

Technical Report

FINHA 100 Series Building Structural Calculations

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TABLE OF CONTENTS

INTRODUCTION.....	3
1. INITIAL DATA FOR CALCULATION	3
1.1 General description	3
1.2 Units.....	13
1.3 Materials used and reference data.....	13
1.4 Static loads	15
1.5 Seismic loads	16
1.6 Design load combinations	17
The basic combinations.....	17
Special combinations.....	17
1.7 Assigning loads and constrains.....	17
2. STRENGTH ANALYSIS	18
2.1 Frame design models	18
2.2 Frame A100, span 4.3 m.....	18
2.3 Frame P100, span 2.0 m	21
2.4 Frame V100, span 3.0 m.....	24
2.5 Frame W100, span 2.4 m.....	26
CONCLUSION	27
LIST OF USED SOURCES	28

INTRODUCTION

This calculation was performed to confirm that the strength and stability characteristics of the FINHA 100 series building with connectors comply with the requirements of building codes SP 64.13330.2017 “SNiP II-25-80. Wooden Structures.” The calculation is performed for load cases corresponding to extreme operating conditions:

- Snow zone VIII;
- Wind zone VII, terrain type C;
- Construction site seismicity of magnitude 9 with soil categories I-IV;

Objective:

- Creating load cases in accordance with SNiP standards;
- Creating finite element models of the designed buildings;
- Performing stability and stress-strain state calculations for given load cases;
- Generating design force combinations in accordance with SNiP standards;
- Determining safety factors

1. INITIAL DATA FOR CALCULATION

1.1 General description

A general view of the FINHA 100 series frames and buildings based on them is shown in Figs. 1–12.

The building frame is assembled from transverse frames made of wooden beams, which are connected to each other via connectors, and longitudinal beams. The frame is installed on the grillage beams, which are also made of wood.

Frame beams are made from 45x100 mm section boards. Frame pitch $L=625$ mm.

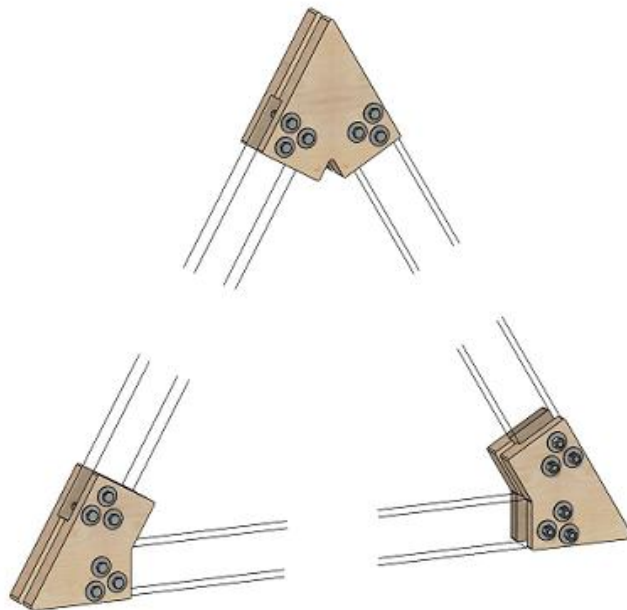


Fig. 1. Building connectors FINHA-A100

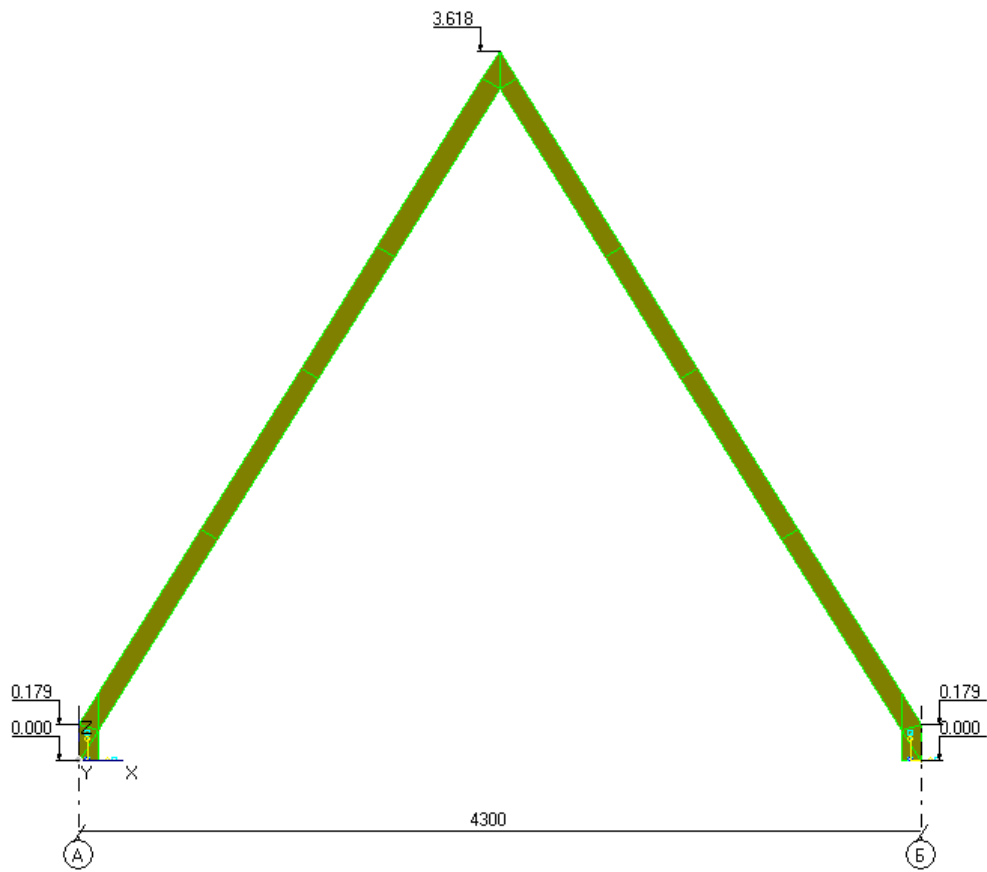


Fig. 2. FINHA-A100 building frame

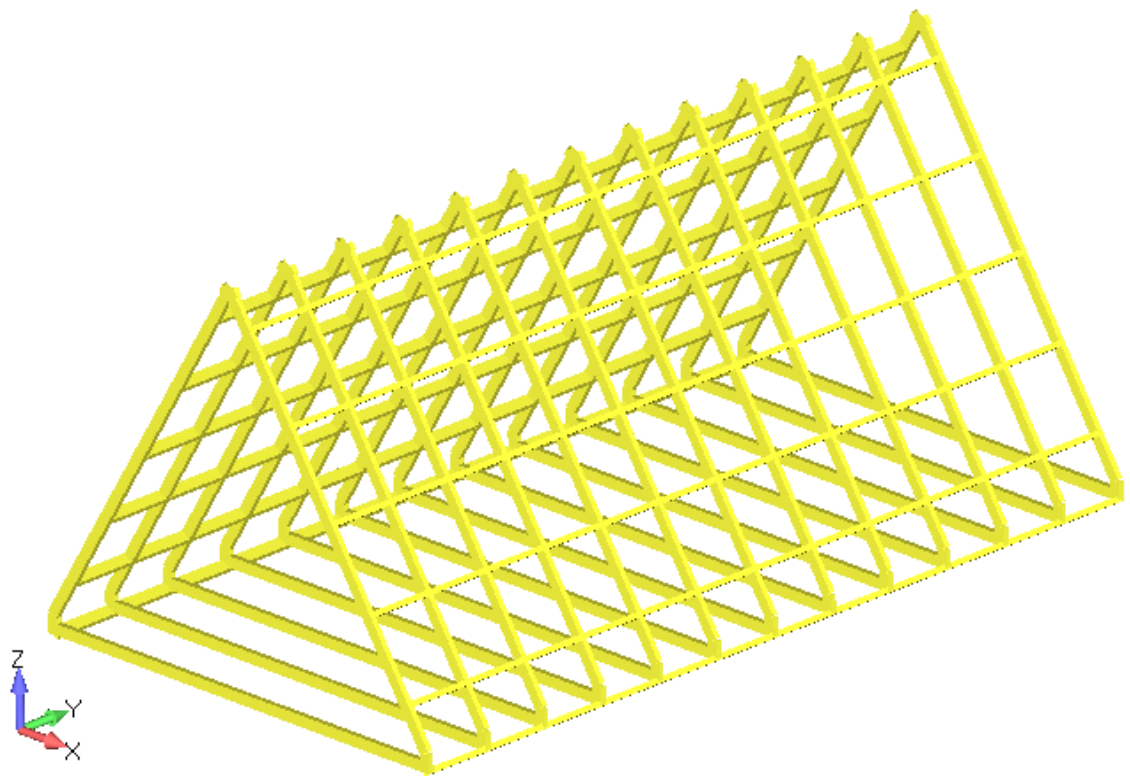


Fig. 3. General view of the FINHA-A 100 building frame, 4.3 meters wide

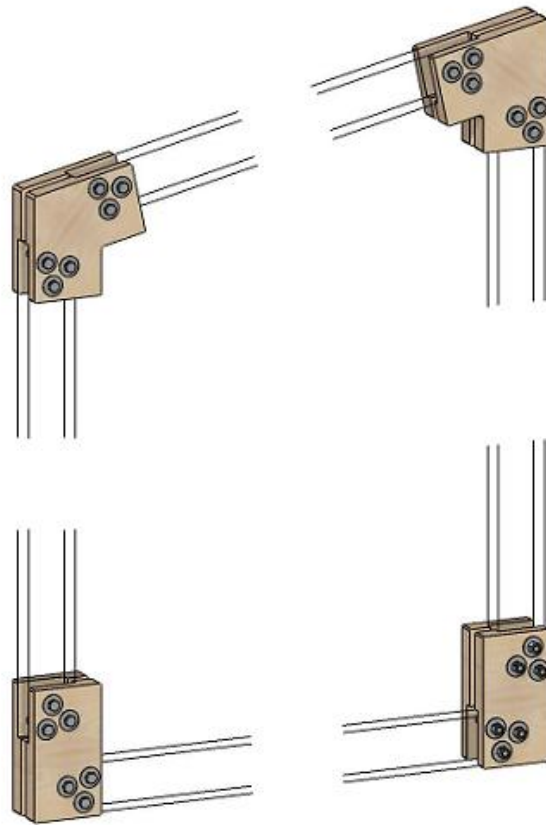


Fig. 4. Building connectors FINHA-P100

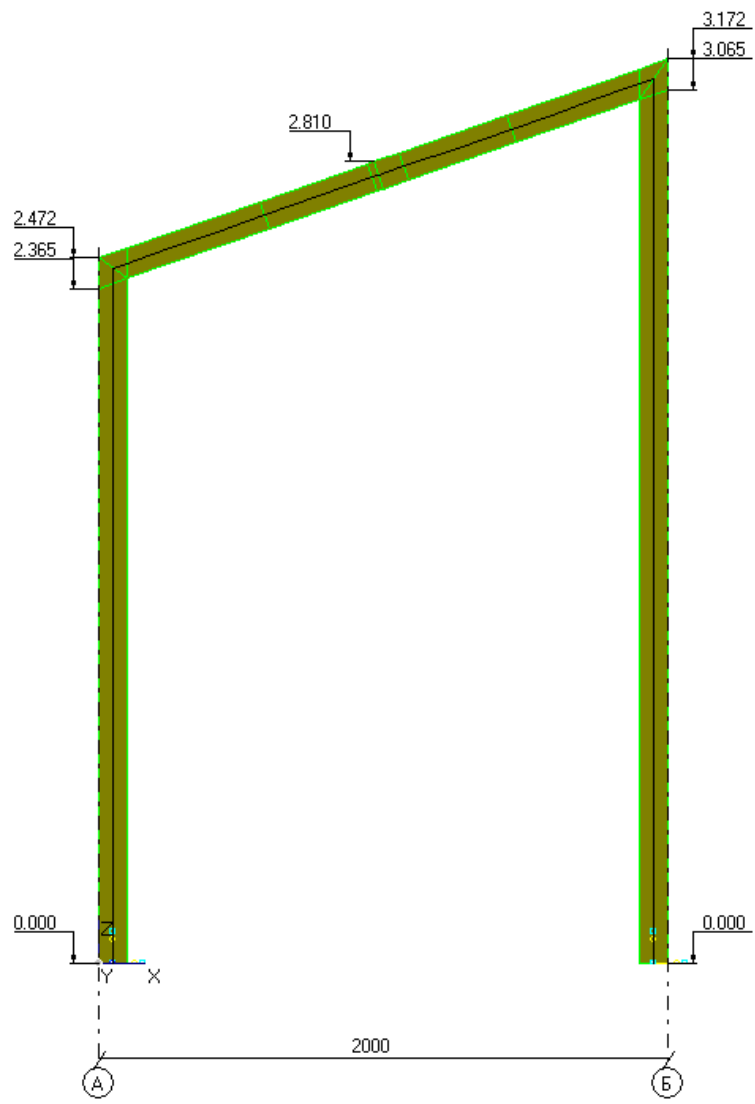


Fig. 5. FINHA-P100 building frame

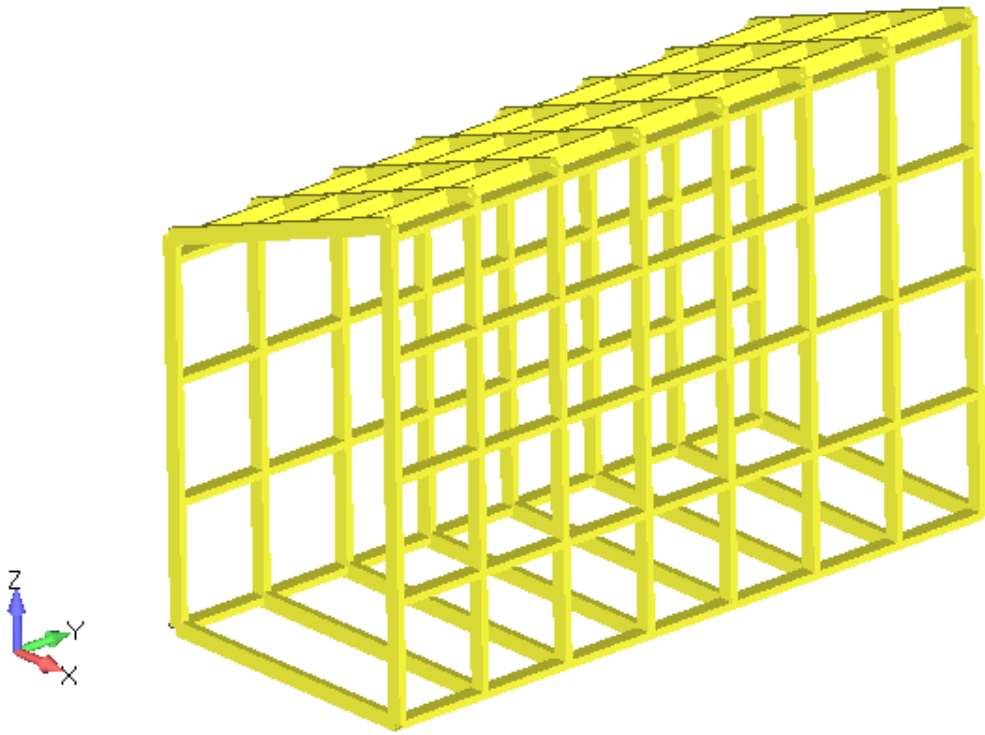


Fig. 6. General view of the FINHA-A100 shed-roof building frame, 2.0 meters wide

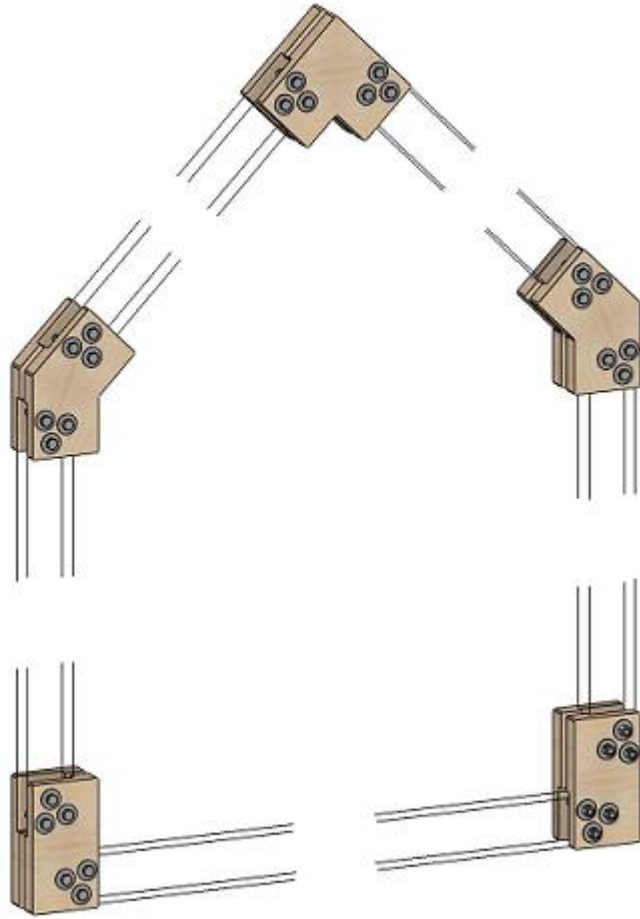


Fig. 7. Building connectors FINHA-V100

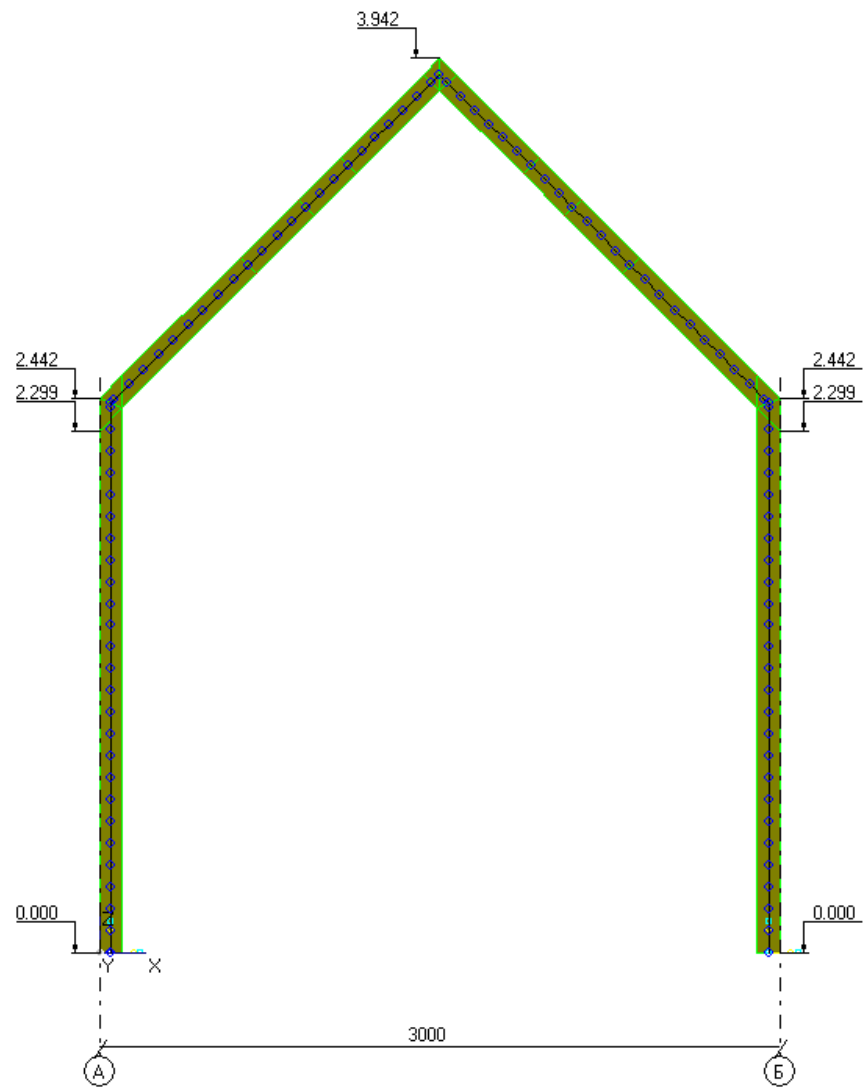


Fig. 8. FINHA-V100 building frame

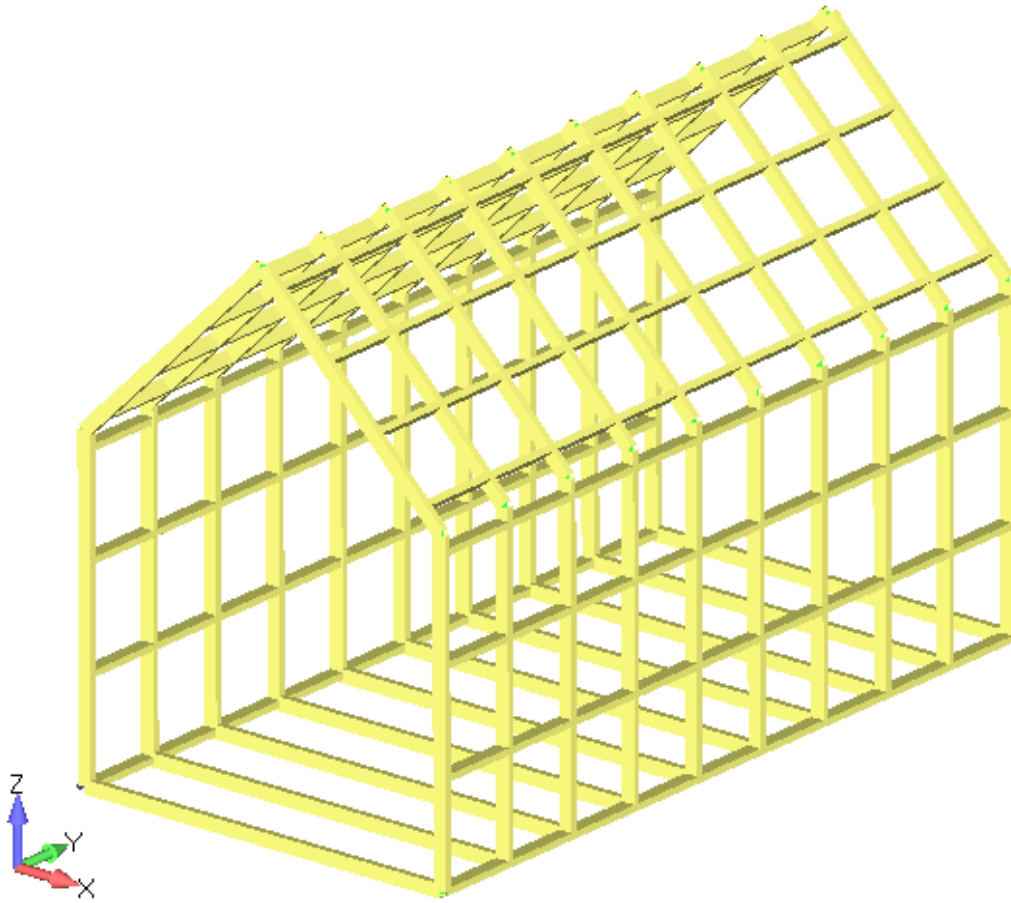


Fig. 9. General view of the FINHA-A 100 gable roof building frame, 3.0 meters wide, slope is 45 deg.

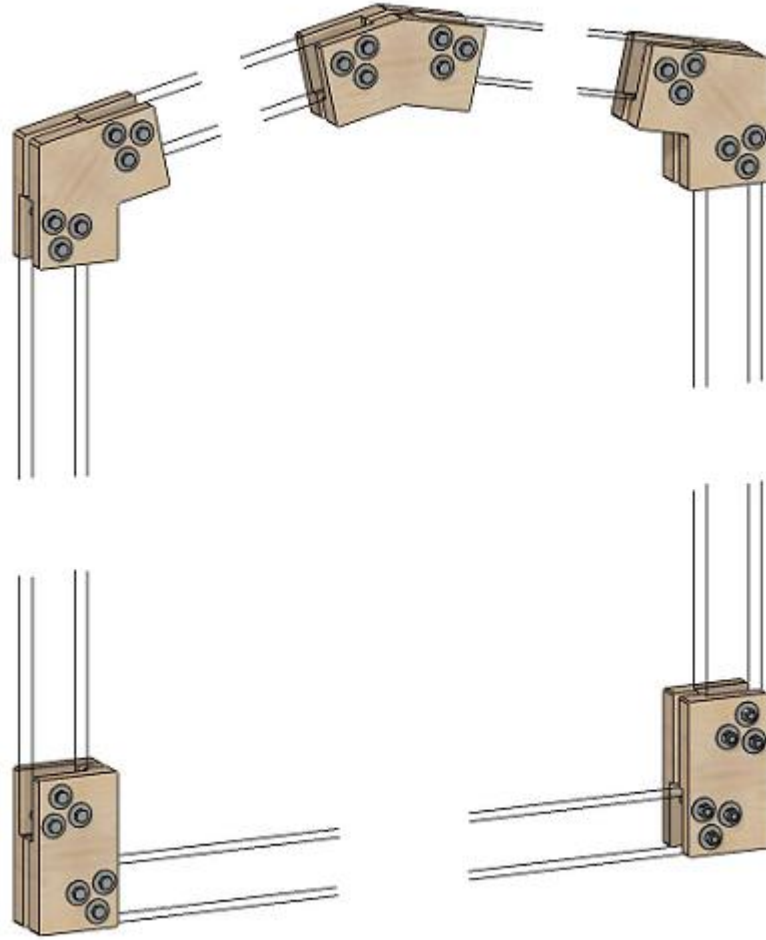


Fig. 10. Building connectors FINHA-W100

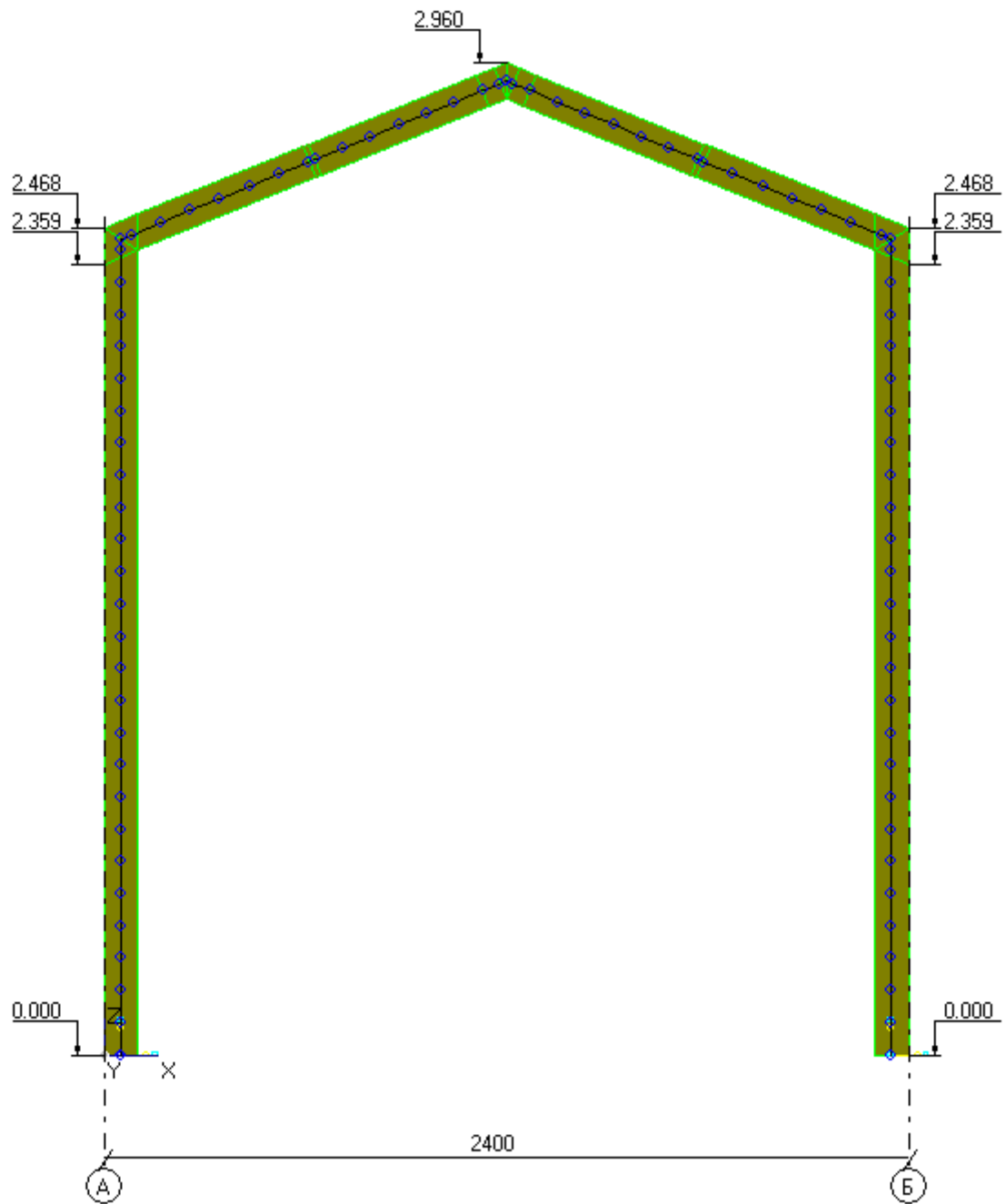


Fig. 11. FINHA-W100 building frame

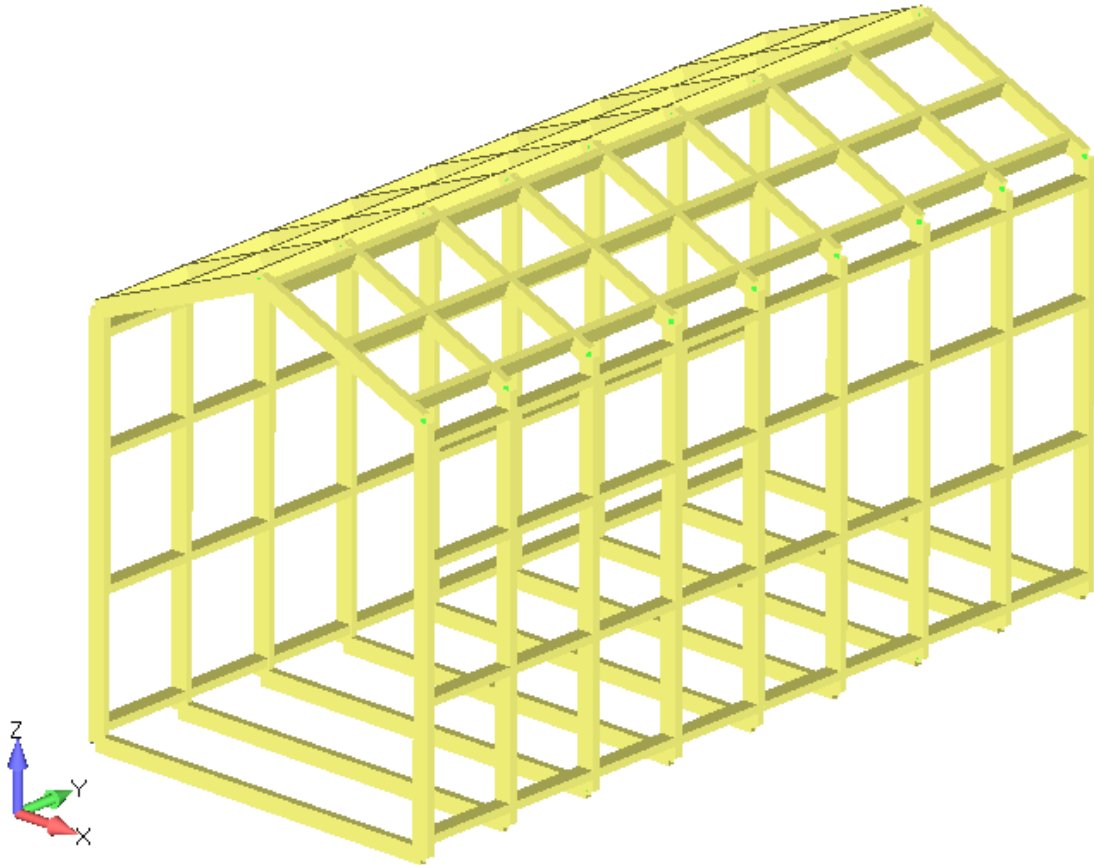


Fig. 12. General view of the FINHA-A100 gable roof building frame, 2.4 meters wide, slope is 22.3 deg.

1.2 Units

The following units are used in this calculation:

- Force – N;
- Length – mm;
- Stress – MPa;

1.3 Materials used and reference data

Wood, grade 1, table 3 [1] :

- $R_{bend}^A = R_{comp} = 24 \text{ MPa}$;
- $R_p^A = 15 \text{ MPa}$;

The design resistance is determined by the relation 1 [1]

$$R^P = R^A \cdot m_{\partial n} \cdot \prod m_i$$

The coefficient of long-term strength $m_{\partial n}$ is taken from the table 4 [1]

- $m_{\partial n} = 0.66$ - under the combined action of permanent and short-term loads;

- $m_{\partial l} = 0.92$ - under the combined action of permanent and seismic loads.

Working conditions coefficients, p. 6.9 [1]:

- $m_b = 0.9$ on table. 9;
- $m_t = 1.0$;
- $m_{cl} = 1.0$ on table. 11;
- $m_{cc} = 1.0$ on table. 13 ;

$$\Pi m_i = m_b \cdot m_t \cdot m \cdot m_{cc} = 0.9 \cdot 1.0 \cdot 1.0 \cdot 1.0 = 0.9$$

Design value of resistance to bending and compression:

- $R_{bend}^A = R_{comp} = 24 \cdot 0.66 \cdot 0.9 = 14$ MPa - under the combined action of permanent and short-term loads;
- $R_{bend}^A = R_{comp} = 24 \cdot 0.92 \cdot 0.9 = 20$ MPa - under the combined action of permanent and seismic loads.

Design value of resistance to tension:

- $R_p^A = 15 \cdot 0.66 \cdot 0.9 = 8.9$ MPa - under the combined action of permanent and short-term loads;
- $R_p^A = 15 \cdot 0.92 \cdot 0.9 = 12.4$ MPa - under the combined action of permanent and seismic loads.

Design bearing strength:

- along the grain $R_{cr0}^A = R_{bend}^A = 14$ MPa;
- cross-grain $R_{cr90}^A = 4.5$ MPa.
- under 45-degree loading., r.6[1]:

$$R_{cr45}^A = R_{cr0}^A / (1 + (R_{cr0}^A / R_{cr90}^A - 1) \cdot \sin^3 45) = 8.0 \text{ MPa}$$

Plywood:

Design value of resistance:

- $R^A = 14$ MPa - under the combined action of permanent and short-term loads;
- $R^A = 20$ MPa - under the combined action of permanent and seismic loads.

Design bearing strength:

- $R_{cr0}^A = R_{bend}^A = 14$ MPa;

The calculation is performed for a group of static loads and a group of seismic loads, on the basis of which the design load combinations are formed.

1.4 Static loads

1. Building's own weight, permanent loading (**weight**).

Weight loads are determined by acceleration along the vertical axis $a = g \cdot \gamma_{Gf}$,

where

$$g = 9810 \text{ mm/c}^2, \gamma_{Gf} = 1.2 - \text{load safety factor.}$$

2. Floor beam load weight, temporary loading (**load**);

The load value is taken in accordance with p. 8.2.2 and table 8.3 [2]:

$$q = P_1 \cdot \gamma_f = 0.0015 \cdot 1.3 = 0.00195 \text{ MPa,}$$

There $P_1 = 0.0015 \text{ MPa}$ – nominal value of uniformly distributed load;

$$\gamma_f = 1.3 - \text{load safety factor.}$$

3. Snow loads: Snow on the left (**snow left**) and Snow on the right (**snow right**), temporary loadings:

Nominal value of uniformly snow load, p.10 [2]

$$S_0 = c_e \cdot c_t \cdot \mu \cdot S_g$$

There

$$c_e = 1.0 - \text{snow drifting factor is taken in accordance with p. 10.6 [2];}$$

$$c_t = 1.0 - \text{thermal coefficient;}$$

μ – the conversion factor from the weight of the snow cover of the ground to the snow load on the roof is taken in accordance with p. 10.4 [2] ;

$$\mu = 1.0 - \text{for roof slope angle up to 30 deg;}$$

$$\mu = 0.5 - \text{for roof slope angle up to 45 deg;}$$

For angles greater than 45 degrees, it is taken into reserve $\mu = 0.5$;

$$S_g = 4.0 \text{ kN/m}^2 - \text{nominal value of snow cover weight on } 1 \text{ m}^2 \text{ for the snow region VIII.}$$

Design value of snow load:

$$S = S_0 \cdot \gamma_{Sf},$$

$$\gamma_{Sf} = 1.4 - \text{load safety factor for snow load.}$$

4. Wind loads, temporary loadings (**wind left** and **wind right**):

Nominal value of wind pressure is taken in accordance with p.11.1.4 [2] for the wind region VII:

$$w_0 = 0.85 \text{ kN/m}^2;$$

$\gamma_{Wf} = 1.4$ – load safety factor for wind load.

1.5 Seismic loads

- Horizontal action in the direction of the transverse axis (**Quake X**);
- Horizontal impact in the direction of the longitudinal axis (**Quake Y**);
- Vertical impact (**Quake Z**).

The seismic load parameters are taken with the estimated seismicity of the region being 9 points, soil category II.

The design seismic load in the direction of the generalized coordinate with number j , applied to node k of the calculation model and corresponding to the i -th eigen mode of the building is determined by the formula:

$$S_{ik}^j = K_0 \cdot K_1 \cdot S_{0ik}^j$$

- $K_0 = 0.8$ - factor that takes into account the purpose of the structure and its responsibility, taken from the table [3];
- $K_1 = 0.15$ - factor taking into account permissible damage to buildings, adopted according the table 4 [3];

S_{0ik}^j - the value of the seismic load for the i -th eigen mode of a building, determined under the assumption of elastic deformation of structures according to the formula:

$$S_{0ik}^j = m_k^j \cdot A \cdot K_\psi \cdot \beta_i \cdot \eta_{ik}^j.$$

There

m_k^j - the mass of the building or the moment of inertia of the corresponding mass of the building, referred to the node k along the generalized coordinate j ;

- $K_\psi = 1.3$ - factor that takes into account the ability of a building to dissipate vibration energy under horizontal impact, taken from table 5.
- $A = 4 \text{ m/s}^2$ - the acceleration value at the foundation level with the estimated seismicity of the area being 9 points, soil category II;

η_{ik}^j - factor depending on the form of deformation of the building during its oscillations according to the i -th mode;

β_i - dynamic coefficient corresponding to the period of oscillations for the i -th eigen mode, adopted in accordance with p. 5.6 [3], for soil of category III (adopted as a reserve), Fig. 13.

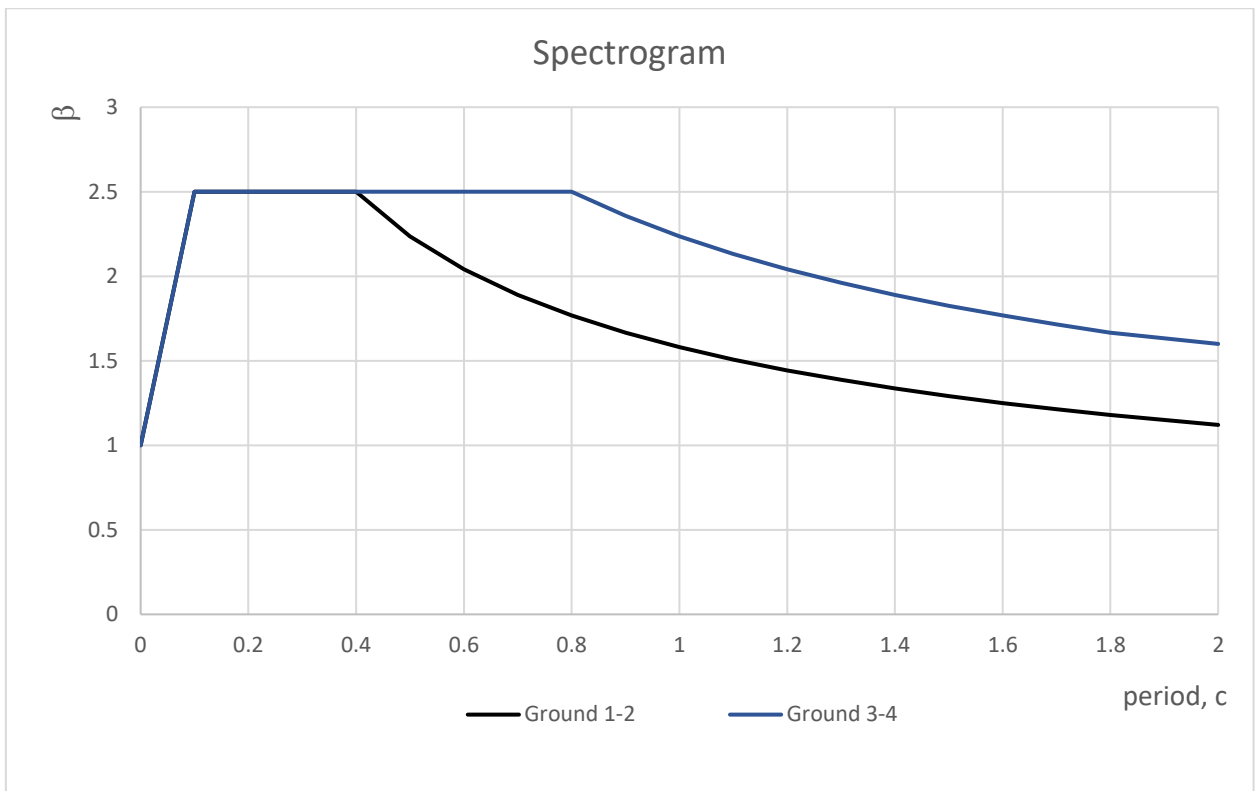


Fig. 13. Spectrogram of dynamic coefficients

1.6 Design load combinations

The coefficients in load combinations are taken in accordance with p. 6.2, 6.3, 6.4 [2] and p. 5.1 [3]

The basic combinations

1. weight + load + snow_left + snow_right
2. weight + load + snow_left + snow_right + 0.9*wind_left
3. weight + load + snow_left + snow_right + 0.9*wind_tor

Special combinations

1. Quake X + 0.9*Weight + 0.8*load + 0.5*snow_left + 0.5*snow_right
2. Quake Y + 0.9*Weight + 0.8*load + 0.5*snow_left + 0.5*snow_right
3. Quake Z + 0.9*Weight + 0.8*load + 0.5*snow_left + 0.5*snow_right
4. Quake X + 0.75*Quake Z + 0.9*Weight + 0.8*load + 0.5*snow_left + 0.5*snow_right
5. Quake Y + 0.75*Quake Z + 0.9*Weight + 0.8*load + 0.5*snow_left + 0.5*snow_right

1.7 Assigning loads and constrains

The static loads from weight (**weight**) are given in the form of acceleration

$$g = -9810 \cdot 1.2 = -11770 \text{ mm/c}^2, \text{ (considering } \gamma_{Gf} = 1.2) \text{ along the Z coordinate axis.}$$

Snow and wind loads are specified as distributed loads applied to beams and studs.

Seismic loads are specified by the spectrogram of dynamic coefficients, see Fig. 6, amplitude A and coefficients K_0, K_1, K_Ψ .

The building model is pivotally fixed at the support points on the piles.

2. STRENGTH ANALYSIS

2.1 Frame design models

The frames are modeled using 100x50 mm Beam-type elements. Connectors are not modeled. Their strength, as shown in the calculation [4], is higher than that of the boards.

2.2 Frame A100, span 4.3 m

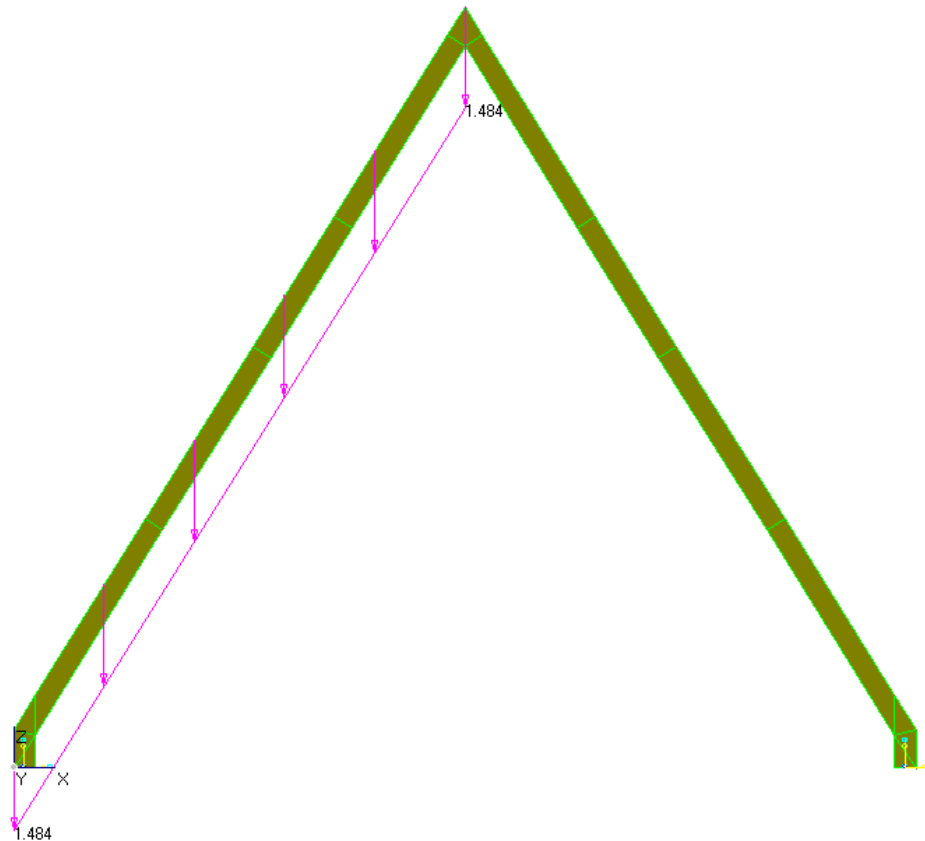


Fig. 14. Frame A100, snow load on the left, kN/m²

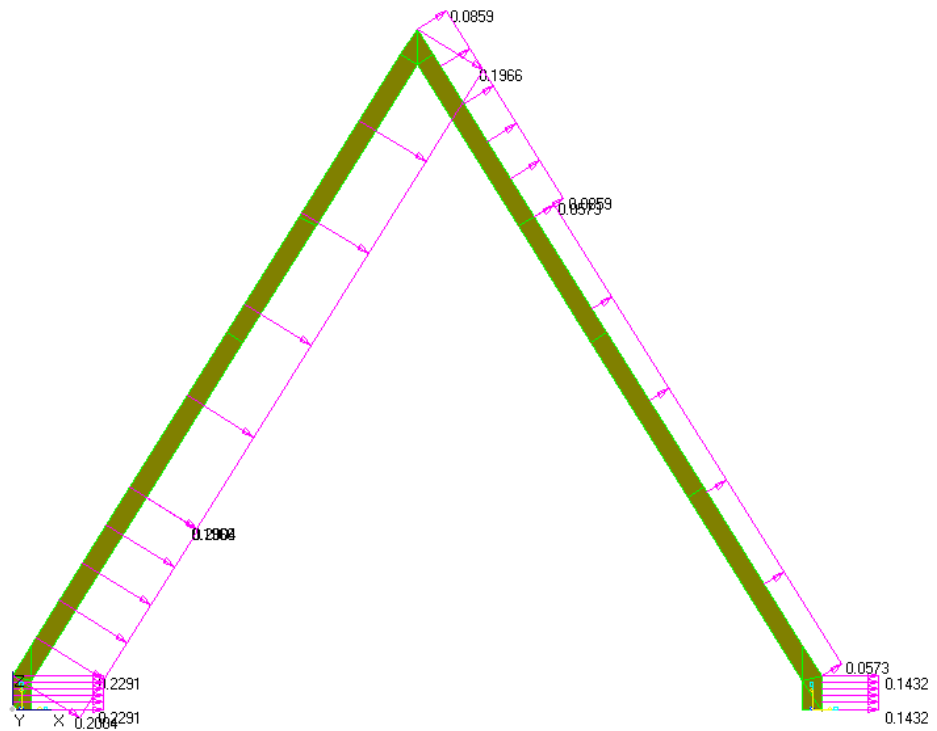


Fig. 15. Frame A100, wind load on the left, kN/m²

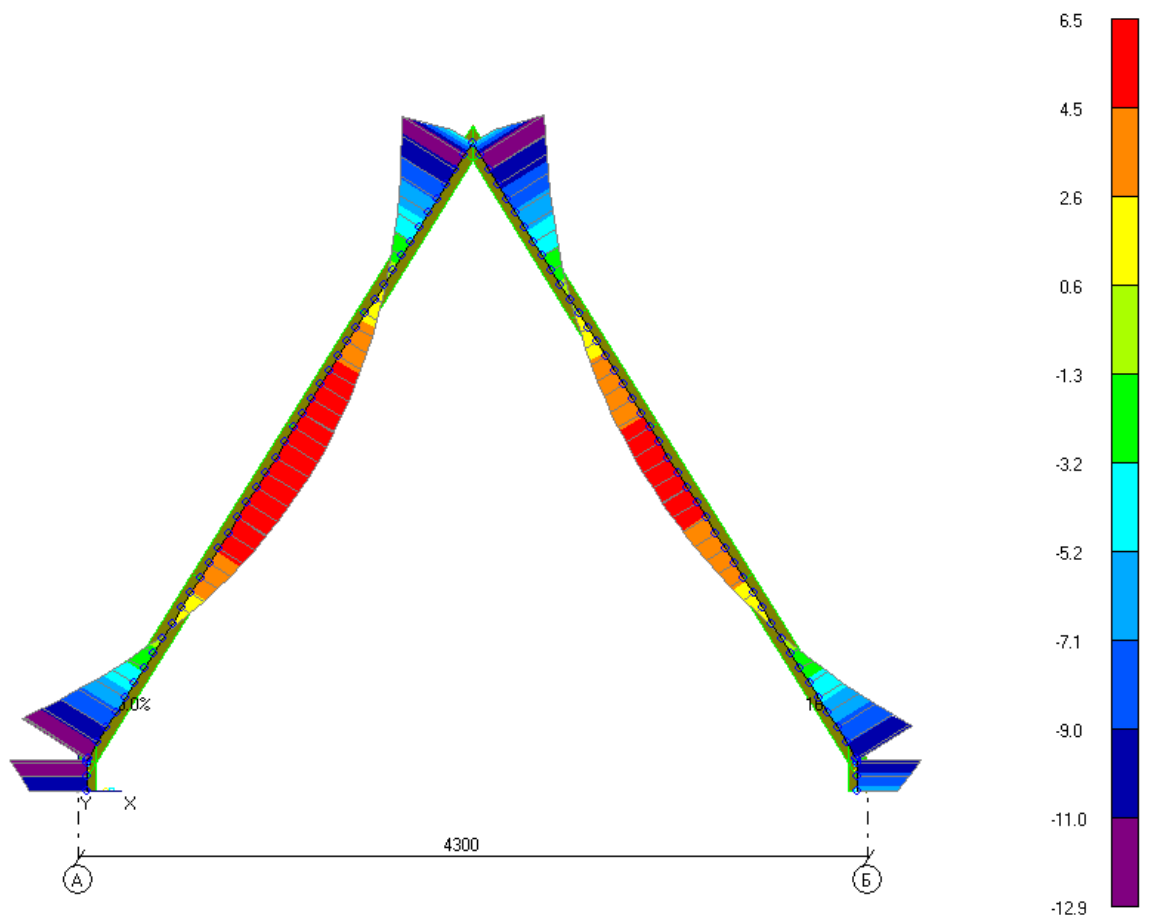


Fig. 16. Frame A100, maximum stresses in basic load combinations, MPa

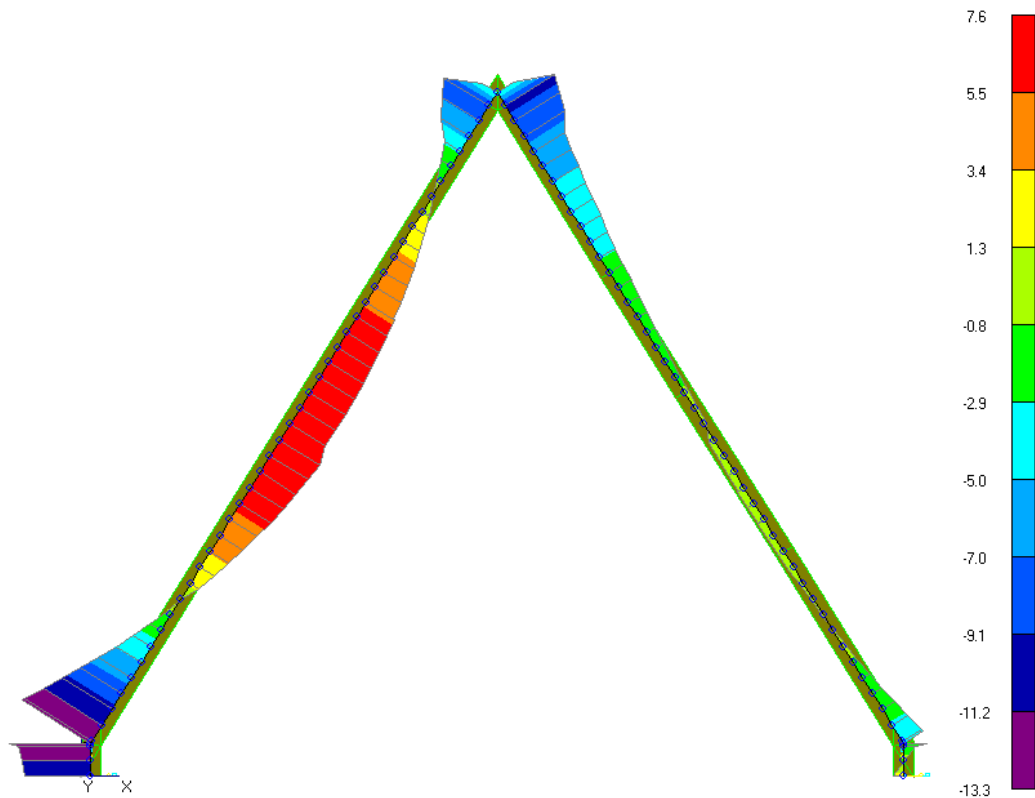


Fig. 17. Frame A100, maximum stresses in special load combinations, MPa

Basic load combinations

Design value of resistance to bending and compression:

- $R_{bend}^A = R_{comp} = 14$ MPa - under the combined action of permanent and short-term loads.

Maximum bending stresses in frame elements: $\sigma_{max} = 12.9$ MPa, fig. 16:

- Factor of safety $\eta = R_p^A / \sigma_{max} = 14/12.9 = \mathbf{1.09}$
- Utilization rate $f = 1/\eta = \mathbf{0.92}$

Special load combinations

Design value of resistance to bending and compression:

- $R_{bend}^A = R_{comp} = 20$ MPa - under the combined action of permanent and short-term loads.

Maximum bending stresses in frame elements: $\sigma_{max} = 13.3$ MPa, fig. 17:

- Factor of safety $\eta = R_p^A / \sigma_{max} = 20/13.3 = \mathbf{1.5}$
- Utilization rate $f = 1/\eta = \mathbf{0.67}$

2.3 Frame P100, span 2.0 m

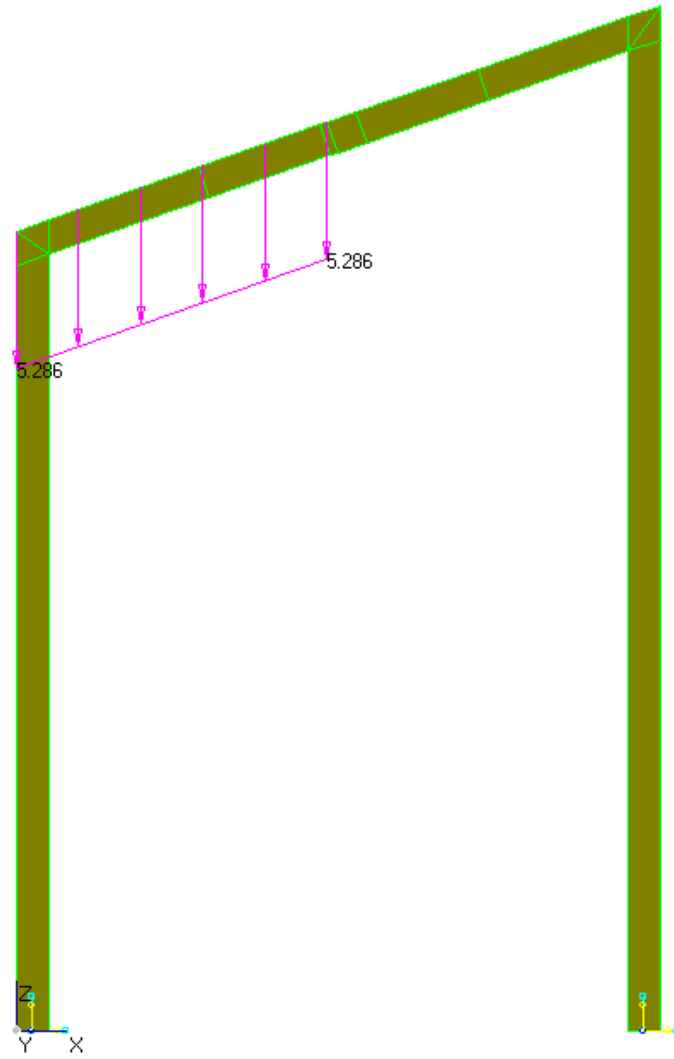


Fig. 18. Frame P100, snow load on the left, kN/m²

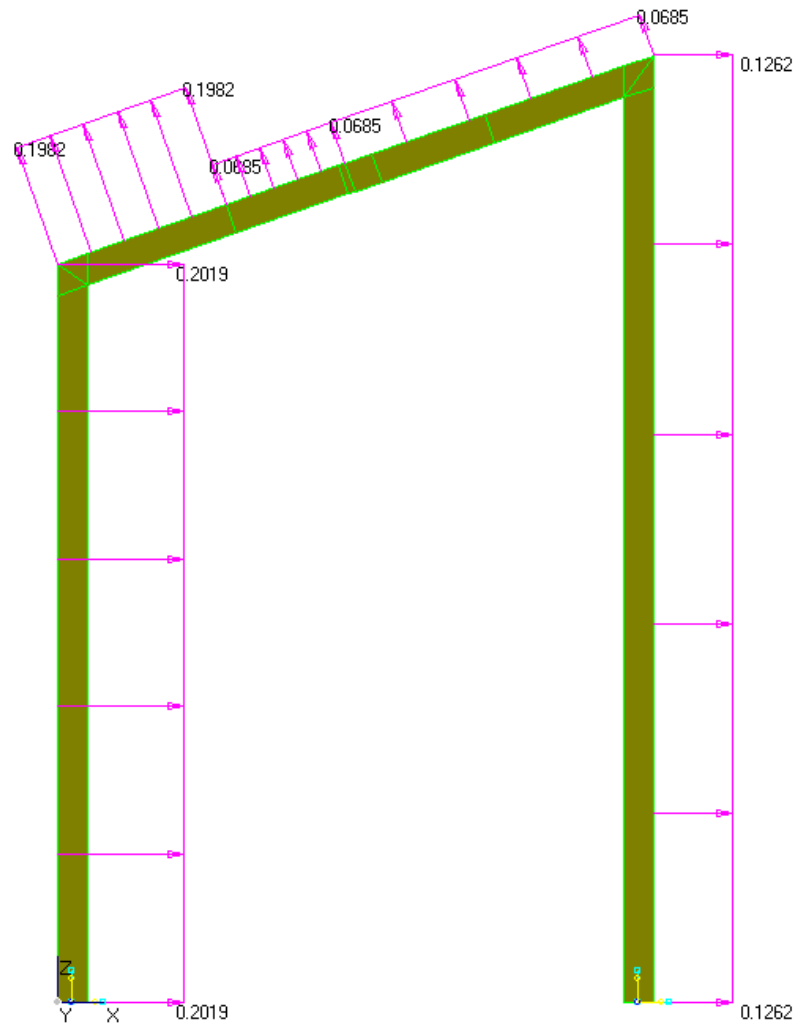


Fig. 19. Frame P100, wind load on the left, kN/m²

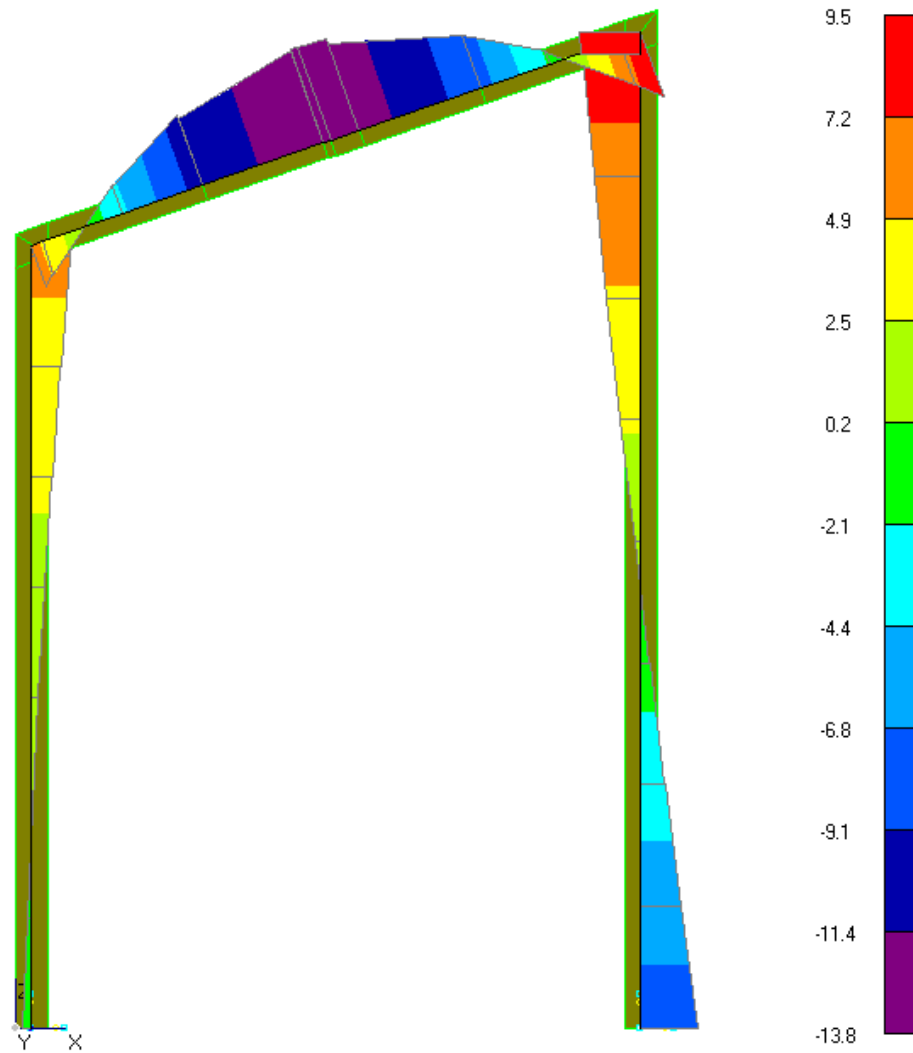


Fig. 20. Frame P100, maximum stresses in basic load combinations, MPa

Basic load combinations

Design value of resistance to bending and compression:

- $R_{bend}^A = R_{comp} = 14$ MPa - under the combined action of permanent and short-term loads.

Maximum bending stresses in frame elements: $\sigma_{max} = 13.8$ MPa, fig. 20:

- Factor of safety $\eta = R_p^A / \sigma_{max} = 14/13.8 = \mathbf{1.01}$
- Utilization rate $f = 1/\eta = \mathbf{0.99}$

2.4 Frame V100, span 3.0 m

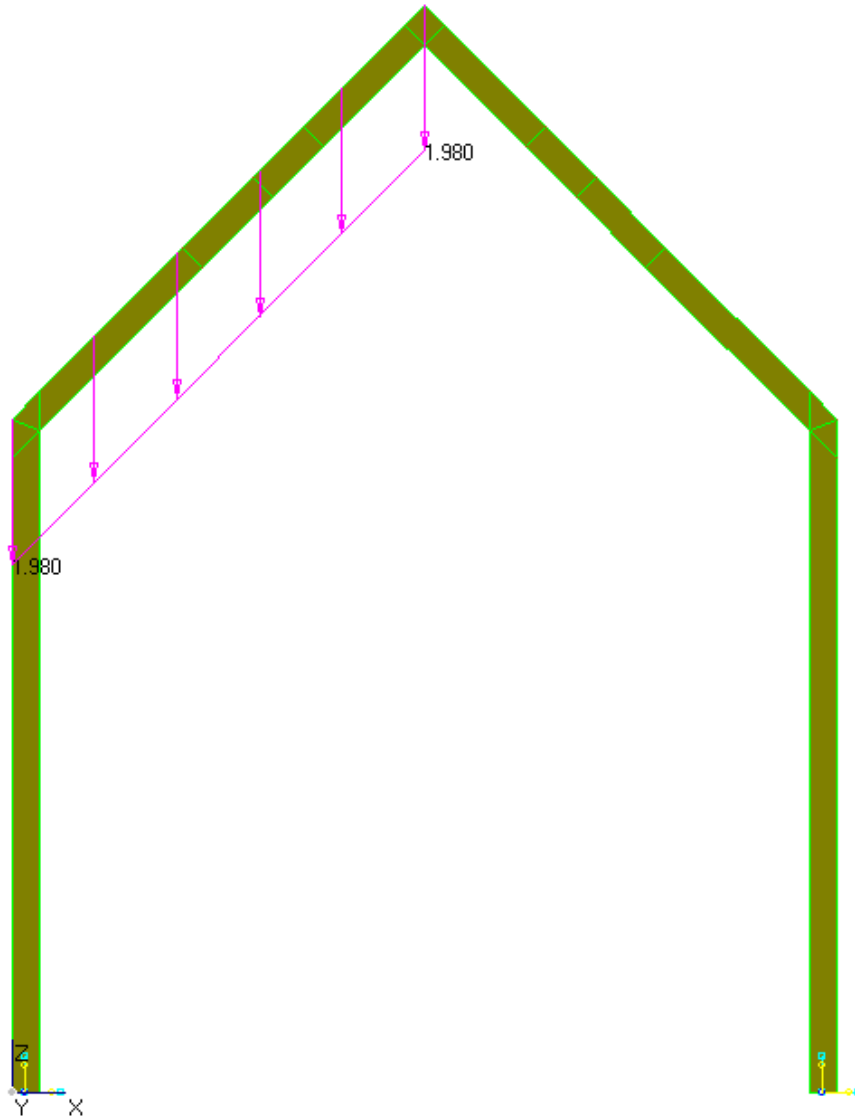


Fig. 21. Frame V100, snow load on the left, kN/m²

Design value of resistance to bending and compression:

- $R_{bend}^A = R_{comp} = 14$ MPa - under the combined action of permanent and short-term loads.

Maximum bending stresses in frame elements: $\sigma_{max} = 13.7$ MPa, fig. 22,

- Factor of safety $\eta = R_p^A / \sigma_{max} = 14 / 13.7 = \mathbf{1.02}$
- Utilization rate $f = 1/\eta = \mathbf{0.98}$

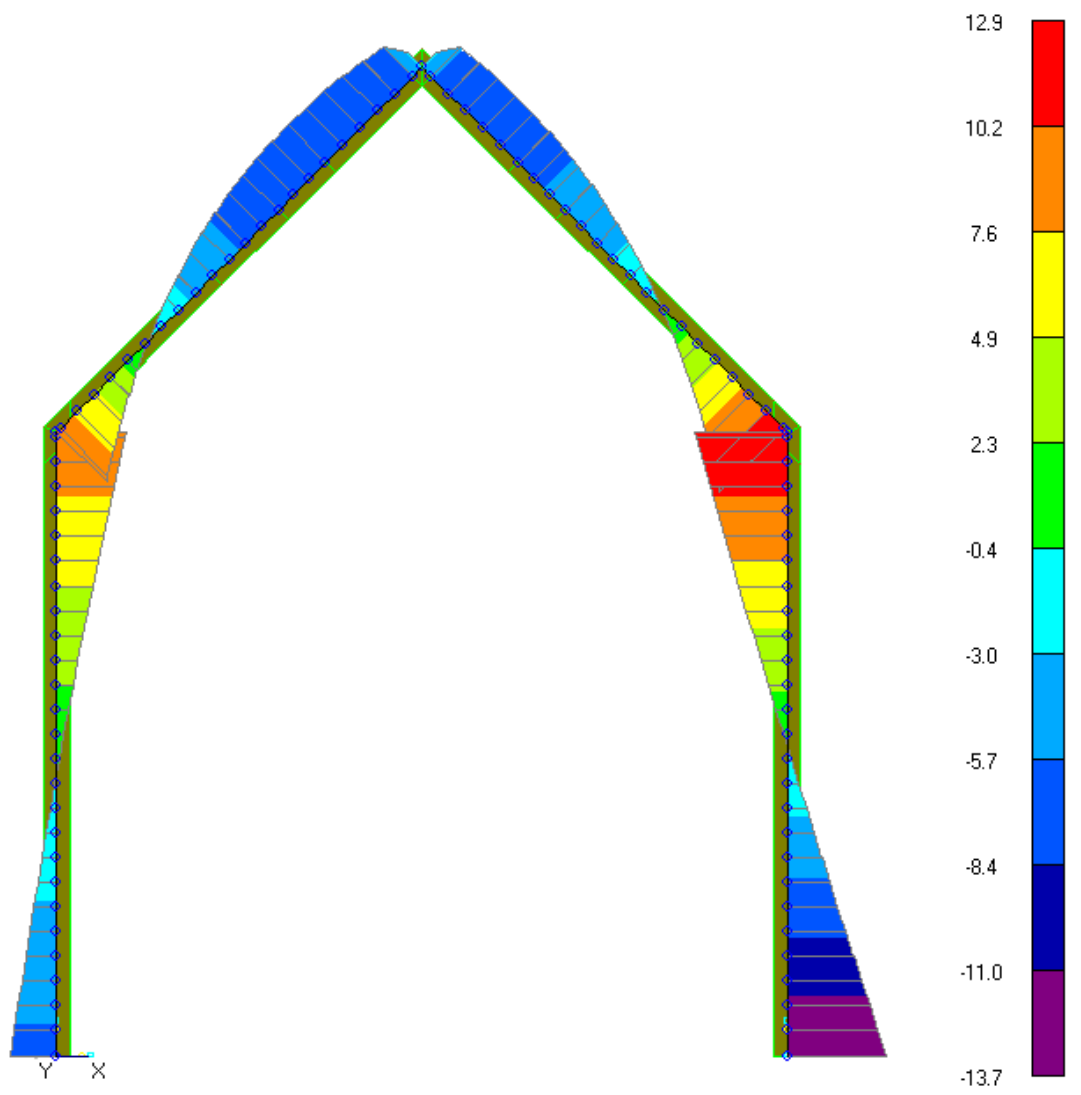


Fig. 22. Frame V100, maximum stresses in basic load combinations, MPa

2.5 Frame W100, span 2.4 m

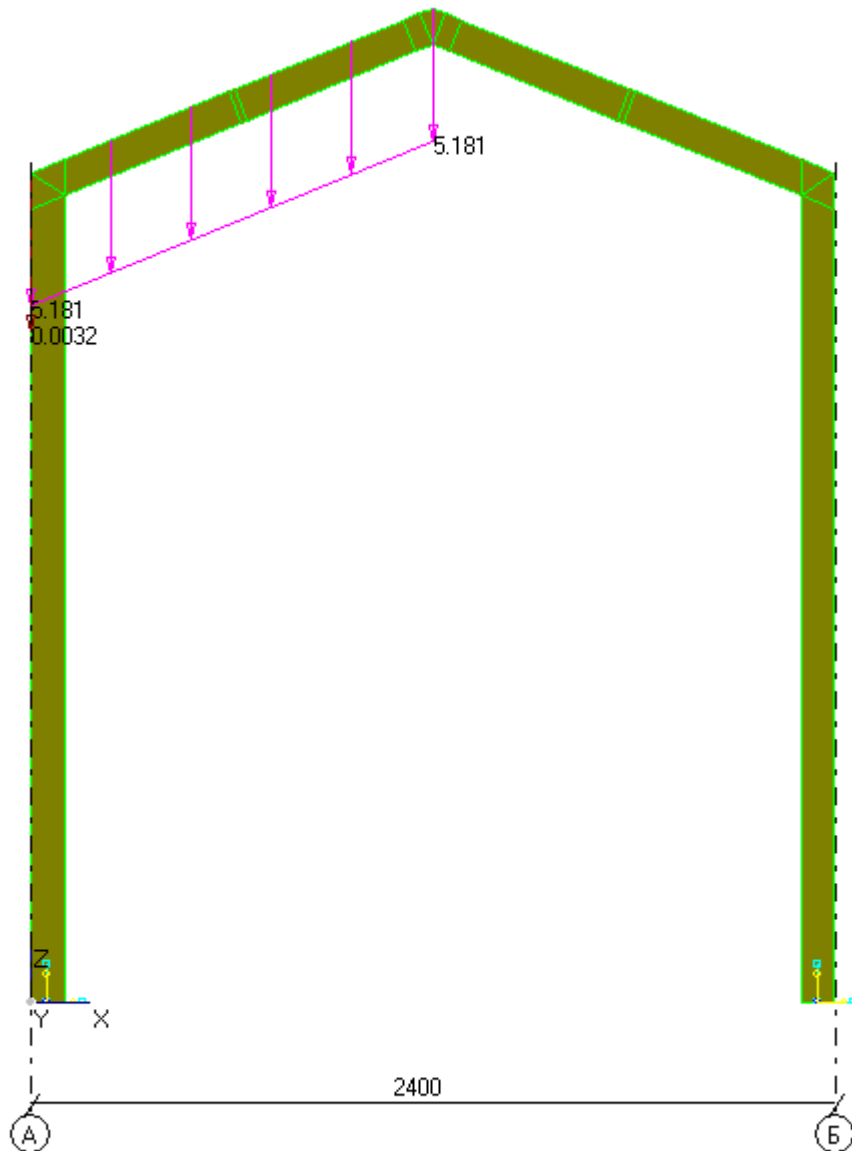


Fig. 23. Frame W100, snow load on the left, kN/m²

Design value of resistance to bending and compression:

- $R_{bend}^A = R_{comp} = 14$ MPa - under the combined action of permanent and short-term loads.

Maximum bending stresses in frame elements: $\sigma_{max} = 14$ MPa, fig. 22,

- Factor of safety $\eta = R_p^A / \sigma_{max} = 14/14 = \mathbf{1.0}$
- Utilization rate $f = 1/\eta = \mathbf{1.0}$

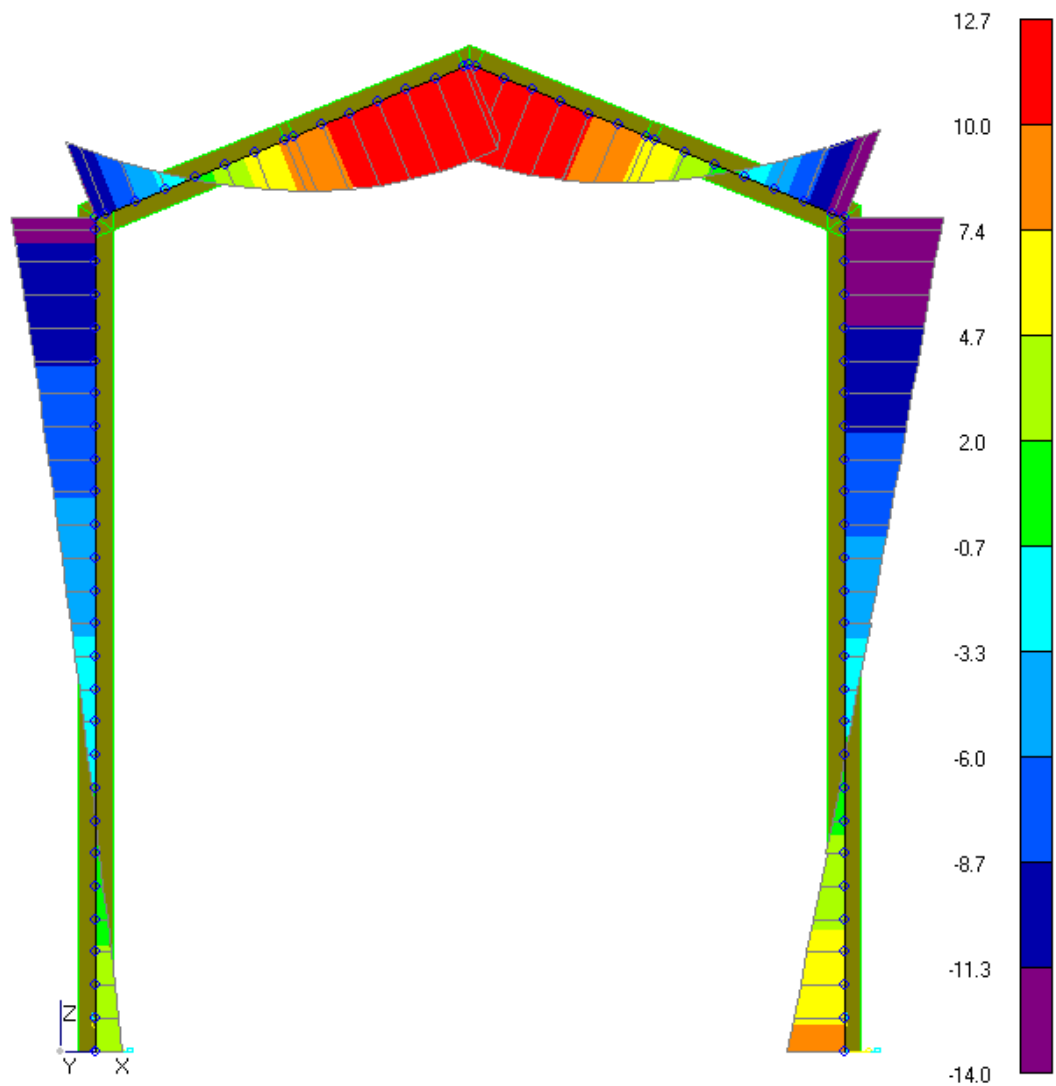


Fig. 24. Frame W100, maximum stresses in basic load combinations, MPa

CONCLUSION

Calculations for extreme operating conditions showed that the FINHA Series 100 building design meets the requirements of building code SP 64.13330.2017 "SNiP II-25-80. Wooden Structures."

The required building safety margin is achieved with the frame widths specified in table 1.

Table. 1.

Frame code	Building width, m
A100	4.3
P100	2.0
V100	3.0
W100	2.4

Snow loads have the greatest impact on the stress state of the frame.

LIST OF USED SOURCES

1. SP 64.13330.2017 SNIP II-25-80. Wooden Structures
2. SP 20.13330.2016 SNIP 2.01.07-85*. Loads and impacts
3. SP 14.13330.2014 SNIP II-7-81*. Construction in seismic areas
4. Technical report "Calculation of the supporting structure of the FINHA-2 series of buildings"
2020