Saimaa University of Applied Sciences
Technology, Lappeenranta
Double Degree Programme in Civil and Construction Engineering

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Strength and building physics analysis of the composite timber beam

Thesis 2019

Abstract

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The main purpose of the thesis was to produce a technical sheet and excel sheets for determining the span length of the Sapisol beams for a roof structure according to Russian norms. The secondary aim was to calculate the drainage capacity of a ventilated duct system in the beam. The client of the thesis is Russian company Promstroyles.

The calculations were performed according to Russian standards. An experimental study was also carried out to determine certain strength characteristics of the composite beam material. In the first part, literature was used and an excel file was compiled, according to which the span length was calculated. In the second part, the ventilation system in the beam was designed.

The results can be applied in technical sheets for beams to use them in Russia, to design engineers working. Also, excel files can be applied to design engineers working with designing the span length and ventilation in the Sapisol beams.

Keywords: Wood Structures, composite beam, ventilation

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1. Introduction

The client of the thesis is Russian company Promstroyles. Sapisol technology is used in France in wooden house construction. Sapisol® insulated panels allow you to reduce your energy costs. The huge benefit of Sapisol is that it can span distance (up to 6 m between supports), save time in finishing work (2). Due to such advantages of this technology and due to low temperatures in Russia the company was interested to use it in Russia. To this aim, in this thesis a technical sheet for these panels is developed. In addition, the main problems lie on the calculation. The company have not developed excel sheets or Mathcad sheets for designing the panel. Also, one of the most important problems is condensation for some regions of Russia.

2. Sapisol beam

The Sapisol beam in the structure is shown in Figure 1 below:

Figure 1. Use of beams in the construction of a pitched roof (18)

Made of two timber faces and a polystyrene (or cork) core, Simonin's insulated panel is made under European Technical Approval. The ceiling panel is available in different thicknesses and can be adapted to suit all types of projects, private, public and industrial. It offers a low-energy solution to your build.

Advantages of the Sapisol insulated panel are the following:

- Excellent thermal performance Sapisol® is airtight and ensures efficient insulation of your home without any thermal bridges. It is made to the highest standards offering a long term level of thermal performance. When installed with a wood fibre under layer, it meets acoustic insulation regulations.
- A timber soffit. With Sapisol, in one step you get: high-performance insulation, a wooden ceiling and completely finished roof overhangs, and a reliable and tough roofing support.
- Wide spans. The huge benefit of Sapisol is that it can span distance (up to 6 m between supports) reducing the need for additional structure, saving build costs as well as freeing up volumes and creating additional living space.
- Bespoke production. SIMONIN SAS can machine details and supply cut to length in the factory workshop for ease of installation, as well as reducing waste at the site.
- A sound and sustainable product. Sapisol® is adaptable and suitable for all environments, sensitive and extremely sensitive, at all altitudes and latitudes.
- Low energy. Sapisol® insulated panels allow you to reduce your energy costs.
- Designed from durable and environmentally friendly materials, is a well-made and environmentally friendly solution. The Simonin Sapisol® panels S186 (R = 5.02) and S220f (R = 6.11) specially designed for low energy housing meet the thermal regulations.
- For new or renovation. New or renovation: With the ceiling insulation board Sapisol®, the options for roofs are limitless (straight roof, low slope roof, curved roof, conical roof or slightly veiled, installation on metal framing) without compromise for thermal insulation of your home.
- Sapisol® is a product not only intended for new constructions, its design allows it to adapt to all types of renovation such as the insulation of existing roof spaces.
- Lightweight and easily transportable, it meets the needs of the most exciting projects and those in the most remote regions of the globe.

- Exceptional works. Sapisol® has been used on several hundred public and private buildings, all around the world. It has been used in specialist projects as well as bioclimatic houses, for 25 years Sapisol® has proved its performance and efficiency.
- The Sapisol® insulation panel is suitable for all environments. Sapisol was used in Antarctica for the Concordia station, at 3000 m altitude. The floor, the facades and the roof are made of Sapisol® providing comfortable insulation for residents (2).

Below there are variants of the beams with insulation from polystyrene and cork (Figures 2-3).

Figure 2. Variant of the beams with insulation from polystyrene (17)

Figure 3. Variant of the beams with insulation from cork

Figures 4-7 show the variants of beams in the structure 18).

Figure 4 shows how the beam can be used in swimming pools, sport halls and wide spans in case of timber truss.

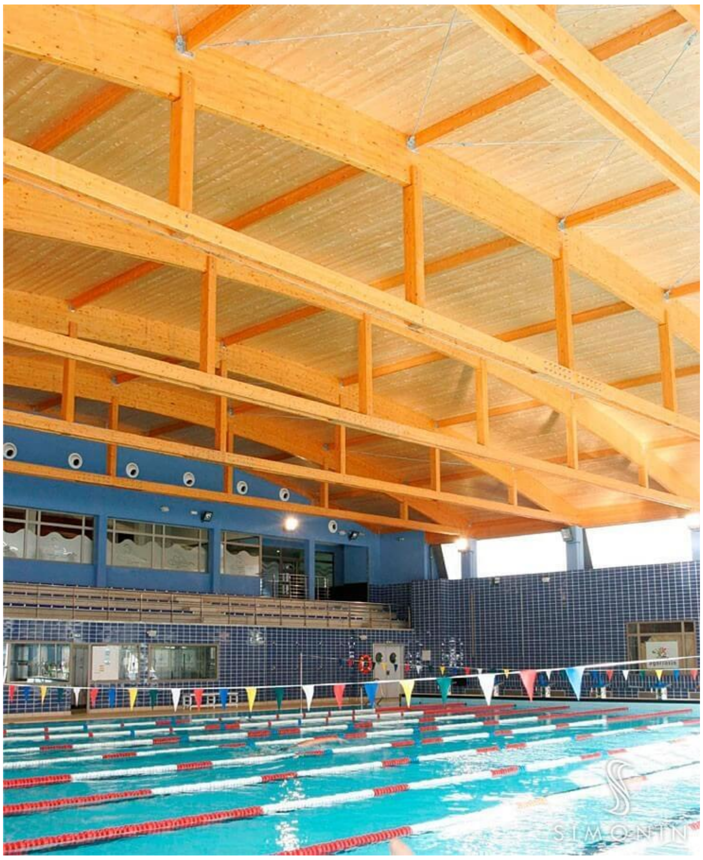


Figure 4. Swimming pools, sport halls and wide spans (19)

Figure 5 shows how the beam can be used in the roof structure with a semicircular roof.

Figure 5. Use of beams in the roof structure with a semicircular roof (19)

Figure 6 shows how the beam can be used in the roof structure with a flat roof.

Figure 6. Use of beams in the roof structure with a flat roof (20)

On the Figure 7 you can see Variant of the layers of the roof structure. The beam can be differently oriented to the existing slope of the roof. Also, the roof slope can be round in shape or in the shape of a cone. Figures 8 and 9 show the options for using beams with different finishes in the building (1)

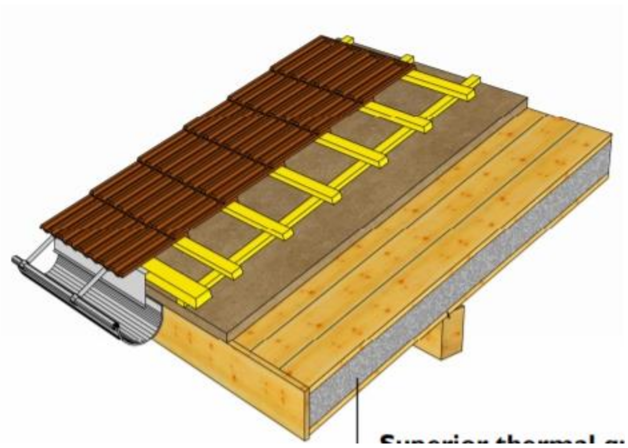


Figure 7. Variant of the layers of the roof structure

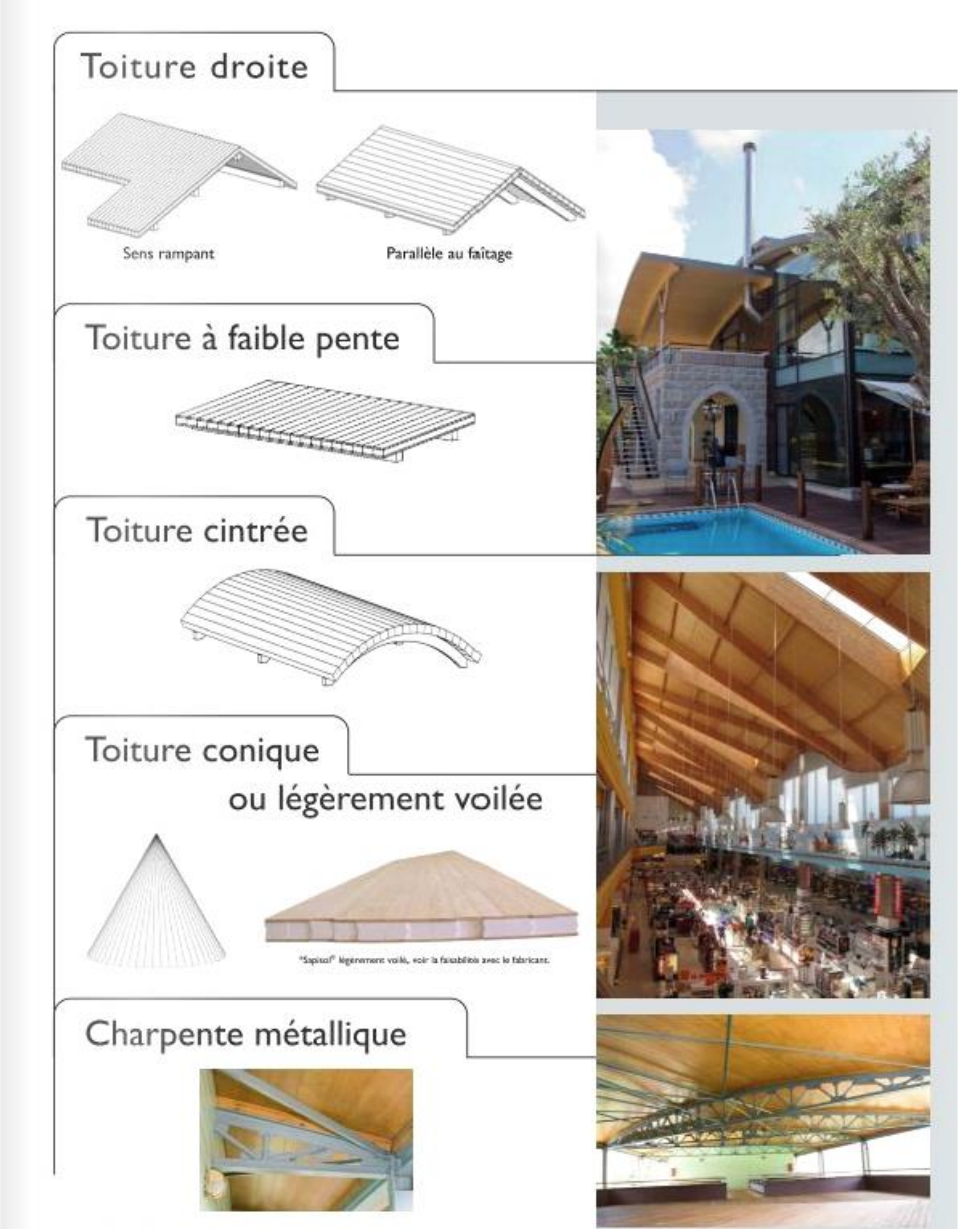


Figure 8. Variants of using a beam in a building (1)

Also, different wood species and different finishes can be used for the beam (Figure 9).

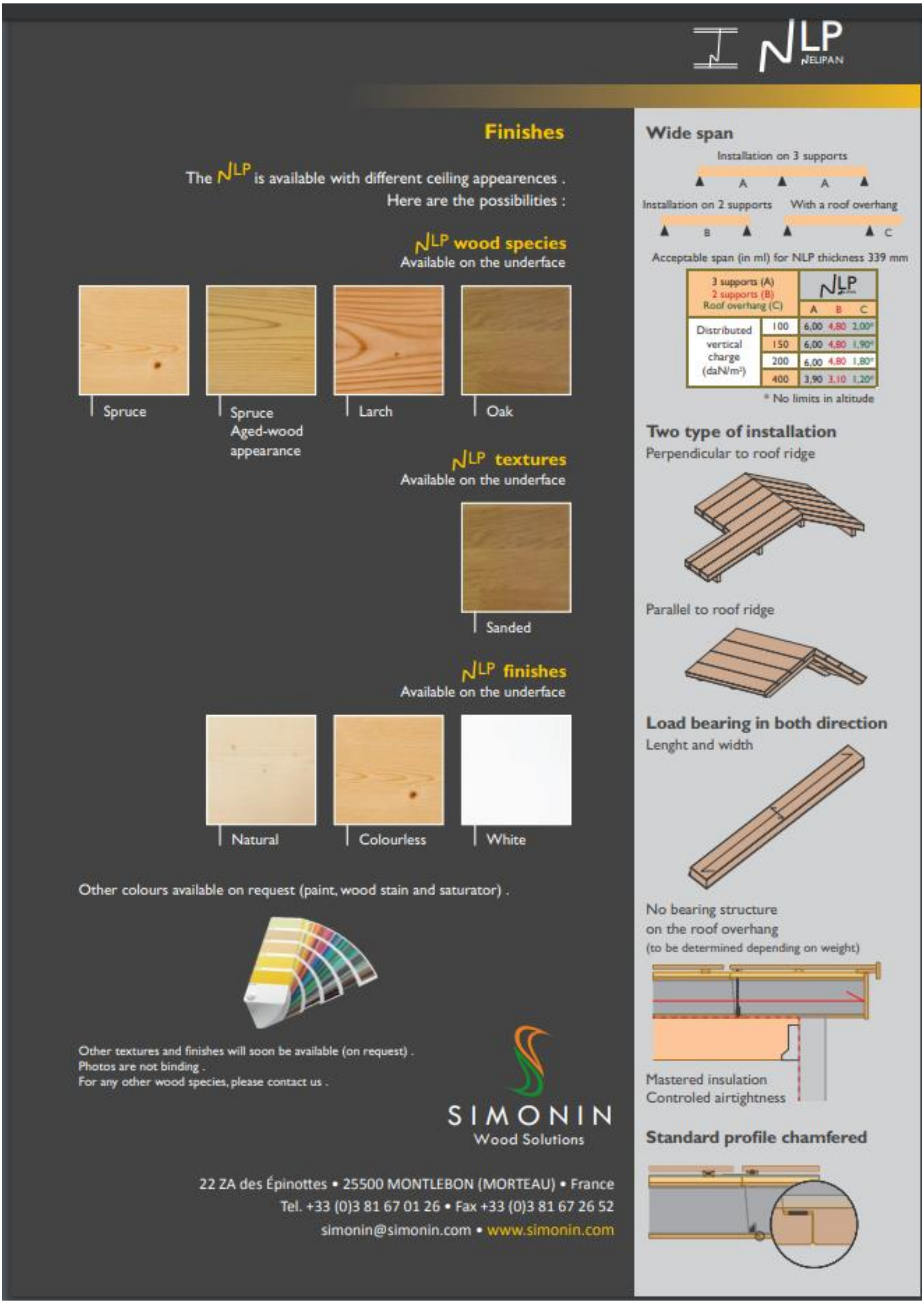


Figure 9. Options for beams and their use in the building (1)

2.1 Determination of insulation material

Two variants of beams with insulation from cork and polystyrene were considered (Figure 10).

Figure 10. Two versions of beams with insulation from cork and polystyrene

The first variant is polystyrene PPS 25 and the second variant is cork.

Since the cork is much more expensive than polystyrene, PPS-25 polystyrene foam is selected as a heat-insulating material. Polystyrene PPS-25 is the most common brand of polystyrene foam used in modern civil and industrial construction.

Polystyrene PPS-25 (old name PSB-S 35) is a good heat-insulating material. Polystyrene is durable. It is convenient to install and has a low cost.

The main scope of polystyrene foam is the insulation of roofs, walls, ceilings, and floors.

The main technical characteristics of the Polystyrene PPS-25 are as follow:

- density from 25 to 35 kg/m^3.
- compressive strength at 10% deformation = not less than 0.16 MPa
- bending strength chapel = not less than 0.25 MPa
- thermal conductivity = not more than 0.037 W / m^2 x s (3).

Sizes of expanded polystyrene plates: PPS-25 insulation is supplied in plates with a thickness of 20-500 mm in increments of 10 mm.

3. The main idea of thermal insulation and building physics

Thermal insulation is the process of retarding the flow of heat from transferring between adjacent surfaces. Specially engineered methods or processes, and appropriate object shapes and materials are needed to achieve thermal insulation.

Thermal insulation materials, known as insulators, are installed in commercial buildings to improve the energy consumption of the buildings' cooling and heating systems (2).

Different insulating materials and other types of material have specific thermal conductivity values that can be used to measure their insulating effectiveness. It can be defined as the amount of heat/energy (expressed in kcal, Btu or J) that can be conducted in unit time through unit area of unit thickness of material, when there is a unit temperature difference. Thermal conductivity can be expressed in kcal m-1 °C-1, Btu ft-1 °F-1 and in the SI system in watt (W) m-1 °C-1. Thermal conductivity is also known as the k-value (7).

The rate of transmission is also closely related to the propagating medium, heat flow by transmission occurs by a combination of conduction, convection, and radiation. Heat is lost or gained by transmission through the ceilings, walls, floors, windows, and doors (6).

3.1 Building physics theory of resistance calculation

Heat transfer Mechanisms are as follows:

1. Conduction

By this mode, heat energy is passed through a solid, liquid or gas from molecule to molecule in a material. In order for the heat to be conducted, there should be physical contact between particles and some temperature difference. Therefore, thermal conductivity is the measure of the speed of heat flow passed from particle to particle. The rate of heat flow through a specific material will be influenced by the difference of temperature and by its thermal conductivity.

2. Convection

By this mode, heat is transferred when a heated air/gas or liquid moves from one place to another, carrying its heat with it. The rate of heat flow will depend on the temperature of the moving gas or liquid and on its rate of flow.

3. Radiation

Heat energy is transmitted in the form of light, as infrared radiation or another form of electromagnetic waves. This energy emanates from a hot body and can travel freely only through completely transparent media (7).

Steady state conduction is the form of conduction that happens when the temperature difference(s) driving the conduction are constant, so that (after an equilibration time), the spatial distribution of temperatures (temperature field) in the conducting object does not change any further. Thus, all partial derivatives of temperature with respect to space may either be zero or have nonzero values, but all derivatives of temperature at any point with respect to time are uniformly zero. In steady state conduction, the amount of heat entering any region of an object is equal to amount of heat coming out:

$$q = -\lambda * gradT \qquad (1)$$

where q is the heat flux (amount of heat flowing per second and per unit area) and grad T the temperature gradient (Figure 11). The sign in the expression is chosen so that always $\lambda > 0$ as heat always flows from a high temperature to a low temperature. This is a direct consequence of the second law of thermodynamics (4).

In case of in the one-dimensional case:

$$q_x = -\lambda \frac{dT}{dx} = -\lambda \frac{\Delta t}{\delta} \qquad (2)$$

q_x - the heat flux (amount of heat flowing per second and per unit area),

λ - the thermal conductivity,

Δt - the temperature difference,

δ – the layer thickness,

dT/dx is the temperature gradient.

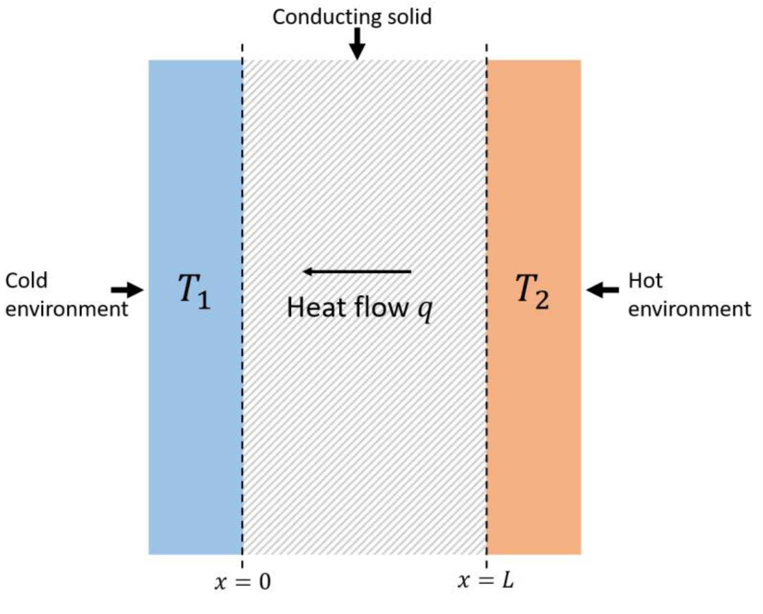


Figure 11. Conduction

Energy codes in Russia start to establish in 1955, norms and rules first mentioned the performance of the building envelope and heat losses, and they formed norms to regulate the energy characteristics of the building envelope. And the most recent version of Russia energy code (12) was published in 2003. The energy codes of Russia were established by experts of government institutes or nongovernmental organization like ABOK. The energy code of Russia has been revised several times since 1955, the 1995 versions reduced energy depletion per square meter for heating by 20%, and the 2000 version reduced by 40%.The code also has a mandatory requirement on thermal insulation of buildings accompany with some voluntary provisions, mainly focused on heat loss from the building shell (8).

Calculation of total thermal resistance is done in Russia according to (23) (calculated as per formulas (3-5)). The calculation is made on the site (14,15).

$$R = \frac{1}{\alpha} \qquad (3)$$

$$R_i = \frac{\delta_i}{\lambda_i} \qquad (4)$$

$$R = \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} \qquad (5)$$

α - the heat transfer coefficient at the outer or internal surface

R – the thermal resistance

4. Reduced section method

Due to the fact, that the wood and polystyrene have different modulus of elasticity, Sapisol beam is a composite multi-modular material, i.e. a material with non-uniform thickness properties. The calculation of the material is carried out according to the method of reduced section (as per formulas 6-10) (Figure 12) (9).

$$b_i = \frac{E_i}{E_1} \qquad (6)$$

$$z_0 = \frac{\sum_{i=1}^{n} F_i' \cdot z_i}{\sum_{i=1}^{n} F_i'} \qquad (7)$$

$$I' = \sum_{j=1}^{n} \left[\frac{b_i \delta_i^3}{12} + F_i' (z_i - z_0)^2 \right] \qquad (8)$$

bi- reduced width of the i layer,

b- actual layer width,

zi- the distance from the lower point of the center section to the i layer,

F’i- reduced cross-sectional area of the i layer,

Z0- distance from the bottom of the section to the neutral axis.

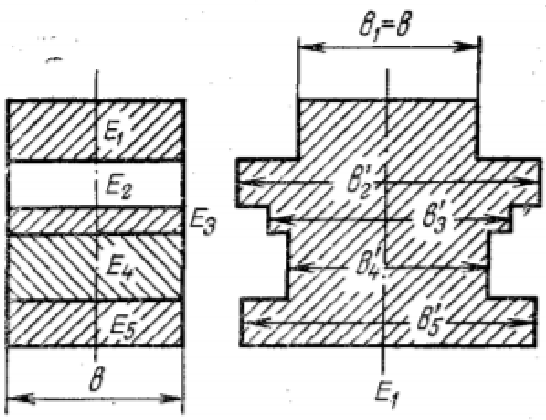


Figure 12. Reduced section method. Determination of stresses (9)

$$\sigma_i = \frac{ME(z_i' - z_0)}{I'E_1} \qquad (9)$$

$$\tau_i = \frac{QS_i'}{b_i' l'} \leq R_c \qquad (10)$$

I'- moment of inertia of the equivalent section relative to the neutral axis.

σi- bending stress in the upper extreme fiber of the i layer if the layer is located above the neutral axis, and in the lower extreme fiber of the i layer if the layer is below the neutral axis.

M- bending moment,

Ei- modulus of elasticity of the i layer,

τ_i- shear stress,

Q- shear force,

S'i- static moment of the part of the equivalent section lying between the controlled joint of the layers and the end fiber of the section on the same side of the neutral axis.

Rсдв.с- shear strength.

In case of this composite beam bending stress and shear stress have the following distribution (Figure 13)

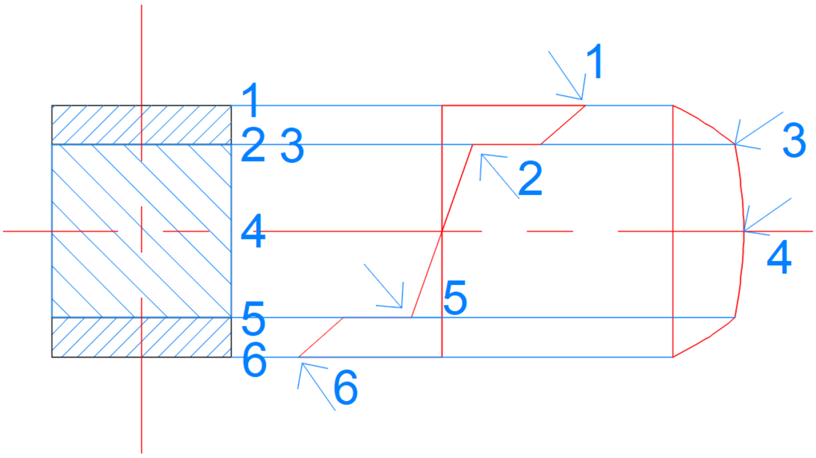


Figure 13. Bending and shear stress distribution in the cross section of the beam.

Strength characteristics for timber:

1) $\sigma < \mathrm{R_и}$, $\mathrm{R_и}$ is the design bending strengths (fm,y,d),

3) τ < Rск, Rск – is the design shear strength for the actual condition (f,v,d),

6) $\sigma < \mathrm{R_и}$, $\mathrm{R_и}$ is the design bending strengths. (fm,y,d),

For insulation material:

2) $\sigma < \mathrm{R_c}$, $\mathrm{R_c}$ – is the design compressive,

4) τ <Rск, Rск – is the design shear strength for the actual condition,

5) $\sigma < \mathrm{R_p}$, $\mathrm{R_p}$– is the design tensile strength.

Distribution of normal and shear stresses in the cross section of the composite beam is shown in Excel in Figure 14 below.

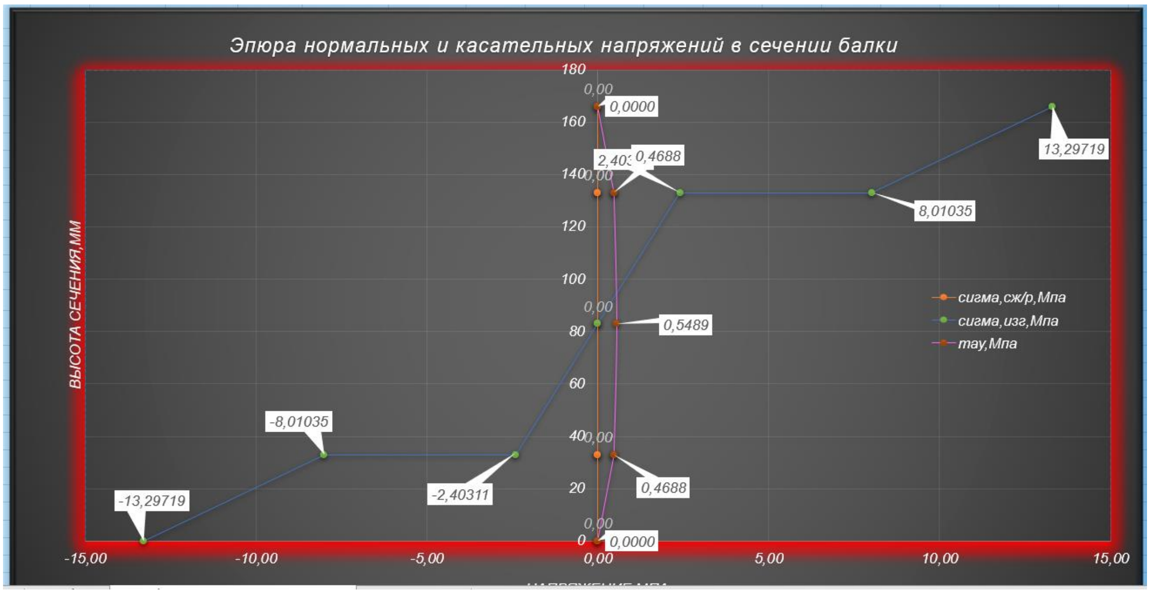


Figure 14. Distribution of normal and shear stresses in the cross section of the composite beam in Excel.

To obtain the actual stress distribution, it is necessary to obtain the modulus of elasticity E of the polystyrene during the experiment.

5. Calculation part

5.1 Calculation of total heat Resistance for different panels

Sapisol with polystyrene and boards thickness 20 mm, 33 mm, 43 mm

Calculation of thermal resistance is made on the website (14).

The calculations of total heat resistance for different panels are shown in APPENDIX 3.

Table 1. Total heat Resistance for different panels

Beam type		s 190	s 240	s 290	s 216	s 256	s 316	s 236	s 286	S 336
layers, mm	pine	20	20	20	33	33	33	43	43	43
	polystyrene	150	200	250	150	200	250	150	200	250
	pine	20	20	20	33	33	33	43	43	43
Width, mm		145	145	145	145	145	145	145	145	145
Weight, kH/m^2		0.23	0.25	0.26	0.36	0.37	0.38	0.46	0.47	0.48
Total heat Resistance, R		3,91	5,07	6,23	4,05	5,22	6,38	4,16	5,33	6,49

Sapisol with polystyrene PPS-25 and boards thickness 20 mm, 33 mm, 43 mm.

Characteristics for heat calculation for different cases of boards and insulation are shown below:
Timber (pine) - λ=0,09, from SP.50.13330.12, δ1= 20 mm, δ2= 33 mm, δ3= 43 mm.
Insulation (polystyrene PPS-25)- λ=0,043, δ1= 150 mm, δ2= 200 mm, δ3= 250 mm.

5.2 Calculation of the material strength

Ultimate limit state calculation.

Strength characteristics for timber are as follows:

τ <Rск, $R_{ск}$ – is the design shear strength for the actual condition (f,v,d)

$\sigma < R_{см}$, Rc – is the design compressive strength perpendicular to the grain (fc,90,d)

$\sigma < R_{и}$, $R_{и}$ is the design bending strengths. (fm,y,d)

According to SP 64.13330.2017 Wooden structures (11) for pine of wood grade 2 of the design value of pine strength is calculated as per formula (11).

$$R^{p} = R^{A} \cdot m_{дл} \cdot \prod m_{i} \qquad (11)$$

R^{p} is design value of pine strength,

R^{A} is design value of pine strength for wood grade 2,

$m_{дл}$ is coefficient of long durability,

mдл =0,8 (Tab. 3 from Table 9 (11)),

$\prod m_{i}$ is composition of the coefficient of working conditions,

Rи=22,5 Мпа (Tab. 3 2.в from Table 9 (11)),

$m_{в}$ = 1 – coefficient of operating conditions of structures (Figure 15 from Table 9 (11));

Таблица 9

Условие эксплуатации (таблица 1)	1 и 2	3	4а	4б
Коэффициент $m_в$	1	0,9	0,85	0,75

Figure 15. Coefficient of operating conditions of structures (11)

$m_Т$ = 1 – coefficient of temperature conditions (11),

$m_б$ = 1– for section height less than 50 cm (11),

$m_{сл}$ – coefficient taking into account the thickness of the layer (Figure 16 from table 11 (11)),

Таблица 11

Толщина слоя, мм	10 и менее	19	26	33	42
Коэффициент $m_{сл}$	1,2	1,1	1,05	1,0	0,95

Figure 16. Coefficient taking into account the thickness of the layer (11)

$m_{c.c.}$ = 1 – coefficient of service life, we take the value for the term service 50 years (Figure 17), (11).

Таблица 13

Вид напряженного состояния	Значение коэффициента $m_{c.c}$ при сроке службы сооружения		
	≤50 лет	75 лет	100 лет и более
Изгиб, сжатие, смятие вдоль и поперек волокон древесины	1,0	0,9	0,8
Растяжение и скалывание вдоль волокон древесины	1,0	0,85	0,7
Растяжение поперек волокон древесины	1,0	0,8	0,5

Figure 17. Coefficient of service life, we take the value for the term (11)

For timber values of design strength are as follows:

Rи=mдл*mв*mт*mб*mсл*mс.с.*Rсж=0,8* 0,9*1*1*mсл*1*22,5 MPa

For board layer thickness 20 mm мсл=1,1

Rи= 0,8*0,9*1*1*1,1*1*22,5=17,82 MPa

For board layer thickness 33 mm мсл=1,0

Rи= 0,8*0,9*1*1*1,0*1*22,5=16,2 MPa

For board layer thickness 43 mm мсл=0,95

Rи =0,8*0,9*1*1*0,95*1*22,5=15,39 MPa

The design shear strength for along the grain for glued elements

Tab. 3.5 б) Rск=2,25 MPa.

The design compressive strength perpendicular to the grain for glued elements

Tab. 3.5 б) Rсм=4,5 MPa.

For insulation material values of design strength are as follows:

т <Rск, $R_{ск}$ – is the design shear strength for the actual condition.

$\sigma < R_c$, Rc – is the design compressive

$\sigma < R_p$, Rp – is the design tensile strength

$\sigma < R_{см}$, Rc – is the design compressive strength perpendicular to the grain (fc,90,d).

According to (16) for polystyrene PPS-25 R_c=0,16 MPa

Since the tensile strength, shear, modulus of elasticity in the GOST 15588-2014 are not given, they were experimentally determined.

5.3 Calculation of the span length for different panels

Three cases of the static scheme are considered.

The 1st case (single-span beam with distributed load) is shown in Figure 18 below:

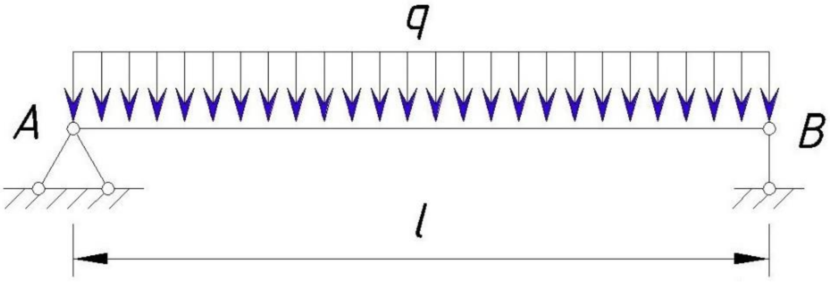


Figure 18. Single-span beam with distributed load

Figure 19 shows distribution of bending moments and shear forces.

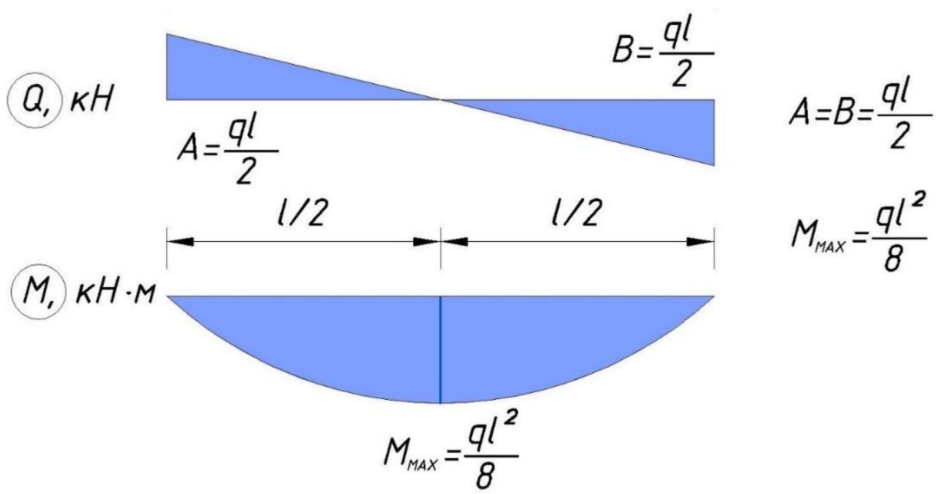


Figure 19. Distribution of bending moments and shear forces.

The 2nd case (two-span beam with distributed load over the entire span) and static scheme are shown in Figure 20 and 21 below:

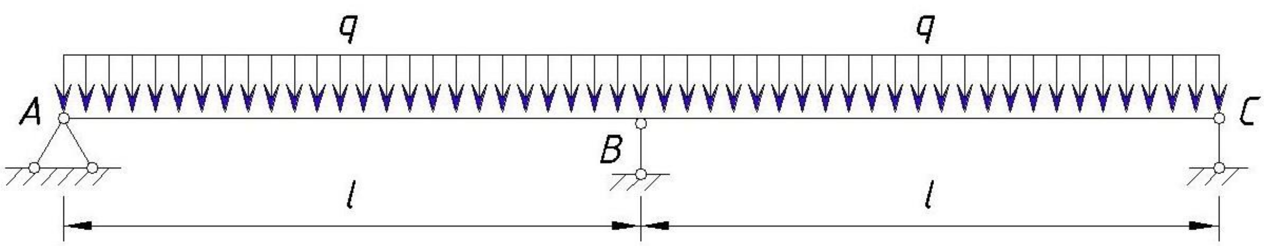


Figure 20. Two-span beam with distributed load over the entire span

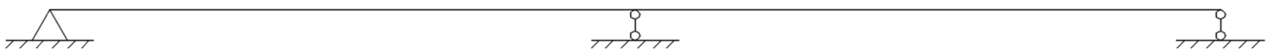


Figure 21. Two-span beam static scheme

N=3Д-2Ш-Соп=3*1-2*0-4=-1

The beam is statically indefinable. Force method used to determine internal forces by formulas (12-14).

The basic system of the method of forces is shown in Figure 22 below:

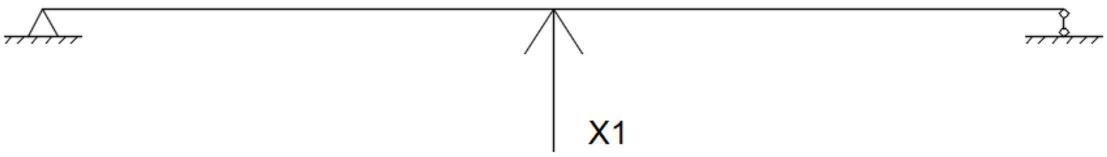


Figure 22. The basic system of the method of forces

Distribution of bending moment M01 is shown in Figure 23.

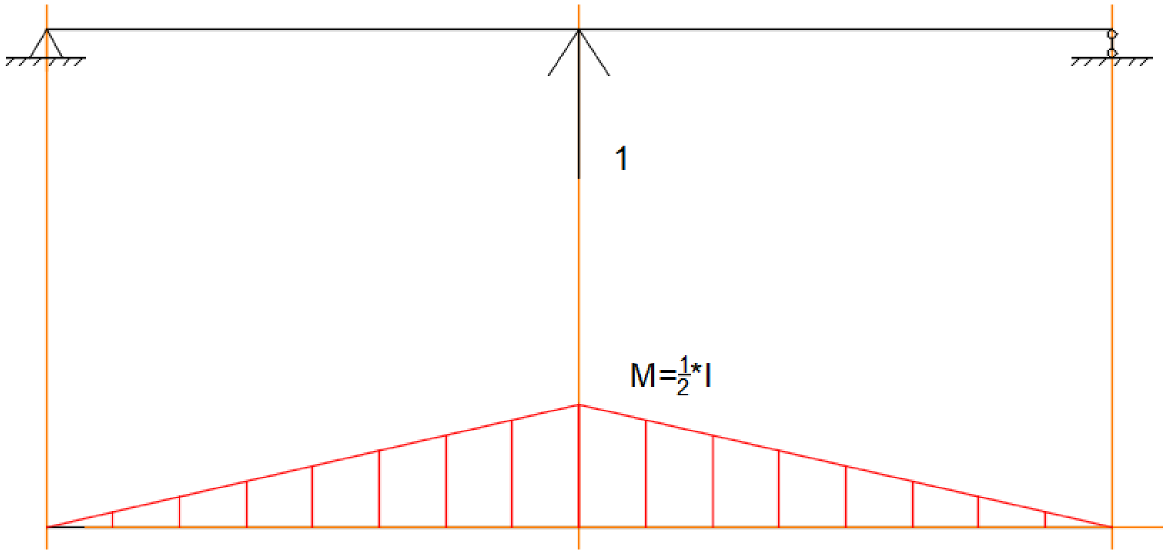


Figure 23. Distribution of bending moment M01

$$\delta_{11}X + \Delta_{1F1} = 0 \qquad (12)$$

$$\delta_{11} = \sum_{m=0}^{m} \int_{0}^{l} \frac{M_1^0 \cdot M_1^0}{EI} \cdot dx = \frac{1}{EI} \cdot \left(\frac{l_1}{6} \cdot 2 \cdot \left(\frac{1}{2} l_1\right)^2\right) \cdot 2 = \frac{1}{EI} \frac{l_1^3}{6} \quad (13)$$

Distribution of bending moment M0F is shown in Figure 24.

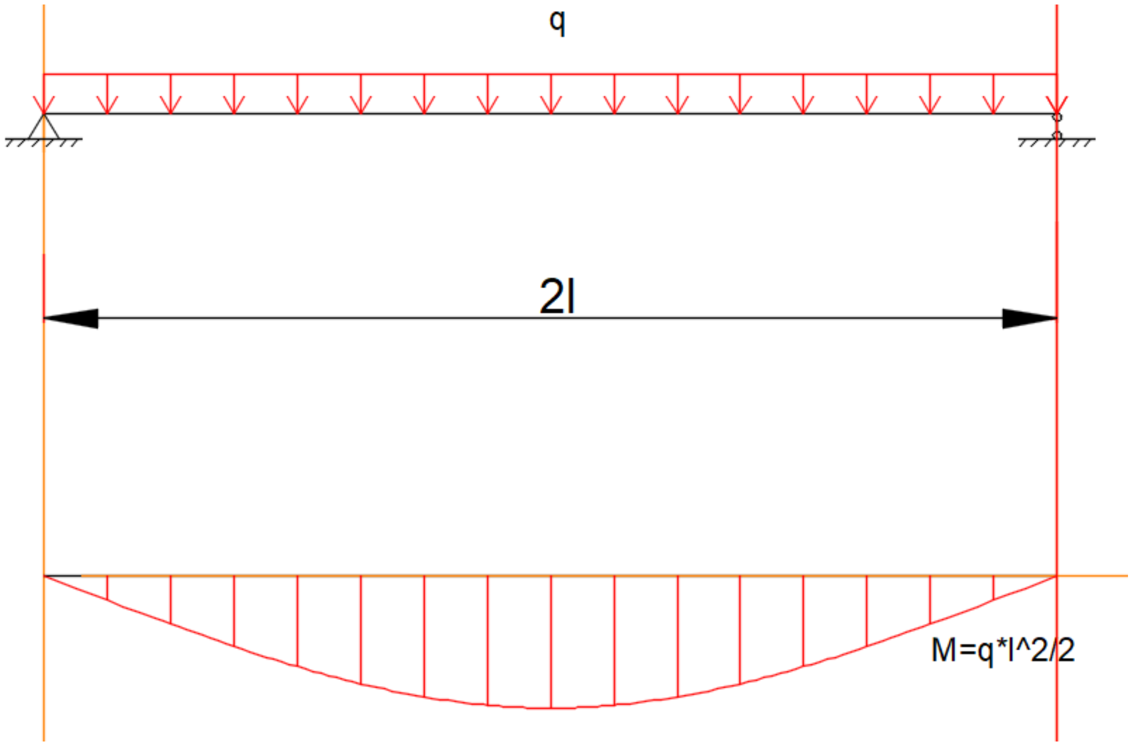


Figure 24. Distribution of bending moment M0F

$$\Delta_{1F1} = \sum_{m=0}^{m} \int_{0}^{l} \frac{M_1^0 \cdot M_F^0}{EI} \cdot dx = \frac{1}{EI} \cdot \left(\frac{l_1}{6} \cdot \left(\frac{1}{2} l_1 \cdot \frac{q {l_1}^2}{2} + 4hf\right)\right) \cdot 2 \quad (14)$$

$h = \frac{1}{4} l_1$, $f = \frac{1}{2} * \frac{q {l_1}^2}{2} + \frac{q {l_1}^2}{8}$

$$\Delta_{1F1} = \frac{1}{EI} \cdot \left(2 * \frac{l_1}{6} \cdot \left(\frac{q {l_1}^3}{4} + 4 * \frac{1}{4} l_1 \cdot \frac{3 q {l_1}^2}{8}\right)\right) = \frac{1}{EI} \frac{l_1}{3} * \frac{5 q {l_1}^3}{8} = \frac{5 q {l_1}^4}{EI * 3 * 8} = \frac{5 q {l_1}^4}{24EI}$$

$$\frac{l_1^3}{6EI} * X_1 - \frac{5 q {l_1}^4}{24EI} = 0$$

$$\frac{l_1^3}{6} * X_1 = \frac{5 q {l_1}^4}{24}$$

$$X_1 = \frac{5 q l_1}{4} = R_B$$

$$M_F = M_1^0 X_1 + M_F^0$$

Distribution of bending moment Mф is shown in Figure 25 below:

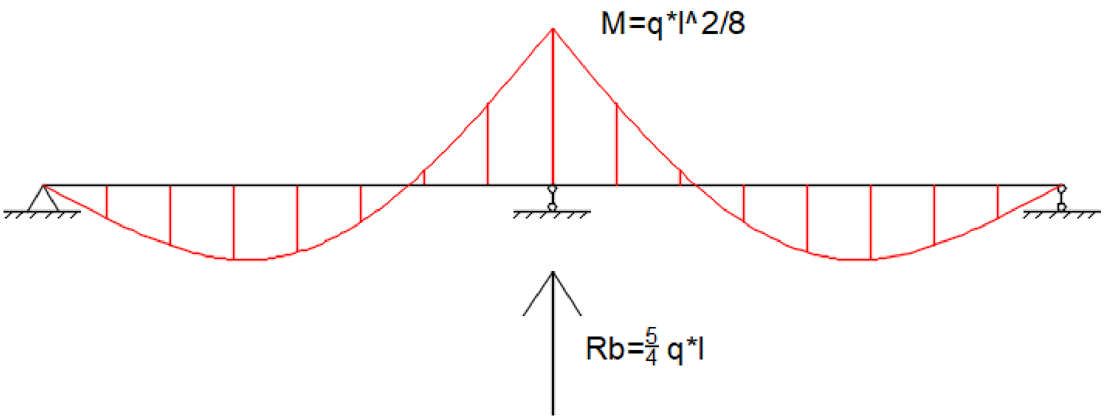


Figure 25. Distribution of bending moment Mф

$$\sum Y = 0$$

$$2R_A + R_B = 2ql_1$$

$$2R_A = 2ql_1 - R_B = 2ql_1 - R_B = 2ql_1 - \frac{5ql_1}{4}$$

$$R_A = R_c = \frac{3}{8}ql_1$$

$$M_{(D)} = M_{(E)} = M_{\left(\frac{3}{8}l_1\right)} = \frac{3}{8}ql_1 * \frac{3}{8}ql_1 - \frac{q\left(\frac{3}{8}l_1\right)^2}{2}$$

$$M_{(D)} = (\frac{3}{8})^2 ql_1 * \left[ql_1^2 \quad - \frac{ql_1^2}{2}\right] = \frac{9}{64}\frac{ql_1^2}{2} = \frac{9}{128}ql_1^2$$

Distribution of bending moments and shear forces is shown in Figure 26 below.

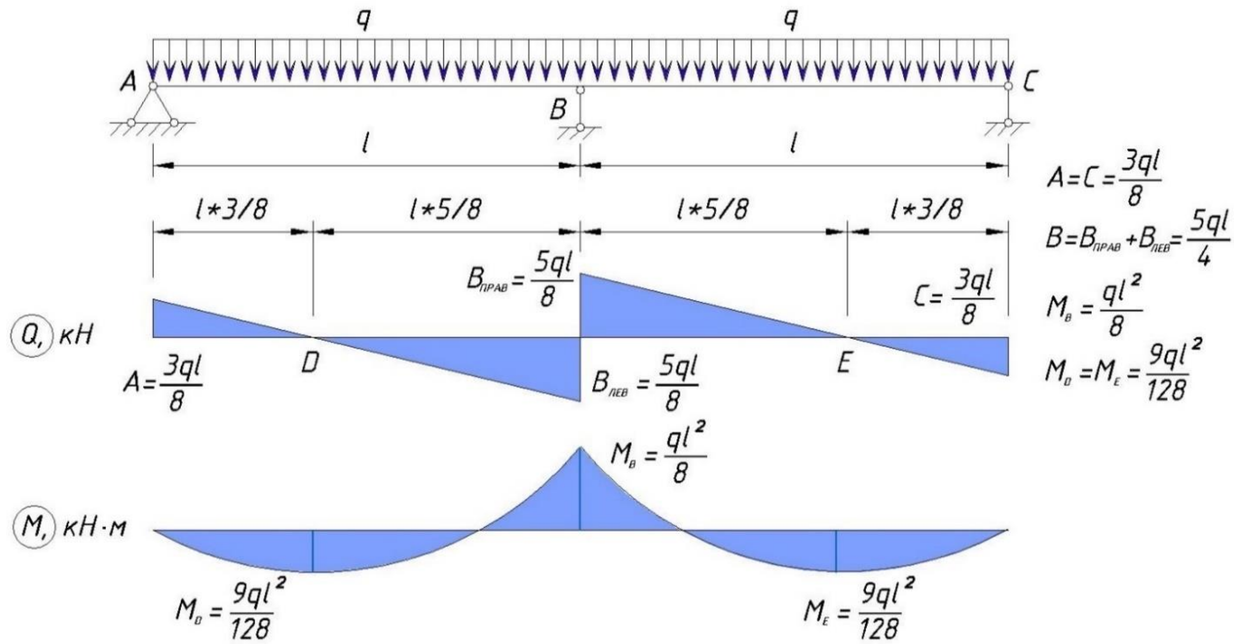


Figure 26. Distribution of bending moments and shear forces.

The 3rd case (two-span beam with distributed load on one span) is shown in Figure 27 below.

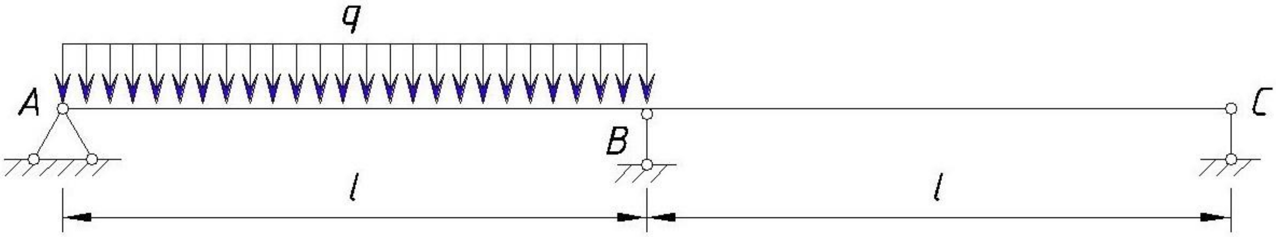


Figure 27. Two-span beam with distributed load on one span.

N=3Д-2Ш-Соп=3*1-2*0-4=-1

The beam is statically indefinable.

Figure 28 shows the basic system of the force method.

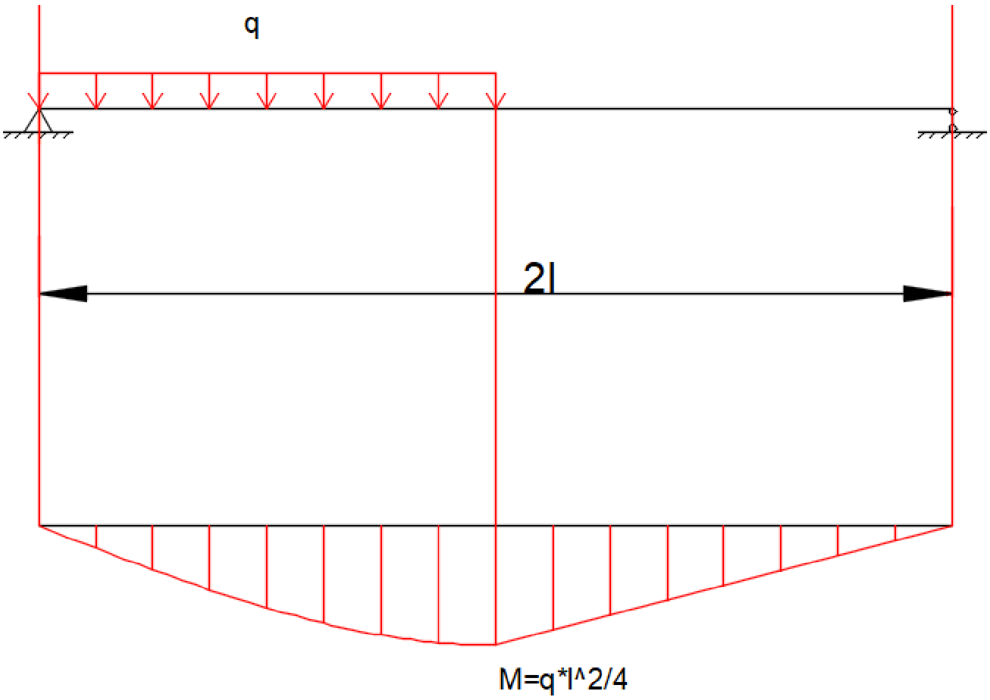


Figure 28. Distribution of bending moment M0F

$$\sum M_A = 0$$

$$R_c \cdot 2l_1 = \frac{ql_1^2}{2}$$

$$R_c = \frac{1}{4} ql_1$$

$$\sum Y = 0$$

$$R_A + R_c = ql_1$$

$$R_A = \frac{3}{4} ql_1$$

$$\delta_{11} X + \Delta_{1F2} = 0$$

$$\delta_{11} = \sum_{m=0}^{m} \int_0^l \frac{M_1^0 \cdot M_1^0}{EI} \cdot dx = \frac{1}{EI} \cdot \left(\frac{l_1}{6} \cdot 2 \cdot \left(\frac{1}{2} l_1\right)^2\right) \cdot 2 = \frac{1}{EI} \frac{l_1^3}{6}$$

$$\Delta_{1F} = \sum_{m=0}^{m} \int_0^l \frac{M_1^0 \cdot M_{F2}^0}{EI} \cdot dx$$

$$\Delta_{1F} = -\frac{1}{EI}\cdot\frac{l_1}{6} * 2\cdot\frac{ql_1^2}{4} * \frac{1}{2}l_1 - \frac{1}{EI}\cdot\frac{l_1}{6}\left(\frac{ql_1^2}{4}\cdot\frac{1}{2}l_1 + 4\cdot\frac{1}{2}\cdot\frac{1}{2}l_1\left(\frac{1}{2}\frac{ql_1^2}{4} + \frac{ql_1^2}{8}\right)\right) =$$

$$= -\frac{ql_1{}^4}{24EI} - \frac{3ql_1{}^4}{48EI} = -\frac{5ql_1{}^4}{48EI}$$

$$\frac{l_1^3}{6EI} * X_1 - \frac{5ql_1{}^4}{48EI} = 0$$

$$\frac{l_1^3}{6} * X_1 = \frac{5ql_1{}^4}{48}$$

$$X_1 = \frac{5ql_1}{8} = R_B$$

$$M_F = M_1^0 X_1 + M_F^0$$

Figure 29 shows distribution of bending moment Mф.

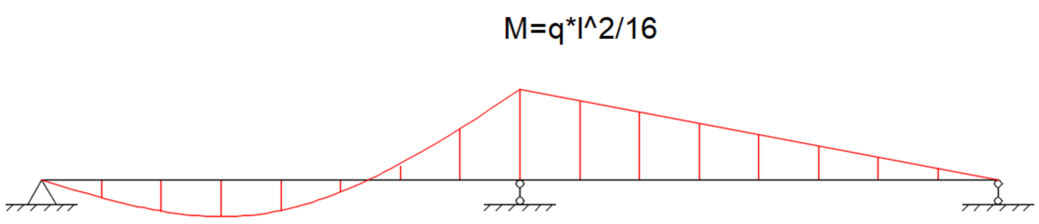


Figure 29. Distribution of bending moment Mф

$$R_c = -\frac{1}{16}ql_1$$

$$\sum Y = 0$$

$$R_A + R_B + R_c = ql_1$$

$$R_A = ql_1 - R_C - R_B = ql_1 + \frac{1}{16}ql_1 - \frac{5ql_1}{8} = \frac{7ql_1}{16}$$

On the AB part bending moment is as follow:

$$M_{(x)} = \frac{7}{16}ql_1 * x - \frac{qx^2}{2}$$

$$M'_{(x0)} = \frac{7}{16}ql_1 - qx_0 = 0$$

$$x_0 = \frac{7}{16}l_1$$

$$M_{\left(x_0=\frac{7}{16}l_1\right)} = \frac{7}{16}ql_1 * \frac{7}{16}l_1 - \frac{q(\frac{7}{16}l_1)^2}{2}$$

$$M_{\left(\frac{7}{16}l_1\right)} = \frac{49ql_1^2}{256} - \frac{1}{2}\frac{49ql_1^2}{256} = \frac{49ql_1^2}{512}$$

Figure 30 shows distribution of bending moments and shear forces.

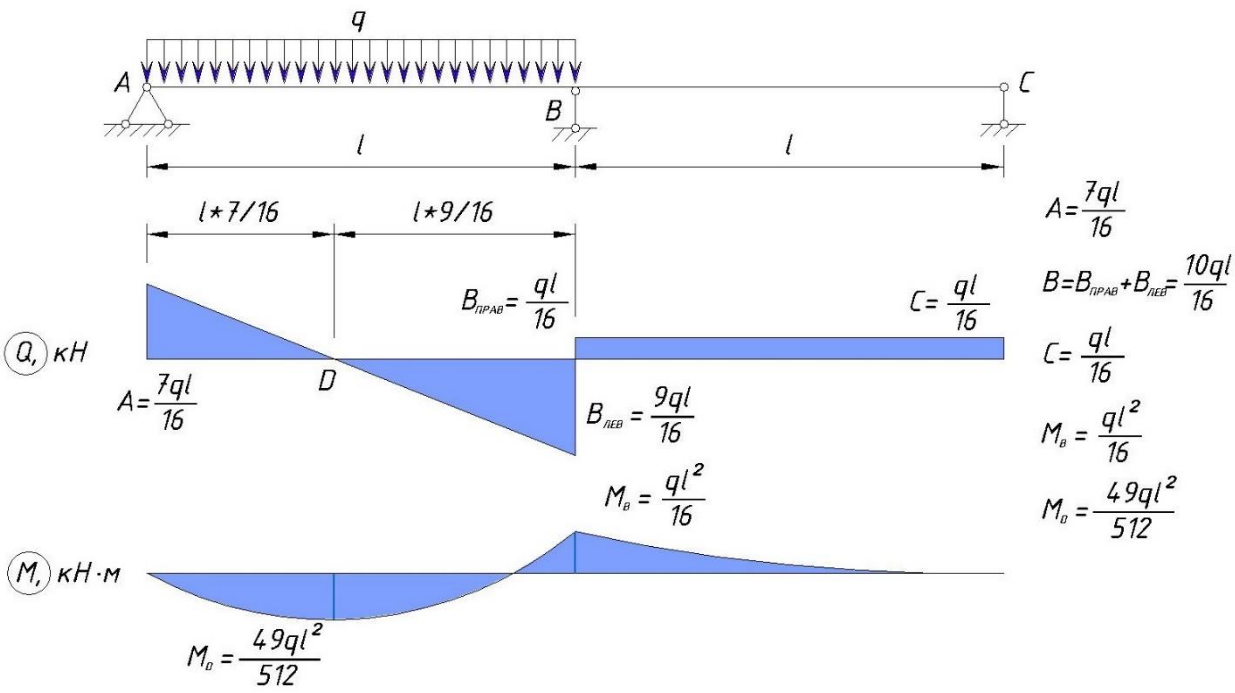


Figure 30. Distribution of bending moments and shear forces.

The 4th case (cantilever beam with distributed load over the entire span) is shown in Figure 31. The beam is statically definable. Distribution of bending moments and shear forces (Figure 31). On the console part bending moment and shear force are calculated as per formulas (15-16)

$$M = \frac{ql^2}{2} \qquad (15)$$

$$Q = ql \qquad (16)$$

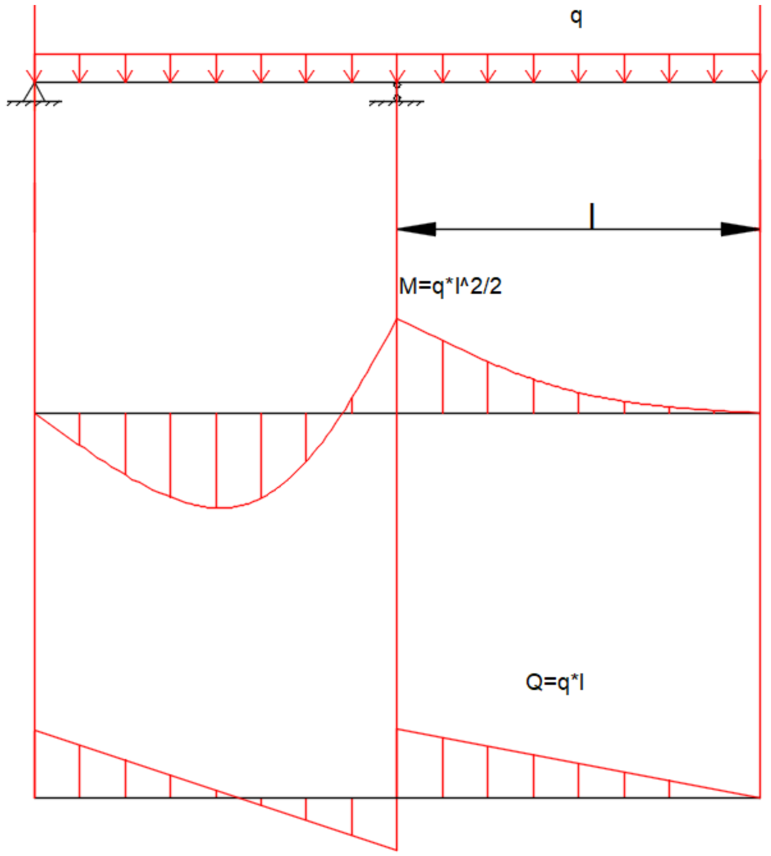


Figure 31. Distribution of bending moments and shear forces.

Defining deflections for the Service Limit State

Deflections are calculated as per the formula 17 using Russian norms.

Deflection determination taking into account the influence of shear deformations from transverse forces:

$$f = \frac{f_0}{k}\left[1 + c\left(\frac{h}{l}\right)^2\right] \qquad (17)$$

The maximum deflection of the articulated and cantilever bending elements of constant and variable sections f should be determined by the formula 17.

f_0 - found by integrating the differential equation.

- f_0 - deflection of a beam of constant cross section h without taking into account shear deformations.
- k- a coefficient that takes into account the effect of cross section height variability, taken equal to 1 for beams of constant cross section;

- c - coefficient taking into account the effect of shear deformations on shear force;
- h - maximum section height;
- l - beam span.

Figure 32 shows the values of the coefficients k and c for the basic design schemes of beams.

Таблица Е.4

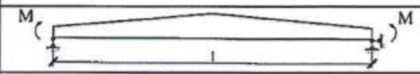
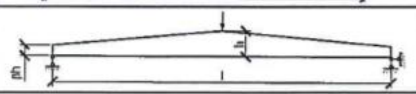
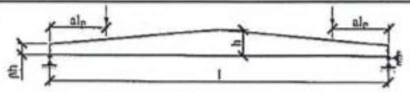
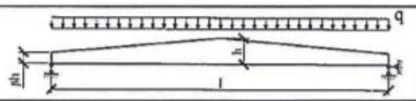
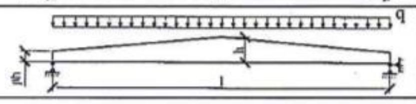
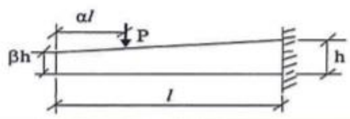
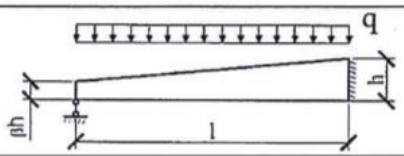
Поперечное сечение балки	Расчетная схема	k	c
Прямо-угольное		β	0
То же		$0{,}23 + 0{,}77\beta$	$16{,}4+7{,}6\beta$
»		$0{,}5\alpha + (1 - 0{,}5\alpha)\beta$	$[45 - 24\alpha(1-\beta) + 3\beta] \times \frac{1}{3 - 4\alpha^2}$
»		$0{,}15 + 0{,}85\beta$	$15{,}4 + 3{,}8\beta$
Двутав-ровое		$0{,}4 + 0{,}6\beta$	$(45{,}3 + 6{,}9\beta)\gamma$
Прямо-угольное		$0{,}23 + 0{,}77\beta + 0{,}6\alpha(1-\beta)$	$[8{,}2 + 2{,}4(1-\beta)\alpha + 3{,}8\beta] \times \frac{1}{(2+\alpha)(1-\alpha)}$
То же		$0{,}35 + 0{,}65\beta$	$5{,}4 + 2{,}6\beta$
Примечание – γ – отношение площади поясов к площади стенки двутавровой балки (высота стенки принимается между центрами тяжести поясов).			

Figure 32. The values of the coefficients k and c for the basic design schemes of beams

(11)

C for rectangular section with distributed load: c=15,4+3,8*1=19,2

F=f0/1(1+19.2*(h/l) ^2)

The deflection of the beam f0 is determined by integrating the approximate differential equation (formulas (18-23)).

$$EIw''(x) = -M(x) \qquad (18)$$

$$EIw'(x) = -\int M(x)\,dx + C_1 \qquad (19)$$

$$EIw\ \ (x) = -\iint M(x)\,dx\,dx + C_1x + D_1 \qquad (20)$$

For the console section, the maximum deflection will be at the edge of the console (Figure 33).

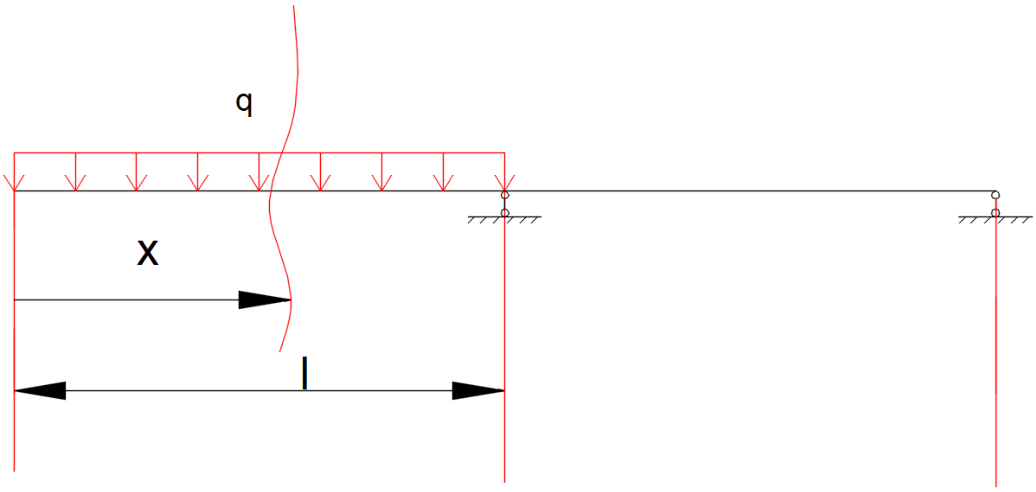


Figure 33. Console static scheme

$$EIw''(x) = -M(x) = \frac{qx^2}{2}$$

$$EIw'(x) = -\int M(x)\,dx + C_1 = \frac{qx^3}{6} + C_1$$

$$EIw\ \ (x) = -\iint M(x)\,dx\,dx + C_1x + D_1 = \frac{qx^4}{24} + C_1x + D_1$$

For x=l w=0,$\theta = 0$

$EIw\ \ (l) = \frac{ql^4}{24} + C_1 l + D_1 = 0, D_1 = \frac{ql^4}{8}$

$EIw'(l) = \frac{ql^3}{6} + C_1 = 0,\ C_1 = -\frac{ql^3}{6}$

$$EIw\ \ (x) = \frac{qx^4}{24} - \frac{ql^3}{6}x + \frac{ql^4}{8}$$

$$EIw\ \ (0) = \frac{q0^4}{24} - \frac{ql^3}{6}0 + \frac{ql^4}{8} = \frac{ql^4}{8}$$

On the Figure 34 you can see Static scheme for the deflection calculation in a case of a span beam with a distributed load.

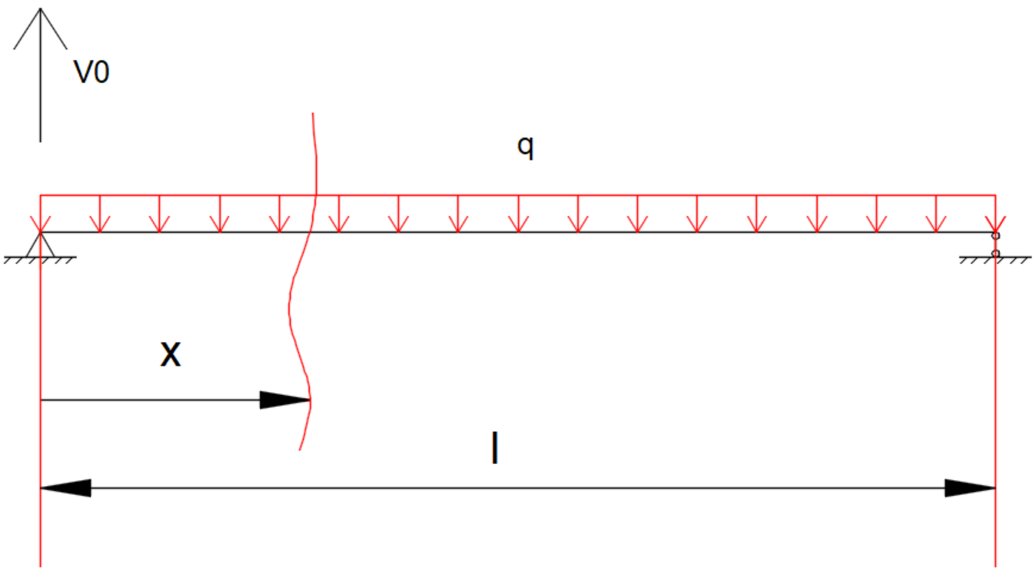


Figure 34. Static scheme

$$EIw''(x) = -M(x) = -V_0 x + \frac{qx^2}{2}$$

$$EIw'(x) = -\int M(x)\,dx + C_1 = -\frac{V_0 x^2}{2} + \frac{qx^3}{6} + C_1$$

$$EIw\ \ (x) = -\iint M(x)\,dx\,dx + C_1 x + D_1 = -\frac{V_0 x^3}{6} + \frac{qx^4}{24} + C_1 x + D_1$$

Deflection at the beginning of the beam $D_1 = 0$, determination C_1

$$EIw\ \ (l) = 0$$

$$EIw\ \ (l) = -\frac{V_0 l^3}{6} + \frac{ql^4}{24} + C_1 l + D_1 = 0$$

$$C_1 = \frac{l^2}{6}(V_0 - \frac{ql}{4})$$

Then the equation of deflection for a beam with a distributed load span l

$$EIw\ \ (x) = -\frac{V_0 x^3}{6} + \frac{qx^4}{24} + \frac{l^2}{6}\left(V_0 - \frac{ql}{4}\right)x \qquad (21)$$

On the Figure 35 you can see Static scheme for the deflection calculation in a case of a single-span beam with a distributed load.

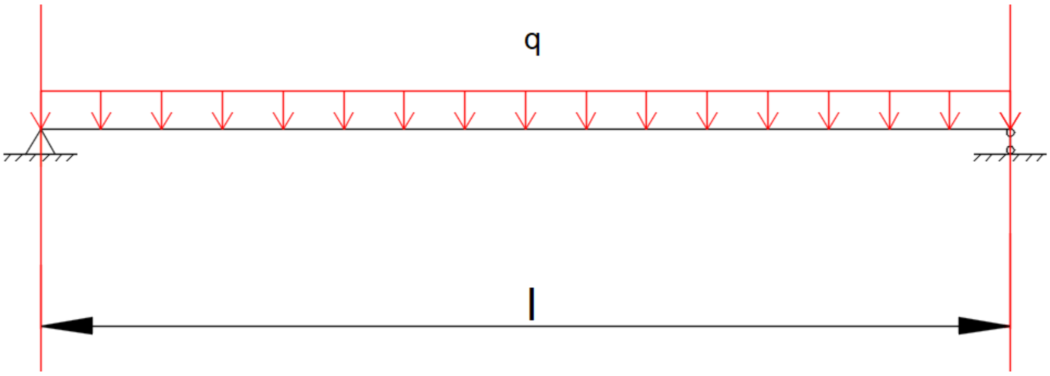


Figure 35. Static scheme of single-span beam

$$V_0 = \frac{ql}{2} \qquad (14)$$

$$EIw \quad (x) = -\frac{qlx^3}{12} + \frac{qx^4}{24} + \frac{ql^3}{24}x$$

For a single-span beam, the maximum deflection will be in the middle of the span

$$EIw_{max}(x) = EIw \quad (l/2)$$

On the Figure 36 you can see Static scheme for the deflection calculation in a case of a a two-span beam with a distributed load of 2 spans of the beam.

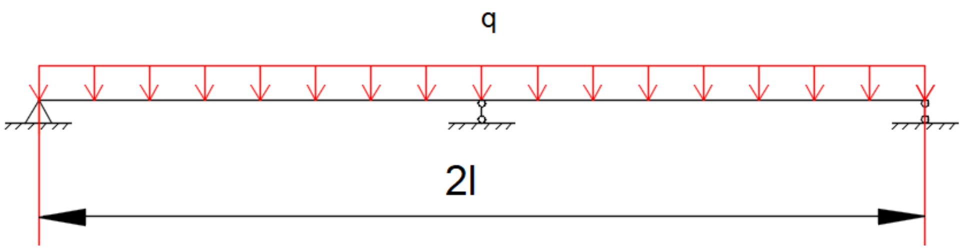


Figure 36. Static scheme for the case of a two-span beam with a distributed load of 2 spans of the beam

$$V_0 = \frac{3ql}{8} \qquad (22)$$

$$EIw \quad (x) = -\frac{qlx^3}{16} + \frac{qx^4}{24} + \frac{ql^3}{48}x$$

Extremum of the deflection function is as follow:

$$EIw'(x) = -\frac{3qlx^3}{16} + \frac{qx^3}{6} + \frac{ql^3}{48} = 0$$

$$x^3 \; - 1.125lx^2 \; + 0.125l^3 = 0$$

$$x \approx 0.4215l$$

$$EIw_{max}(x) \approx EIw \quad (0.4215l)$$

On the Figure 37 you can see Static scheme for the deflection calculation in a case of a two-span beam with a distributed load of 1 span of the beam for 1 span of the beam.

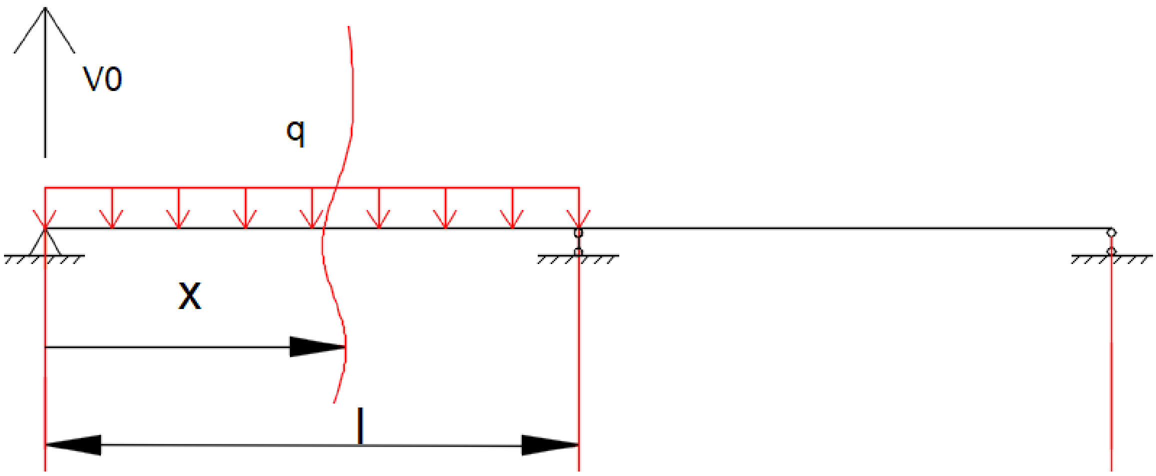


Figure 37. Static scheme for the case of a two-span beam with a distributed load of 1 span of the beam for 1 span

$$V_0 = \frac{7ql}{16} \qquad (23)$$

$$EIw \quad (x) = -\frac{7qlx^3}{16 * 6} + \frac{qx^4}{24} + \frac{ql^3}{32}x$$

Extremum of the deflection function is as follow:

$$EIw'(x) = -\frac{7qlx^3}{32} + \frac{qx^3}{6} + \frac{ql^3}{32} = 0$$

$$x^3 \; - 1.3125lx^2 \; + 0.1875l^3 = 0$$

$$x \approx 0.4724l$$

$$EIw_{max}(x) \approx EIw\ \ (0.4724l)$$

On the Figure 38 you can see Static scheme for the deflection calculation in a case of a two-span beam with a distributed load of 1 beam span for 2 span of the beam.

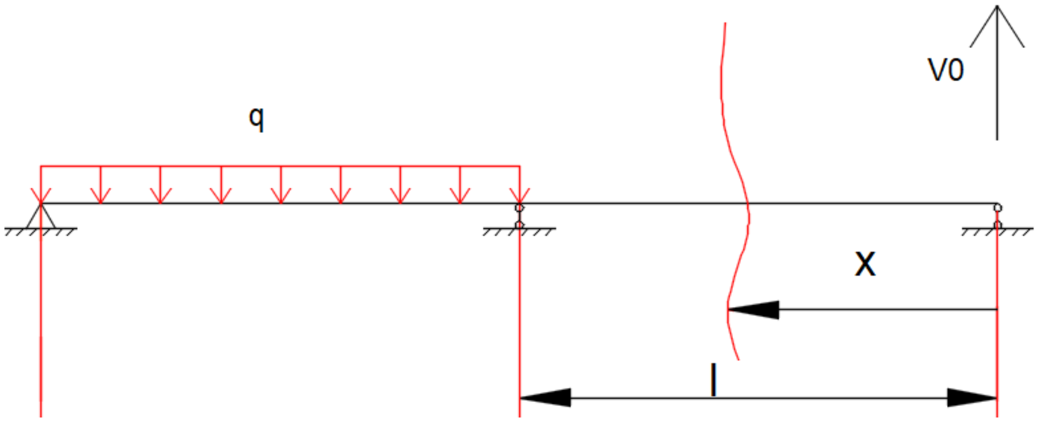


Figure 38. Static scheme for the case of a two-span beam with a distributed load of 1 beam span for second span.

$$EIw''(x) = -M(x) = -\frac{ql}{16}x$$

$$EIw'(x) = -\int M(x)\,dx + C_1 = -\frac{ql}{32}x^2 + C_1$$

$$EIw\ \ (x) = -\iint M(x)\,dx\,dx + C_1x + D_1 = -\frac{ql}{32*3}x^3 + C_1x + D_1$$

Deflection at the beginning of the beam $D_1 = 0$, for x=l w=0,

Determination of C_1 :

$EIw\ \ (l) = -\frac{ql}{32*3}l^3 + C_1l = 0,\ C_1 = \frac{ql^3}{96}$

$$EIw\ \ (x) = -\frac{ql}{32*3}x^3 + \frac{ql^3}{96}x$$

Extremum of the deflection function is as follow:

$$EIw'(x) = -\frac{ql}{32}x^2 + \frac{ql^3}{96} = 0$$

$$\frac{ql}{32}x^2 = \frac{ql^3}{96}$$

$$x\ \ = \frac{l}{\sqrt{3}} \approx 0.577l$$

$$\mathrm{EIw_{max}(x) \approx EIw \quad (0.577l)}$$

The equations for determining the shear forces, bending moments, as well as deflections are recorded in an excel file for further calculation.

According to SP 20.13330.2011 “Loads and actions” (21)

Appendices D, D.2 ultimate deflections are l / 120-l / 250.

Ultimate deflection l/350 was taken to design.

5.4 Calculation of the bending stiffness EI

Determination of design modulus of elasticity for wood materials (11):

$$E^{II} = E_{\text{ср}} \cdot m_{дл,E} \cdot \prod m_i \quad (24)$$

E^{II}- design modulus of elasticity for wood materials

$E_{\text{ср}}$ - Average modulus of elasticity in bending,

Пm- composition of correction factors,

E0cp=10000 MPa

According to table 4 for mode D $\mathrm{m_{дл,E}} = 1$

Пm= mв*mт*mб*mсл*mс.с.

For board layer thickness 25 mm: Пm= mв*mт*mб*mсл*mс.с=0,9*1*1*1,1*1=0,99

$$\mathrm{E}^{"} = 10000 * 0{,}99\mathrm{MPa} = 9900\mathrm{MPa}$$

For board layer thickness 33 mm: Пm= mв*mт*mб*mсл*mс.с=0,9*1*1*1 *1=0,9

$$\mathrm{E}^{"} = 10000 * 0{,}9\mathrm{MPa} = 9000\mathrm{MPa}$$

For board layer thickness 43 mm: Пm= mв*mт*mб*mсл*mс.с=0,9*1*1*0,95*1=0,855

$$\mathrm{E}^{"} = 10000 * 0{,}855\mathrm{MPa} = 8550\mathrm{MPa}$$

I- reduced moment of inertia is calculated by the method of reduced section.

The stiffness of the reduced section is multiplied by 0.7 (11).

5.5 Calculation in Excel

According to theory, an excel file was compiled to calculate the internal stress of the composite section. General definition of excel sheet is shown below. More information about excel sheet is shown in APPENDIX 1.

Data should be entered in green cells. Excel can be divided into two parts.

The first 50 lines determine the internal stresses of the sigma tau based on the geometry, elastic modulus, and loads M Q N (Figure 39,40).

Input parameters: E1, E2, h1, h2, h3, b, M, Q, N.

Output parameters: chart σ(h), τ(h).

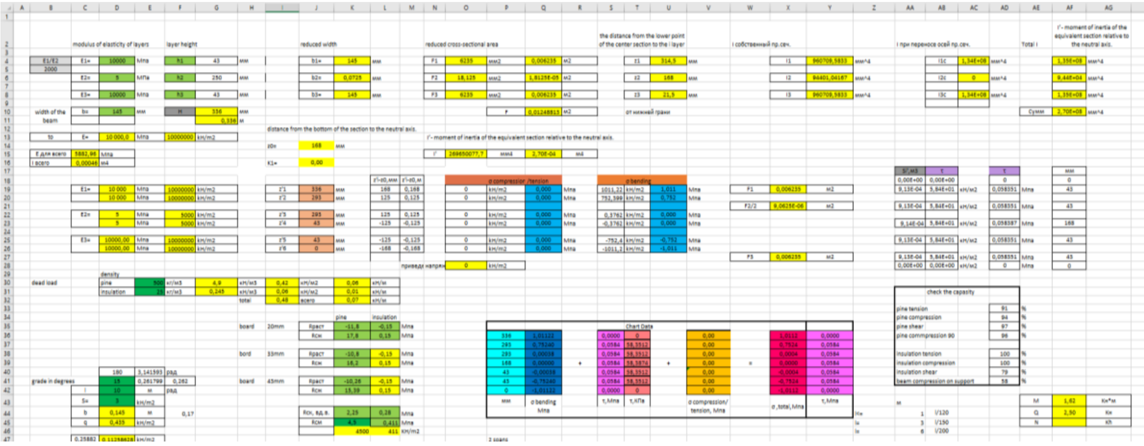


Figure 39. The first part of excel

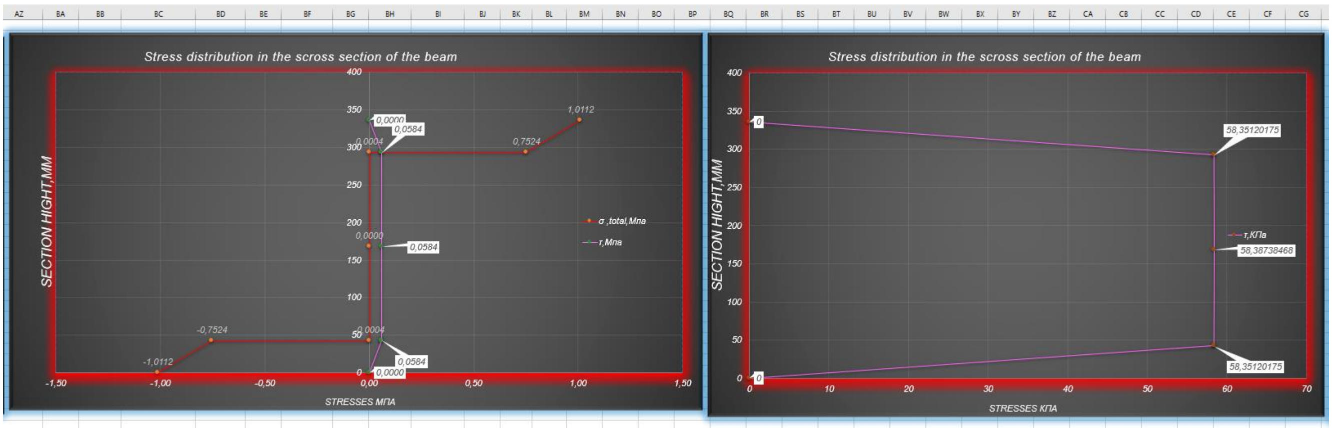


Figure 40. The first part of excel

In lines 50-66, M, Q and f determined for different support conditions, loads, and spans (Figure 41-43).

Input parameters: l, q, EI.

Output parameters: M, Q, f.

2 spans

распределенная на всю | A | распределенная на половину | ultimate diflection l/ 350

1 variant M Q | maximum MQf

			EI,kh*m2	kH/m2	q,kH/м	M1	Q1	x	f0,прогиб,mm	f,прогиб,mm	M2	Q2	M3	Q3	x1	f0,прогиб1,mm	f,прогиб1,mm	x2	f0,прогиб2,mm	f,прогиб2,mm	l	пр. Пр.,мм	M	Q	f
		2697	161	1,5	0,2	1,0	0,8	2,508	9,04	9,60	0,73	0	0,5	0,7	2,81078	15,28	16,21	3,43315	6,69	7,10	5,95	17	1,0	0,8	0,79
				2,0	0,3	1,0	1,0	2,23	7,56	8,15	0,77	0	0,5	0,9	2,4996627	12,78	13,77	3,0531443	5,60	6,03	5,29	15,11832	1,0	1,0	1,35
0,7	EI for pine 20	1869		2,5	0,4	1,1	1,1	2,054	6,82	7,44	0,82	0	0,5	1,0	2,3023209	11,52	12,57	2,8121066	5,05	5,51	4,87	13,92477	1,1	1,1	1,36
				3,0	0,4	1,1	1,2	1,937	6,47	7,14	0,87	0	0,6	1,1	2,1707597	10,93	12,06	2,6514148	4,79	5,28	4,60	13,12907	1,1	1,2	1,07
0,7	EI for pine 33	1699		3,5	0,5	1,2	1,4	1,839	6,14	6,84	0,92	0	0,6	1,2	2,0611254	10,38	11,56	2,517505	4,55	5,06	4,36	12,46598	1,2	1,4	0,91
				4,0	0,6	1,3	1,5	1,761	5,90	6,64	0,96	0	0,6	1,4	1,9734179	9,97	11,21	2,4103771	4,37	4,91	4,18	11,93551	1,3	1,5	0,73
0,7	EI for pine 43	1614		4,5	0,6	1,3	1,6	1,683	5,54	6,29	0,99	0	0,6	1,5	1,8857104	9,36	10,63	2,3032492	4,10	4,66	3,99	11,40505	1,3	1,6	0,77
				5,5	0,8	1,4	1,8	1,565	5,07	5,87	1,05	0	0,7	1,7	1,7541493	8,57	9,92	2,1425574	3,75	4,35	3,71	10,60935	1,4	1,8	0,69
				6,5	0,9	1,5	2,1	1,487	4,89	5,74	1,12	0	0,7	1,9	1,6664418	8,25	9,69	2,0354295	3,62	4,25	3,53	10,07888	1,5	2,1	0,39
				7,5	1,1	1,5	2,3	1,409	4,54	5,42	1,16	0	0,8	2,0	1,5787343	7,67	9,16	1,9283017	3,36	4,01	3,34	9,548411	1,5	2,3	0,39
				8,5	1,2	1,6	2,5	1,37	4,60	5,54	1,24	0	0,8	2,2	1,5348806	7,77	9,368	1,8747377	3,41	4,10	3,25	9,283178	1,6	2,5	-0,1

left part | rigth part

x,maximum deflection place | шаг 5 см | 0,05 м

Figure 41. M, Q and f determined for different design patterns, loads, and spans

49			2 variant					B	1 span		
50											
51	EI,kh*m2	kH/m2	q,kH/м	M1,кН*м	Q1,кН	M2,кН*м	Q2,кН	l,м	x	f0,прогиб,мм	f,прогиб,мм	пр. Пр,мм
52	161	1,5	0,2	0	0,55	0,7	0	5,1057477	2,55287	11,79	12,77	14,59
53		2,0	0,3	0	0,67	0,8	0	4,6880047	2,344	11,20	12,31	13,39
54		2,5	0,4	0	0,79	0,9	0	4,3630935	2,18155	10,53	11,72	12,47
55		3,0	0,4	0	0,88	0,9	0	4,0845982	2,0423	9,71	10,97	11,67
56		3,5	0,5	0	0,98	1,0	0	3,8989346	1,94947	9,42	10,76	11,14
57		4,0	0,6	0	1,07	1,0	0	3,7132711	1,85664	8,86	10,25	10,61
58		4,5	0,6	0	1,16	1,0	0	3,5740234	1,78701	8,56	10,01	10,21
59		5,5	0,8	0	1,31	1,1	0	3,3	1,65	7,61	9,12	9,43
60		6,5	0,9	0	1,46	1,1	0	3,1	1,55	7,00	8,58	8,86
61		7,5	1,1	0	1,52	1,1	0	2,8	1,4	5,38	6,87	8,00
62		8,5	1,2	0	1,72	1,2	0	2,8	1,4	6,10	7,79	8,00
63												

Figure 42. M, Q and f determined for different design patterns, loads, and spans

ultimate diflection l/ 200

cantilever

3 variant | C

EI,kh*m2	kH/m2	q,kH/м	M1	Q1	M2	Q2	M3	Q3слева	Q3справа	l1	l2	fo,прогиб,мм	прогиб,мı	пр. Пр
161,39	1,48	0,21498	0	0,4	0,4	0,0	0,7	-0,2	0,5	5	2,46004	6,10	8,28	12,3
	1,98265	0,28748	0	-0,1	0,0	0,0	0,7	0,0	0,7	2	2,27438	5,96	8,45	11,3
	2,48265	0,35998	0	0,0	0,0	0,0	0,8	0,0	0,8	2	2,08871	5,31	7,94	10,4
	2,98265	0,43248	0	0,0	0,0	0,0	0,8	0,0	0,8	2	1,94947	4,84	7,60	9,7
	3,48265	0,50498	0	0,1	0,0	0,0	0,9	0,0	0,9	2	1,85664	4,65	7,57	9,2
	3,98265	0,57748	0	0,1	0,0	0,0	0,9	0,1	1,0	2	1,7638	4,33	7,35	8,8
	4,48265	0,64998	0	1,4	1,6	0,0	0,9	-0,2	1,1	5	1,67097	3,92	6,97	8,3
	5,48265	0,79498	0	0,3	0,1	0,0	1,0	0,2	1,3	2	1,57814	3,82	7,14	7,8
	6,48265	0,93998	0	0,4	0,1	0,0	1,0	0,2	1,4	2	1,48531	3,54	7,03	7,4
	7,48265	1,08498	0	0,6	0,1	0,0	1,1	0,3	1,5	2	1,39248	3,16	6,69	6,9
	8,48265	1,22998	0	0,7	0,2	0,0	1,0	0,4	1,6	2	1,29964	2,72	6,21	6,5

Figure 43. M, Q and f determined for different design patterns, loads, and spans

Thus, if you connect two parts:

Input parameters: l, q, EI, E1, E2, h1, h2, h3, b.

Output parameters: chart σ(h), τ(h), f.

The two parts are connected by connecting the output M Q (AF: 43-44) and the input M Q (Figure 44). This must be done manually.

СТАНДОТ... =AC62

	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
37	0,00		0,7524	0,0584								
38	0,00		0,0004	0,0584		insulation tension			100	%		
39	0,00	=	0,0000	0,0584		insulation compression			100	%		
40	0,00		-0,0004	0,0584		insulation shear			79	%		
41	0,00		-0,7524	0,0584		beam compression on support			58	%		
42	0,00		-1,0112	0,0000								
43	σ compression/ tension, Мпа		σ ,total,Мпа	τ,Мпа		м				M	=AC62	Кн*м
44					l<=	1	l/120			Q	2,50	Кн
45					l=	3	l/150			N		Kh
46					l=	6	l/200					
47												
48	оловину		ultimate diflection l/			350						
49												
50									maximum	MQf		
51	f0,прогиб1,mm	f,прогиб1,mm	x2	f0,прогиб2,mm	f,прогиб2,mm	l	пр. Пр.,мм	M	Q	f		EI,kh*m2
52	15,28	16,21	3,43315	6,69	7,10	5,95	17	1,0	0,8	0,79		161
53	12,78	13,77	3,0531443	5,60	6,03	5,29	15,118318	1,0	1,0	1,35		
54	11,52	12,57	2,81210659	5,05	5,51	4,87	13,924767	1,1	1,1	1,36		
55	10,93	12,06	2,65141479	4,79	5,28	4,60	13,129066	1,1	1,2	1,07		
56	10,38	11,56	2,51750495	4,55	5,06	4,36	12,465981	1,2	1,4	0,91		
57	9,97	11,21	2,41037708	4,37	4,91	4,18	11,935514	1,3	1,5	0,73		
58	9,36	10,63	2,30324921	4,10	4,66	3,99	11,405047	1,3	1,6	0,77		
59	8,57	9,92	2,14255741	3,75	4,35	3,71	10,609346	1,4	1,8	0,69		
60	8,25	9,69	2,03542954	3,62	4,25	3,53	10,078879	1,5	2,1	0,39		
61	7,67	9,16	1,92830167	3,36	4,01	3,34	9,5484113	1,5	2,3	0,39		
62	7,77	9,368	1,87473773	3,41	4,10	3,25	9,2831777	1,6	2,5	-0,1		
63	left part			rigth part								
64												

Figure 44. Connection of the output M Q (AF: 43-44) and the input M Q.

Checking the capacity and deflection made by entering material data (K-L) :(35-45) in the cells AD: (33-41) (Figure 45).

	V	W	X	Y	Z	AA	AB	AC	AD	AE
22	Мпа									
23	Мпа					9,14E-04	5,84E+01	кН/м2	0,058387	Мпа
24										
25	Мпа					9,13E-04	5,84E+01	кН/м2	0,058351	Мпа
26	Мпа									
27		F3	0,006235	м2		9,13E-04	5,84E+01	кН/м2	0,058351	Мпа
28						0,00E+00	0,00E+00	кН/м2	0	Мпа
29										
30										
31							check the capasity			
32										
33						pine tension			91	%
34						pine compression			94	%
35						pine shear			97	%
36	0,00		1,0112	0,0000		pine commpression 90			96	%
37	0,00		0,7524	0,0584						
38	0,00		0,0004	0,0584		insulation tension			100	%
39	0,00	=	0,0000	0,0584		insulation compression			100	%
40	0,00		-0,0004	0,0584		insulation shear			79	%
41	0,00		-0,7524	0,0584		beam compression on support			58	%
42	0,00		-1,0112	0,0000						
43	σ compression/		σ ,total,Мпа	τ,Мпа		м				M

Figure 45. Checking the capacity

In lines 68-83, the values of the span length of the beams were obtained in theoretical calculation (Figure 46).

insulation	150	150	150	200	200	200	250	250	250
board	20	20	20	20	20	20	20	20	20
	A	B	C	A	B	C	A	B	C
1	7,5	6,5	3	8,5	7,5	3,6	10	9	4,1
1,5	6,5	6	2,7	8	7	3,2	9	8	3,7
2	6	5,5	2,4	7,3	6,5	2,9	8	7	3,3
2,5	5,6	5	2,3	6,8	6	2,7	7,6	6,8	3
3	5,4	4,8	2,2	6,5	5,5	2,6	7,2	6,5	2,9
3,5	5	4,5	2,1	6	5,2	2,4	7	6,2	2,6
4	5	4,2	2	5,7	5	2,3	6,5	6	2,5
5	4,6	4	1,8	5,5	4,8	2,1	6	5,5	2,4
6	4,3	3,7	1,7	5,1	4,5	2	5,5	5,2	2,2
7	4,1	3,5	1,6	4,7	4,2	1,9	5,1	5	2,1
8	4	3,3	1,5	4,4	4	1,8	4,8	4,7	2

insulation	150	150	150	200	200	200	250	250	250
board	33	33	33	33	33	33	33	33	33
	A	B	C	A	B	C	A	B	C
1	8,8	7,8	3,7	10,3	9	4,3	11,5	10,2	4,9
1,5	7,9	7	3,2	9,3	8,2	3,9	10,5	9,2	4,4
2	7,3	6,5	3,1	8,6	7,5	3,5	9,6	8,6	4,1
2,5	6,8	6,1	2,9	8	7	3,3	9,1	8	3,7
3	6,3	5,8	2,7	7,6	6,6	3,1	8,7	7,6	3,5
3,5	6	5,5	2,6	7,3	6,3	3	8,3	7,3	3,4
4	5,8	5	2,4	7	6,2	2,8	7,9	7	3,2
5	5,5	4,7	2,3	6,5	5,6	2,5	7,4	6,5	3
6	5,1	4,4	2,1	6,1	5,3	2,4	7	6,2	2,8
7	5	4,3	2	5,8	5	2,3	6,5	5,9	2,6
8	4,8	4,2	1,9	5,5	4,8	2,2	6,1	5,5	2,5

insulation	150	150	150	200	200	200	250	250	250
board	43	43	43	43	43	43	43	43	43
	A	B	C	A	B	C	A	B	C
1	9,6	8,5	4,1	11	9,9	4,8	12,6	11	5,3
1,5	8,7	7,7	3,7	10	9	4,3	11,4	10,1	4,9
2	8	7,1	3,4	9,4	8,3	4	10,5	9,4	4,5
2,5	7,6	6,7	3,1	8,8	7,8	3,7	9,9	8,8	4,2
3	7,2	6,4	3	8,3	7,4	3,5	9,4	8,4	4
3,5	6,8	6,1	2,8	8	7,1	3,4	9	8	3,8
4	6,5	5,8	2,6	7,7	6,6	3,2	8,6	7,7	3,6
5	6,1	5,4	2,5	7,1	6,3	3	8	7,2	3,4
6	5,8	5,1	2,4	6,7	6	2,8	7,6	6,8	3,2
7	5,5	4,9	2,3	6,4	5,7	2,6	7,2	6,4	3
8	5,2	4,7	2,2	6,1	5,4	2,5	7	6,2	2,8

Figure 46. Theoretical values of the span length

After the experimental determination of the deflection, its calculated value was reduced by a factor of 10, the coefficient k2 in part 7 (Figure 47).

90				
91				
92			k2	10
93		коэффициент n		21,544347
94				
95			n^1/4	2,1544347
96				
97				

Figure 47. k2 (I: 92)

In lines 90-101, the values of the span length of the beams were obtained taking into account k2 (Figure 48).

insulation	150	150	150	200	200	200	250	250	250
board	20	20	20	20	20	20	20	20	20
	A	B	C	A	B	C	A	B	C
1	3,481	3,017	1,392	3,945	3,481	1,671	4,642	4,177	1,903
1,5	3,017	2,785	1,253	3,713	3,249	1,485	4,177	3,713	1,717
2	2,785	2,553	1,114	3,388	3,017	1,346	3,713	3,249	1,532
2,5	2,599	2,321	1,068	3,156	2,785	1,253	3,528	3,156	1,392
3	2,506	2,228	1,021	3,017	2,553	1,207	3,342	3,017	1,346
3,5	2,321	2,089	0,975	2,785	2,414	1,114	3,249	2,878	1,207
4	2,321	1,949	0,928	2,646	2,321	1,068	3,017	2,785	1,160
5	2,135	1,857	0,835	2,553	2,228	0,975	2,785	2,553	1,114
6	1,996	1,717	0,789	2,367	2,089	0,928	2,553	2,414	1,021
7	1,903	1,625	0,743	2,182	1,949	0,882	2,367	2,321	0,975
8	1,857	1,532	0,696	2,042	1,857	0,835	2,228	2,182	0,928

insulation	150	150	150	200	200	200	250	250	250
board	33	33	33	33	33	33	33	33	33
	A	B	C	A	B	C	A	B	C
1	4,085	3,620	1,717	4,781	4,177	1,996	5,338	4,734	2,274
1,5	3,667	3,249	1,485	4,317	3,806	1,810	4,874	4,270	2,042
2	3,388	3,017	1,439	3,992	3,481	1,625	4,456	3,992	1,903
2,5	3,156	2,831	1,346	3,713	3,249	1,532	4,224	3,713	1,717
3	2,924	2,692	1,253	3,528	3,063	1,439	4,038	3,528	1,625
3,5	2,785	2,553	1,207	3,388	2,924	1,392	3,853	3,388	1,578
4	2,692	2,321	1,114	3,249	2,878	1,300	3,667	3,249	1,485
5	2,553	2,182	1,068	3,017	2,599	1,160	3,435	3,017	1,392
6	2,367	2,042	0,975	2,831	2,460	1,114	3,249	2,878	1,300
7	2,321	1,996	0,928	2,692	2,321	1,068	3,017	2,739	1,207
8	2,228	1,949	0,882	2,553	2,228	1,021	2,831	2,553	1,160

insulation	150	150	150	200	200	200	250	250	250
board	43	43	43	43	43	43	43	43	43
	A	B	C	A	B	C	A	B	C
1	4,456	3,945	1,903	5,106	4,595	2,228	5,848	5,106	2,460
1,5	4,038	3,574	1,717	4,642	4,177	1,996	5,291	4,688	2,274
2	3,713	3,296	1,578	4,363	3,853	1,857	4,874	4,363	2,089
2,5	3,528	3,110	1,439	4,085	3,620	1,717	4,595	4,085	1,949
3	3,342	2,971	1,392	3,853	3,435	1,625	4,363	3,899	1,857
3,5	3,156	2,831	1,300	3,713	3,296	1,578	4,177	3,713	1,764
4	3,017	2,692	1,207	3,574	3,063	1,485	3,992	3,574	1,671
5	2,831	2,506	1,160	3,296	2,924	1,392	3,713	3,342	1,578
6	2,692	2,367	1,114	3,110	2,785	1,300	3,528	3,156	1,485
7	2,553	2,274	1,068	2,971	2,646	1,207	3,342	2,971	1,392
8	2,414	2,182	1,021	2,831	2,506	1,160	3,249	2,878	1,300

Figure 48. Values of the span length of beams taking into account k2

Span lengths results is shown in APPENDIX 2.

6. Calculation of the drainage capacity of a ventilated duct system

The republic of Karelia, the Leningrad region and the Novgorod region were considered as the place to use this composite beam. The Republic of Karelia was selected because of 1) most cities are in Karelia, 2) the northernmost territory, 3) the largest area of the region, 4) it is located near Finland and has similar snow and wind conditions.

The city of Petrozavodsk is selected.

6.1. Calculation of the drainage capacity of a ventilated duct system

According to SP 17.1330.2017 “Roofs. Updated edition of SNiP II-26-76” (22) Appendix A: A.3 3 Calculation of the drainage capacity of the system of ventilated channels and the number of aeration pipes in the combined roof of buildings and structures.

A.3.1 The amount of moisture, g /m^2, removed from the insulation through ventilated channels per a period with monthly average temperatures above 0 ° C, is calculated as per the formula (25).

$$q = \frac{fN\sum_{i=1}^{n}[(B_{2i} - B_{1i})\tau_i \cdot v_i]}{F} \qquad (25)$$

f- the cross-sectional area of the channel, m^2;

N - the number of ventilated channels in the roof area or on the entire roof;

n - the number of months with an average outdoor temperature t i> 0 ° C;

τ_i - the duration of the month, s;

Vi - monthly average air velocity in the channels, m / s;

F– the area of the roof or its section, m^2.

B2i - the moisture content of the air leaving the channels at a temperature ti, g / m^3, is calculated as per the formula (26);

$$B_{2i} = \frac{1{,}168E_k}{t_k^C + 273} \qquad (26)$$

B1i - the actual moisture content of the air entering the channels at a temperature ti and the average relative humidity of the outside air for this month (Figure 56), g / m^3, is determined by the formula (27);

$$B_{1i} = \frac{1{,}168e_{\text{н}}}{t_{\text{н}} + 273} \qquad (27)$$

The average monthly temperature of the outdoor air taking into account solar radiation is calculated as per the formula (28), (22).

$$t_{н}^{c} = t_{н} + \frac{\rho J_{рад} \psi}{\alpha_{н}} \quad (28)$$

The air temperature at the outlet of the channels is calculated as per the formula (29).

$$t_{k}^{c} = \frac{k_{в} t_{в} + k_{н} t_{н}^{с}}{k_{в} + k_{н}} \quad (29)$$

Ek - the partial pressure of saturated water vapor at the air outlet from the channels, Pa, determined by tк c (13, tables C.1 and C.2);

tск - the air temperature at the outlet of the channels (Figure 55), ° C, determined by the formula (A.3) here tв is the room air temperature, ° C;

kв, kн– heat transfer coefficients of the coating parts below the center of the channel section and above it, W / ($m^2 \cdot$ ° C);

tсн - the average monthly temperature of the outdoor air taking into account solar radiation determined by the formula A.M. Shklover taking into account the transparency of the atmosphere: (A.4) here tн is the average monthly outdoor temperature, ° C (12, table 5.1);

ρ - the heat absorption coefficient;

J rad - the average monthly value of solar radiation, W / m 2 (12, table 8.1);

Ψ – coefficient of transparency of the atmosphere (for urban development take Ψ = 0.7);

αн - heat transfer coefficient (take αn = 23 W / ($m^2 \cdot$ ° C)). (A.5) where **ен** is the average water vapor pressure of outdoor air for a given month, Pa.

The air velocity in the channel for each of n months is calculated as per the formula (30) (22 A.6).

$$v_j = v_{e_i} \cdot \sqrt{\frac{k_2 - k_1}{Л\frac{L}{d} + \Sigma\varepsilon + 1}} \quad (30)$$

where –Vei is the weighted average wind speed, m / s, at a height of 10 m for each summer month; for this calculation was adopted = 2.3 m / s;

k1, k2– aerodynamic coefficients at the channel entrance and exit are shown in Table A.3 (Figure 49).

For this example, k1 - k2 = 0.3. If the height of the building is greater than or less than 10 m, the air velocity in the channel is determined taking into account the change in wind speed in height according to the formula (31)

V'ei - the weighted average wind speed, m / s, at an altitude of less or more than 10 m for every summer month;

$$\overline{V'_{e_i}} = \overline{V_{e_i}} * \left(\frac{H}{10}\right)^{0.2} \qquad (31)$$

H– height to the entrance to the opening of the ventilation duct, m.

L - the length of the ventilated channel, m;

Т а б л и ц а А.3

Направление ветра, град	Обозначение	Аэродинамические коэффициенты при					
		$3S/H_o$			$6S/H_o$		
		L/H_o			L/H_o		
		1	2	3	4	6	8
90°	k_1	+0,6	+0,6	+0,6	+0,5	+0,5	+0,5
	k_2	-0,6	-0,2	-0,15	-0,15	-0,1	-0,05
45°	k_1	+0,2	+0,2	+0,2	+0,2	+0,2	+0,2
	k_2	-0,8	-0,6	-0,3	-0,1	-0,1	-0,1
S – длина зданий, м; H_o – высота здания от уровня земли до верха козырька, м; *L* – ширина здания, длина вентилируемых каналов, м.							

Figure 49. Aerodynamic coefficients at the channel entrance and exit (22)

Л - the coefficient of resistance to friction, is calculated as per the formula (32), (22).

$$Л = 0{,}11\Delta^{0.25} + \frac{1}{\Delta \cdot 10^4 + 90} \qquad (32)$$

Δ - the reduced roughness of the channel walls, is calculated as per the formula (33);

$$\Delta = \frac{\Delta_1 + \Delta_2}{2d} \qquad (33)$$

Δ1 and Δ2 are the absolute roughness of the material of the channel walls, taken according to table A.4;

d - the equivalent diameter of the channel, m; for a rectangular channel with sides a and b; is calculated as per the formula (34)

$$d = \frac{2ab}{a + b} \qquad (34)$$

According to this algorithm, an Excel file was compiled to automate the calculation (APPENDIX 4).

6.2. Determination of the amount of condensate formed during the winter period

The determination of the amount of condensate formed in the structure is carried out on the site (15) and shown in APPENDIX 5.

Of all the thicknesses of the boards (20.33.34 mm) and the insulation (150,200,250 mm), fulfilling the standards for thermal protection, the most amount of condensate is formed in the following version of the layer thicknesses 33,150,33 mm.

According to Russian standards, the amount of condensate formed is considered during the coldest month. For Petrozavodsk, this is January with an average temperature of -10.3 s and a humidity of 86%, 0,77 kg / m^2 of condensate is formed during January, 2,3 kg / m^2 of condensate is formed during winter period.

Also 3 options of the beam were considered.

For Petrozavodsk with the length of the vent. channel 7 m:

1) 20/200/20: 2.26 kg / m^2 of moisture is formed during winter period. 2.27 kg /m^2 of condensate is removed by 4 channels with dimensions 10 * 10 mm in a board for 1 summer period.

2) 33/200/33: 1.9 kg / m^2 of moisture is formed during winter period. 2.12 kg / m^2 of condensate is removed by 3 channels with dimensions 12 * 10 mm in size in a board for 1 summer period.

3) 43/200/43: 1.8 kg /m^2 of moisture is formed during winter period. 1.96 kg / m^2 of condensate is removed by 3 channels with dimensions 11 * 10 mm in size in a board for 1 summer period.

The drawings of the cross-section of the beams shown in APPENDIX 6.

6.3. Determination dimensions of ventilation holes in the boards

As a solution to the problem of removing excess moisture from the beam structure, ventilation of the board at the border of the inside layer of pine and the insulation is proposed.

Based on the amount of condensate formed in the winter, the size and number of rectangular ventilation channels is calculated according to the joint venture of (22), using the Excel file. 2 ventilated channels with dimensions of 20 * 10 mm in the board remove condensate 2.51 kg /m^2 for 1 summer period (Figure 50).

Paragraph 4.5 (22), which states that the height of the ventilated duct must be at least 50 mm and the minimum area of the inlet of the ventilation duct in the cornice section is 200 cm2 / m, and the outlet openings on the ridge - 100 cm^2 / m, is not observed, but using formulas theoretically possible to remove moisture from the structure during the summer period.

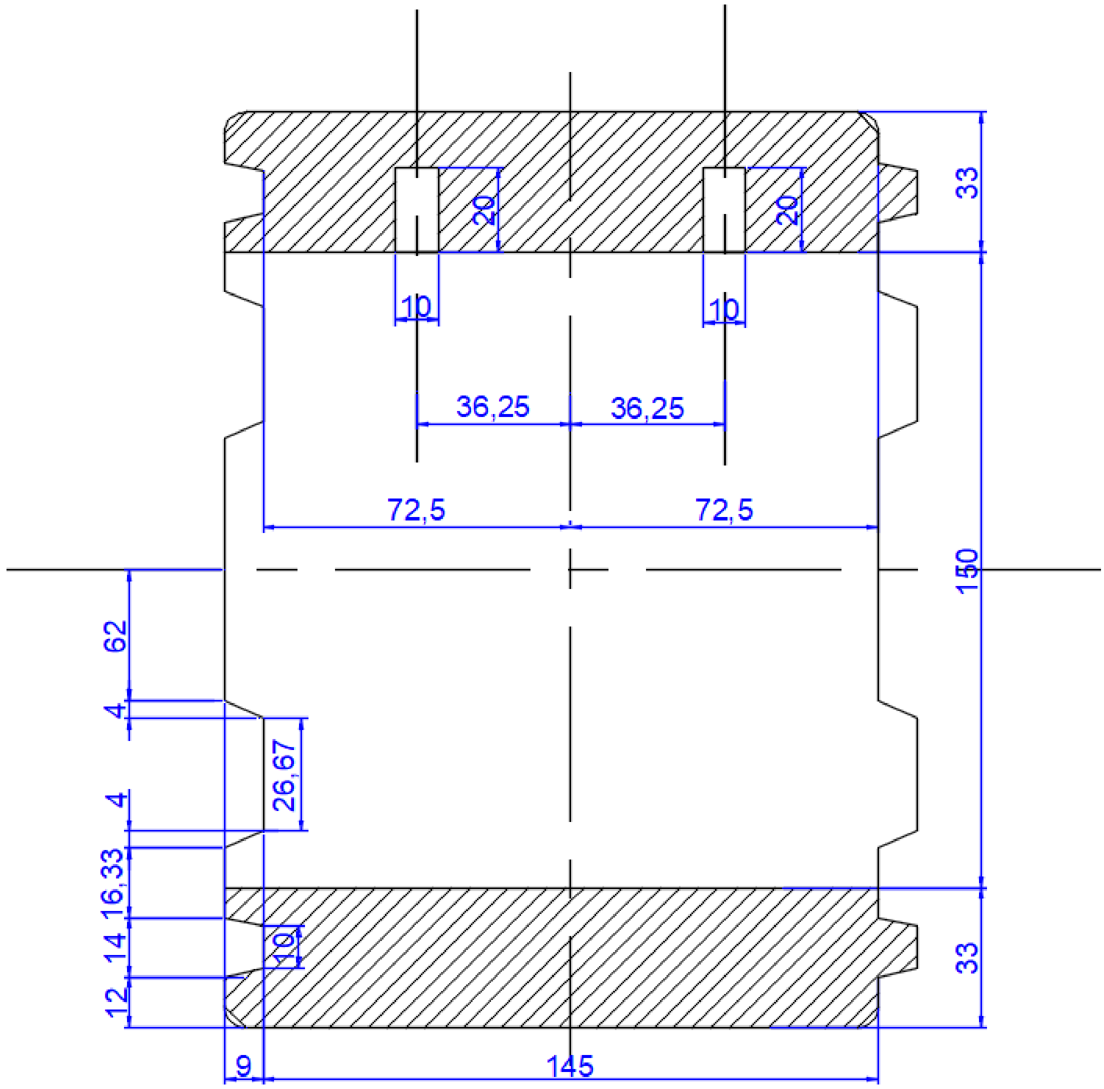


Figure 50. Cross section of the composite with ventilation channels.

7. Experimental research

According to (16) for polystyrene PPS-25 R_c=0,16 MPa

Since the tensile strength, shear, modulus of elasticity in the (16) is not given.

The mechanical characteristics of composite beams 215 x 175 x 1500 long, polystyrene PPS 25 with dimensions in compression 50 x 50 x 50mm, in tension 60 x 30 x 30mm and in shear 180 x 50 x 15mm experimentally are determined in the interdepartmental laboratory of Saint Petersburg State University of Architecture and Civil Engineering (Figure 51).

Figure 51. Samples for research

7.1 Determination of tensile strength of the polystyrene PPS-25

Samples for Determination of tensile strength are shown in Figure 52.

Figure 53 shows a device for determination of tensile strength.

The results of determination of tensile strength of the polystyrene are shown in the Graph 1 and Table 2. The value of modulus of elasticity was also received.

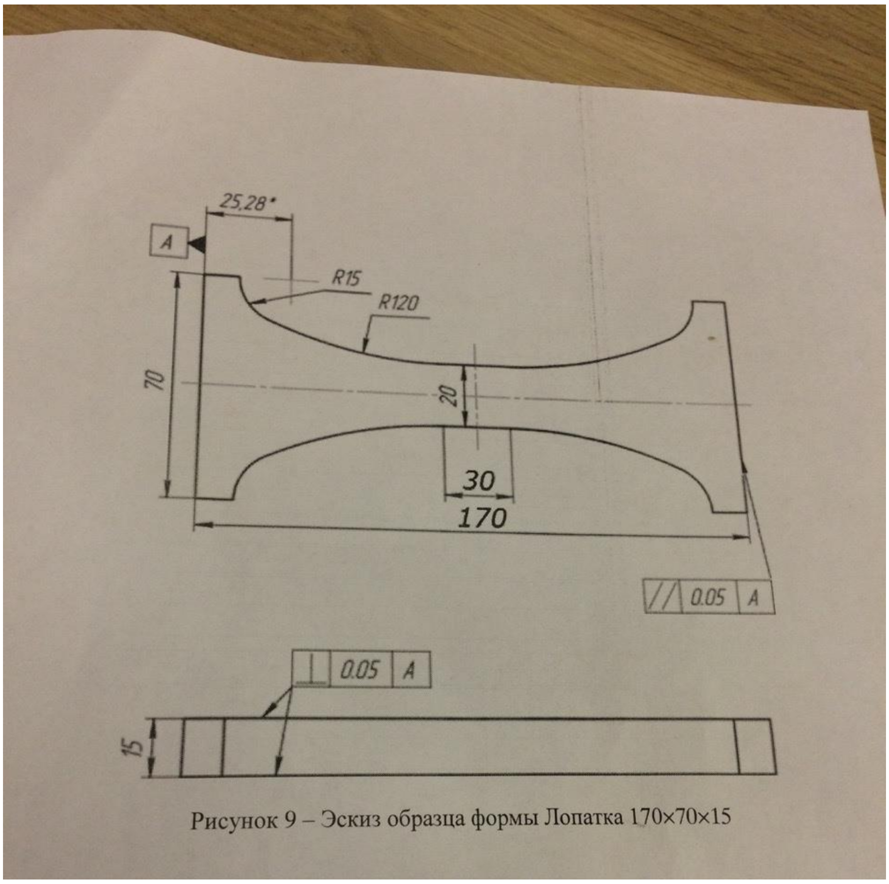


Figure 52. Samples for determination of tensile strength

Figure 53. Determination of tensile strength of the polystyrene

Graph 1. Determination of tensile strength of the polystyrene

Table 2. Determination of tensile strength of the polystyrene

	Tensile strength [MPa]	Modulus of elasticity E (Automatically) [MPa]	Maximum laod [kN]	note	thickness [mm]	Width [mm]	length [mm]	Poisson's ratio
1	0,19426	11,93910	0,06	1	15,00	20,00	25,00	1,00
2	0,20723	14,06654	0,06	2	15,00	20,00	25,00	1,00
3	0,21505	15,70567	0,06	3	15,00	20,00	25,00	1,00
4	0,20058	14,00627	0,06	4	15,00	20,00	25,00	1,00
5	0,18654	13,75799	0,06	5	15,00	20,00	25,00	1,00
6	0,20073	13,89511	0,06	mean	15,00	20,00	25,00	1,00

7.2 Determination of modulus of elasticity of the polystyrene PPS-25 in compression case

Samples for Determination of modulus of elasticity are shown in Figure 64. Figure 65 shows a device for determination of modulus of elasticity. The results of determination of modulus of elasticity are shown in Graph 2 and Table 3. The value of Compression strength was also received.

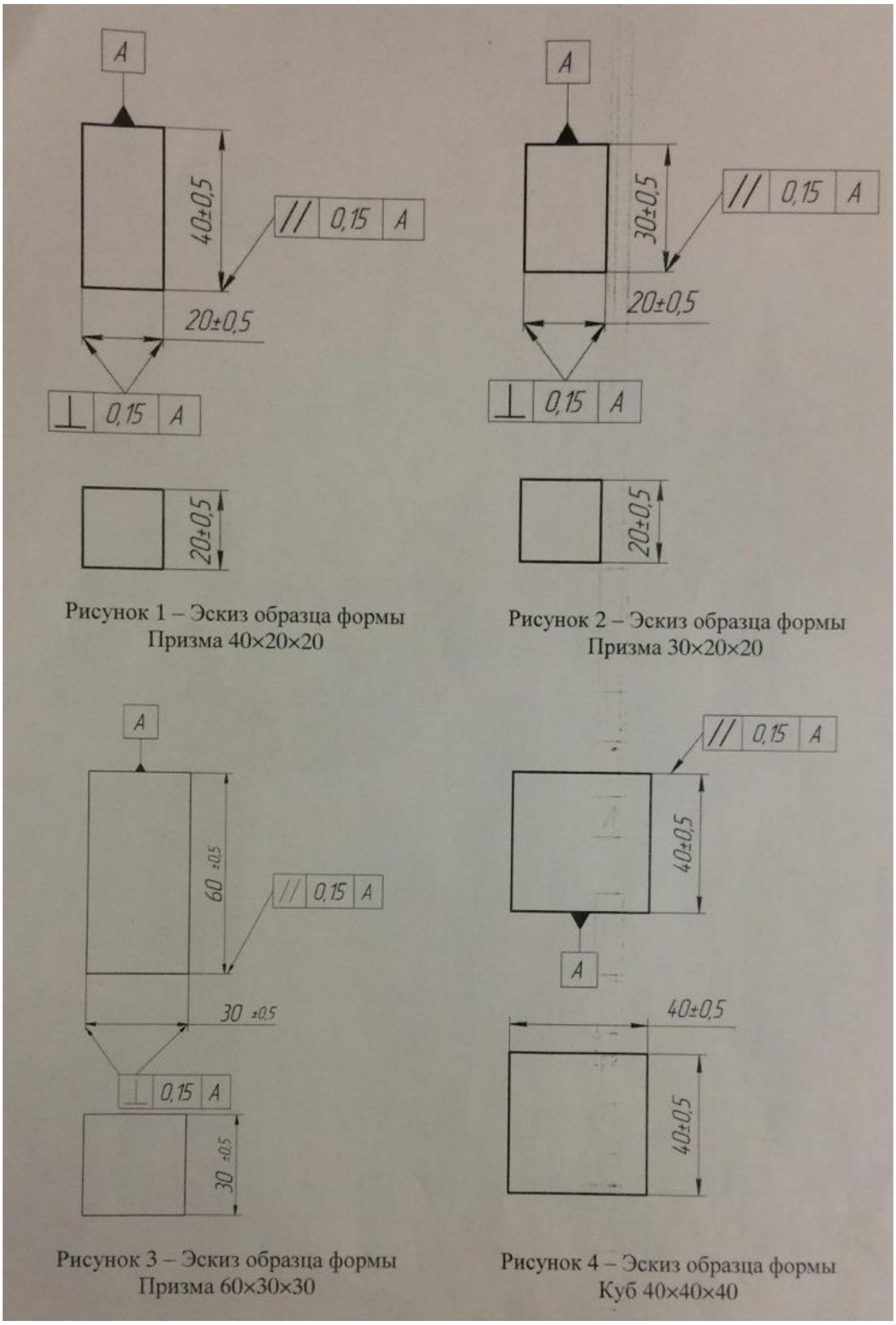
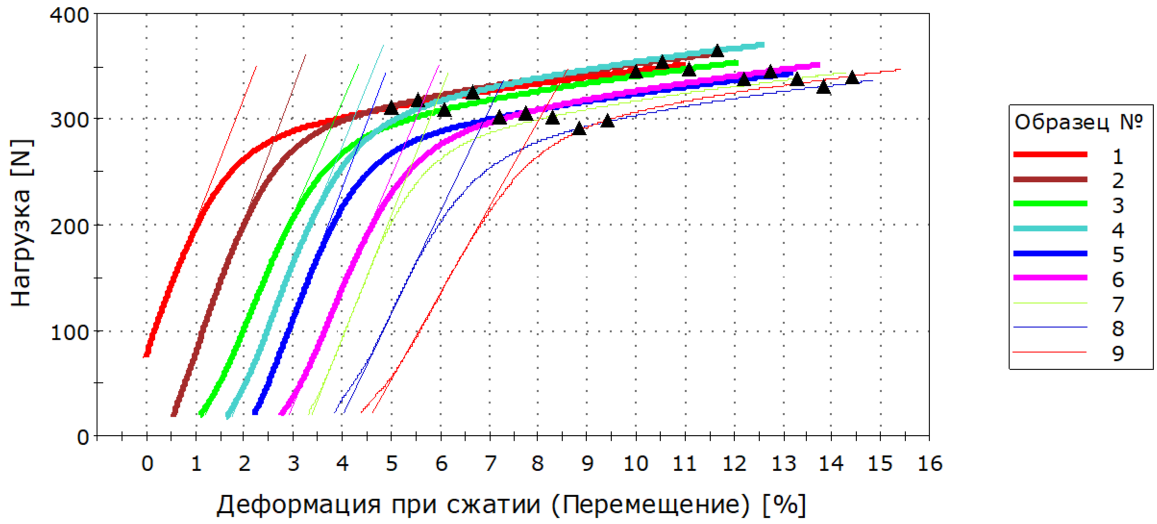


Figure 54. Samples for determination of modulus of elasticity

Figure 55. Determination of modulus of elasticity

График испытания образцов ППС-25 пенопласта, кубы 50x50x50 t=20°C



Graph 2. Determination of modulus of elasticity

Table 3. Determination of modulus of elasticity

	Maximum laod [N]	Modulus of elasticity E [MPa]	Compression strength under maximum load [MPa]	Compression strength, elongation 5% [MPa]	Poisson's ratio
1	351,70	3,92	0,14	0,12	1
2	361,83	5,05	0,15	0,13	2
3	353,99	4,42	0,15	0,13	3
4	371,54	4,68	0,15	0,14	4
5	343,86	4,72	0,14	0,13	5
6	351,69	4,15	0,14	0,13	6
7	344,89	4,49	0,14	0,12	7
8	337,43	3,63	0,14	0,12	8
9	347,49	3,02	0,14	0,12	9
mean	351,60	4,23	0,15	0,13	

7.3 Determination of shear strength of the polystyrene PPS-25

Rск is shear strength. Samples for Determination of shear strength are shown in Figure 56. Figure 57 shows a device for determination of shear strength. The results of determination of shear strength are shown in Graph 3 and Table 4.

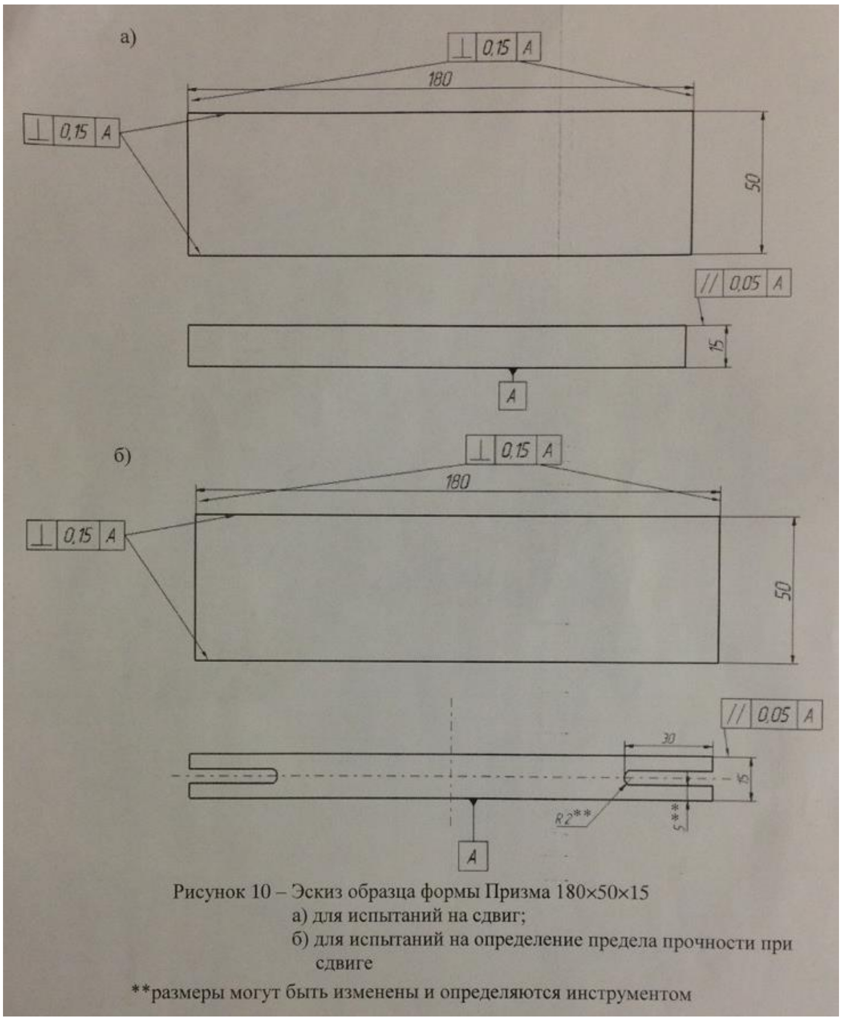
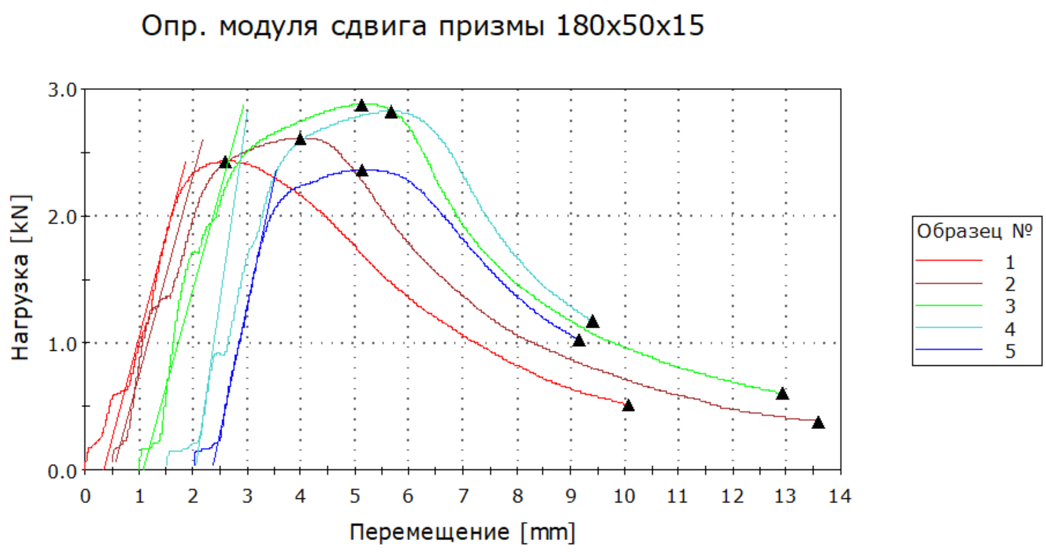


Рисунок 10 – Эскиз образца формы Призма 180×50×15
а) для испытаний на сдвиг;
б) для испытаний на определение предела прочности при сдвиге
**размеры могут быть изменены и определяются инструментом

Figure 56. Samples for determination of shear strength


Figure 57. Determination of shear strength



Graph 3. Determination of shear strength.

Table 4. Determination of shear strength.

	Maximum load P [kN]	Displacemant [mm]	Shear strength Rск [MPa]	Elongation [mm]	Thickness [mm]	Width [mm]
1	2,43	2,61	3,24	10,06	15,0	50,0
2	2,61	3,50	3,49	13,10	15,0	50,0
3	2,88	4,14	3,84	11,92	15,0	50,0
4	2,83	4,18	3,77	7,88	15,0	50,0
5	2,37	3,12	3,16	7,13	15,0	50,0
mean	2,62	3,51	3,50	10,02	15,0	50,0

	Length [mm]	note	Load [kN]
1	180,0	1	0,98
2	180,0	2	1,36
3	180,0	3	1,72
4	180,0	4	0,91
5	180,0	5	1,30
mean	180,0		1,25

7.4 Experimental determination of the nature of fracture, maximum bearing capacity

Composite beam with loading and support conditions is shown in Figure 58 and 60.

Figure 58. Composite beam with support conditions

On the Figure 59 you can see the beam on the support 100 mm.

Figure 59. Beam on the support 100 mm

On the Figure 60 you can see movement measuring instrument.

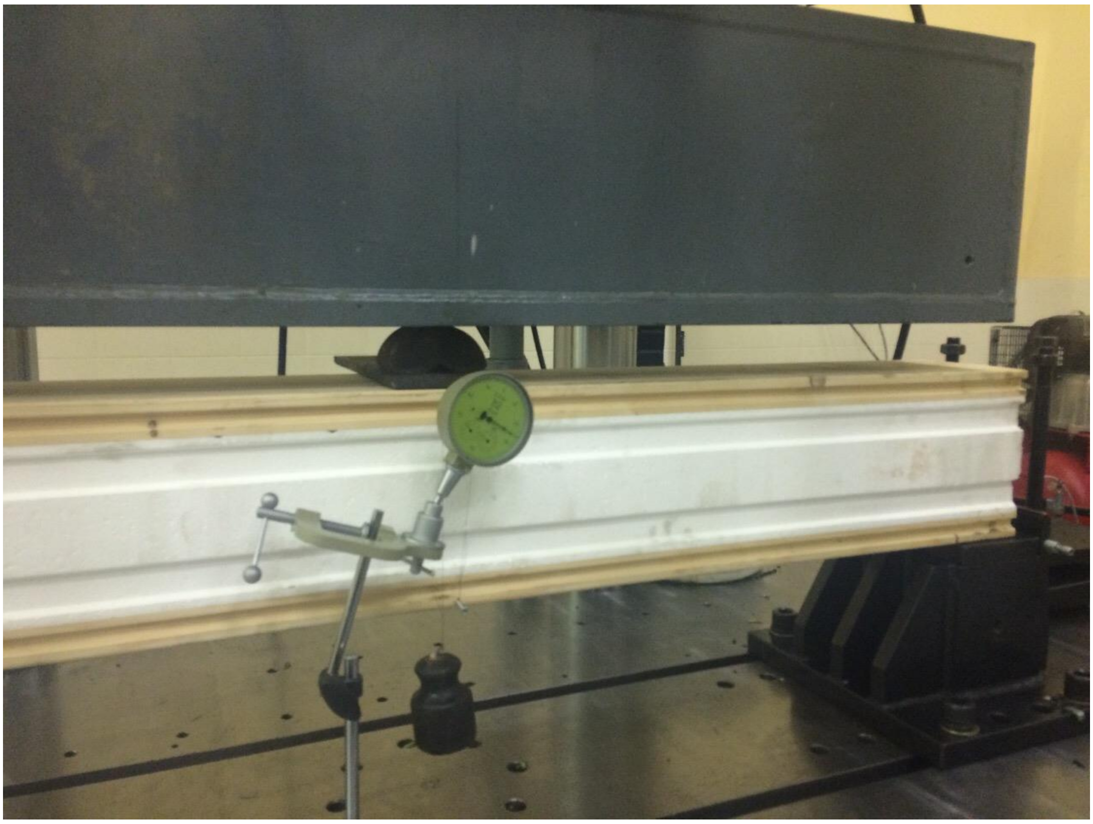


Figure 60. Composite beam with loading and support conditions

The deformed beam after loading is shown in the Figures 61-63.

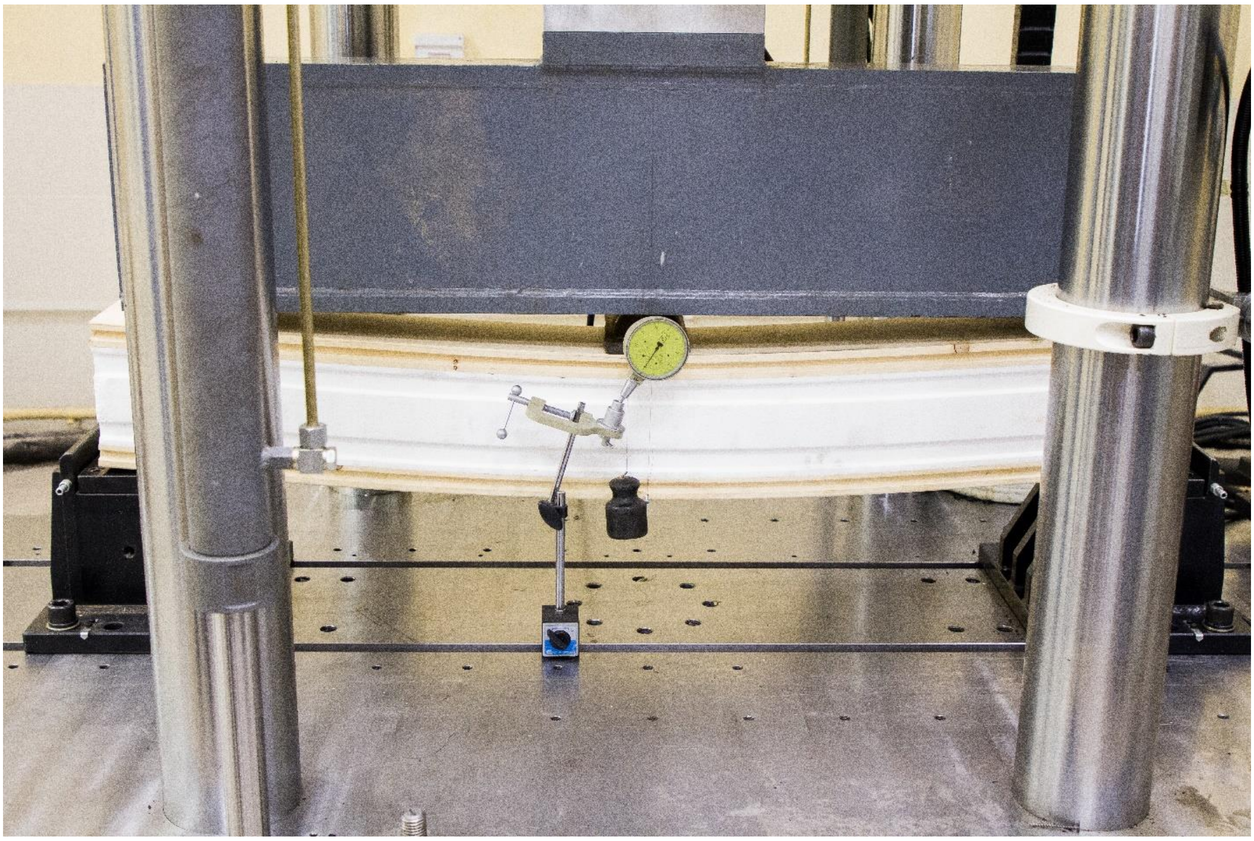


Figure 61. Deformed beam

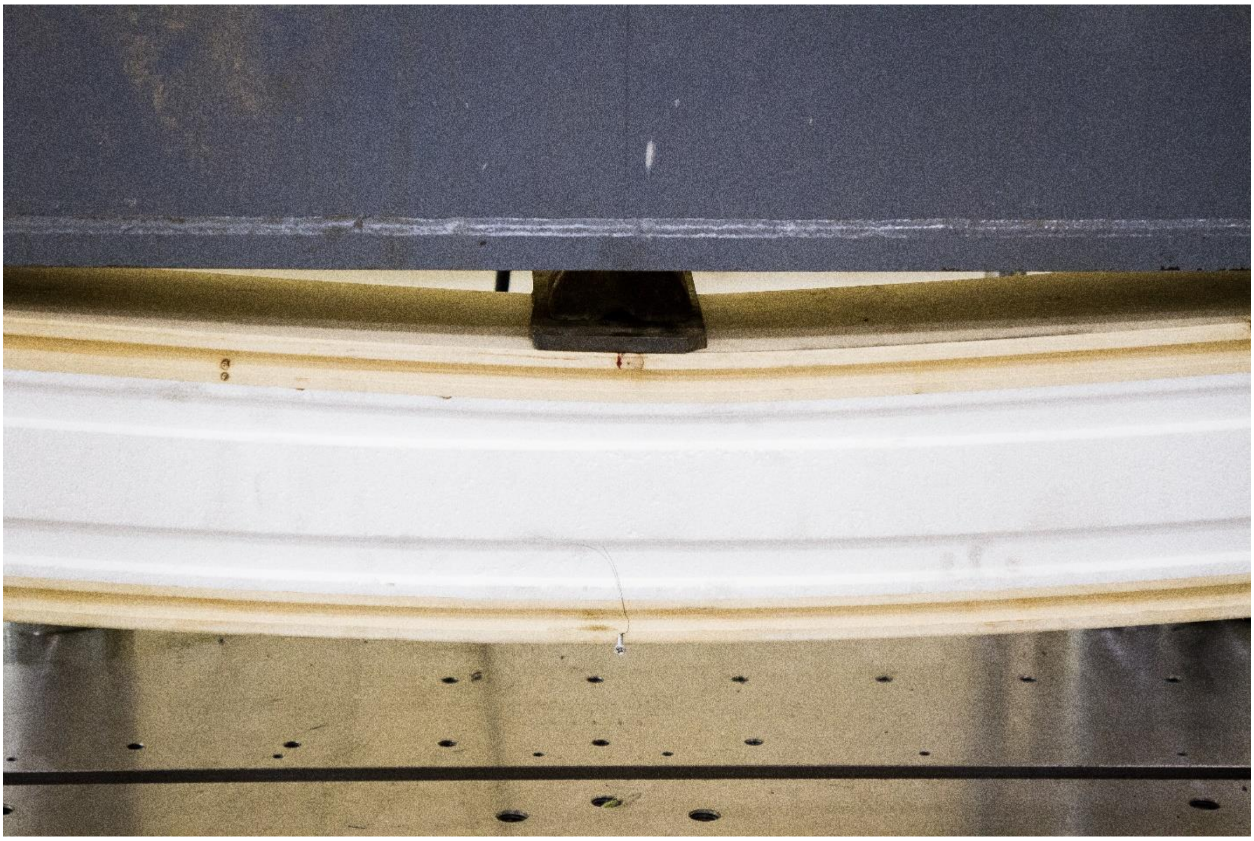


Figure 62. Deformed beam

Figure 63. Deformed beam

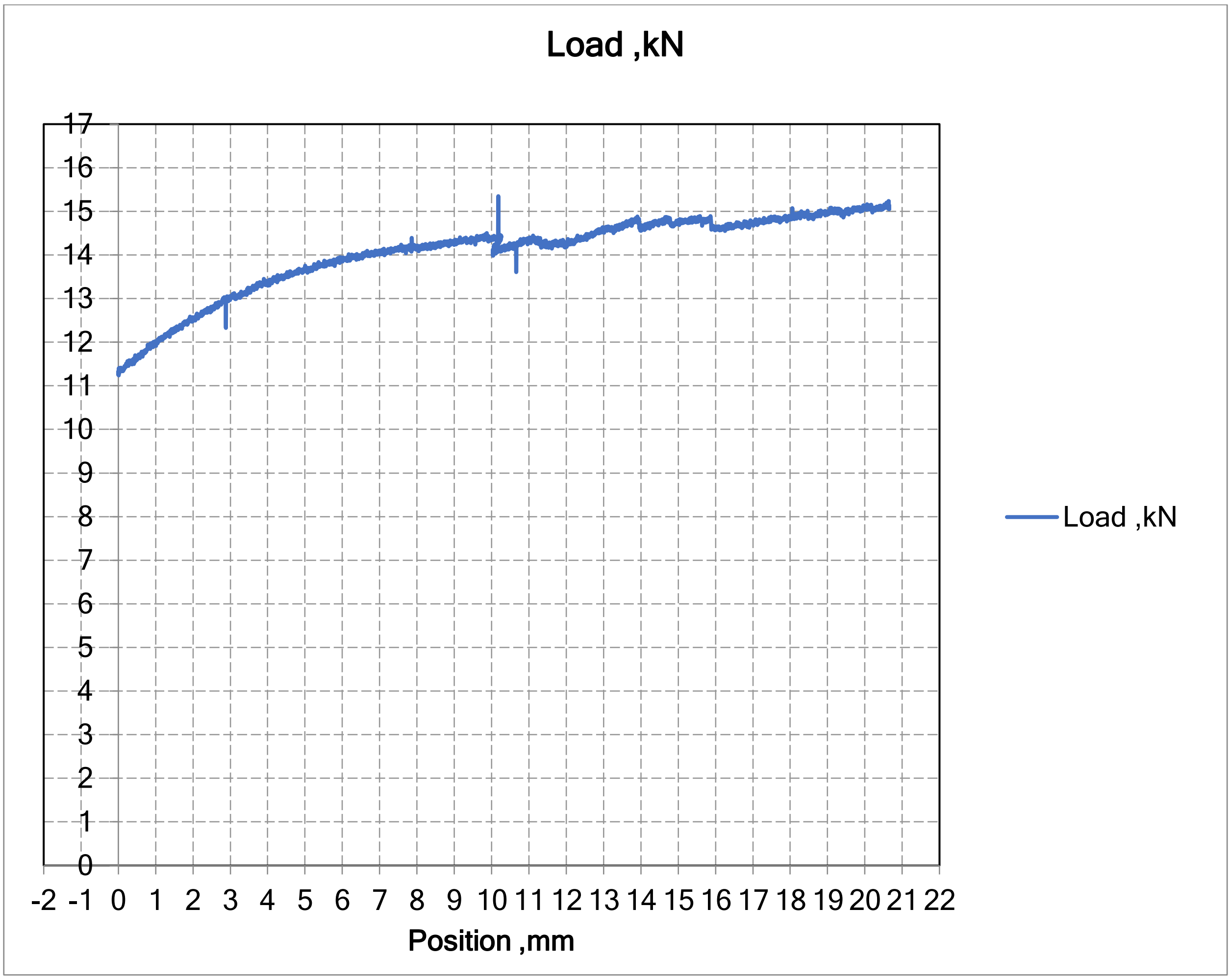
The destruction of the beam occurred at a load of P = 14.5 kH in the upper board under compression (Figure 64).

Figure 64. Destruction in the compressed zone of wood

Beam after destruction in the compression zone is shown in Figure 65.

Figure 65. Beam after destruction in the compression zone

The destruction of the beam occurred at a load of P = 14.5 kH in the upper board under compression (Graph 4).



Graph 4. Graph during beam destruction

Theoretical stress distribution during beam destruction was calculated using Excel file and is shown in Figure 66.

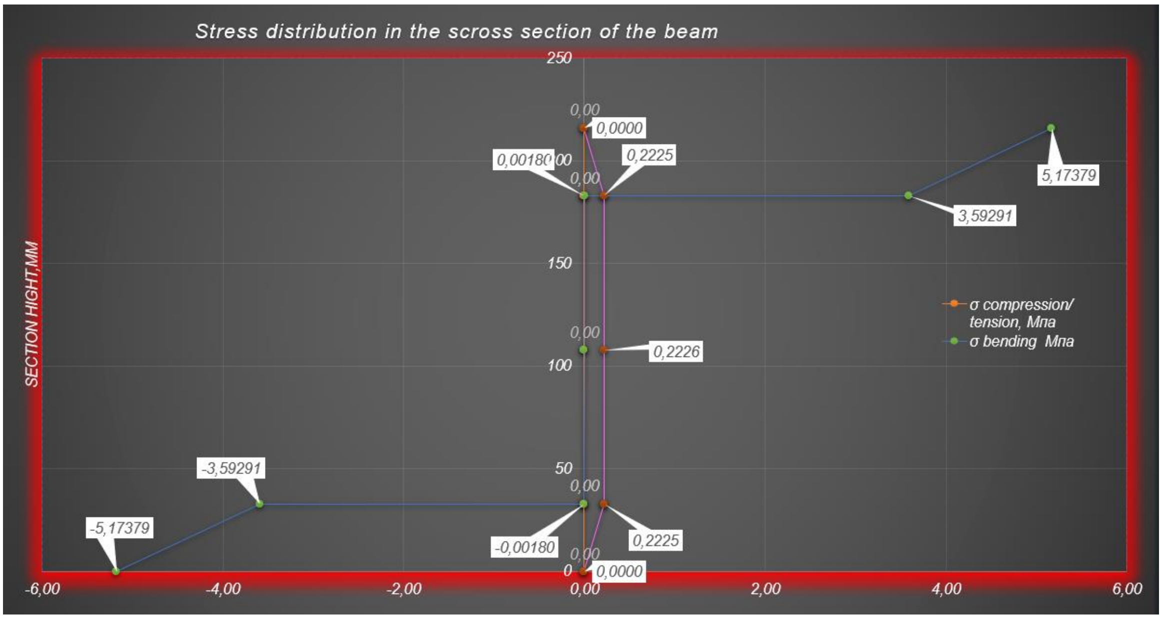
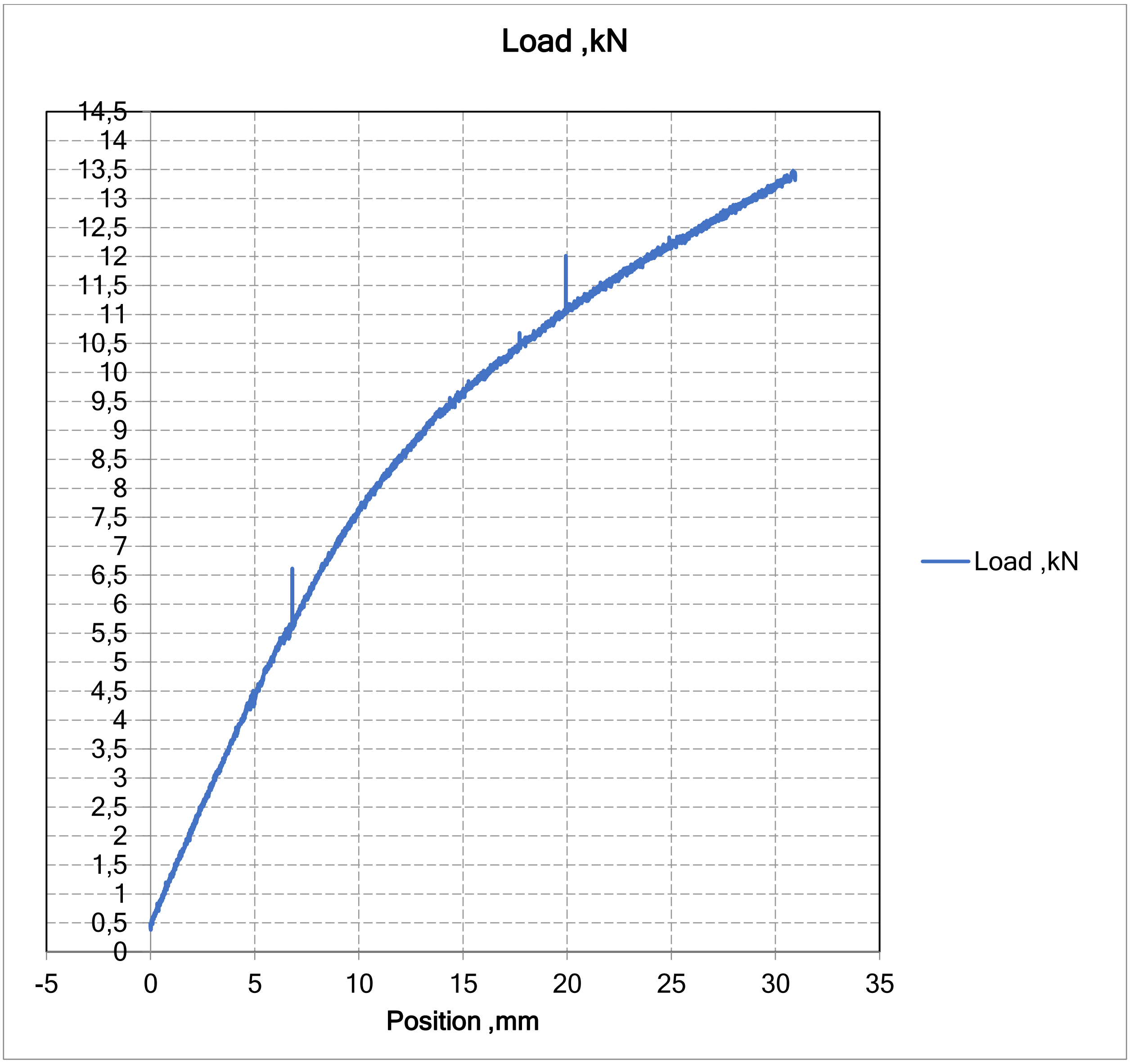


Figure 66. Theoretical stress distribution during beam destruction

7.5 Experimental determination of the deflection and bending stiffness

Data from bending test machine were used to determine deflection and bending stiffness. Elastic and elastic-plastic deformations of the beam during the loading are shown in Graph 5.



Graph 5. Elastic and elastic-plate deformations

The elastic deformations of the beam were considered to determine the experimental stiffness of the beam. Span length l=1,3м since when the deformation scheme on the supports span is 1,5м-2*0,1м. Table 5 shows the experimental determination of bending stiffness.

Table 5. Experimental determination of bending stiffness

l,м	P kH	indicator, мм	f, мм	f, м	EI exp	0,7EI	k2
1,3	0	83,02	0	0			
1,3	4,5	87,3	4,28	0,00428	48	510	11
1,3	5,5	88,57	5,55	0,00555	45	510	11
1,3	10	97,0	13,98	0,01398	33	510	16

The experimental deflection is approximately in 10 more than the theoretical one, therefore, we reduce the rigidity of the EI cross section by 10 times. K2- shows how much experimental stiffness EI is less than designed.

7.6 Compression strength perpendicular to the grain on the support for the beam

Because the polystyrene has low Compression strength it is necessary to take into account polystyrene's deformation on the support parts of the beam. Figures 67,68 show beam on the support after loading.

Figure 67. Beam on the support after loading

On the Figure 68 you can see the deformation of the polystyrene on the support.

Figure 68. The support for the beam 100 mm

Using the Graph 5, it is possible to determine at what load the elastic deformations were replaced by elastic-plastic. After that $R_{cм}$ is calculated (Table 6).

Table 6. Determination compressive strength perpendicular to the grain on the support for the beam.

P, load	9	кН
b	0,17	м
lsupp	0,1	м
Area	0,017	м2
	264,7059	кН/м2
$R_{cм}$	0,264706	MPa

P – load on the beam,

b – the beam width,

lsupp – the length of the beam on the support,

Area – the Area of of the beam on the support,

$R_{cм}$ - the design compressive strength perpendicular to the grain on the support for the beam,

8. Conclusion

An excel file was compiled to calculate spans length, stresses using the reduced section method and Russian norms. A table of span length was compiled for 3 design schemes, 3 options for thicknesses of boards and 3 variations of thicknesses of insulation. A table of thermal resistance was compiled. An excel file was compiled to calculate the amount of moisture, removed from the insulation through ventilated channels. 3 beams with ventilated channels were developed. During the experimental research, the actual beam bending stiffness was obtained. All calculations were done according to the Russian norms.

The design procedure of this beam can be added in the Russian normative documentation SP 64.13330.2017 «Wooden structures». Calculation of moisture removal can be made with certain assumptions for this design. Despite of the fact that the foam has a strength of 0.15 MPa and a timber of 12 MPa the destruction of the polystyrene does not occur, only slight crushing on the supports. Because of little bending stiffness the main factor determining the span length is deflection. Standard roofing system with tiles can be used for the roof structure. It is necessary to develop a place of air inlet and outlet to ventilation canal in the beam and adjust calculation of the drainage capacity of a ventilated duct system.

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FIGURES

GRAPHS

TABLES

	modulus of elasticity of layers			layer height		
E1/E2	E1=	10000	MPa	h1	43	mm
2000						
	E2=	5	MPa	h2	250	mm
	E3=	10000	MPa	h3	43	mm
width of the beam	b=	145	mm	H	336	mm
					0,336	m
to	E=	10 000,0	Mpa	10000000	kH/m2	
E of section	5882,96	Мпа				
I of section	0,00046	м4				
	E1=	10 000	Мпа	10000000	kH/m2	
		10 000	Мпа	10000000	kH/m2	
	E2=	5	Мпа	5000	kH/m2	
		5	Мпа	5000	kH/m2	
	E3=	10000,00	Мпа	10000000	kH/m2	
		10000,00	Мпа	10000000	kH/m2	
		density				
dead load		pine	500	кг/м3	4,9	кН/м3
		insulation	25	кг/м3	0,245	кН/м3
						total

bending+compression or tension

	reduced width			reduced cross-sectional area					the point
	b1=	145	mm	F1	6235	мм2	0,006235	м2	
	b2=	0,0725	mm	F2	18,125	мм2	1,8125E-05	м2	
	b3=	145	mm	F3	6235	мм2	0,006235	м2	
						F	0,01248813	м2	
distance from the bottom of the section to the neutral axis.									
				I'- moment of inertia of the equivalent section relative to the neutral axi					
z0=	168	mm							
				I'	269650077,7	мм4	2,70E-04	м4	
K1=	0,00								

the distance from the lower point of the center section to the i layer			I собственный пр.сеч.			
z1	314,5	mm		I1	960709,5833	мм^4
z2	168	mm		I2	94401,04167	мм^4
z3	21,5	mm		I3	960709,5833	мм^4
from the bottom of the beam						

utral axis.

I при переносе осей пр.сеч.			Total I	I'- moment of inertia of the equivalent section relative to the neutral axis.	
I1c	1,34E+08	мм^4		1,35E+08	мм^4
I2c	0	мм^4		9,44E+04	мм^4
I3c	1,34E+08	мм^4		1,35E+08	мм^4
			Сумм	2,70E+08	мм^4

distance from the bottom of the section to the neutral axis.

I'- moment of inertia of the equivalent section relative to the neutral axis.

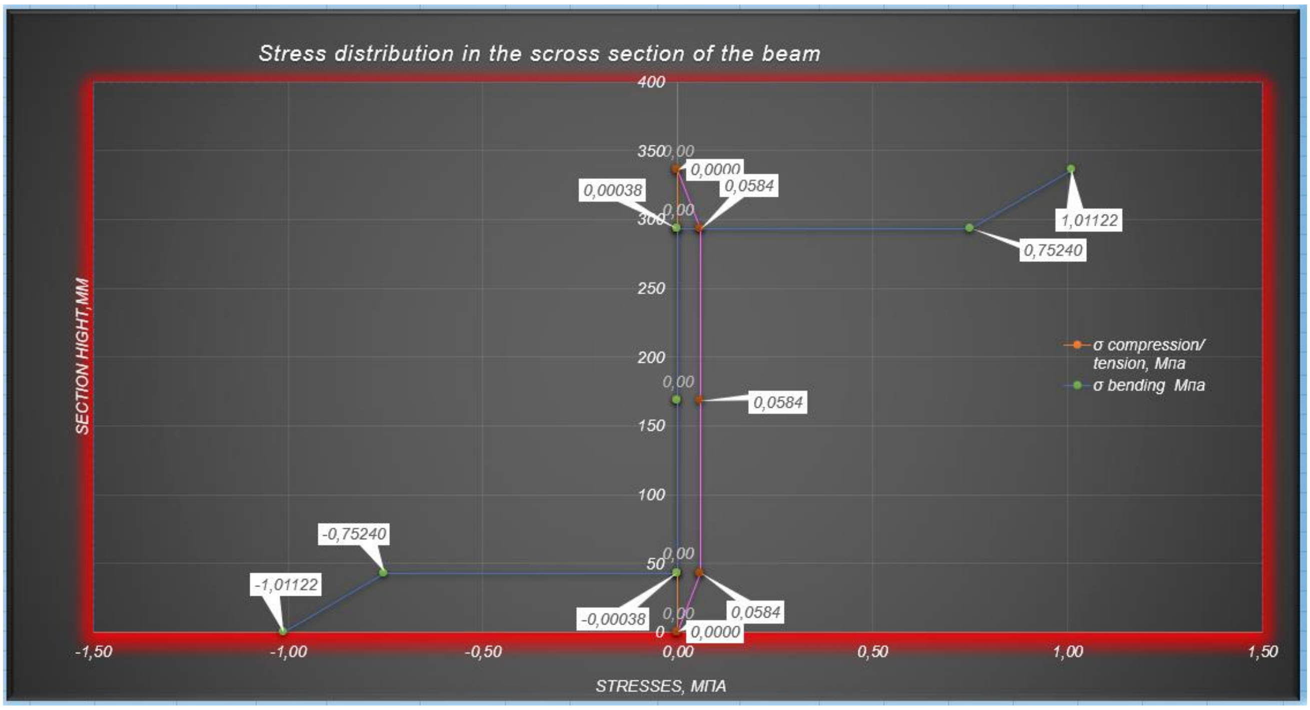
z0=	168	mm			
		I'	269650077,7	мм4	2,70E-04	м4
K1=	0,00				

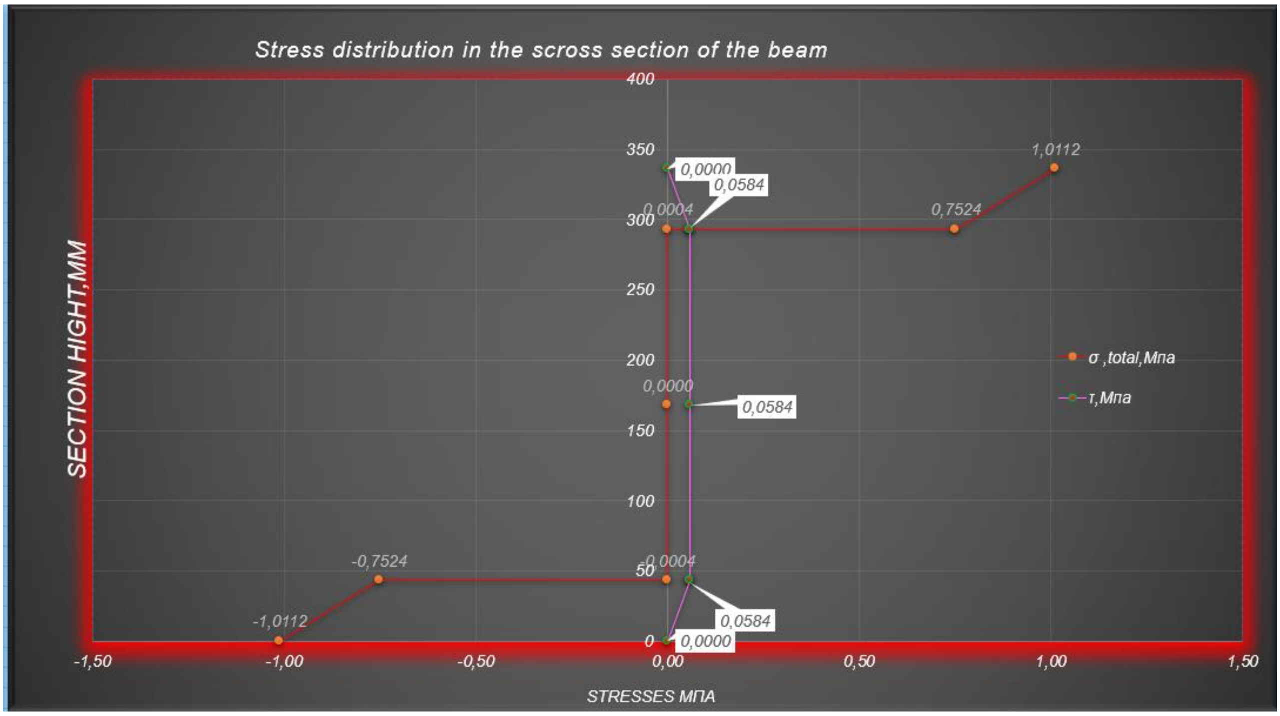
			z'i-z0,мм	z'i-z0,м	σ compressior /tension				σ bending			
z'1	336	мм	168	0,168	0	kH/m2	0,000	MPa	1011,22	kH/m2	1,011	MPa
z'2	293	мм	125	0,125	0	kH/m2	0,000	MPa	752,399	kH/m2	0,752	MPa
z'3	293	мм	125	0,125	0	kH/m2	0,000	MPa	0,3762	kH/m2	0,000	MPa
z'4	43	мм	-125	-0,125	0	kH/m2	0,000	MPa	-0,3762	kH/m2	0,000	MPa
z'5	43	мм	-125	-0,125	0	kH/m2	0,000	MPa	-752,4	kH/m2	-0,752	MPa
z'6	0	мм	-168	-0,168	0	kH/m2	0,000	MPa	-1011,2	kH/m2	-1,011	MPa
				приведе напряж	0	kH/m2						

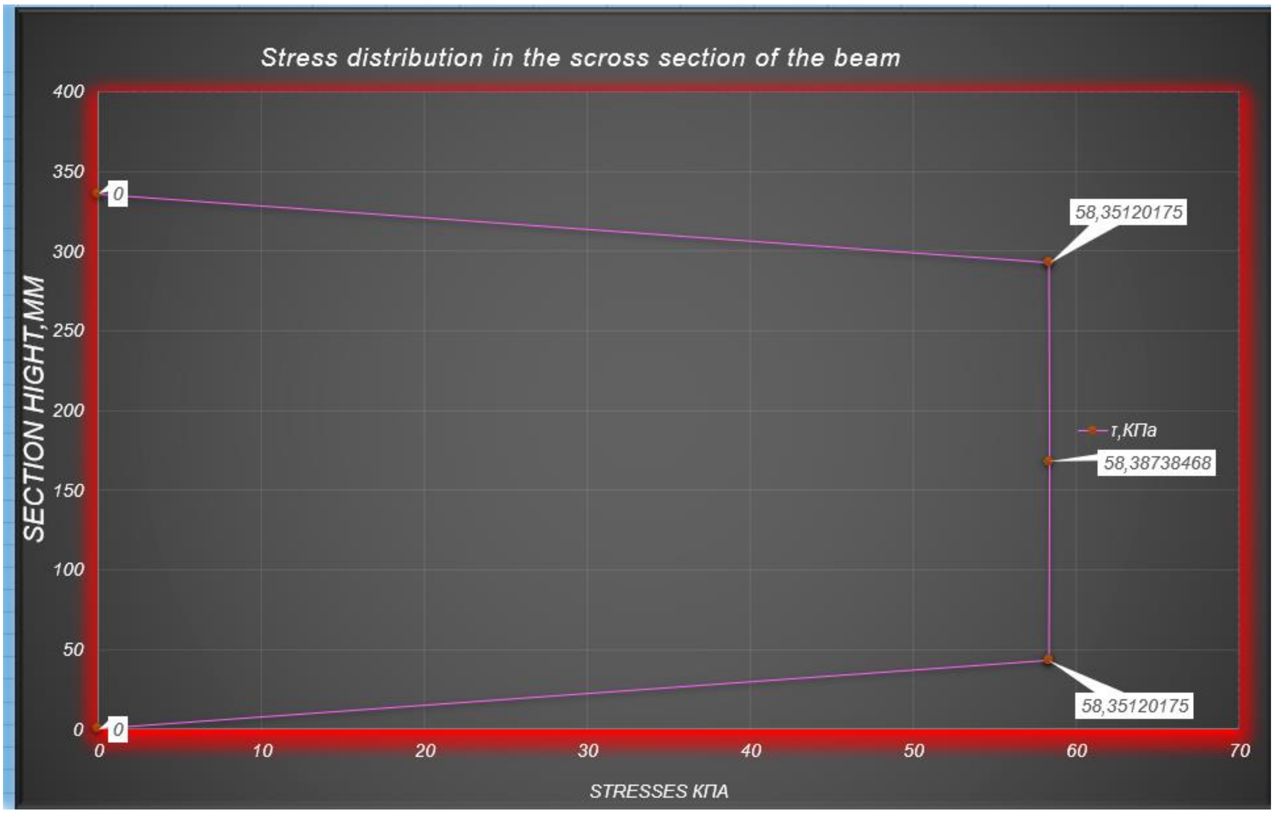
APPENDIX 1

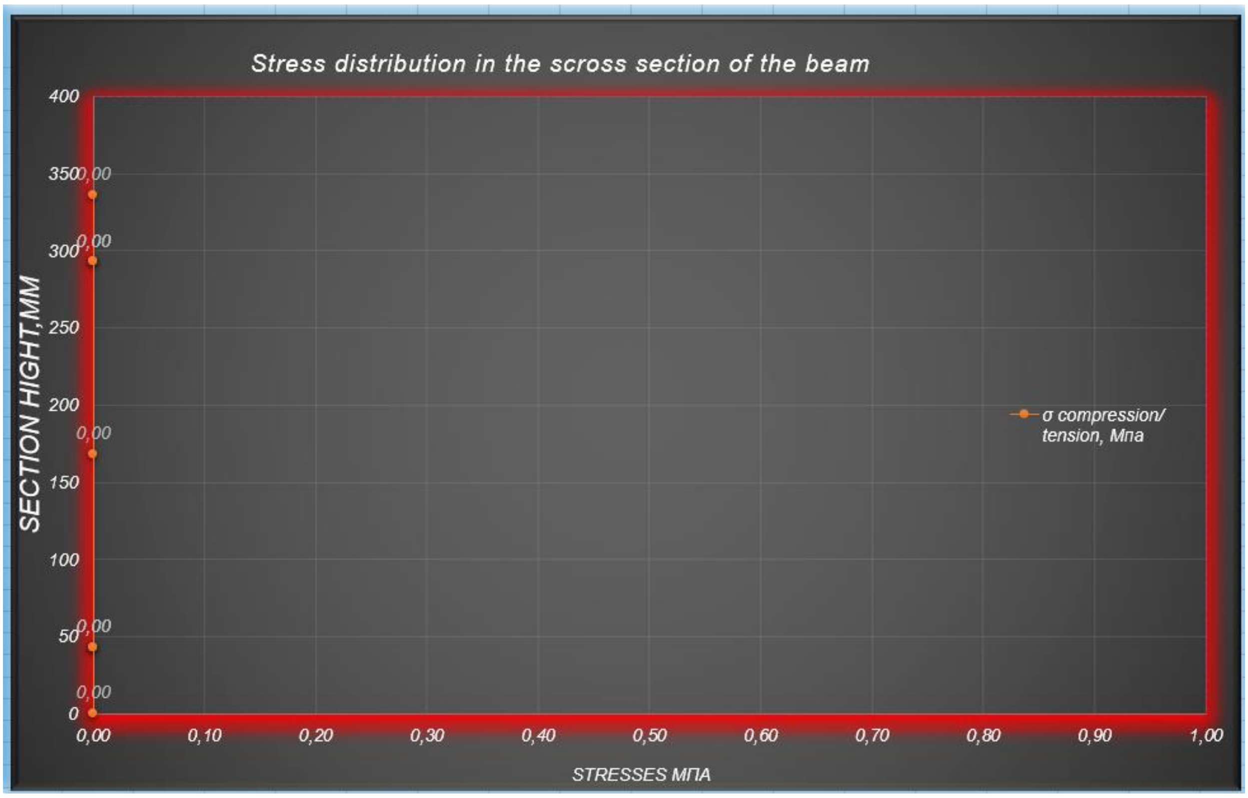
			Si',м3	τ		τ		мм
			0,00E+00	0,00E+00		0		0
F1	0,006235	м2	9,13E-04	5,84E+01	кН/м2	0,058351	Мпа	43
F2/2	9,0625E-06	м2	9,13E-04	5,84E+01	кН/м2	0,058351	Мпа	43
			9,14E-04	5,84E+01	кН/м2	0,058387	Мпа	168
			9,13E-04	5,84E+01	кН/м2	0,058351	Мпа	43
F3	0,006235	м2	9,13E-04	5,84E+01	кН/м2	0,058351	Мпа	43
			0,00E+00	0,00E+00	кН/м2	0	Мпа	0

			Chart Data						
336	1,01122		0,0000	0		0,00		1,0112	0,0000
293	0,75240		0,0584	58,3512		0,00		0,7524	0,0584
293	0,00038		0,0584	58,3512		0,00		0,0004	0,0584
168	0,00000	+	0,0584	58,3874	+	0,00	=	0,0000	0,0584
43	-0,00038		0,0584	58,3512		0,00		-0,0004	0,0584
43	-0,75240		0,0584	58,3512		0,00		-0,7524	0,0584
0	-1,01122		0,0000	0		0,00		-1,0112	0,0000
мм	σ bending Мпа		τ,Мпа	τ,КПа		σ compression/ tension, Мпа		σ ,total,Мпа	τ,Мпа




Stress distribution in the scross section of the beam
SECTION HIGHT,MM
STRESSES МПА
σ ,total,Mпа
τ,Mпа
1,0112
0,7524
-0,7524
-1,0112
0,0000
0,0584
0,0004
0,0000
0,0584
0,0004
0,0584
0,0000


Stress distribution in the scross section of the beam
SECTION HIGHT,MM
STRESSES КПА
τ,КПа
58,35120175
58,38738468
58,35120175
0
0



2 spans

распределенная на всю — **A** — ultimate diflection l/ 350

1 variant M Q

EI,kh*m2	kH/m2	q,kH/м	M1	Q1	x	f0,прогиб,mm	f,прогиб,mm	M2	Q2	M3	Q3	x1	f0,прогиб1,mm	f,прогиб1,mm	x2	f0,прогиб2,mm	f,прогиб2,mm	l	пр. Пр.,м
161	1,5	0,2	1,0	0,8	2,508	9,04	9,60	0,73	0	0,5	0,7	2,81078	15,28	16,21	3,43315	6,69	7,10	5,95	17
	2,0	0,3	1,0	1,0	2,23	7,56	8,15	0,77	0	0,5	0,9	2,49966268	12,78	13,77	3,0531443	5,60	6,03	5,29	15,1183
	2,5	0,4	1,1	1,1	2,054	6,82	7,44	0,82	0	0,5	1,0	2,30232089	11,52	12,57	2,81210659	5,05	5,51	4,87	13,9247
	3,0	0,4	1,1	1,2	1,937	6,47	7,14	0,87	0	0,6	1,1	2,1707597	10,93	12,06	2,65141479	4,79	5,28	4,60	13,1290
	3,5	0,5	1,2	1,4	1,839	6,14	6,84	0,92	0	0,6	1,2	2,06112537	10,38	11,56	2,51750495	4,55	5,06	4,36	12,4659
	4,0	0,6	1,3	1,5	1,761	5,90	6,64	0,96	0	0,6	1,4	1,97341791	9,97	11,21	2,41037708	4,37	4,91	4,18	11,9355
	4,5	0,6	1,3	1,6	1,683	5,54	6,29	0,99	0	0,6	1,5	1,88571045	9,36	10,63	2,30324921	4,10	4,66	3,99	11,4050
	5,5	0,8	1,4	1,8	1,565	5,07	5,87	1,05	0	0,7	1,7	1,75414925	8,57	9,92	2,14255741	3,75	4,35	3,71	10,6093
	6,5	0,9	1,5	2,1	1,487	4,89	5,74	1,12	0	0,7	1,9	1,66644179	8,25	9,69	2,03542954	3,62	4,25	3,53	10,0788
	7,5	1,1	1,5	2,3	1,409	4,54	5,42	1,16	0	0,8	2,0	1,57873433	7,67	9,16	1,92830167	3,36	4,01	3,34	9,54841
	8,5	1,2	1,6	2,5	1,37	4,60	5,54	1,24	0	0,8	2,2	1,5348806	7,77	9,368	1,87473773	3,41	4,10	3,25	9,28317
													left part			rigth part			

2 variant — **B**

EI,kh*m2	kH/m2	q,kH/м	M1,кН*м	Q1,кН	M2,кН*м	Q2,кН	l,м	x	f0,прогиб,мм	f,прогиб,мм	пр. Пр,мм
161	1,5	0,2	0	0,55	0,7	0	5,10574772	2,55287	11,79	12,77	14,59
	2,0	0,3	0	0,67	0,8	0	4,68800472	2,344	11,20	12,31	13,39
	2,5	0,4	0	0,79	0,9	0	4,3630935	2,18155	10,53	11,72	12,47
	3,0	0,4	0	0,88	0,9	0	4,08459817	2,0423	9,71	10,97	11,67
	3,5	0,5	0	0,98	1,0	0	3,89893462	1,94947	9,42	10,76	11,14
	4,0	0,6	0	1,07	1,0	0	3,71327107	1,85664	8,86	10,25	10,61
	4,5	0,6	0	1,16	1,0	0	3,5740234	1,78701	8,56	10,01	10,21
	5,5	0,8	0	1,31	1,1	0	3,3	1,65	7,61	9,12	9,43
	6,5	0,9	0	1,46	1,1	0	3,1	1,55	7,00	8,58	8,86
	7,5	1,1	0	1,52	1,1	0	2,8	1,4	5,38	6,87	8,00
	8,5	1,2	0	1,72	1,2	0	2,8	1,4	6,10	7,79	8,00

EI,kh*m2	kH/m2	q,kH/м	M1	Q1	M2	Q2	M3	Q3слева	Q3справа	l1	l2	fo,прогиб,мм	прогиб,мм	пр. Пр,мм
								C						
161,39	1,48	0,21498	0	0,4	0,4	0,0	0,7	-0,2	0,5	5	2,46004	6,10	8,28	12,30
	1,98265	0,28748	0	-0,1	0,0	0,0	0,7	0,0	0,7	2	2,27438	5,96	8,45	11,37
	2,48265	0,35998	0	0,0	0,0	0,0	0,8	0,0	0,8	2	2,08871	5,31	7,94	10,44
	2,98265	0,43248	0	0,0	0,0	0,0	0,8	0,0	0,8	2	1,94947	4,84	7,60	9,75
	3,48265	0,50498	0	0,1	0,0	0,0	0,9	0,0	0,9	2	1,85664	4,65	7,57	9,28
	3,98265	0,57748	0	0,1	0,0	0,0	0,9	0,1	1,0	2	1,7638	4,33	7,35	8,82
	4,48265	0,64998	0	1,4	1,6	0,0	0,9	-0,2	1,1	5	1,67097	3,92	6,97	8,35
	5,48265	0,79498	0	0,3	0,1	0,0	1,0	0,2	1,3	2	1,57814	3,82	7,14	7,89
	6,48265	0,93998	0	0,4	0,1	0,0	1,0	0,2	1,4	2	1,48531	3,54	7,03	7,43
	7,48265	1,08498	0	0,6	0,1	0,0	1,1	0,3	1,5	2	1,39248	3,16	6,69	6,96
	8,48265	1,22998	0	0,7	0,2	0,0	1,0	0,4	1,6	2	1,29964	2,72	6,21	6,50

			pine	insulation	
board	20mm	Rраст	-11,8	-0,15	Мпа
		Rсж	17,8	0,15	Мпа
bord	33mm	Rраст	-10,8	-0,15	Мпа
		Rсж	16,2	0,15	Мпа
board	43mm	Rраст	-10,26	-0,15	Мпа
		Rсж	15,39	0,15	Мпа
		Rск, вд.в.	2,25	0,28	Мпа
		Rсм	4,5	0,411	Мпа
			4500	411	KH/m2

check the capasity		
pine tension	91	%
pine compression	94	%
pine shear	97	%
pine commpression 90	96	%
insulation tension	100	%
insulation compression	100	%
insulation shear	79	%
beam compression on support	58	%

м				
		M	1,62	Кн*м
1	l/120	Q	2,50	Кн
3	l/150	N		Kh
	l/200			

	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	7,5	6,5	3	8,5	7,5	3,6	10	9	4,1	8,8	7,8	3,7	10,3	9	4,3	11,5	10,2	4,9	9,6	8,5	4,1
1,5	6,5	6	2,7	8	7	3,2	9	8	3,7	7,9	7	3,2	9,3	8,2	3,9	10,5	9,2	4,4	8,7	7,7	3,7
2	6	5,5	2,4	7,3	6,5	2,9	8	7	3,3	7,3	6,5	3,1	8,6	7,5	3,5	9,6	8,6	4,1	8	7,1	3,4
2,5	5,6	5	2,3	6,8	6	2,7	7,6	6,8	3	6,8	6,1	2,9	8	7	3,3	9,1	8	3,7	7,6	6,7	3,1
3	5,4	4,8	2,2	6,5	5,5	2,6	7,2	6,5	2,9	6,3	5,8	2,7	7,6	6,6	3,1	8,7	7,6	3,5	7,2	6,4	3
3,5	5	4,5	2,1	6	5,2	2,4	7	6,2	2,6	6	5,5	2,6	7,3	6,3	3	8,3	7,3	3,4	6,8	6,1	2,8
4	5	4,2	2	5,7	5	2,3	6,5	6	2,5	5,8	5	2,4	7	6,2	2,8	7,9	7	3,2	6,5	5,8	2,6
5	4,6	4	1,8	5,5	4,8	2,1	6	5,5	2,4	5,5	4,7	2,3	6,5	5,6	2,5	7,4	6,5	3	6,1	5,4	2,5
6	4,3	3,7	1,7	5,1	4,5	2	5,5	5,2	2,2	5,1	4,4	2,1	6,1	5,3	2,4	7	6,2	2,8	5,8	5,1	2,4
7	4,1	3,5	1,6	4,7	4,2	1,9	5,1	5	2,1	5	4,3	2	5,8	5	2,3	6,5	5,9	2,6	5,5	4,9	2,3
8	4	3,3	1,5	4,4	4	1,8	4,8	4,7	2	4,8	4,2	1,9	5,5	4,8	2,2	6,1	5,5	2,5	5,2	4,7	2,2

insulation	150	150	150	200	200	200	250	250	250	150	150	150	200	200	200	250	250	250	150	150	150
board	20	20	20	20	20	20	20	20	20	33	33	33	33	33	33	33	33	33	43	43	43

	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	3,481	3,017	1,392	3,945	3,481	1,671	4,642	4,177	1,903	4,085	3,620	1,717	4,781	4,177	1,996	5,338	4,734	2,274	4,456	3,945	1,903
1,5	3,017	2,785	1,253	3,713	3,249	1,485	4,177	3,713	1,717	3,667	3,249	1,485	4,317	3,806	1,810	4,874	4,270	2,042	4,038	3,574	1,717
2	2,785	2,553	1,114	3,388	3,017	1,346	3,713	3,249	1,532	3,388	3,017	1,439	3,992	3,481	1,625	4,456	3,992	1,903	3,713	3,296	1,578
2,5	2,599	2,321	1,068	3,156	2,785	1,253	3,528	3,156	1,392	3,156	2,831	1,346	3,713	3,249	1,532	4,224	3,713	1,717	3,528	3,110	1,439
3	2,506	2,228	1,021	3,017	2,553	1,207	3,342	3,017	1,346	2,924	2,692	1,253	3,528	3,063	1,439	4,038	3,528	1,625	3,342	2,971	1,392
3,5	2,321	2,089	0,975	2,785	2,414	1,114	3,249	2,878	1,207	2,785	2,553	1,207	3,388	2,924	1,392	3,853	3,388	1,578	3,156	2,831	1,300
4	2,321	1,949	0,928	2,646	2,321	1,068	3,017	2,785	1,160	2,692	2,321	1,114	3,249	2,878	1,300	3,667	3,249	1,485	3,017	2,692	1,207
5	2,135	1,857	0,835	2,553	2,228	0,975	2,785	2,553	1,114	2,553	2,182	1,068	3,017	2,599	1,160	3,435	3,017	1,392	2,831	2,506	1,160
6	1,996	1,717	0,789	2,367	2,089	0,928	2,553	2,414	1,021	2,367	2,042	0,975	2,831	2,460	1,114	3,249	2,878	1,300	2,692	2,367	1,114
7	1,903	1,625	0,743	2,182	1,949	0,882	2,367	2,321	0,975	2,321	1,996	0,928	2,692	2,321	1,068	3,017	2,739	1,207	2,553	2,274	1,068
8	1,857	1,532	0,696	2,042	1,857	0,835	2,228	2,182	0,928	2,228	1,949	0,882	2,553	2,228	1,021	2,831	2,553	1,160	2,414	2,182	1,021

A- double span beam B- single span beam C-cantilever beam	insulation board	150 20	150 20	150 20	200 20	200 20	200 20	250 20	250 20	250 20
Distributed load kH/m2		A	B	C	A	B	C	A	B	C
	1	3,48	3,02	1,39	3,95	3,48	1,67	4,64	4,18	1,90
	1,5	3,02	2,78	1,25	3,71	3,25	1,49	4,18	3,71	1,72
	2	2,78	2,55	1,11	3,39	3,02	1,35	3,71	3,25	1,53
	2,5	2,60	2,32	1,07	3,16	2,78	1,25	3,53	3,16	1,39
	3	2,51	2,23	1,02	3,02	2,55	1,21	3,34	3,02	1,35
	3,5	2,32	2,09	0,97	2,78	2,41	1,11	3,25	2,88	1,21
	4	2,32	1,95	0,93	2,65	2,32	1,07	3,02	2,78	1,16
	5	2,14	1,86	0,84	2,55	2,23	0,97	2,78	2,55	1,11
	6	2,00	1,72	0,79	2,37	2,09	0,93	2,55	2,41	1,02
	7	1,90	1,62	0,74	2,18	1,95	0,88	2,37	2,32	0,97
	8	1,86	1,53	0,70	2,04	1,86	0,84	2,23	2,18	0,93

A- double span beam B- single span beam C-cantilever beam	insulation board	150 33	150 33	150 33	200 33	200 33	200 33	250 33	250 33	250 33
Distributed load kH/m2		A	B	C	A	B	C	A	B	C
	1	4,08	3,62	1,72	4,78	4,18	2,00	5,34	4,73	2,27
	1,5	3,67	3,25	1,49	4,32	3,81	1,81	4,87	4,27	2,04
	2	3,39	3,02	1,44	3,99	3,48	1,62	4,46	3,99	1,90
	2,5	3,16	2,83	1,35	3,71	3,25	1,53	4,22	3,71	1,72
	3	2,92	2,69	1,25	3,53	3,06	1,44	4,04	3,53	1,62
	3,5	2,78	2,55	1,21	3,39	2,92	1,39	3,85	3,39	1,58
	4	2,69	2,32	1,11	3,25	2,88	1,30	3,67	3,25	1,49
	5	2,55	2,18	1,07	3,02	2,60	1,16	3,43	3,02	1,39
	6	2,37	2,04	0,97	2,83	2,46	1,11	3,25	2,88	1,30
	7	2,32	2,00	0,93	2,69	2,32	1,07	3,02	2,74	1,21
	8	2,23	1,95	0,88	2,55	2,23	1,02	2,83	2,55	1,16

A- double span beam B- single span beam C-cantilever beam	insulation board	150 43	150 43	150 43	200 43	200 43	200 43	250 43	250 43	250 43
Distributed load kH/m2		A	B	C	A	B	C	A	B	C
	1	4,46	3,95	1,90	5,11	4,60	2,23	5,85	5,11	2,46
	1,5	4,04	3,57	1,72	4,64	4,18	2,00	5,29	4,69	2,27
	2	3,71	3,30	1,58	4,36	3,85	1,86	4,87	4,36	2,09
	2,5	3,53	3,11	1,44	4,08	3,62	1,72	4,60	4,08	1,95
	3	3,34	2,97	1,39	3,85	3,43	1,62	4,36	3,90	1,86
	3,5	3,16	2,83	1,30	3,71	3,30	1,58	4,18	3,71	1,76
	4	3,02	2,69	1,21	3,57	3,06	1,49	3,99	3,57	1,67
	5	2,83	2,51	1,16	3,30	2,92	1,39	3,71	3,34	1,58
	6	2,69	2,37	1,11	3,11	2,78	1,30	3,53	3,16	1,49
	7	2,55	2,27	1,07	2,97	2,65	1,21	3,34	2,97	1,39
	8	2,41	2,18	1,02	2,83	2,51	1,16	3,25	2,88	1,30

Теплотехнический расчет ограждающих конструкций зданий
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Тепловая защита	Защита от переувлажнения	Конденстат в вент. пространстве
Rc Rэ Rт		Rтр

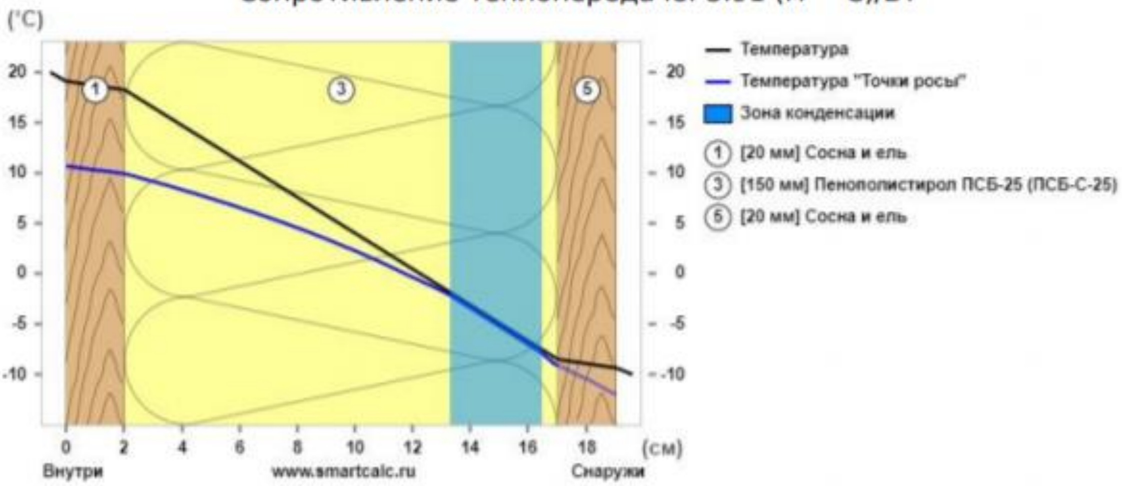
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	˚C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	˚C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•˚C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•˚C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•˚C)/Вт

Сопротивление теплопередаче: 3.91 (м²•˚C)/Вт



Слои конструкции (изнутри наружу)

№	Тип	d[мм]	Материал	λ	R	Tmax	Tmin
			Сопротивление тепловосприятию		0.11	20.0	19.1
1	☐	20	Сосна и ель	0.18	0.11	19.1	18.3
3	☐	150	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	3.49	18.3	-8.5
5	☐	20	Сосна и ель	0.18	0.11	-8.5	-9.4
			Сопротивление теплоотдаче		0.08	-9.4	-10.0
Термическое сопротивление ограждающей конструкции					3.71		
Сопротивление теплопередаче ограждающей конструкции [R]					3.91		

Теплотехнический расчет ограждающих конструкций зданий
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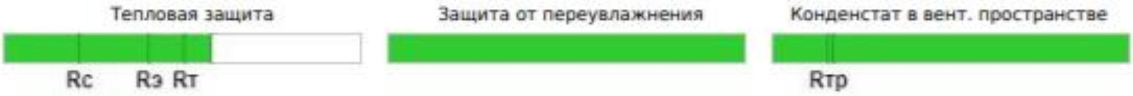


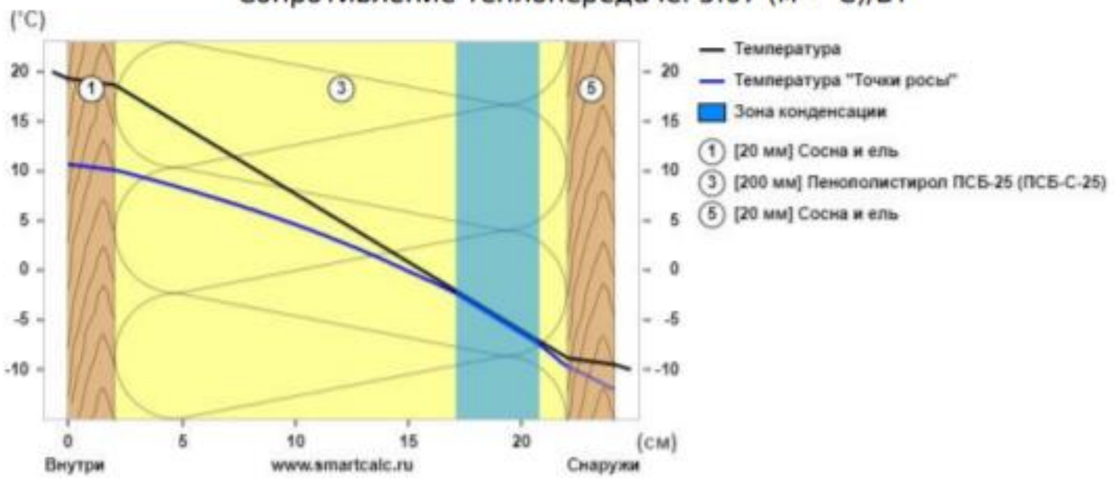
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	°C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	°C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•°C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•°C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•°C)/Вт

Сопротивление теплопередаче: 5.07 (м²•°C)/Вт



Слои конструкции (изнутри наружу)

№	*Тип*	*d[мм]*	*Материал*	*λ*	*R*	*Tmax*	*Tmin*
			Сопротивление тепловосприятию		0.11	20.0	19.3
1	☐	20	Сосна и ель	0.18	0.11	19.3	18.7
3	☐	200	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	4.65	18.7	-8.8
5	☐	20	Сосна и ель	0.18	0.11	-8.8	-9.5
			Сопротивление теплоотдаче		0.08	-9.5	-10.0
Термическое сопротивление ограждающей конструкции					4.87		
Сопротивление теплопередаче ограждающей конструкции [R]					5.07		

Теплотехнический расчет ограждающих конструкций зданий
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Тепловая защита	Защита от переувлажнения	Конденсат в вент. пространстве
Rc Rэ Rт		Rтр

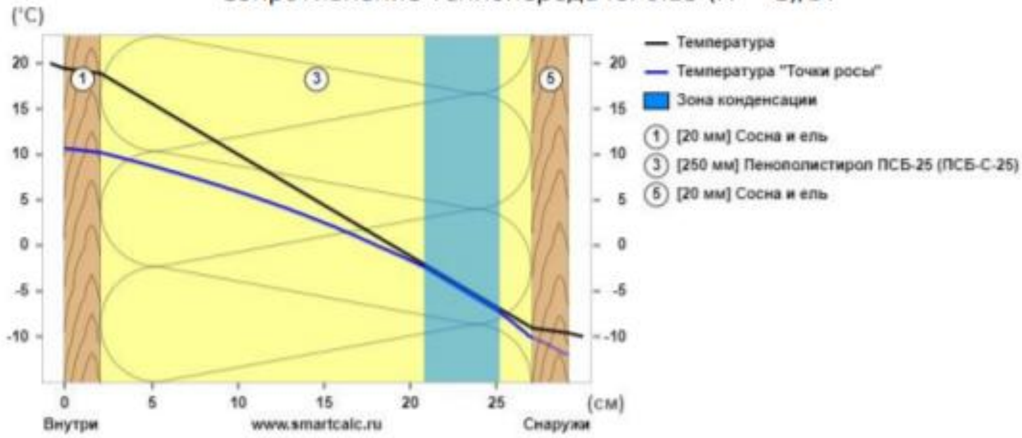
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	°C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	°C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•°C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•°C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•°C)/Вт

Сопротивление теплопередаче: 6.23 (м²•°C)/Вт



Слои конструкции (изнутри наружу)

№	Тип	d[мм]	Материал	λ	R	Tmax	Tmin
			Сопротивление тепловосприятию		0.11	20.0	19.4
1	☐	20	Сосна и ель	0.18	0.11	19.4	18.9
3	☐	250	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	5.81	18.9	-9.1
5	☐	20	Сосна и ель	0.18	0.11	-9.1	-9.6
			Сопротивление теплоотдаче		0.08	-9.6	-10.0
Термическое сопротивление ограждающей конструкции					6.04		
Сопротивление теплопередаче ограждающей конструкции [R]					6.23		

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Теплотехнический расчет ограждающих конструкций зданий
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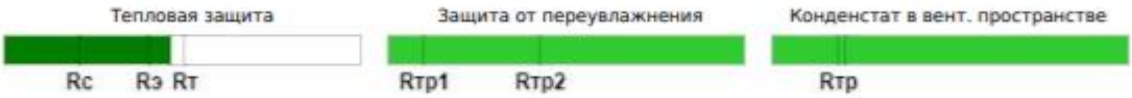


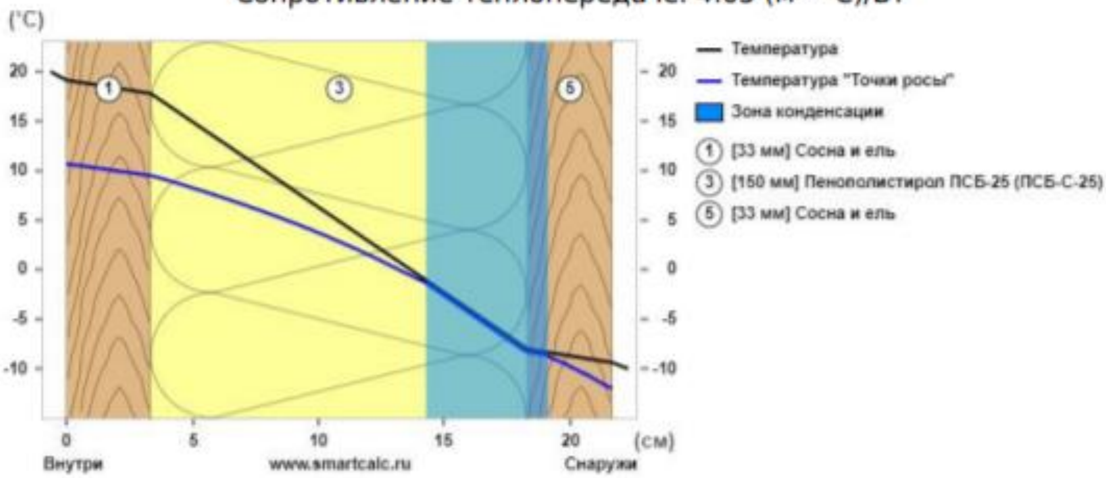
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	°C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	°C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•°C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•°C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•°C)/Вт

Сопротивление теплопередаче: 4.05 (м²•°C)/Вт



Слои конструкции (изнутри наружу)

№	*Тип*	*d[мм]*	*Материал*	*λ*	*R*	*Tmax*	*Tmin*
			Сопротивление тепловосприятию		0.11	20.0	19.1
1	☐	33	Сосна и ель	0.18	0.18	19.1	17.8
3	☐	150	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	3.49	17.8	-8.0
5	☐	33	Сосна и ель	0.18	0.18	-8.0	-9.4
			Сопротивление теплоотдаче		0.08	-9.4	-10.0

Термическое сопротивление ограждающей конструкции	3.86
Сопротивление теплопередаче ограждающей конструкции [R]	4.05

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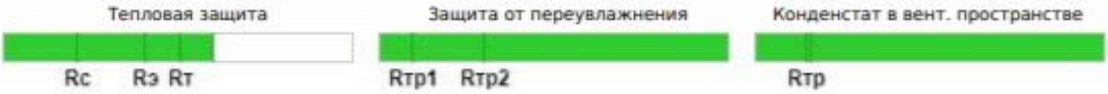


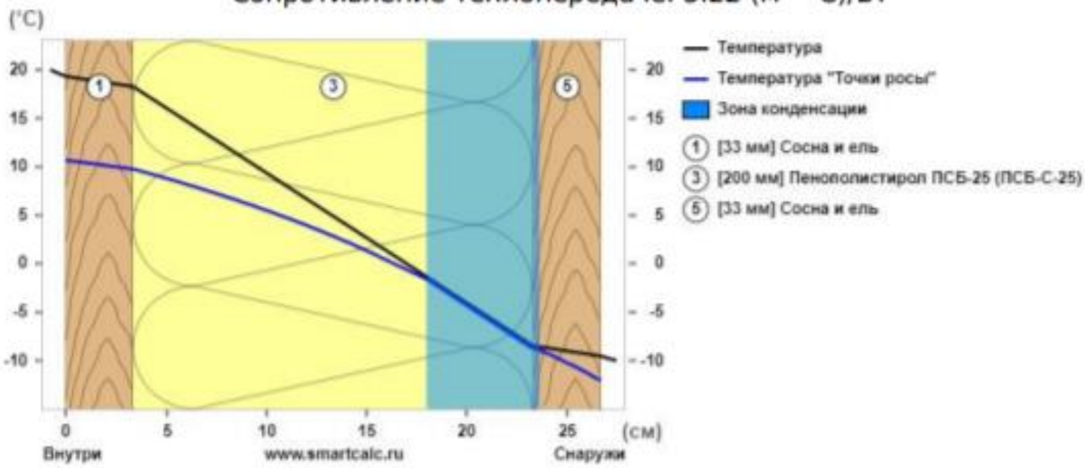
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	°C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	°C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•°C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•°C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•°C)/Вт

Сопротивление теплопередаче: 5.22 (м²•°C)/Вт



Слои конструкции (изнутри наружу)

№	Тип	d[мм]	Материал	λ	R	Tmax	Tmin
			Сопротивление тепловосприятию		0.11	20.0	19.3
1	☐	33	Сосна и ель	0.18	0.18	19.3	18.3
3	☐	200	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	4.65	18.3	-8.5
5	☐	33	Сосна и ель	0.18	0.18	-8.5	-9.5
			Сопротивление теплоотдаче		0.08	-9.5	-10.0

Термическое сопротивление ограждающей конструкции	5.02
Сопротивление теплопередаче ограждающей конструкции [R]	5.22

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Тепловая защита — Rc Rэ Rт
Защита от переувлажнения
Конденсат в вент. пространстве — Rтр

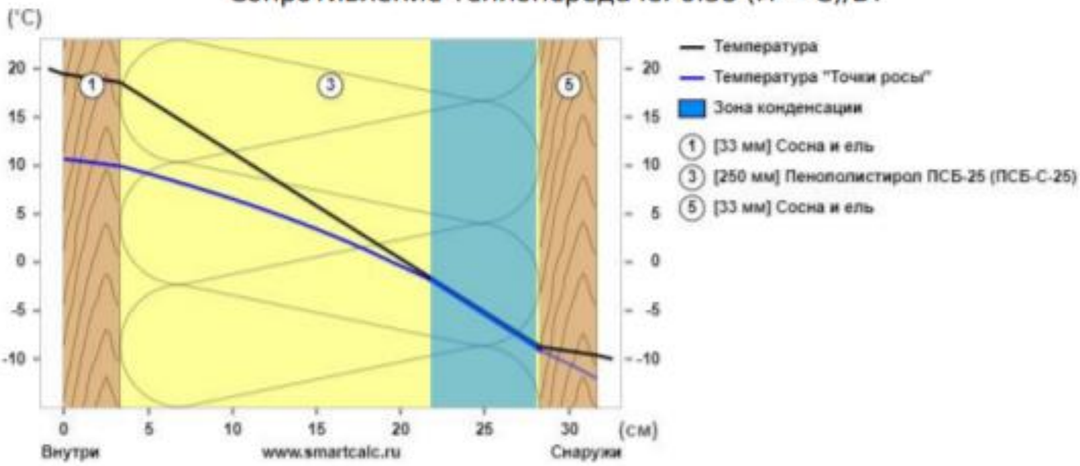
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	°C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	°C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•°C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•°C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•°C)/Вт

Сопротивление теплопередаче: 6.38 (м²•°C)/Вт



Слои конструкции (изнутри наружу)

№	Тип	d[мм]	Материал	λ	R	Tmax	Tmin
			Сопротивление тепловосприятию		0.11	20.0	19.5
1	☐	33	Сосна и ель	0.18	0.18	19.5	18.6
3	☐	250	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	5.81	18.6	-8.7
5	☐	33	Сосна и ель	0.18	0.18	-8.7	-9.6
			Сопротивление теплоотдаче		0.08	-9.6	-10.0

Термическое сопротивление ограждающей конструкции	6.18
Сопротивление теплопередаче ограждающей конструкции [R]	6.38

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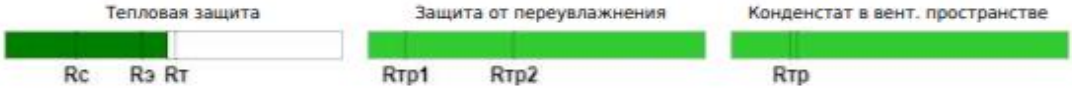


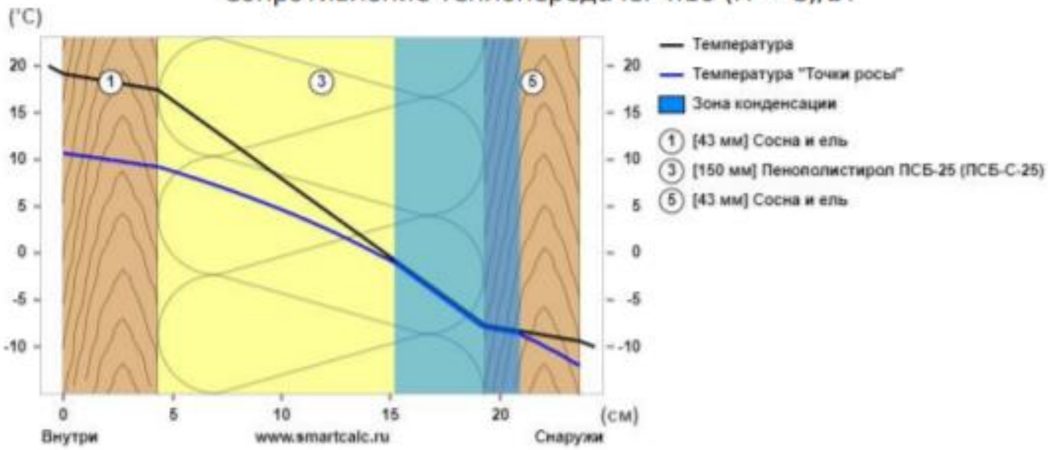
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	°C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	°C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•°C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•°C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•°C)/Вт

Сопротивление теплопередаче: 4.16 (м²•°C)/Вт



Слои конструкции (изнутри наружу)

№	Тип	d[мм]	Материал	λ	R	Tmax	Tmin
			Сопротивление тепловосприятию		0.11	20.0	19.2
1	☐	43	Сосна и ель	0.18	0.24	19.2	17.5
3	☐	150	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	3.49	17.5	-7.7
5	☐	43	Сосна и ель	0.18	0.24	-7.7	-9.4
			Сопротивление теплоотдаче		0.08	-9.4	-10.0

Термическое сопротивление ограждающей конструкции	3.97
Сопротивление теплопередаче ограждающей конструкции [R]	4.16

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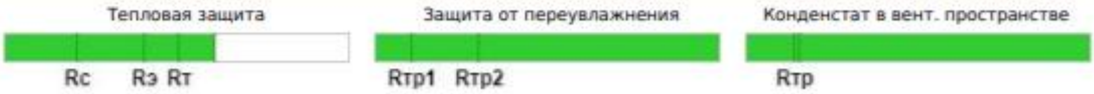


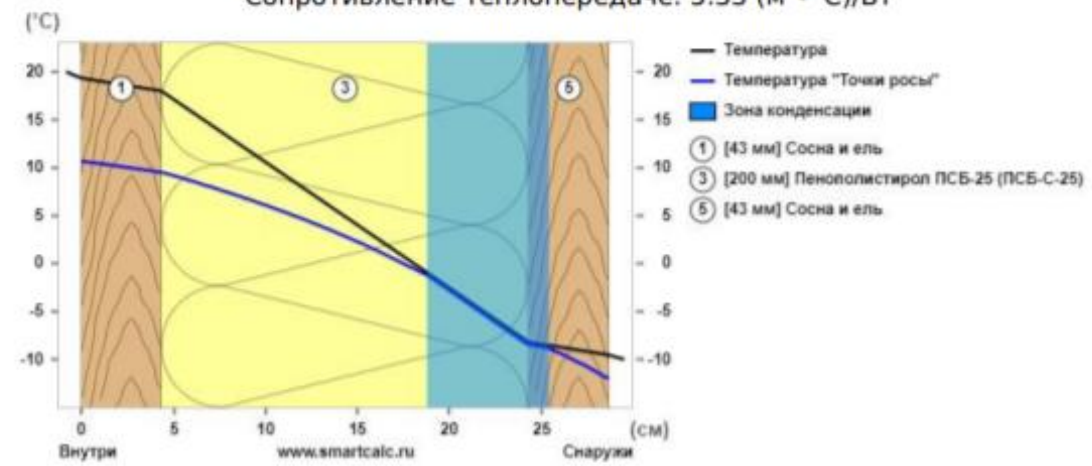
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	°C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	°C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rс]	*1.84*	(м²•°C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•°C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•°C)/Вт

Сопротивление теплопередаче: 5.33 (м²•°C)/Вт



Слои конструкции (изнутри наружу)

№	Тип	d[мм]	Материал	λ	R	Tmax	Tmin
			Сопротивление тепловосприятию		0.11	20.0	19.4
1	☐	43	Сосна и ель	0.18	0.24	19.4	18.0
3	☐	200	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	4.65	18.0	-8.2
5	☐	43	Сосна и ель	0.18	0.24	-8.2	-9.5
			Сопротивление теплоотдаче		0.08	-9.5	-10.0
Термическое сопротивление ограждающей конструкции					5.13		
Сопротивление теплопередаче ограждающей конструкции [R]					5.33		

Теплотехнический расчет ограждающих конструкций зданий
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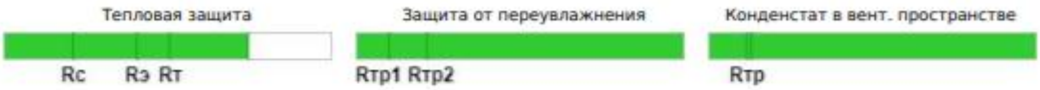


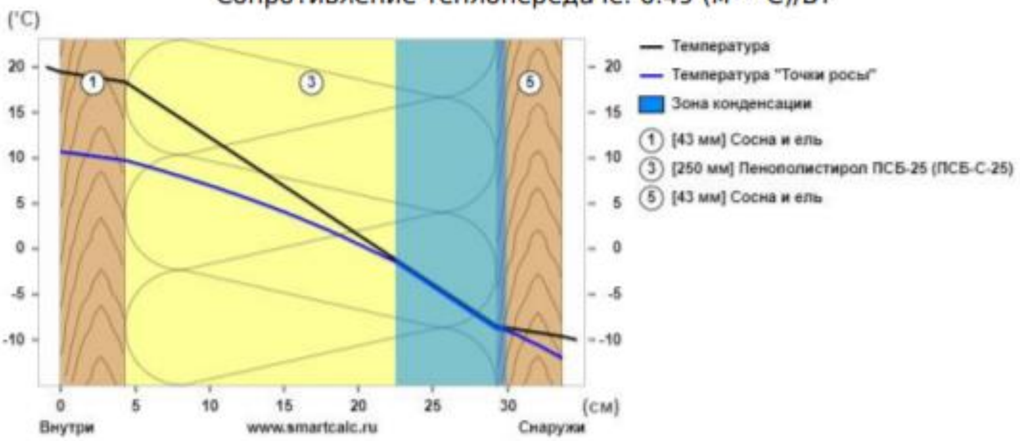
Теплотехнический расчет

Регион:	*Республика Карелия*
Населенный пункт:	*Петрозаводск*
Помещение:	*Жилое помещение*
Вид конструкции:	*Чердачное перекрытие или утепленная кровля*

Тепловая защита

Температура холодной пятидневки с обеспеченностью 0.92	*-28*	˚C
Продолжительность отопительного периода	*235*	суток
Средняя температура воздуха отопительного периода	*-3.2*	˚C
Условия эксплуатации помещения	*Б*	
Количество градусо-суток отопительного периода (ГСОП)	*5452*	°C•сут
Требуемое сопротивление теплопередаче		
Санитарно-гигиенические требования [Rc]	*1.84*	(м²•˚C)/Вт
Нормируемое значение поэлементных требований [Rэ]	*3.48*	(м²•˚C)/Вт
Базовое значение поэлементных требований [Rт]	*4.35*	(м²•˚C)/Вт

Сопротивление теплопередаче: 6.49 (м²•˚C)/Вт



Слои конструкции (изнутри наружу)

№	*Тип*	*d[мм]*	*Материал*	*λ*	*R*	*Tmax*	*Tmin*
			Сопротивление тепловосприятию		0.11	20.0	19.5
1	☐	43	Сосна и ель	0.18	0.24	19.5	18.4
3	☐	250	Пенополистирол ПСБ-25 (ПСБ-С-25)	0.043	5.81	18.4	-8.5
5	☐	43	Сосна и ель	0.18	0.24	-8.5	-9.6
			Сопротивление теплоотдаче		0.08	-9.6	-10.0

Термическое сопротивление ограждающей конструкции	6.29
Сопротивление теплопередаче ограждающей конструкции [R]	6.49

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ψ	0,7						
ρ	0,75						
αн	23						
k1-k2	0,3						
Σξ	36						
N	2						
a	20	мм	0,02	м	d	0,013333	м
b	10	мм	0,01	м			
Vei,м/с	2,3	м/с	for the summer months, the average wind speed at the entrance to the canal				
H	6	м					
Δ1	0,3	мм	0,0003	м	Δ	0,04875	
Δ2	1	мм	0,001	м			
					Л	0,053419	
Lbeam	7	ventilated channel length					
bbeam	0,145	м			G	0,067913	coefficient
Fbeam	1,015	м2					

	4	5	6	7	8	9	10	
Наименование	April	May	June	July	August	September	October	
$t_н$, ºC	1,8	8,4	13,7	16,5	14,3	9,1	3,3	from SP
$φ_н$, %								
$e_н$, Па	480	680	1040	1340	1280	960	670	from Sp
B_1, г/м³	2,0	2,8	4,2	5,4	5,2	4,0	2,8	
$J_{рад}$, Вт/м²	170	229	244	238	183	126	58	from SP
$t_к^с$, ºC	6,3	14	19,4	21,8	18,7	12,6	5,6	
$E_к$, Па	956	1599	2252	2612	2156	1459	909	
B_2, г/м³	4,0	6,5	9,0	10,3	8,6	6,0	3,8	
	739493,5	1391941	1797554	1866946	1295294	752454,393	369650,9	
tсн	5,7	13,6	19,3	21,9	18,5	12,0	4,6	
тау,с	2678400	2678400	2678400	2678400	2678400	2678400	2678400	
f,м2	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	
V'ei,м/с	2,08	2,08	2,08	2,08	2,08	2,08	2,08	
vi,м/с	0,1	0,1	0,1	0,1	0,1	0,1	0,1	
q,г/м2	291	549	708	736	510	297	146	
							2511	g/m2
							2,51	kg/m2

ubakus

All statements without guarantee

Petrozavodsk, U=0,23 W/(m²K)

Moisture proofing

For the calculation of the amount of condensation water, the component was exposed to the following constant climate for 90 days: inside: 20°C und 55% Humidity; outside: -10.3°C und 86% Humidity (Climate according to user input).

Under these conditions, a total of 2,2 kg of condensation water per square meter is accumulated.In the summer, this amount would dry within 78 days (Drying season according to DIN 4108-3:2018-10), individual layers, however, suffer from too much moisture.

#		Material	sd-value [m]	Condensate [kg/m²]	Condensate [Gew.-%]	Weight [kg/m²]
1	2 cm	Pine	0,12	-	-	10,4
2	20 cm	Insulation/Polystyrene (EPS 040)	0,60	2,2		6,0
3	2 cm	Pine	2,00	1,7	17 (!)	10,4
	24 cm	Whole component	2,72	2,2 (!)		26,8

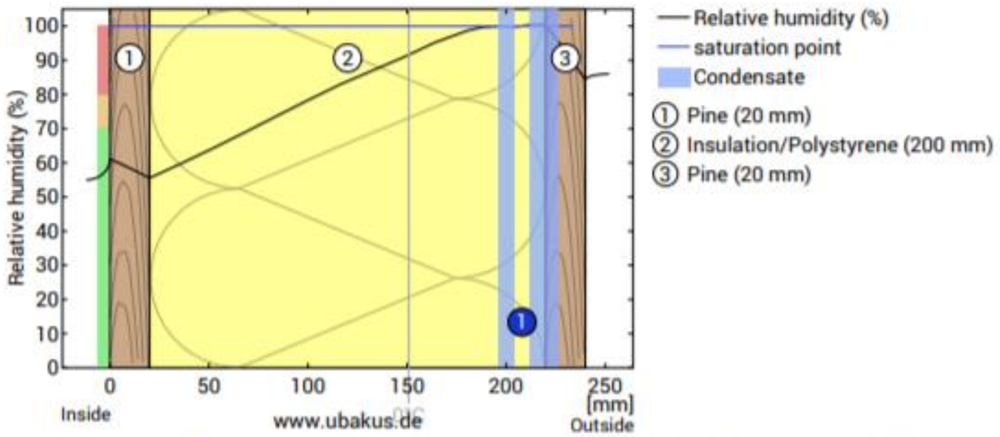
Condensation areas

(1) Condensate: 2,2 kg/m² Affected layers: Insulation/Polystyrene (EPS 040), Pine

Note: A condensation amount of more than 3% can permanently damage your component. In order to prevent damp damage despite large amounts of condensation water, it must be ensured that the condensation water can be distributed in the component by capillary conducting building materials and can dry quickly on the surface.

Humidity

The temperature of the inside surface is 18,3 °C leading to a relative humidity on the surface of 61%.Mould formation is not expected under these conditions.
The following figure shows the relative humidity inside the component.



Notes: Calculation using the Ubakus 2D-FE method. Convection and the capillarity of the building materials were not considered. The drying time may take longer under unfavorable conditions (shading, damp / cool summers) than calculated here.

ubakus

All statements without guarantee

Petrozavodsk, U=0,22 W/(m²K)

Moisture proofing

For the calculation of the amount of condensation water, the component was exposed to the following constant climate for 90 days: inside: 20°C und 55% Humidity; outside: -10.3°C und 86% Humidity (Climate according to user input).

Under these conditions, a total of 1,9 kg of condensation water per square meter is accumulated.In the summer, this amount would dry within 86 days (Drying season according to DIN 4108-3:2018-10), individual layers, however, suffer from too much moisture.

#		Material	sd-value [m]	Condensate [kg/m²]	[Gew.-%]	Weight [kg/m²]
1	3,3 cm	Pine	0,20	-	-	17,2
2	20 cm	Insulation/Polystyrene (EPS 040)	0,60	1,9		6,0
3	3,3 cm	Pine	3,30	1,7	10 (!)	17,2
	26,6 cm	Whole component	4,10	1,9 (!)		40,3

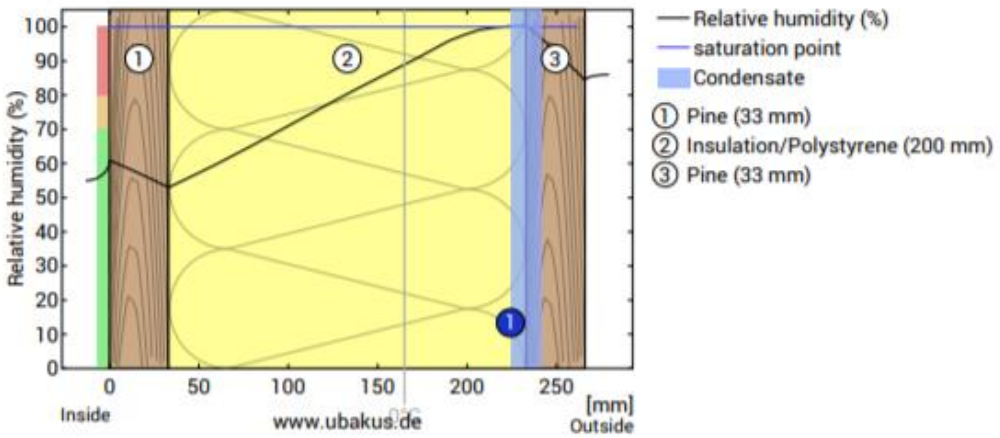
Condensation areas

1 Condensate: 1,9 kg/m² Affected layers: Insulation/Polystyrene (EPS 040), Pine

Note: A condensation amount of more than 3% can permanently damage your component. In order to prevent damp damage despite large amounts of condensation water, it must be ensured that the condensation water can be distributed in the component by capillary conducting building materials and can dry quickly on the surface.

Humidity

The temperature of the inside surface is 18,4 °C leading to a relative humidity on the surface of 61%.Mould formation is not expected under these conditions.
The following figure shows the relative humidity inside the component.



Notes: Calculation using the Ubakus 2D-FE method. Convection and the capillarity of the building materials were not considered. The drying time may take longer under unfavorable conditions (shading, damp / cool summers) than calculated here.

ubakus

All statements without guarantee

Petrozavodsk, U=0,22 W/(m²K)

Moisture proofing

For the calculation of the amount of condensation water, the component was exposed to the following constant climate for 90 days: inside: 20°C und 55% Humidity; outside: -10.3°C und 86% Humidity (Climate according to user input).

Under these conditions, a total of 1,8 kg of condensation water per square meter is accumulated.In the summer, this amount would dry within 90 days (Drying season according to DIN 4108-3:2018-10), individual layers, however, suffer from too much moisture.

#		Material	sd-value [m]	Condensate [kg/m²]	Condensate [Gew.-%]	Weight [kg/m²]
1	4,3 cm	Pine	0,26	-	-	22,4
2	20 cm	Insulation/Polystyrene (EPS 040)	0,60	1,8		6,0
3	4,3 cm	Pine	4,30	1,7	7,7 (!)	22,4
	28,6 cm	Whole component	5,16	1,8 (!)		50,7

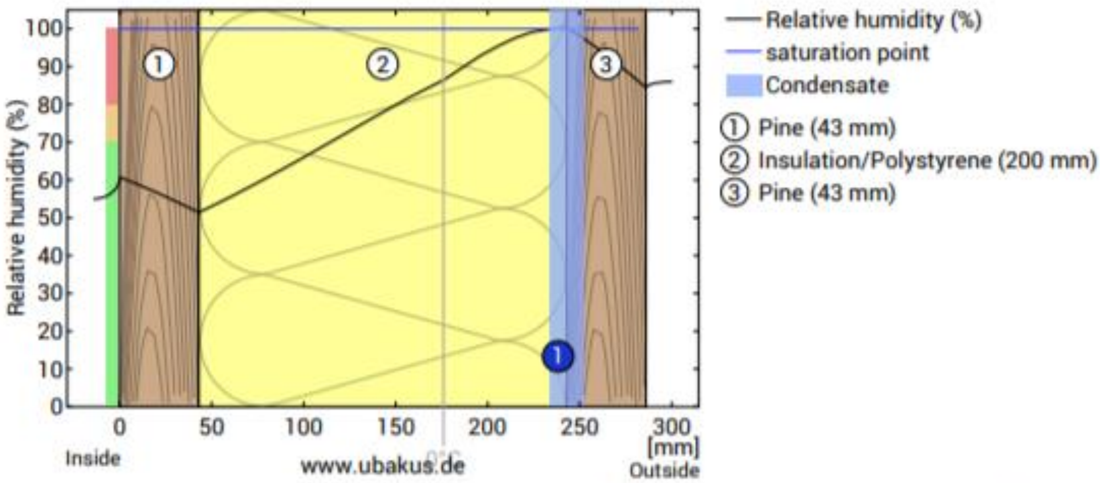
Condensation areas

1 Condensate: 1,8 kg/m² Affected layers: Insulation/Polystyrene (EPS 040), Pine

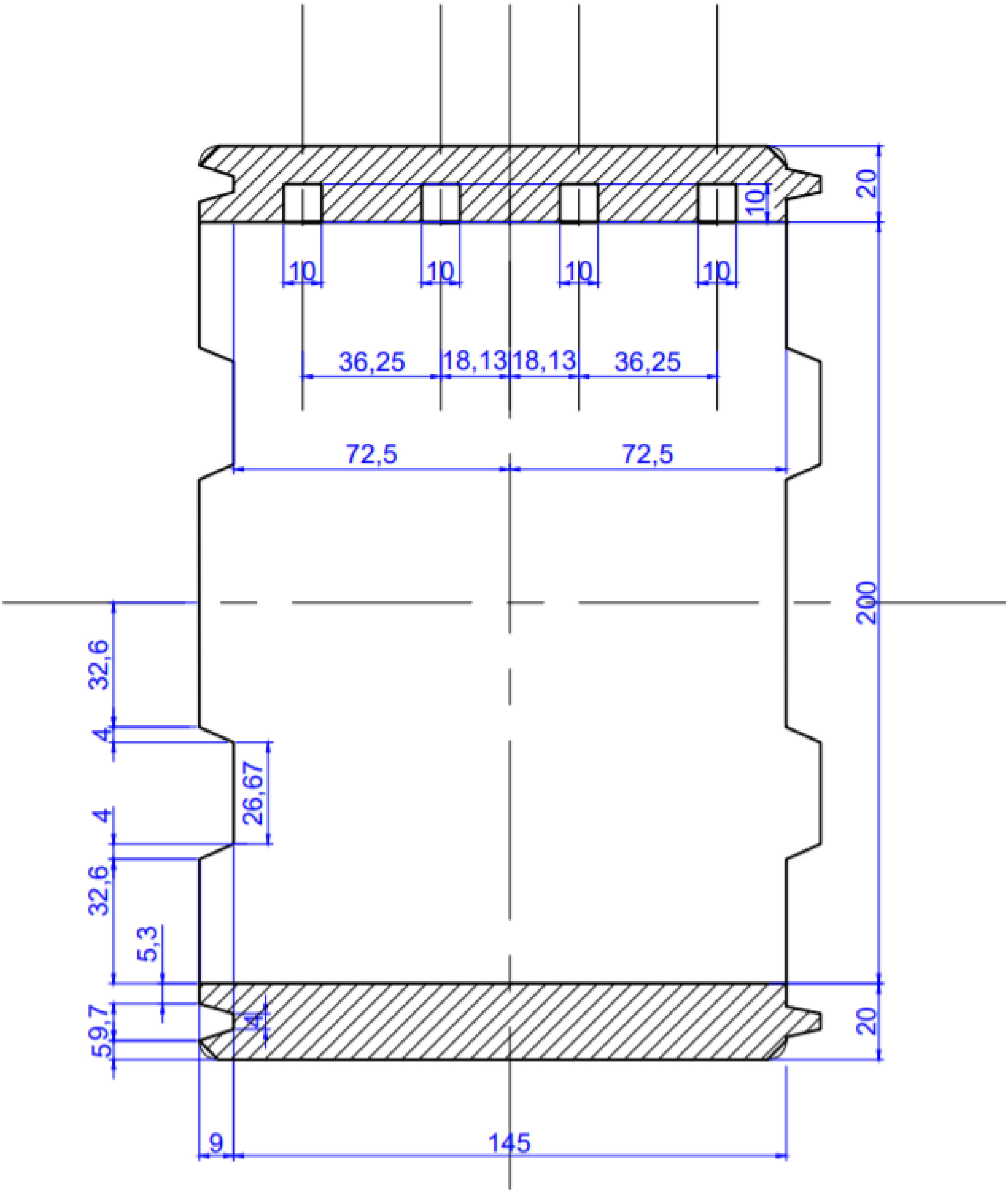
Note: A condensation amount of more than 3% can permanently damage your component. In order to prevent damp damage despite large amounts of condensation water, it must be ensured that the condensation water can be distributed in the component by capillary conducting building materials and can dry quickly on the surface.

Humidity

The temperature of the inside surface is 18,4 °C leading to a relative humidity on the surface of 61%.Mould formation is not expected under these conditions.
The following figure shows the relative humidity inside the component.



Notes: Calculation using the Ubakus 2D-FE method. Convection and the capillarity of the building materials were not considered. The drying time may take longer under unfavorable conditions (shading, damp / cool summers) than calculated here.



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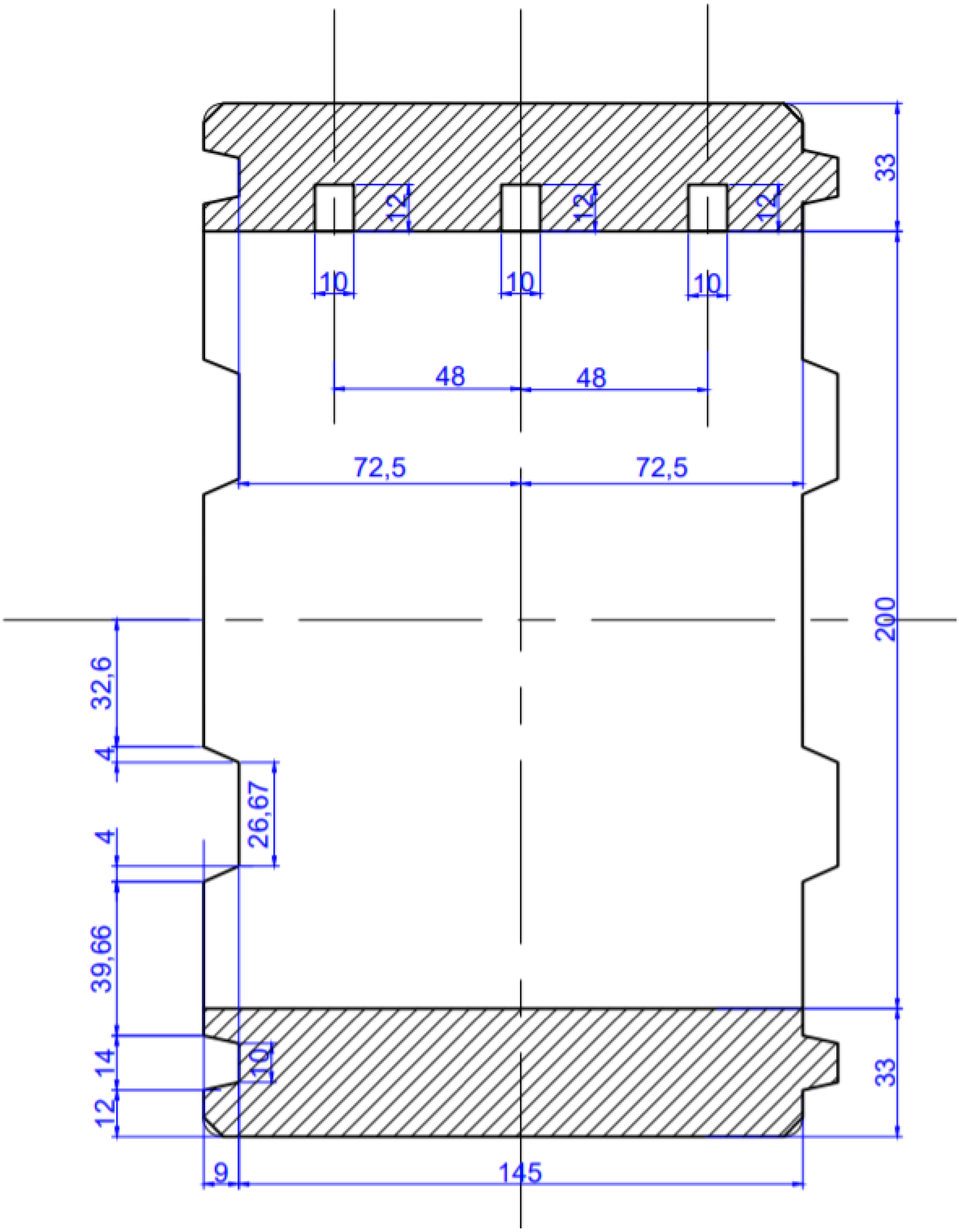
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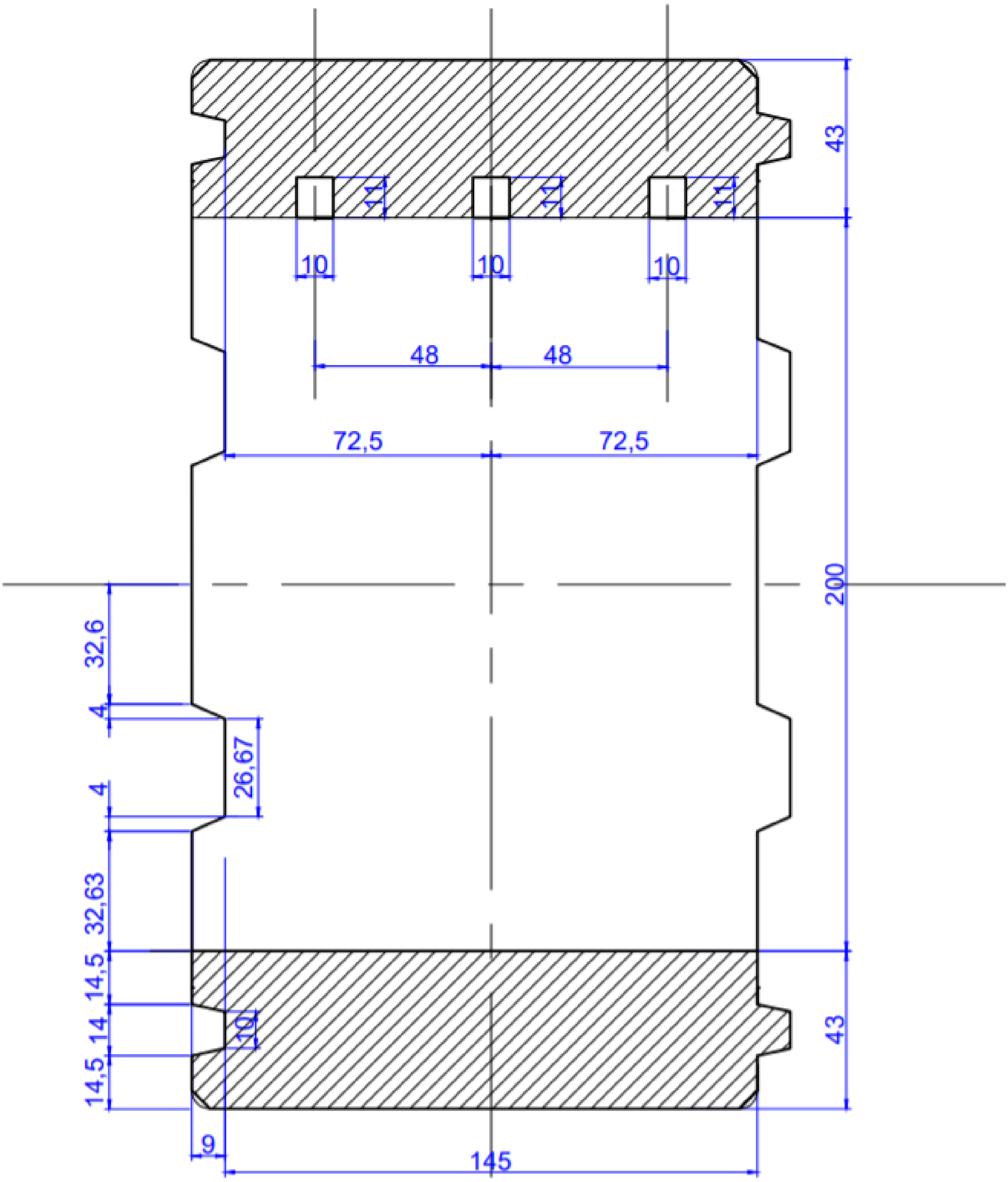
APPENDIX 6



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