.

A couple acting as a load on a beam is positive when it is counterclockwise and negative when it is clockwise. If other sign conventions are used, changes may occur in the signs of the terms appearing in the equations derived in this section.

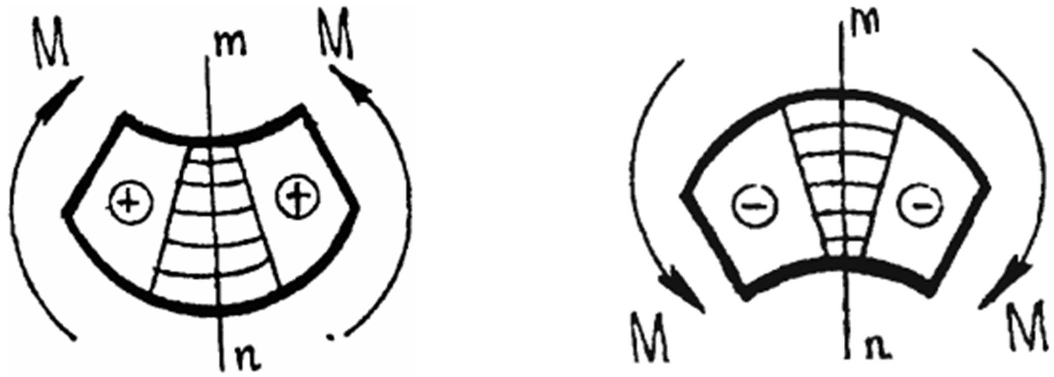

Figure 2 – *The sign conventions of Bending Moments M*

Diagrams of bending moments M draw on the side of the *stretched* fibers (*positive* values lay *down* the axis of diagrams, *negative - up*).

Ordinates diagrams Q and M are put perpendicular to the baseline.

The bending moments are zero on the hinges; the maximal and minimum values in the diagram of M correspond to the change of signs in the diagram of Q.

In constructing diagrams should be remembered that the *abrupt* Q diagrams occur where concentrated forces applied (including reaction), and the diagram M - concentrated in places of application of external moments.

3 EXAMPLES OF CALCULATIONS

Problem 1. *Cantilever beam*

Output data:

To draw a diagram of the internal forces and bending moments for the cantilever beam shown in Figure 3, and to determine the maximum values of the internal forces acting in the beam, if $F = 50\ kN$, $q = 40\ kN/m$, $M = 60\ kNm$, distances $a = 2\ m$, $b = 1\ m$, $c = 3\ m$. Choose the cross-section shape.

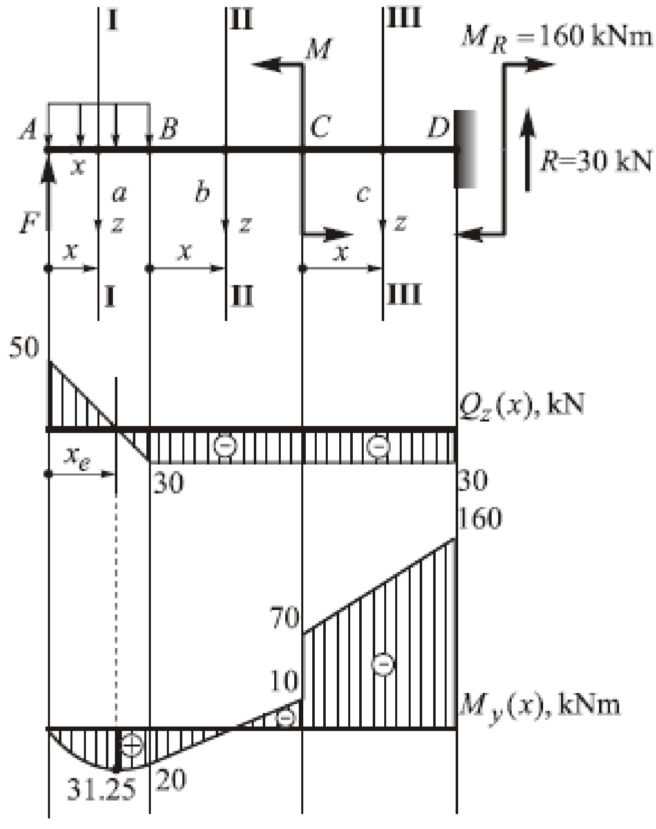

Figure 3

Solution:

We can start to draw diagrams without determination reactions of support for cantilever beam.

Equations of internal forces in an arbitrary cross-sections of the portions:

Section 1-1 (segment 1) $0 \le x_1 \le 2{,}0\ m$

Condition of equilibrium for left side of beam:

$\sum F_y = 0;\quad Q_1 = F - qx$

if $x_1 = 0 \quad Q_1 = 50 \quad kN,$
$x_1 = 2\,m \quad Q_1 = F - q \cdot 2 = 50 - 40 \cdot 2 = -30 \;kN$
$\sum M_1 = 0; \qquad M_1 = F \cdot x_1 - q\dfrac{x_1^2}{2}$
$x_1 = 0 \qquad M_1 = 0 \quad kNm,$
$x_1 = 2\,m \quad M_1 = 50 \cdot 2 - 40\frac{2^2}{2} = 20 \; kNm.$

Determine M_{max} :

$$Q_1 = \frac{dM}{dx} = F - qx_e = 0 \quad \rightarrow \quad x_e = \frac{F}{q} = \frac{50}{40} = 1{,}25\,m,$$

$$M_1(x_e = 1{,}25) = F \cdot 1{,}25 - q\frac{1{,}25^2}{2} = 50 \cdot 1{,}25 - 40\frac{1{,}25^2}{2} = 62{,}5 - 31{,}25 = 31{,}25 \; kNm.$$

Section II-II (segment 2) $0 \le x_2 \le 1{,}0\,m$
$Q_2 = F - q \cdot 2 = -30 \; kN$
$M_2 = F \cdot (2 + x_2) - q2(\frac{2}{2} + x_2)$
$x_2 = 0 \qquad M_2 = 50 \cdot 2 - 40\frac{2^2}{2} = 20 \quad kNm,$
$x_2 = 1\,m \quad M_2 = 50 \cdot 3 - 40 \cdot 2\left(\frac{2}{2} + 1\right) = 150 - 160 = -10 \; kNm.$

Section III-III (segment 3) $0 \le x_3 \le 3{,}0\,m$
$Q_3 = F - q \cdot 2 = -30 \; kN$
$M_3 = F \cdot (a + b + x_3) - q \cdot a\left(\frac{a}{2} + b + x_3\right) - M$
$x_3 = 0 \qquad M_3 = 50 \cdot 3 - 40 \cdot 2\left(\frac{2}{2} + 1\right) - 60 = 150 - 160 - 60 = -70 \; kNm,$
$x_3 = 1\,m \quad M_3 = 50 \cdot 6 - 40 \cdot 2\left(\frac{2}{2} + 1 + 3\right) - 60 = 300 - 400 - 60 = -160$

The cross-section of the beam is designated by the *maximum* value of the bending moment, which is equal to 160 *kN m*.

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

$$W_x = \frac{M_{\max}}{[\sigma_{allow}]} = \frac{160 \cdot 10^2}{16} = 1000 \; cm^3$$

According to *Assortment* ДСТУ 8239-89 take I-45 (Appendices 2) $W_x = 1231$ cm^3.

Problem 2. *Simple beam.*

Output data:

For the simple beam shown in Figure 4: 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:

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

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:

$$M_1 = -F \cdot x_1$$

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) $3{,}0 \le x_2 \le 8{,}0\ m$

*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 kNm,

x_2=8,0 m — — kNm.

*M*aximum bending moment M is in the section, in which s*hear force* Q_2 = 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

— kNm.

Section 3-3 (segment 3)

.

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.

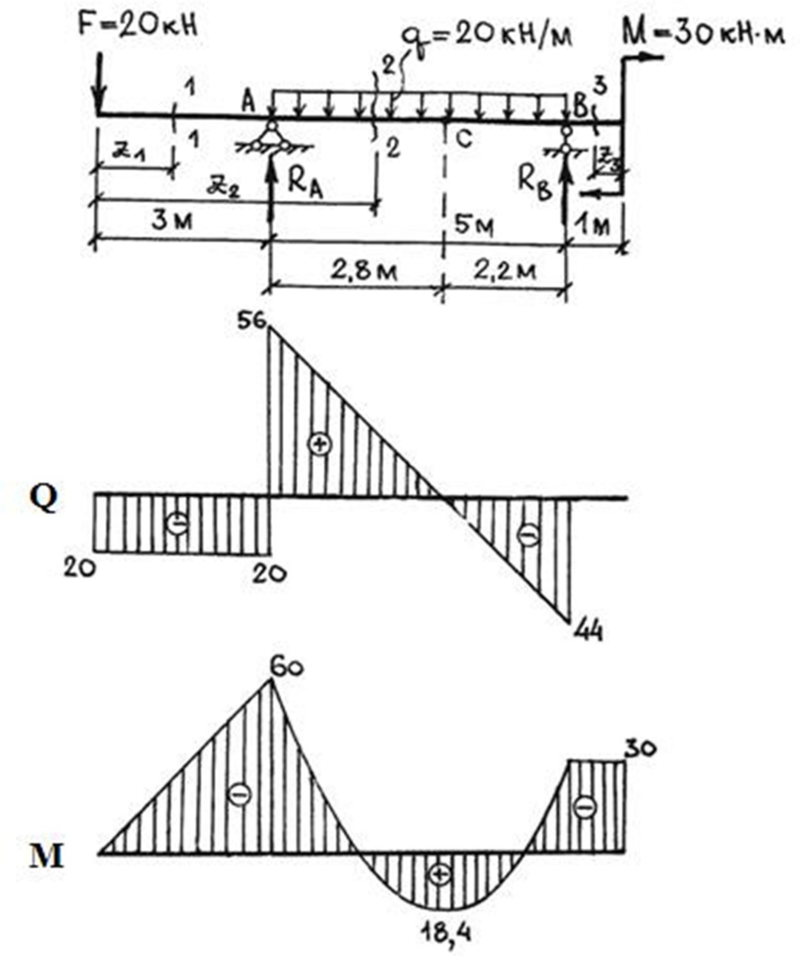

Figure 4 – Diagrams Q and M for beam Problem 2

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 2) W_z=*407* cm^3.

Wooden beam of rectangular section. Considering [σ] = 10 *MPa*, and h = 2b, we determine

$$W_x = \frac{M_{max}}{[\sigma]} = \frac{60}{10 \cdot 10^3} = 6 \cdot 10^3 \text{ cm}^3.$$

Section modulus of rectangular section

$$\frac{h}{2} = b, \qquad W_z = \frac{bh^2}{6} = \frac{h \cdot h^2}{2 \cdot 6} = \frac{h^3}{12}$$

So $$\frac{h^3}{12} \geq \frac{M_{max}}{[\sigma]} \rightarrow \quad h \geq \sqrt[3]{\frac{12 \cdot M_{max}}{[\sigma]}}, \quad \text{h} = 41{,}6 \; cm.$$

Wooden beam of circular section. Considering [σ] = 10 *MPa*.

Section modulus of circular section

$$W_z = \frac{\pi d^3}{32}, \quad \text{so} \; \frac{\pi d^3}{32} \geq 6 \cdot 10^3 \text{ cm}^3 \; \rightarrow \quad d \geq \sqrt[3]{\frac{32 \cdot M_{max}}{\pi \cdot [\sigma]}} = \sqrt[3]{\frac{32 \cdot 6 \cdot 10^3}{3{,}14}} = 39{,}4 \text{ cm}.$$

Problem 3. *Frame***.**

Output data:

For the frame shown in Figure 5 to determine constrained reactions and to draw a diagram ***Q*** and ***M***, and longitudinal forces ***N***.

Solution: We determine the support reactions using the equations static equilibrium:

$$\sum F_x = 0 \; \Rightarrow \; q \cdot 2{,}0 - F - H_B = 0.$$

$$H_B = 20 \cdot 2{,}0 - 10 = 30 \; kN$$

$$\sum M_A = 0; \; -q \cdot 2{,}0 \cdot 1{,}0 - M + R_B \cdot 3{,}0 - H_B \cdot 2{,}0 = 0,$$

$$R_B = \frac{q \cdot 2{,}0 \cdot 1{,}0 + M + H_B \cdot 2{,}0}{3{,}0} = \frac{20 \cdot 2{,}0 \cdot 1{,}0 + 50 + 30 \cdot 2{,}0}{3{,}0} = 50 \; kN$$

$$\sum M_B = 0; \; -q \cdot 2{,}0 \cdot 3{,}0 - M + F \cdot 2{,}0 + R_A \cdot 3{,}0 + = 0,$$

$$R_A = \frac{q \cdot 2{,}0 \cdot 3{,}0 + M - F \cdot 2{,}0}{3{,}0} = \frac{20 \cdot 2{,}0 \cdot 3{,}0 + 50 - 10 \cdot 2{,}0}{3{,}0} = 50 \; kN.$$

The obtained value of support reactions are positive sign, i. e. their directions coincide with accepted.

Checking:

$$\sum F_y = -R_A + R_B = -50 + 50 = 0.$$

2. To determine *Q, N* and *M*, we use the section method. We cut the frame into four sections and consider the sections 1-1, 2-2, 3-3, 4-4. If one part of the frame

is discarded in each of the sections, the balance of the remaining part provided by the corresponding shear and longitudinal forces, bending moments.

For all sections, the shear force Q is determined from the equation of equilibrium forces projections on the axis, perpendicular to the corresponding bars and crossbars, longitudinal force N - from the equation of forces projections on the axis, parallel to the corresponding bars and crossbars; the bending moment M - from the equation of the sum of moments all forces acting on the left part, about the center of gravity of the sections.

Section 1-1 (segment 1)

$$Q_1 = -q \cdot z_1; \qquad N = R_A; \qquad M_1 = -\frac{q \cdot z_1^2}{2}$$

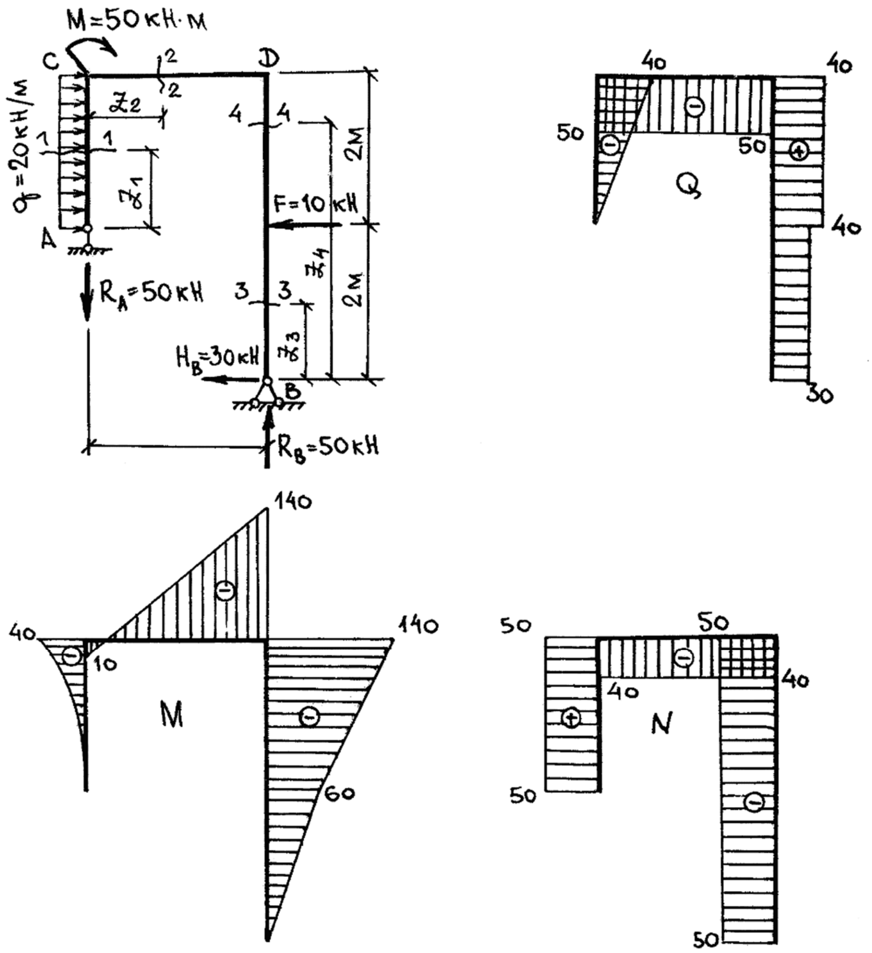

Figure 5 – Diagrams *Q, M* and *N*, considered for Problem 3

In this segment, shear force Q changes according to proportional ratio, longitudinal force N has a constant value and stretched the rod. Bending moment M changes by the square parabola law:

if $\quad z_1 = 0 \qquad Q_1 = 0; \qquad N_1 = R_A = 50\ kN; \qquad M_1 = 0;$

$\quad z_1 = 2{,}0\ m \quad Q_1 = -q \cdot 2{,}0 = -20 \cdot 2{,}0 = -40\,kN; \qquad N_1 = R_A = 50\ kN;$

$$M_1 = -\frac{q \cdot 2{,}0^2}{2} = -\frac{20 \cdot 2{,}0^2}{2} = -40 \ \ kN\,m.$$

Section 2-2 (segment 2) $0 < z_2 < 3{,}0 \ m.$

$Q_2 = -R_A; \quad N_2 = -q \cdot 2{,}0; \qquad M_2 = -R_A \cdot z_2 - q \cdot 2{,}0 \cdot 1{,}0 + M.$

In this segment, shear force Q has a constant value; longitudinal force N has a constant value too. Bending moment M changes by linear law:

if $z_2 = 0 \qquad Q_2 = -R_A = -50 \ \ kN; \qquad N_2 = -q \cdot 2{,}0 = -20 \cdot 2{,}0 = -40\,kN;$

$M_2 = -q \cdot 2{,}0 \cdot 1{,}0 + M = -20 \cdot 2{,}0 \cdot 1{,}0 + 50 = 10 \ \ kN\,m;$

$z_2 = 3{,}0\,м \quad Q_2 = -R_A = -50 \ \ kN; \qquad N_2 = -q \cdot 2{,}0 = -20 \cdot 2{,}0 = -40\,kN;$

$M_2 = -R_A \cdot 3{,}0 - q \cdot 2{,}0 \cdot 1{,}0 + M = -50 \cdot 3{,}0 - 20 \cdot 2{,}0 \cdot 1{,}0 + 50 =$

$= -140 \ kN \cdot m.$

Section 3-3 (segment 3) $0 < z_3 < 2{,}0 \ \ m.$

$$Q_3 = H_B; \quad N_3 = -R_B; \quad M_3 = -H_B \cdot z_3.$$

Shear and longitudinal forces have a constant value in this segment; bending moment M changes by linear law:

if $z_3 = 0 \qquad Q_3 = H_B = 30 \ \ kN; \ N_3 = -R_B = -50 \ \ kN; \qquad M_3 = 0;$

$z_3 = 2{,}0 \ \ m \quad Q_3 = H_B = 30 \ \ kN; \ N_3 = -R_B = -50 \ \ kN;$

$M_3 = -H_B \cdot 2{,}0 = -30 \cdot 2{,}0 = -60 \ \ kN\,m.$

Section 4-4 (segment 4) $2{,}0 \ m < z_4 < 4{,}0 \ m.$

$Q_4 = H_B + F; \qquad N_4 = -R_B; \quad M_4 = -H_B \cdot z_4 - F \cdot (z_4 - 2).$

Shear and longitudinal forces have a constant value in this segment; bending moment M changes by linear law:

if $z_4 = 2{,}0 \ \ m \qquad Q_4 = H_B + F = 30 + 10 = 40 \ \ kN; \qquad N_4 = -R_B = -50 \ \ kN;$

$M_4 = -H_B \cdot 2{,}0 = -30 \cdot 2{,}0 = -60 \ \ kN\,m;$

$z_4 = 4{,}0 \ \ m \quad Q_4 = H_B + F = 30 + 10 = 40 \ \ kN; \qquad N_4 = -R_B = -50 \ \ kN;$

$M_4 = -H_B \cdot 4{,}0 - F \cdot 2{,}0 = -30 \cdot 4{,}0 - 10 \cdot 2{,}0 = -140 \ \ kN\,m;$

We draw the diagrams Q, N and M based on the results of the calculations, taking into account the signs of the get values. The positive direction of the ordinate axis is chosen upward (i. e., outside the contour of the frame), when drawing diagrams Q, N; when constructing a M-diagram – downward, because this diagram is based on stretched fibers.

3. As can be seen from the example, the calculation of the frame is associated with large computations, which can lead to false results. Therefore, the values found and M should be checked using equations that were not used above.

The verification of the correctness of the values found, and M, is carried out under the condition of equilibrium of all joints of the frame. To do this, we need to cut the joint C and D, and apply the forces in the sections of the joints, Q, N and M with the directions corresponding to the sign convention (Fig. 6, b).

Joint C. The difference of this joint is the presence in it of an external moment $M = 50$ *kN m*. Applied it to the joint and writing three conditions of equilibrium (Fig. 6, a).

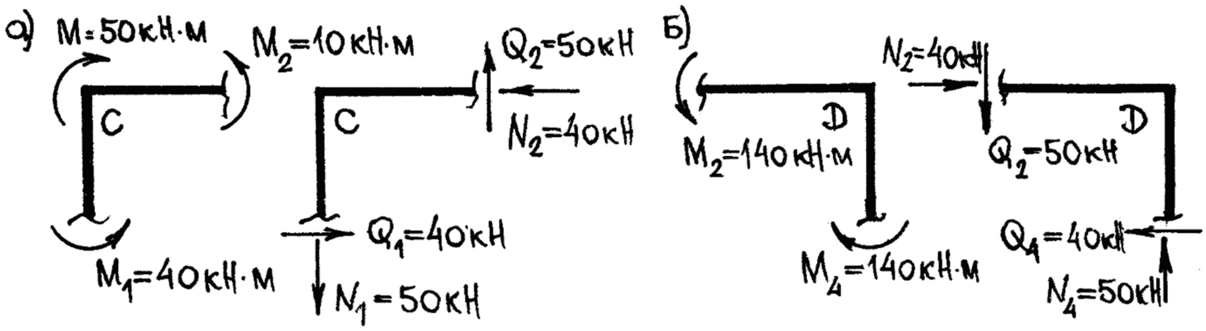

Figure 6 – Joints *C* and *D* with effort in there sections

$\Sigma M_C = M_1 + M_2 - M = 40 + 10 - 50 = 0;$

$\Sigma z = Q_1 - N_2 = 40 - 40 = 0;$

$\Sigma y = -N_1 + Q_2 = -50 + 50 = 0.$

All equations satisfy the equilibrium conditions, i. e., the joint is in equilibrium.

Joint D. Equilibrium equation for this joint *(Fig. 8, b)*:

$\Sigma M_D = M_2 - M_4 = 140 - 140 = 0;$

$\Sigma z = N_2 - Q_4 = 40 - 40 = 0;$

$\Sigma y = -Q_2 + N_4 = -50 + 50 = 0.$

The joint D is also in equilibrium.

We can conclude that the efforts Q, N and M are get correctly.

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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6. Опір матеріалів. Опір матеріалів стержневих елементів конструкцій при базових навантаженнях : (конспект лекцій з дисциплін «Опір матеріалів», «Опір матеріалів та основи будівельної механіки», «Основи теорії споруд» для студентів денної і заочної форм навчання бакалаврів за спеціальностями 192 – Будівництво та цивільна інженерія, 191 –Архітектура та містобудування, 185 – Нафтогазова інженерія та технології / В. П. Шпачук, Н. В. Середа, О. О. Чупринін, В.О. Скляров ; Харків. нац. акад. міськ. госп-ва ім. О. М. Бекетова. – Харків : ХНУМГ ім. О. М. Бекетова, 2018. – 138 с.

APPENDIX

OUTPUT DATA AND PROBLEM TO WORK

PROBLEM 1

DRAW the DIAGRAMS SEAR FORCES and BENDING MOMENTS for CANTILEVER BEAM

For a given steel beam:
1) to draw diagrams of shear forces *Q* and bending moments *M*;
2) choose its cross-section, if [σ] = 160 MPa.

Methodical instructions for Problem 1 and the procedure for performance:

1. According to the code, select the beam scheme in *Figure 7* and the output data to it from table 1.

2. Draw the calculation scheme of the beam at a certain scale; indicate all the dimensions and loads applied on it.

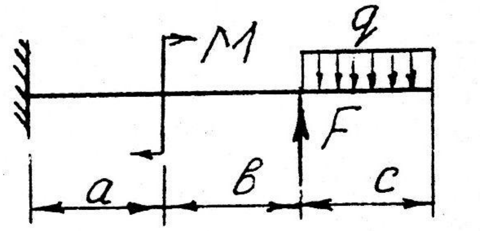
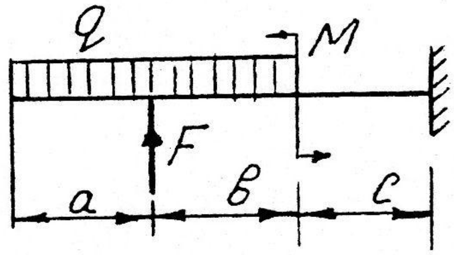
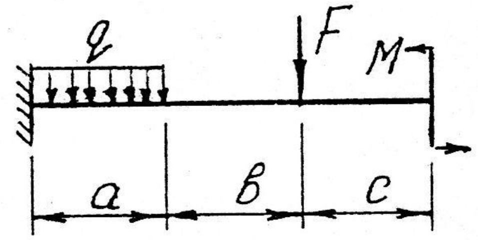
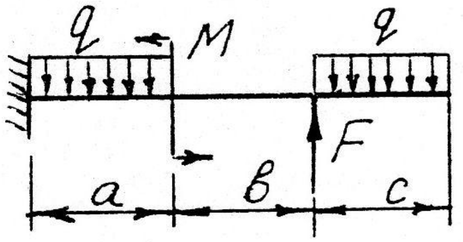
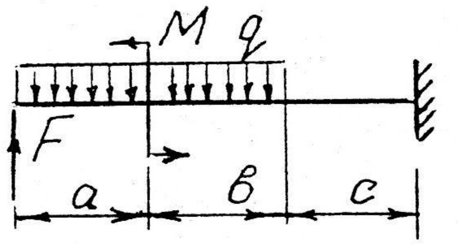
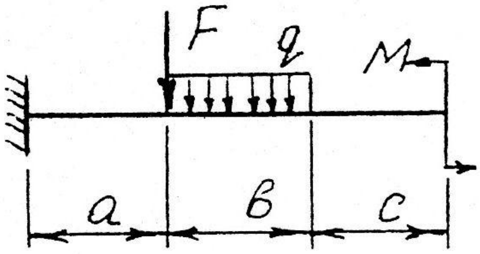
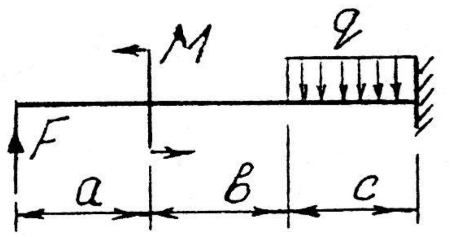
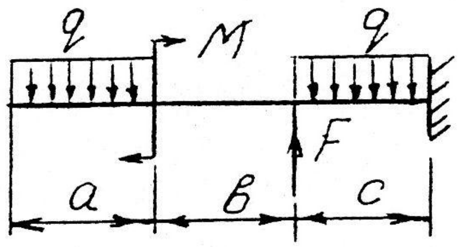
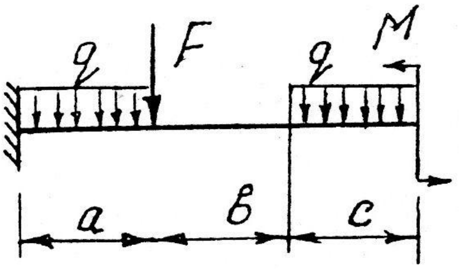
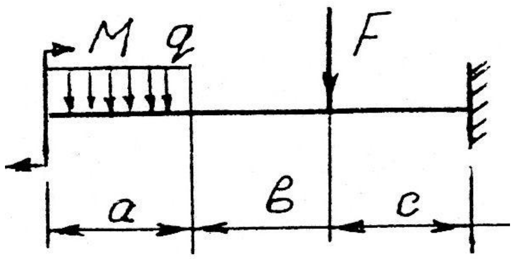
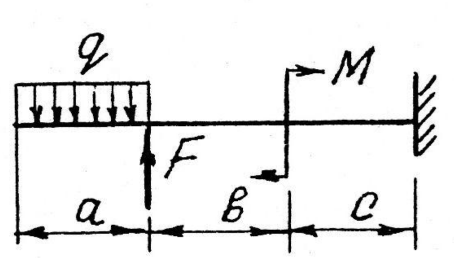
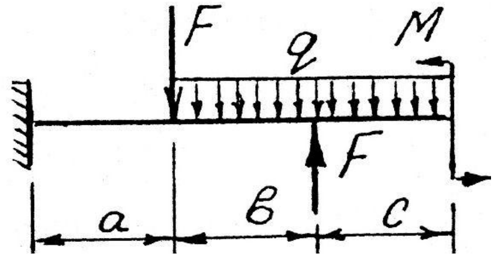
3. To draw a diagram of shear forces Q and bending moments M. Diagrams of cantilever beams can be draw without preliminary determination of constrain reactions.

4. The choice of cross-section of a ***I***-beam is carried out of the strength condition in bending (the *flexure formula*):

$$W_z \geq \frac{M_{max}}{[\sigma]},$$

where $W_z = \frac{I}{y}$ is ***section modulus.***

5. At large bending moments there are cases when it is impossible to choose a standard of ***Rolled Shapes***, because the required ***section modulus*** is greater than that in the State Standard (from *Assortment*). It is necessary to accept a beam from two standard shapes put together, and the shape number to be determined from the condition $0{,}5 \cdot W_z$ (where ***section modulus*** W_z is get by calculation).

1		**7**	
2		**8**	
3		**9**	
4		**10**	
5		**11**	
6		**12**	

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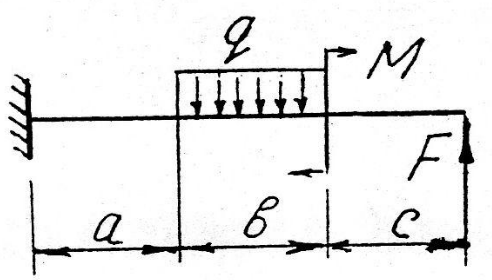

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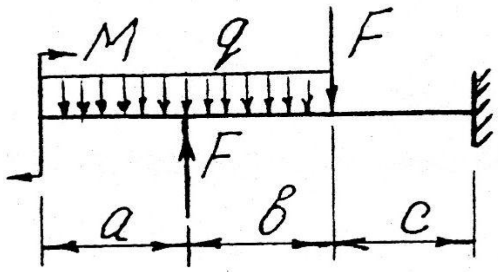

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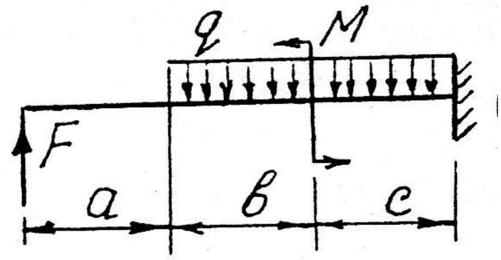

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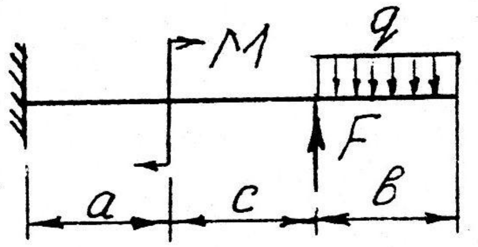

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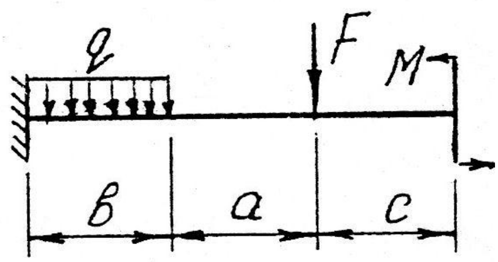

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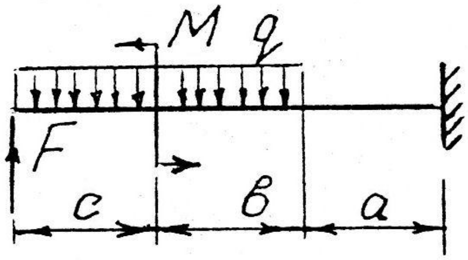

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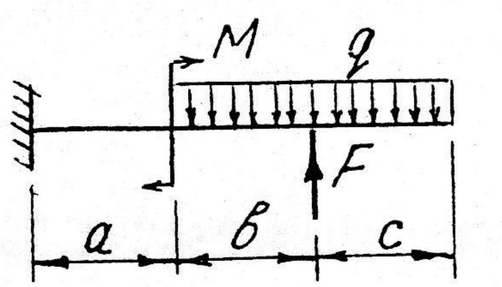

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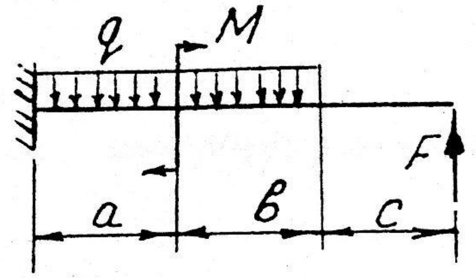

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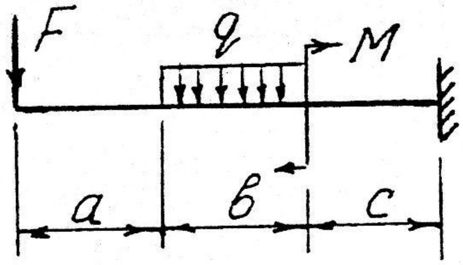

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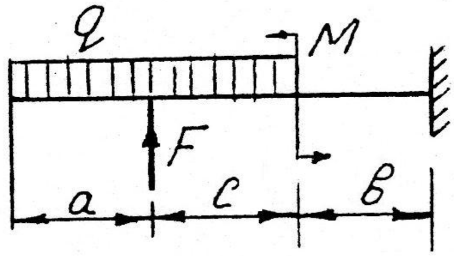

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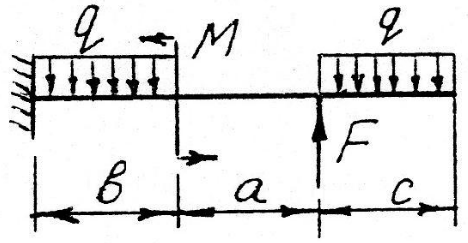

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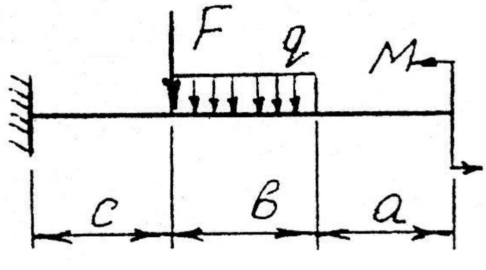


Figure 7 – Schemes to Problem 1

Table 1 – Output Data for Problem 1

№	a, m	b, m	c, m	F, кN	M, kN·m	q, кN/m
1	2,5	3,0	1,0	10	40	10
2	3,0	2,0	1,5	30	20	20
3	2,0	2,5	1,0	20	30	10
4	1,0	3,0	0,5	15	50	5
5	0,5	2,0	1,5	15	40	15
6	3,0	3,0	0,5	25	30	15
7	2,5	2,5	1,0	10	20	10
8	1,5	3,0	0,5	20	10	20
9	1,0	2,5	1,0	20	40	10
10	2,0	2,0	1,5	20	20	10
11	3,0	3,0	1,0	10	30	10
12	2,0	2,0	0,5	10	50	20
13	2,5	2,5	1,5	10	40	10
14	3,0	3,0	1,0	10	30	5
15	3,0	2,0	0,5	20	40	15
16	2,0	3,0	1,5	15	20	10
17	2,5	2,5	1,0	15	30	20
18	3,0	3,0	0,5	10	50	10
19	2,0	2,5	1,5	10	40	5
20	3,0	2,0	1,5	10	20	15
21	2,5	3,0	1,0	20	30	15
22	3,0	2,0	0,5	15	50	20
23	2,5	2,5	1,5	15	40	10
24	2,0	3,0	0,5	15	30	5

PROBLEM 2

DRAW the DIAGRAMS SEAR FORCES and BENDING MOMENTS for SIMPLE BEAM

For a given steel beam:
1) to draw diagrams of shear forces Q and bending moments M;
2) choose its cross-section, if [σ] = 160 MPa.

Methodical instructions for Problem 2 and the procedure for performance:

1. According to the code, select the beam scheme in *Figure 8* and the output data to it from *table 2*.

2. Draw the calculation scheme of the beam at a certain scale, indicate all the dimensions and loads applied on it.

3. Using static equations, determine the vertical reaction of the supports. If, in a result of the calculation, the reaction appears with a negative sign, then the direction of this reaction should be changed to the opposite. To control the correctness of the reaction definition, make an equation of equilibrium that was not used in determining the reactions.

4. To draw diagrams of shear forces Q and bending moments M. Set the limits of loading application, taking into account the location of the forces factors. For each section, write the equation $Q_i = f(z_i)$ and $M_i = f(z_i)$ by means of which determine the values of shear forces and bending moments on limits of segment. To determine the maximum value of M_{max} on the segment with distributed load to use differential dependence

$$\frac{dM}{dz} = Q.$$

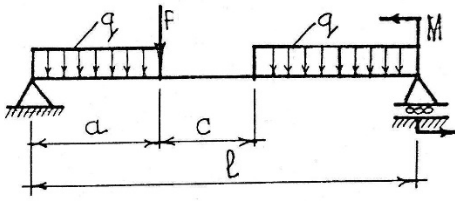
Diagrams Q and M drawn under the calculation scheme of the beam, indicate to numerical values of ordinates at the limits of the segments.

5. Based on the condition of strength from the *flexure formula*

$$W_z \geq \frac{M_{max}}{[\sigma]},$$

choose the section of the beam of ***I***-beam and round profile.

1



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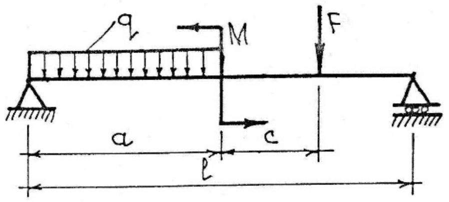

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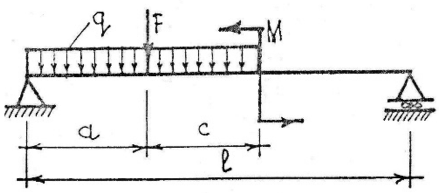

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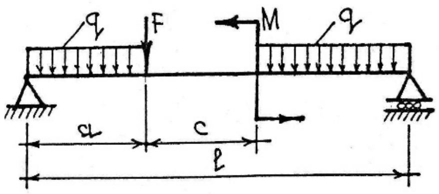

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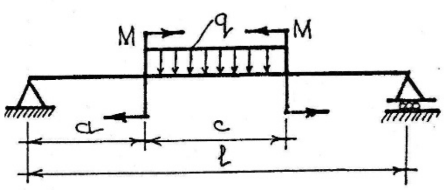

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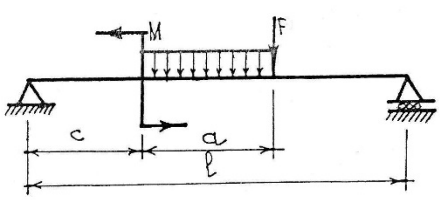

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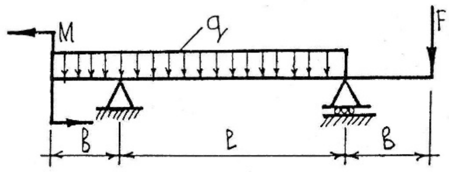

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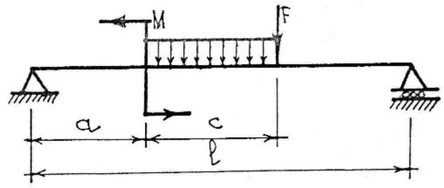

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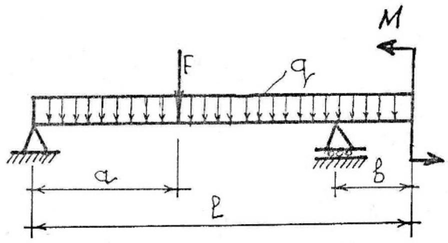

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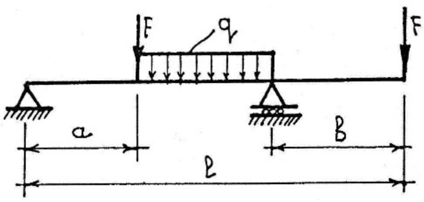

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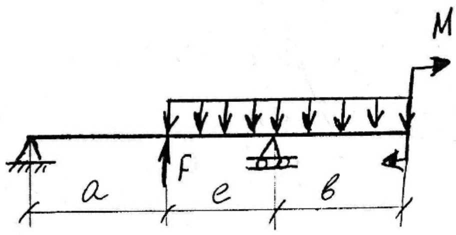

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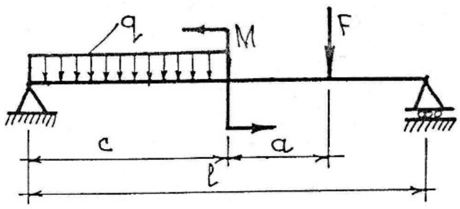

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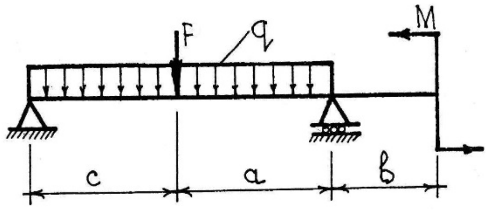

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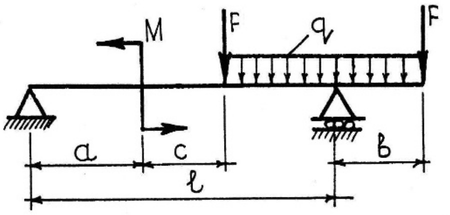

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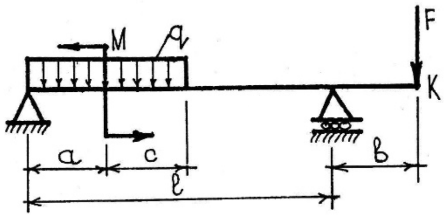

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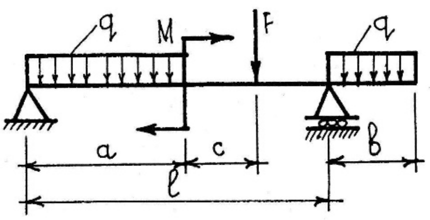

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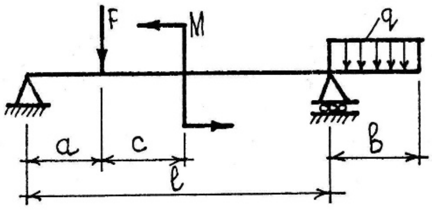

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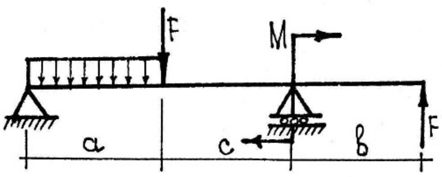

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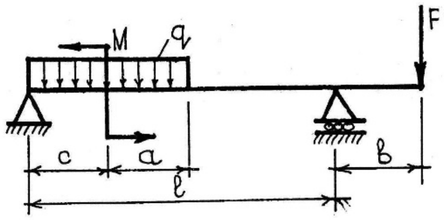

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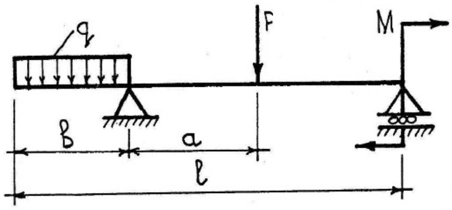

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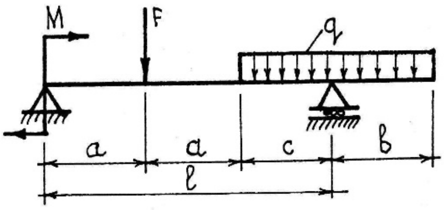

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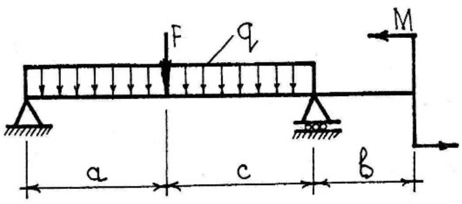

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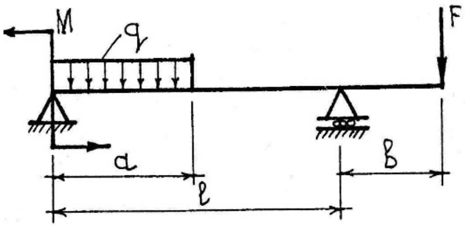

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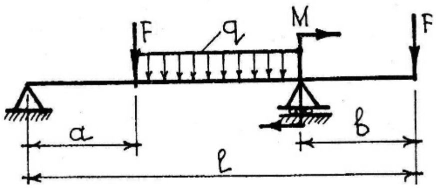


Figure 8 – Schemes to Problem 2

Table 2 – Output data for problem 2

№ var	a , m	b, m	c , m	ℓ , m	F, kN	M, kN·m	q , kN/m
1	2,5	3,0	1,0	8	30	25	20
2	3,0	2,0	1,5	9	10	10	30
3	2,0	2,5	1,0	6	30	40	5
4	1,0	3,0	0,5	5	20	30	15
5	0,5	2,0	1,5	9	30	20	20
6	3,0	3,0	0,5	0	10	10	30
7	2,5	2,5	1,0	8	30	30	5
8	1,5	3,0	0,5	7	20	10	15
9	1,0	2,5	1,0	9	15	40	25
10	2,0	2,0	1,5	6	30	20	10
11	3,0	3,0	1,0	7	10	30	10
12	2,0	2,0	0,5	8	30	25	20
13	2,5	2,5	1,5	8	20	10	30
14	3,0	3,0	1,0	9	15	40	5
15	3,0	2,0	0,5	6	20	30	15
16	2,0	3,0	1,5	5	15	20	10
17	2,5	2,5	1,0	9	35	10	20
18	3,0	3,0	0,5	10	40	30	20
19	2,0	2,5	1,5	8	10	40	30
20	3,0	2,0	1,5	7	30	20	5
21	2,5	3,0	1,0	9	20	30	15
22	3,0	2,0	0,5	6	15	50	25
23	2,5	2,5	1,5	7	35	40	10
24	2,0	3,0	0,5	8	15	30	5

PROBLEM 3

DRAW the DIAGRAMS SEAR FORCES and BENDING MOMENTS and LONGITUDINAL FORCES for FRAME

For a given steel frame:
1) to determine reaction of supports;
2) to draw diagrams of bending moments *M*, shear *Q* and longitudinal forces *N*.

Methodical instructions for Problem 3 and the procedure for performance:

1. According to the code, select the beam scheme in *Figure 9* and the output data from *table 3*.
2. Draw the calculation scheme of the frame.
3. Using static equations, determine the vertical reaction and horizontal of the supports. To control the correctness of the reaction definition, make an equation of equilibrium that was not used in determining the reactions.
4. To draw diagrams of bending moments *M*, shear *Q* and longitudinal forces *N*.
Using the cross-sectional method, divide the frame into sections, set the limits for loading them. For each segment, write the equation $M_i = f(z_i)$, $Q_i = f(z_i)$, $N_i = f(z_i)$, which allow to determine the values of *M, Q* and *N* on the limits of sections.

Diagrams *M, Q* and *N* drawn on a geometric axes of the frame. Considered the viewer is inside of the contour of the frame.

On the diagram *M*, as a rule, do not put signs, and ordinates of bending moments put necessarily on the side of stretched fibers. Diagrams *Q* and *N* denote signs according to the rules.

5. A rule for a longitudinal force *N*: the longitudinal force is considered *positive* when the rod *is stretched* and *negative - in compression*.

6. Check the correctness of the drawing of diagrams *M, Q* and *N* based on the equilibrium condition of all joints of the frame.

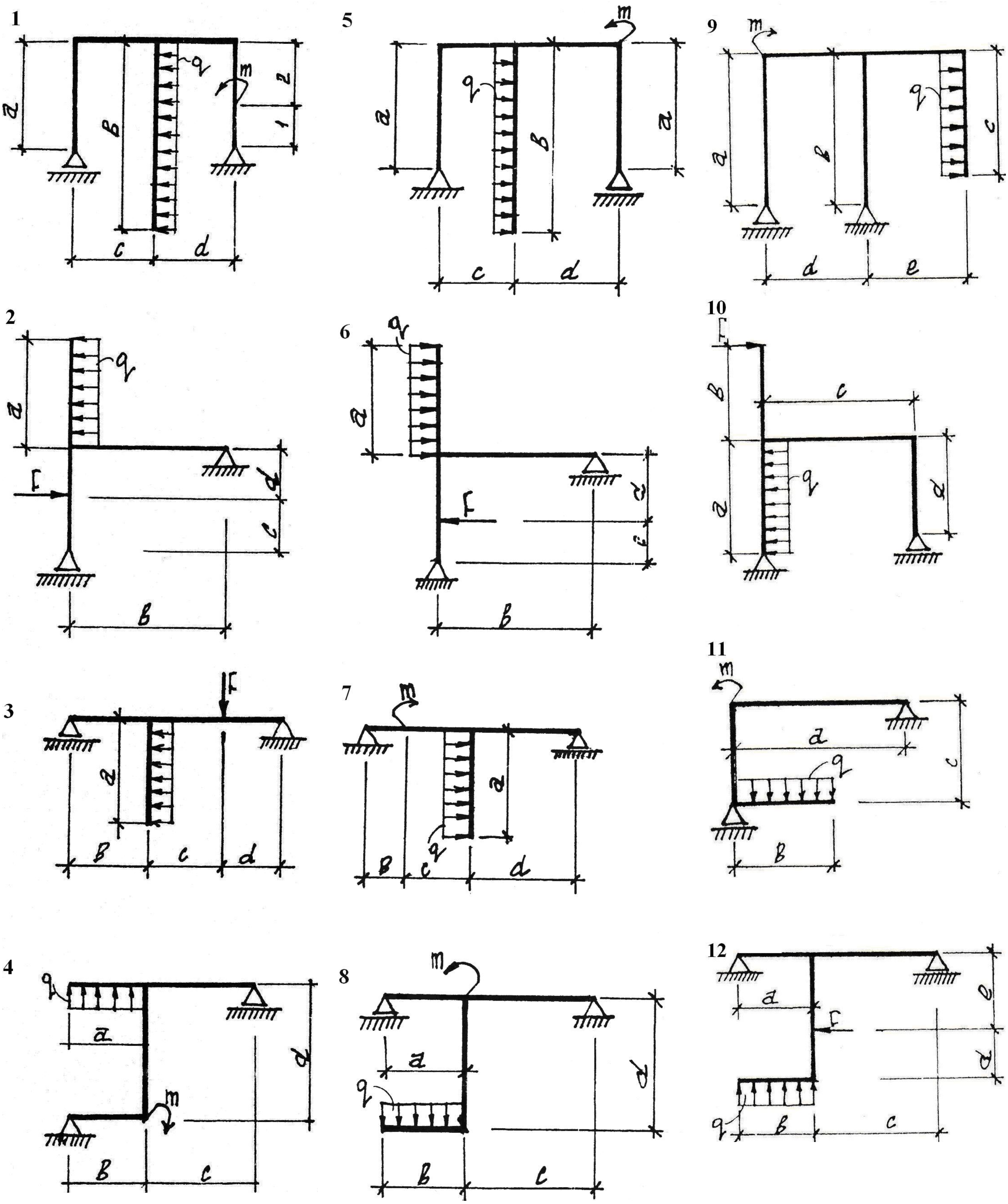


Figure 9 – Schemes to Problem 3

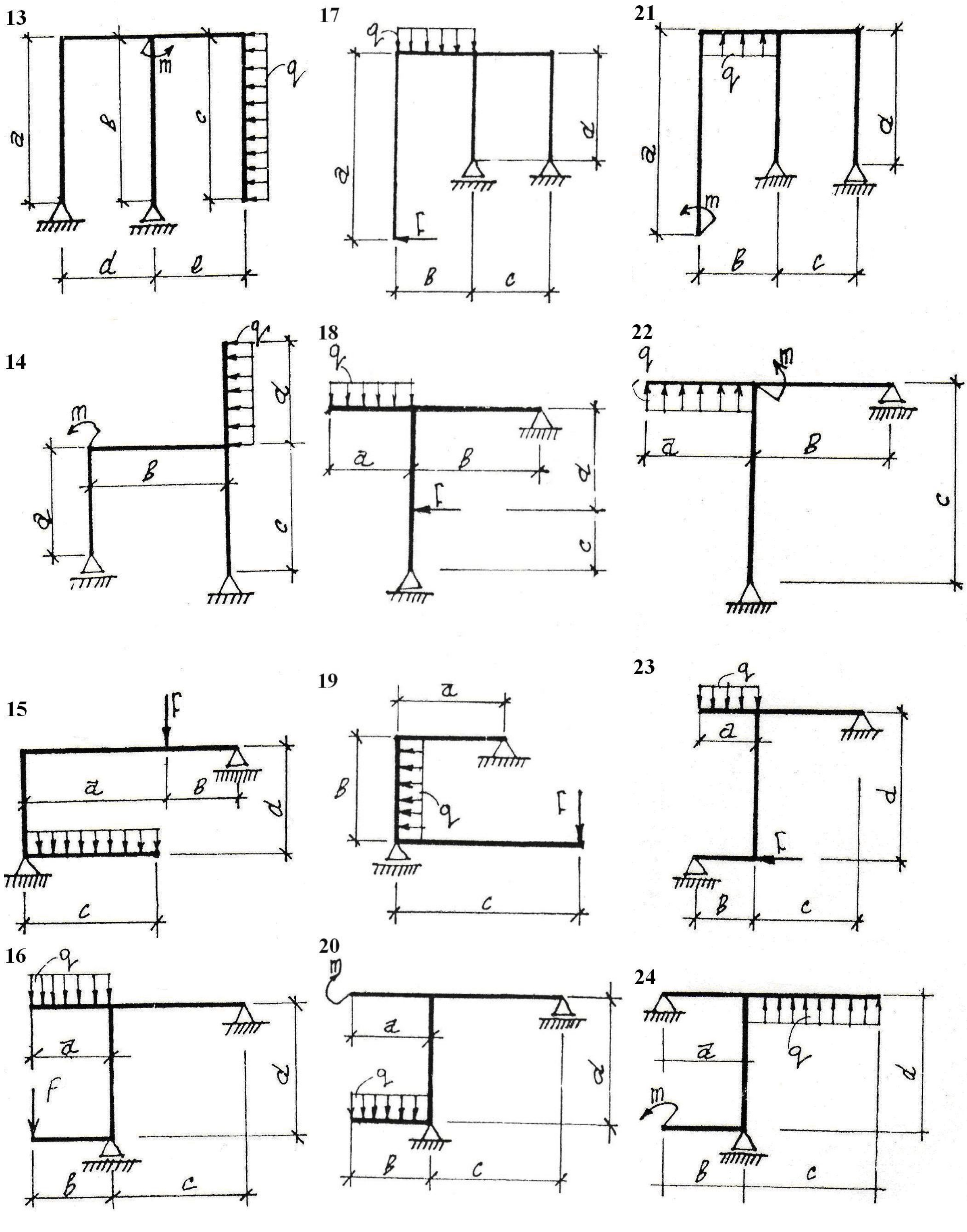
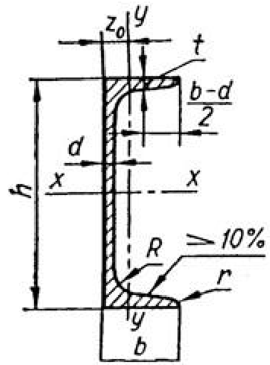


Figure 9 – Schemes to Problem 3

Table 3 – Output data for Problem 3

№	a, m	b, m	c, m	d, m	F, kN	m, kN·m	q, kN/m
1	2,0	2,5	0,5	1,0	30	25	20
2	1,0	3,0	1,0	1,0	10	10	30
3	0,5	2,0	0,5	1,5	30	40	5
4	3,0	3,0	1,0	1,0	20	30	15
5	2,5	2,5	1,5	1,0	30	20	20
6	1,5	3,0	0,5	1,5	10	10	30
7	1,0	2,5	1,0	1,0	30	30	5
8	2,0	3,0	0,5	0,5	20	10	15
9	1,0	2,5	1,0	1,5	15	40	25
10	2,0	2,0	1,5	0,5	30	20	10
11	3,0	3,0	1,0	1,5	10	30	10
12	2,0	2,5	0,5	1,0	30	25	20
13	2,5	3,0	1,5	0,5	20	10	30
14	2,0	2,0	1,0	1,5	15	40	5
15	1,0	3,0	0,5	0,5	20	30	15
16	0,5	2,5	0,5	1,5	15	20	10
17	3,0	2,5	1,0	1,0	35	10	20
18	2,5	3,0	0,5	0,5	40	30	20
19	1,5	2,5	1,0	1,5	10	40	30
20	1,0	2,0	1,5	1,0	30	20	5
21	2,0	3,0	1,0	0,5	20	30	15
22	3,0	2,0	0,5	1,5	15	50	25
23	2,5	2,5	1,5	1,0	35	40	10
24	2,0	3,0	0,5	0,5	15	30	5

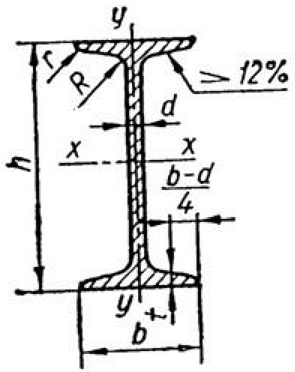


Designations:

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.

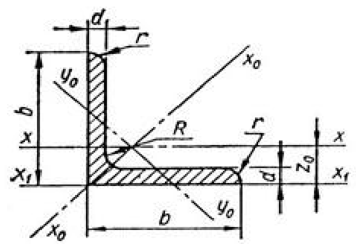
Profile number	Dimensions, mm				cross-sectional area, F cm^2	J_x, cm^4	W_x, cm^3	i_x, cm	S_x, cm^3	J_y, cm^4	W_y, cm^3	i_y, cm	z_0, cm	Mass 1 m, kg
	h	b	d	t										
5	50	32	4,4	7,0	6,16	22,8	9,1	1,92	5,59	5,61	2,75	0,954	1,16	4,84
6,5	65	36	4,4	7,2	7,51	48,6	15,0	2,54	9,0	8,7	3,68	1,08	1,24	5,90
8	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



Designations:

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



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 b	Dimensions, mm d	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
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

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
з навчальної дисципліни

« ОПІР МАТЕРІАЛІВ »
(РОЗРАХУНОК НА ЗГИН.
ПОБУДОВА ДІАГРАМ)

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

(Англійською мовою)

Укладачі: **СЕРЕДА** Наталя Василівна
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Комп’ютерне верстання *А. О. Гарбуз*

План 2019, поз. 174 М

Підп. до друку 15.04.2019 р. Формат 60 х 84/16
Друк на ризографі Ум. друк. арк. 1,3
Зам. № Тираж 50 пр.

Видавець і виготовлювач:
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Свідоцтво суб’єкта видавничої справи:
ДК № 5328 від 11.04.2017.