CALCULATION OF BEAMS FOR BENDING

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Annotation: The bend is called flat or straight if the plane of action of the load passes through the main central axis of inertia of the section. As a result of the construction, a plot of the distribution of the bending moment for each section of the beam was obtained, from which the greatest value is visible. Changes in normal and tangential stresses along the length of the beam depend on the values of transverse forces and bending moments. This study allows you to gain skills that will be used in project practice.

Keywords: beams, axis, plane, curved axis, rod, beam, structure, cross sections.

Bending is a type of loading of a beam, in which a transverse load is applied to it, lying in a plane passing through the longitudinal axis. The curved axis of the rod (elastic line) is located in the same plane. A beam that works when bending is called a beam. A structure consisting of several bent rods connected to each other, most often at an angle of 90 degrees, is called a frame.

The bend is called flat or straight if the plane of action of the load passes through the main central axis of inertia of the section.

With a flat transverse bending, two types of internal forces arise in the beam: the transverse force Qy, where y is the axis of symmetry (the main central axis) and the bending moment Mx., where x is the other main central axis of the section normal to the axis of symmetry. In a frame with a flat transverse bending, three forces arise: longitudinal N, transverse Q force and bending moment M. If the bending moment Mx is the only internal force factor, then such a bend is called pure. In the presence of a transverse force Qy, the bend is called transverse.

For a given beam (Fig.1) with the following initial data:

F=40 кН, M=28 кН, q=12 кН/м, L=3,5 м, α=0,7

it is required to plot the transverse forces and bending moments; determine the diameter of the beam from the strength condition for normal stresses; plot the largest normal and tangential stresses in the beam.

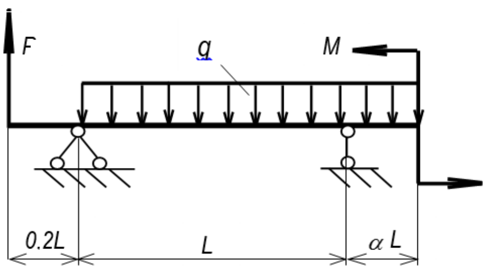


Fig. 1. A beam with a given external load

When calculating beams on two hinged supports, it is necessary first to determine the support reactions from the static equations, since the corresponding reaction falls into both the left and right cut-off parts for any section located between the supports.

For a flat system, the number of static equations is generally equal to three. If the beam is loaded only with vertical loads, then the horizontal reaction of the hinge-fixed support is zero, and one of the equilibrium equations is $\sum F_{ix} = 0$ turns into an identity. Thus, two static equations are used to determine the reactions in the pivoting beam supports:

$$\sum M_A = 0; \ -M + q \cdot 5{,}95 \cdot 2{,}975 + F \cdot 0.7 - V_B \cdot 3{,}5 = 0;$$

$$V_B = \frac{-28 + 12 \cdot 5{,}95 \cdot 2{,}975 + 40 \cdot 0{,}7}{3{,}5} = 60{,}69 \ кН .$$

$$\sum M_B = 0; \ -M + V_A \cdot 3{,}5 + F \cdot 4{,}2 - q \cdot 5{,}95 \cdot 0{,}525 = 0;$$

$$V_A = \frac{28 - 40 \cdot 4{,}2 + 12 \cdot 5{,}95 \cdot 0{,}525}{3{,}5} = -29{,}29 \ кН .$$

Condition $\sum y = 0$ it is used to check the calculated values of the reference reactions.

$$V_A + F - q \cdot 5{,}95 + V_B = 0;$$

$$-29{,}29 + 40 - 12 \cdot 5{,}95 + 60{,}69 = 0; \ 0=0.$$

To plot the transverse forces Q(z) and bending moments M(z) as functions of the longitudinal coordinate z (Fig.2), we use the cross-section method. To obtain these dependencies, the beam is divided into sections whose boundaries are the following points: the beginning and end of the beam; points of application of concentrated efforts; the beginning and end of the action of distributed efforts; sections in which the stiffness of the beam changes abruptly; at points where the orientation of elements changes if we are dealing with a rod system with a complex structure. The given system consists of three sections. Therefore, by sequentially defining the sections belonging to each section and considering the equilibrium of the cut-off parts of the system under the action of all external forces and internal forces on them, we define expressions for internal force factors.

We dissect the beam in an arbitrary section and make up the equation for the transverse force:

1 section $0 \le z1 \le 0.7$ m.

$$Q_I(z_1) = F;$$

The function $Q_I(z_1)$ is a law of variation of the transverse force along the length of the beam, from which it follows that the transverse force is a linear function of the longitudinal coordinate z.

$$\text{at } z1=0 \ \ Q_I(0) = 40 \ кН;$$

$$\text{at } z_1=0{,}7 \text{ м} \ \ Q_I(0{,}7) = 40 \ кН;$$

$$M_I(z_1) = F \cdot z_1;$$

Function $M_I(z_1)$ It is a law of variation of the bending moment along the length of the beam, from which it follows that the bending moment is a linear function of the longitudinal coordinate z.

At $z_1=0$ $M_I(0) = F \cdot 0 = 0\ кНм;$

At $z_1=0,7$ м $M_I(0) = 40 \cdot 0,7 = 28\ кНм;$

2 plot $0,7 \le z_2 \le 4,2$ м.

$$Q_{II}(z_2) = F - q \cdot (z_2 - 0,7) - V_A;$$

при $z_2=0,7$ м $Q_{II}(0,7) = 40 - 12 \cdot (0,7 - 0,7) - 29,29 = 10,71\ кН;$

при $z_2=4,2$ м $Q_{II}(4,2) = 40 - 12 \cdot (4,2 - 0,7) - 29,29 = -31,29\ кН;$

$$M_{II}(z_2) = F \cdot z_2 - q_2 \frac{(z_2 - 0,7)^2}{2} - V_A(z_2 - 0,7);$$

It follows $M_{II}(z_2)$ from the expression that the bending moment is a quadratic function of the longitudinal coordinate z.

at z2=0.7 m

$$M_{II}(0,7) = 40 \cdot 0,7 - 12 \frac{(0,7 - 0,7)^2}{2} - 29,29 \cdot (0,7 - 0,7) = 28\ \ кНм;$$

By $z_2=4,2$ м $M_{II}(4,2) = 40 \cdot 4,2 - 12 \frac{(4,2 - 0,7)^2}{2} - 29,29 \cdot (4,2 - 0,7) = -8,015\ \ кНм;$

Based on the differential dependencies between the bending moment M, the transverse force Q and the load intensity q:

$$\frac{dM}{dz} = Q \quad \frac{dQ}{dz} = q,$$

We determine the maximum value of the bending moment from the condition

$$\frac{dM}{dz} = Q = 0$$

$$Q_{II}(z_2) = F - q \cdot (z_2 - 0,7) - V_A = 0$$

$$z_2^{'} = \frac{F + q \cdot 0,7 - V_A}{q} = \frac{40 + 12 \cdot 0,7 - 29,29}{12} = 1,5925 \quad м$$

$$M_{\max} = M_{II}(1,5925) = 40 \cdot 1,5925 - 12 \frac{(1,5925 - 0,7)^2}{2} - 29,29 \cdot (1,5925 - 0,7) = 32,78\ \ кНм;$$

3 plot $0 \le z_2 \le 2,45$ м.

$$Q_{III}(z_3) = q \cdot z_3;$$

at z_3=0 м $Q_{III}(0) = 12 \cdot 0 = 0\ кН$;

at z_3=2,45 м $Q_{III}(2{,}45) = 12 \cdot 2{,}45 = 29{,}4\ кН$;

$$M_{III}(z_3) = M - q_2 \frac{z_3^2}{2};$$

at z_3=0 м $M_{III}(0) = M = 28\ кНм$;

at z_3=2,45 м $M_{III}(2{,}45) = 28 - 12\frac{2{,}45^2}{2} = -8{,}015\ кНм$.

Plotting begins with drawing a line parallel to the axis of the beam. This line conventionally represents a beam and is the zero ordinate of the plot plot. Then, at the boundaries of the sections, the values of the transverse forces Q(z) and bending moments M (z) for each section are deposited from this line, taking into account their signs. It is customary to stroke the plot with straight lines perpendicular to the longitudinal axis of the beam with the indication of a sign in a circle.

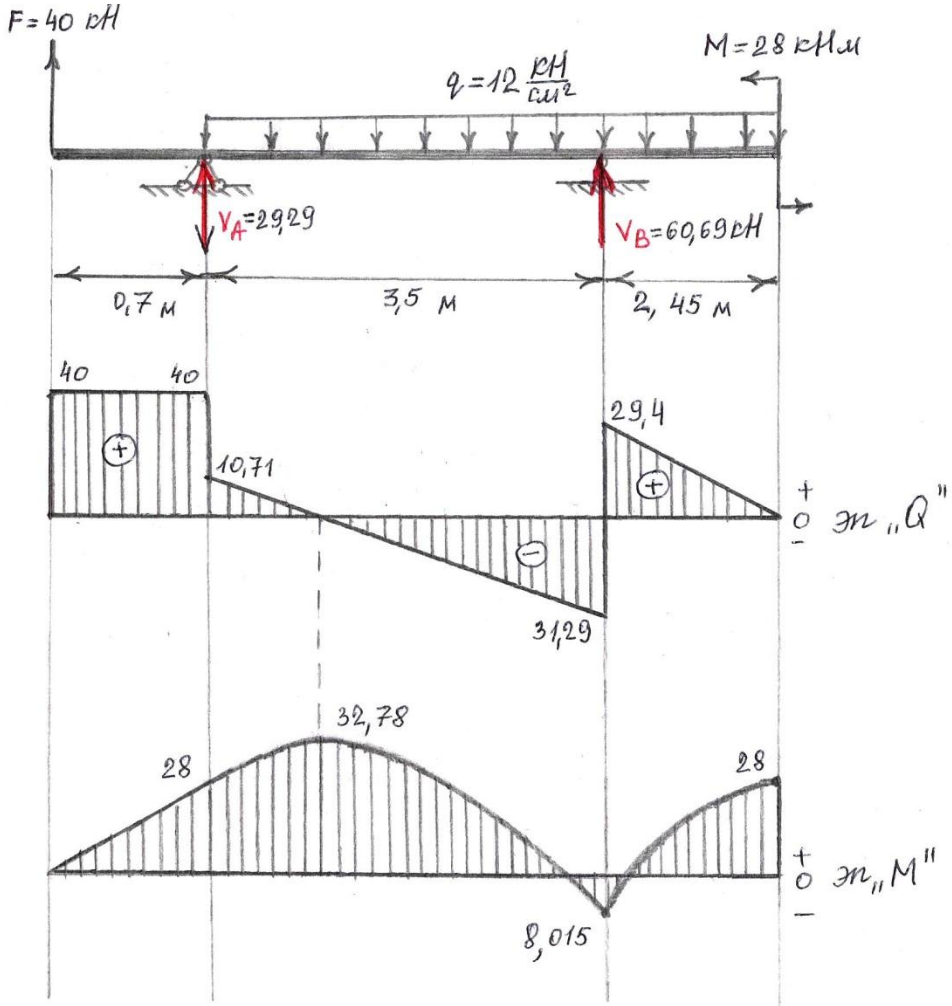
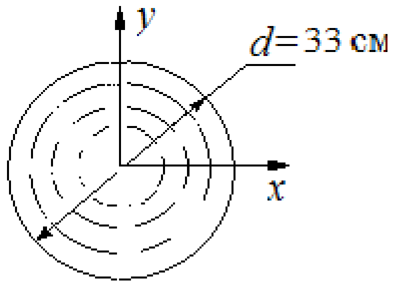


Fig. 2. Diagrams of transverse force and bending moment

As a result of the construction, a plot of the distribution of the bending moment for each section of the beam was obtained, from which the greatest value is visible. For this beam, the maximum bending moment occurs on the 2nd section. The diameter of a beam of circular cross-section (Fig.3) made of wood is determined from the strength condition under normal stresses.



For wood – $[\sigma]=10$ MPa $=1\frac{кН}{см^2}$. The value of the maximum bending moment is taken from the bending moments plot

$M_{\max}=32{,}78\ кНм=3278\ кНсм$.

The bending strength condition has the form:

$$\sigma_{\max}=\frac{M_{vax}}{W_x}\leq[\sigma]$$

The moment of resistance is located from it:

$$W_x\geq\frac{M_{\max}}{[\sigma]}$$

Geometric characteristic for a circular cross-section:

$$W_x=\frac{\pi\cdot d^3}{32}$$

As a result, we get

$$\frac{\pi\cdot d^3}{32}\geq\frac{M_{\max}}{[\sigma]}$$

Where do we find the diameter of the beam

$$d\geq\sqrt[3]{\frac{32\cdot M_{\max}}{\pi\cdot[\sigma]}}\quad d\geq\sqrt[3]{\frac{32\cdot 3278}{3{,}14\cdot 1}}=32{,}2\,\text{см}$$

For a round wooden cross-section, we assume a diameter equal to: d= 33 cm.

Let's plot the largest normal and tangential stresses during bending.

To determine the extreme normal stresses σmax and σmin use the formula:

$$\sigma_{\substack{\max\\ \min}}=\frac{\sigma_x+\sigma_y}{2}\pm\frac{1}{2}\sqrt{(\sigma_x-\sigma_y)^2+4\tau_{yx}^{\ 2}}$$

In our case: $\sigma_x = \sigma; \quad \tau_{yx} = \tau$

The formulas of the main stresses will take the form:

$$\sigma_{\max} = \sigma_1 = \frac{\sigma}{2} + \frac{1}{2}\sqrt{(\sigma)^2 + 4\tau^2}$$

$$\sigma_{\min} = \sigma_2 = \frac{\sigma}{2} - \frac{1}{2}\sqrt{(\sigma)^2 + 4\tau^2}$$

Extreme tangential stresses are inclined to the main platforms at 45° angles. They are mutually perpendicular. One of them has a maximum voltage of □max, and the other has a minimum voltage of □min. It follows from the law of tangential stress pairing that tmax = - tmin .

The values of tm ah can be determined by the formula:

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{1}{2}\sqrt{(\sigma)^2 + 4\tau^2}$$

By calculating the main stresses for a number of points, it is possible to plot the largest normal and tangential stresses.

We investigate the stress state at points lying at different heights of the cross section.

At the point 1: $\tau = 0$, $\sigma = -0{,}93 \frac{\kappa H}{c\mathit{м}^2}$

$$\sigma_{\max} = \sigma_1 = -\frac{\sigma}{2} + \frac{1}{2}\sqrt{(\sigma)^2 + 4 \cdot 0} = -\frac{\sigma}{2} + \frac{\sigma}{2} = 0 \frac{\kappa H}{c\mathit{м}^2}$$

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{1}{2}\sqrt{(\sigma)^2 + 4 \cdot 0} = \frac{\sigma}{2} = 0{,}465 \frac{\kappa H}{c\mathit{м}^2}$$

At the point **2**: $\tau = 0{,}062 \frac{\kappa H}{c\mathit{м}^2}$, $\sigma = 0 \frac{\kappa H}{c\mathit{м}^2}$

$$\sigma_{\max} = \sigma_1 = \frac{0}{2} + \frac{1}{2}\sqrt{0^2 + 4\tau^2} = \tau = 0{,}062 \frac{\kappa H}{c\mathit{м}^2}$$

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{1}{2}\sqrt{(0)^2 + 4\tau^2} = \tau = 0{,}062 \frac{\kappa H}{c\mathit{м}^2}$$

At the point **3**: $\tau = 0 \frac{\kappa H}{c\mathit{м}^2}$, $\sigma = 0 \frac{\kappa H}{c\mathit{м}^2}$

$$\sigma_{\max} = \sigma_1 = \frac{\sigma}{2} + \frac{1}{2}\sqrt{(\sigma)^2 + 4 \cdot 0} = \frac{\sigma}{2} + \frac{\sigma}{2} = \sigma = 0{,}93 \frac{\kappa H}{c\mathit{м}^2}$$

$$\tau_{\max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{1}{2}\sqrt{(\sigma)^2 + 4\cdot 0} = \frac{\sigma}{2} = 0{,}465\,\frac{кН}{см^2}$$

Based on the values found, we construct plots of normal and tangential stresses and plots of the greatest normal and tangential stresses (Fig.4).

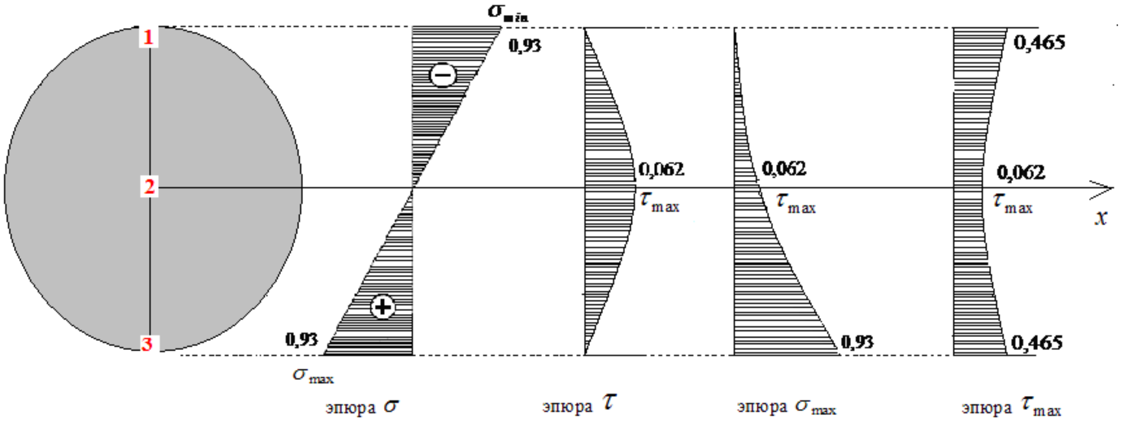


Fig. 4. Plots of normal and tangential stresses and greatest normal and tangential stresses

It can be seen from the diagrams that the normal and tangential stresses vary with the height of the cross-section of the beam. According to the height of the section, there are no points at which the greatest normal and tangential stresses simultaneously acted. Where tangential stresses take extreme values, normal stresses are zero. Changes in normal and tangential stresses along the length of the beam depend on the values of transverse forces and bending moments. This study allows you to gain skills that will be used in project practice.

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