Technical Report

FINHA-2 Series Building Structural Calculations

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INTRODUCTION

This calculation was performed to confirm that the strength and stability characteristics of the FINHA-2 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 or II;
- Construction site seismicity of magnitude 9 with soil categories I or III or 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 FINHA buildings with various layouts is shown in Figs. 1–3.

The building frame is assembled from transverse frames made of wooden beams, which are connected to each other with four bolts through connectors, and longitudinal beams (Fig. 4). The frame is installed on grillage beams. The grillage beams are also made of wood.

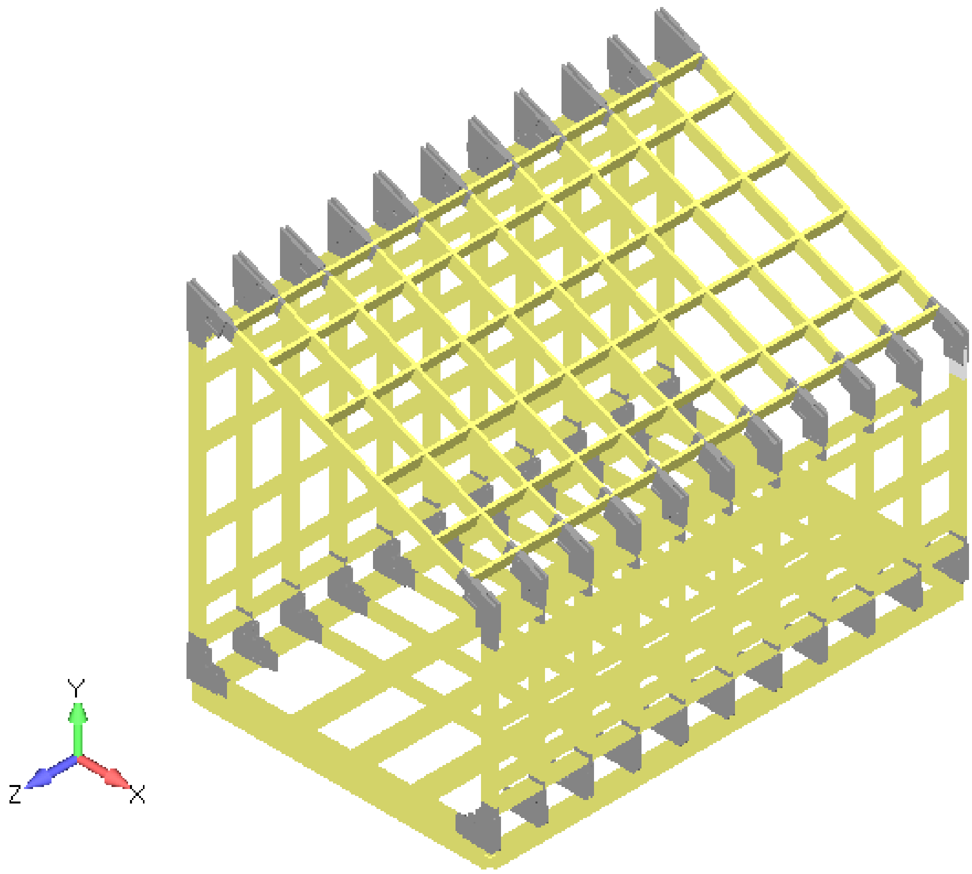

Fig. 1. General view of the frame of the FINHA shed-roof building, frame width 4 m

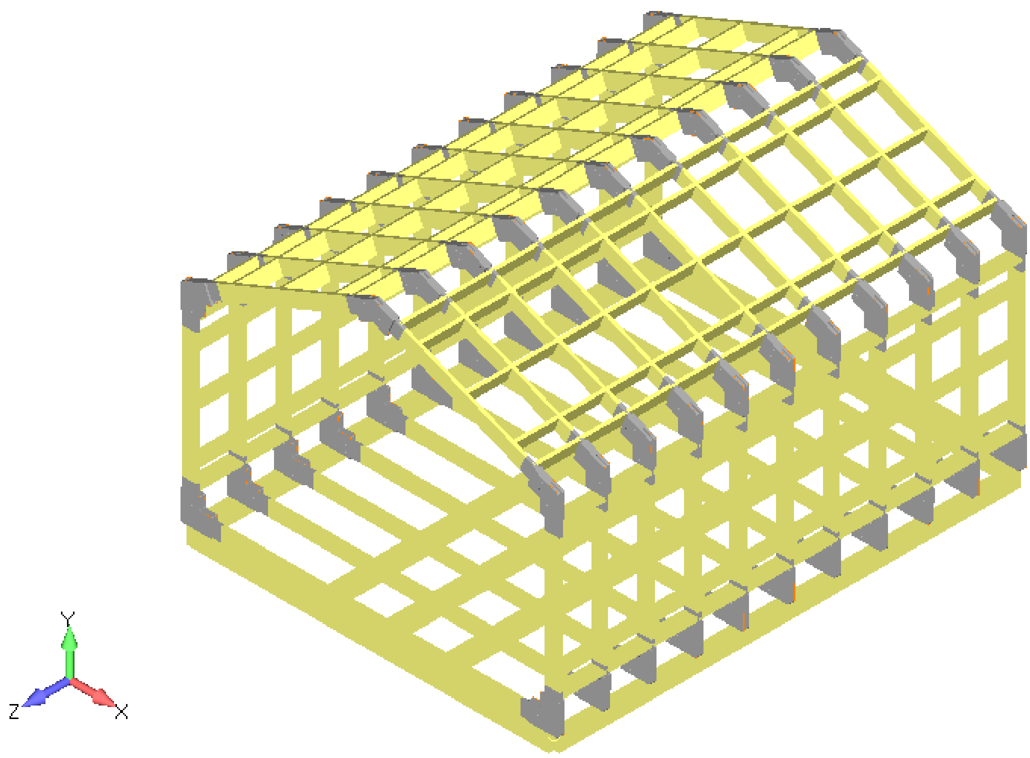

Fig. 2. General view of the frame of the FINHA gable roof building, frame width 5 m

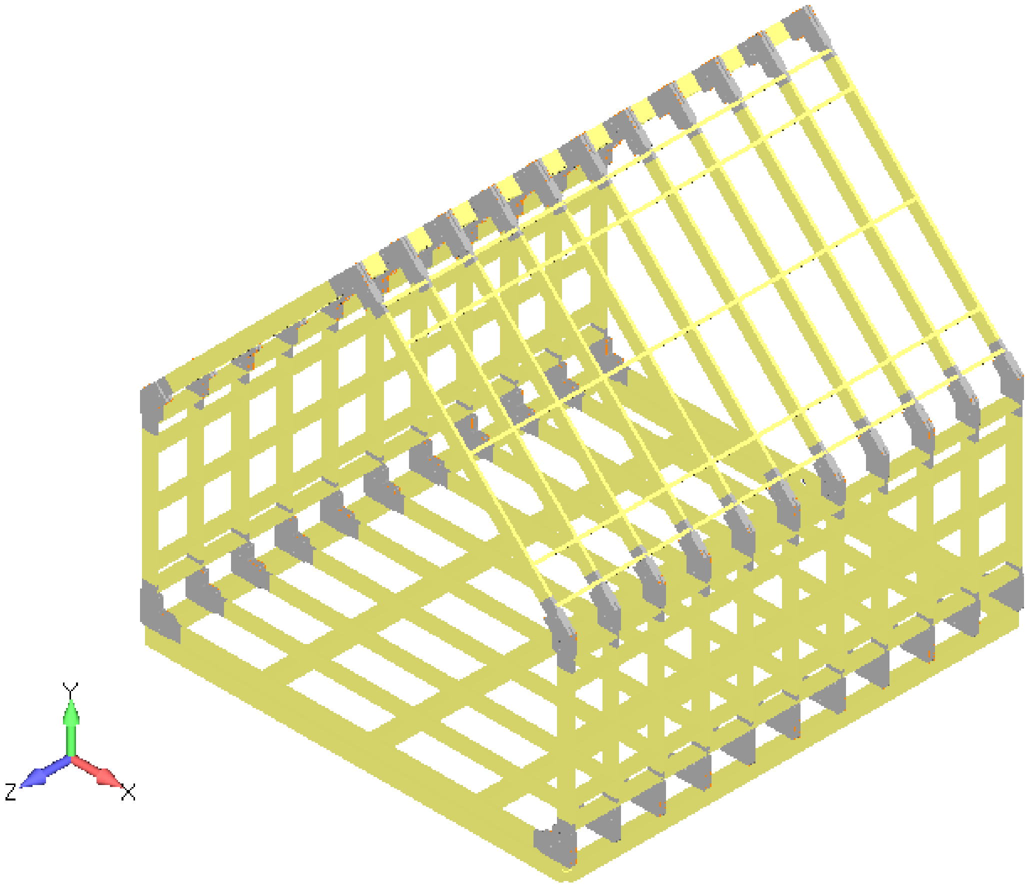

Fig. 3. General view of the frame of the FINHA gable roof building, frame width 6 m, slope is 45 deg.

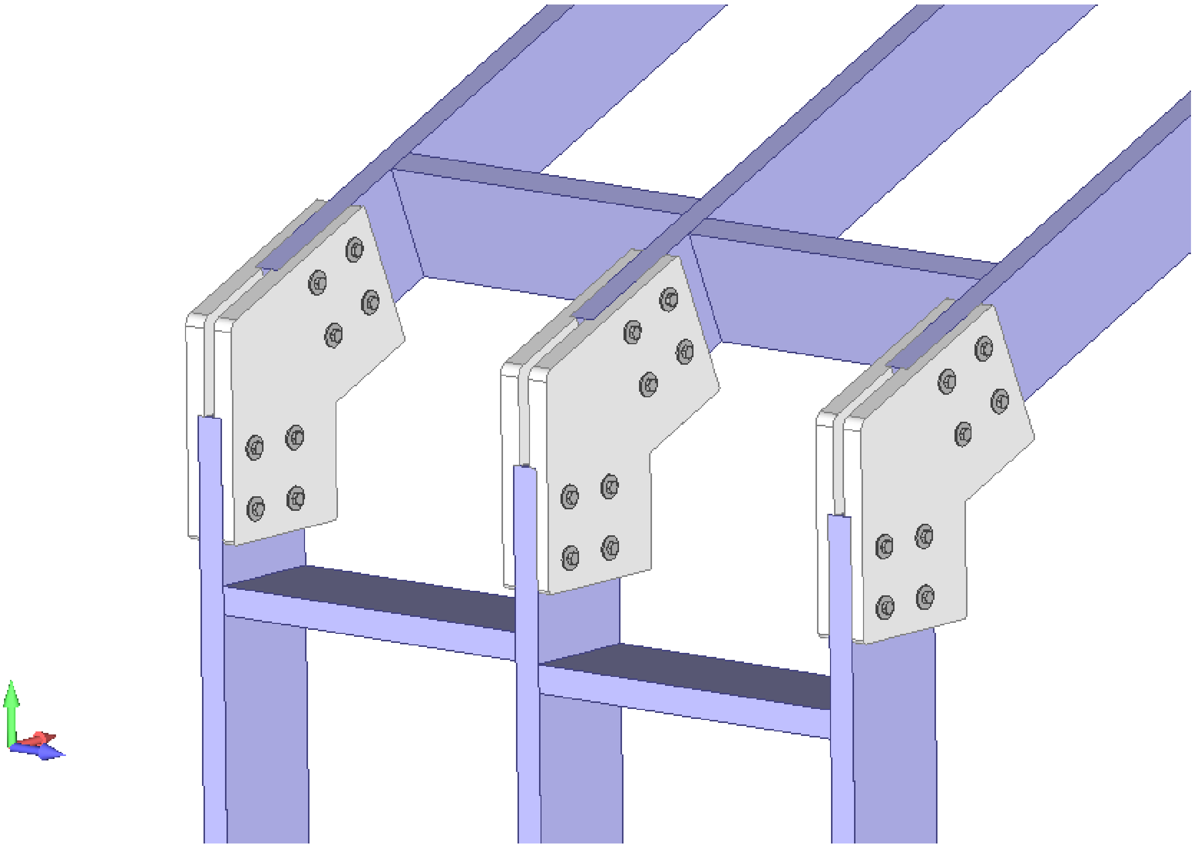

Fig. 4. Fragment of a typical beam connection

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] :

- $R_{и}^{A} = R_{сж}^{A} =$ 24 MPa;
- $R_{p}^{A} =$ 15 MPa;

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

$$R^{p} = R^{A} \cdot m_{дл} \cdot \Pi m_{i}$$

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

- $m_{дл}$ = 0.66 - under the combined action of permanent and short-term loads;
- $m_{дл}$ = 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;
- $m_{сл} =$ 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*1.0*1.0*1.0=0.9

Design value of resistance to bending and compression:

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

Design value of resistance to tension:

- $R_{p}^{A} =$15*0.66*0.9=8.9 MPa - under the combined action of permanent and short-term loads;
- $R_{p}^{A} =$15*0.92*0.9=12.4 MPa - under the combined action of permanent and seismic loads.

Design bearing strength:

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

  $R^A_{cr45} = R^A_{cr0} / (1 + (R^A_{cr0} / R^A_{cr90} - 1) \cdot \sin^3 45)$ =8.0 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.

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

1.5 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 mm/c^2, γ_{Gf} = 1.2 – load safety factor.

1.6 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*1.3 = 0.00195 MPa,

There P_1 = 0.0015 MPa – nominal value of uniformly distributed load;

γ_f = 1.3 – load safety factor.

1.7 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

$c_e \cdot$ = 1.0 – snow drifting factor is taken in accordance with p. 10.6 [2];

$c_t \cdot$ = 1.0 – 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] ;

μ=1.0 – for roof slope angle up to 30 deg;

μ=0.5 – for roof slope angle up to 45 deg;

For angles greater than 45 degrees, it is taken into reserve μ=0.5;

S_g = 4.0 kN/m^2 – nominal value of snow cover weight on 1 m^2 for the snow region VIII.

Design value of snow load:

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

γ_{Sf}=1.4 – load safety factor for snow load.

1.8 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 kN/m^2;

γ_{Wf}=1.4 – load safety factor for wind load.

Snow loads are shown in Figs. 5-7

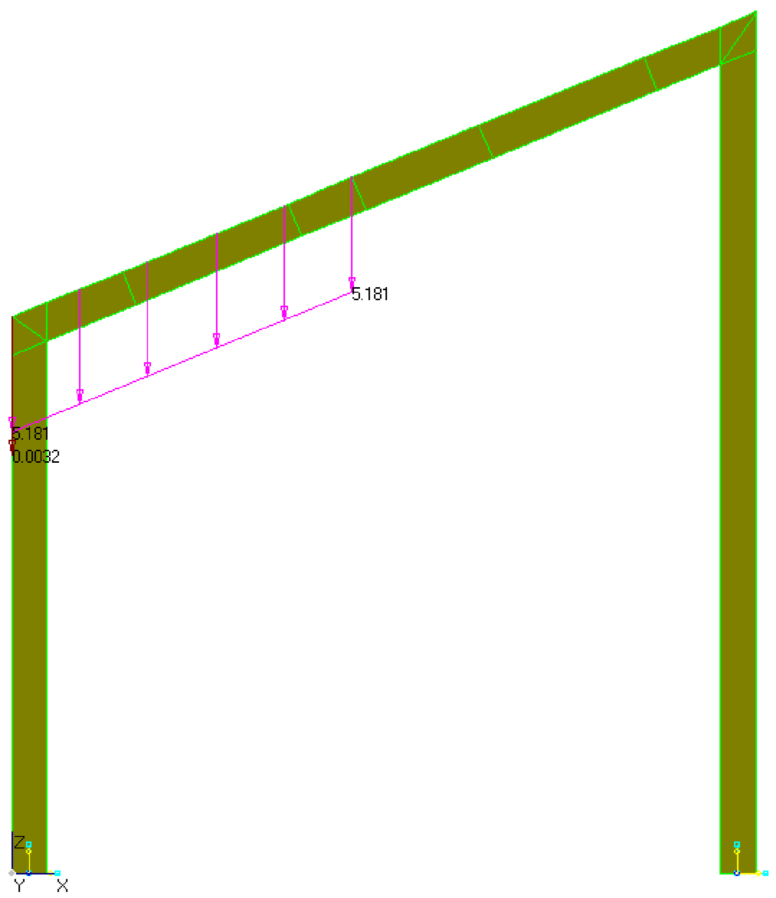

Fig. 5. Shed-roof building. The design snow load on the left, acting in the direction of the Z-axis, kN/m^2

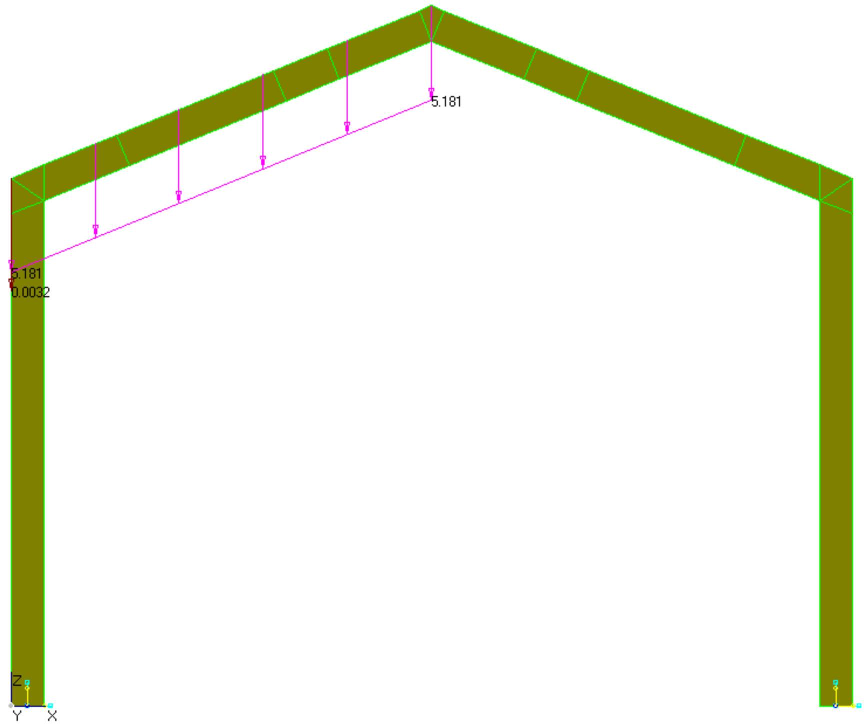

Fig. 6. Gable roof building. The design snow load on the left, acting in the direction of the Z-axis, kN/m^2

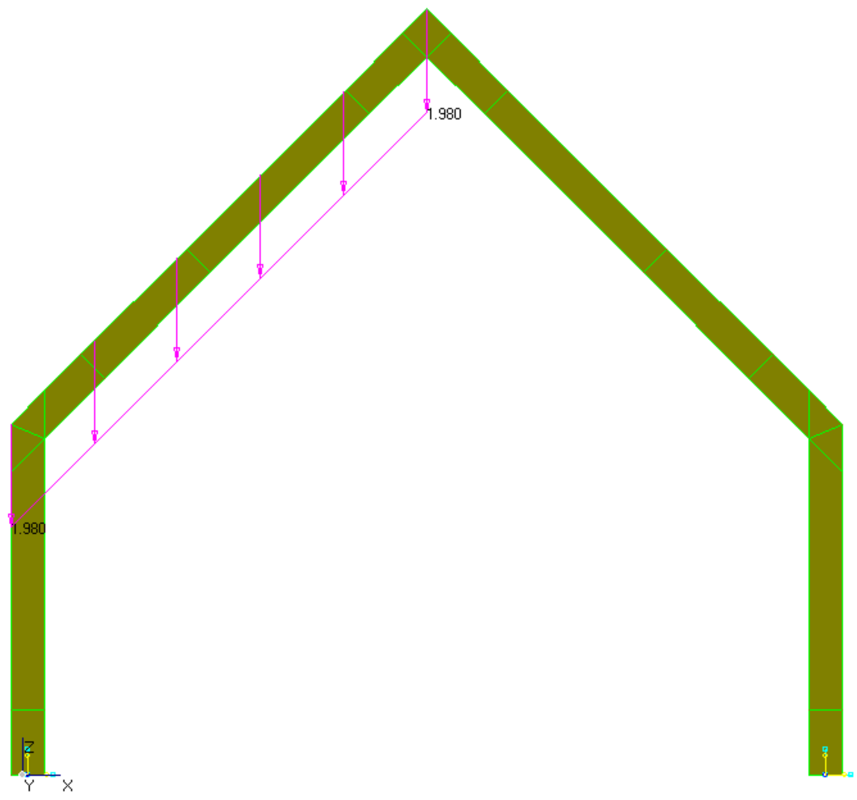

Fig. 7. Gable roof building. The design snow load on the left acting in the direction of the Z-axis, kN/m^2

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 mm/c^2, γ_{Gf} = 1.2 – 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*1.3 = 0.00195 MPa,

   There P_1 = 0.0015 MPa – nominal value of uniformly distributed load;

   γ_f = 1.3 – 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

   $c_e \cdot$ = 1.0 – snow drifting factor is taken in accordance with p. 10.6 [2];

   $c_t \cdot$ = 1.0 – 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] ;

   μ=1.0 – for roof slope angle up to 30 deg;

   μ=0.5 – for roof slope angle up to 45 deg;

   For angles greater than 45 degrees, it is taken into reserve μ=0.5;

   S_g = 4.0 kN/m^2 – nominal value of snow cover weight on 1 m^2 for the snow region VIII.

   Design value of snow load:

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

   γ_{Sf} =1.4 – 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 kN/m^2;

   γ_{Wf} =1.4 – load safety factor for wind load.

The calculation is performed for three load cases:

- wind from the left (wind_left);
- wind from the right (wind_right);
- wind at the end of the building (wind_tor);

The wind load distribution in the wind_left load case is shown in Fig. 4.

The wind_right load case is symmetrical.

The wind load distribution in the wind_tor load case is shown in Fig. 5.

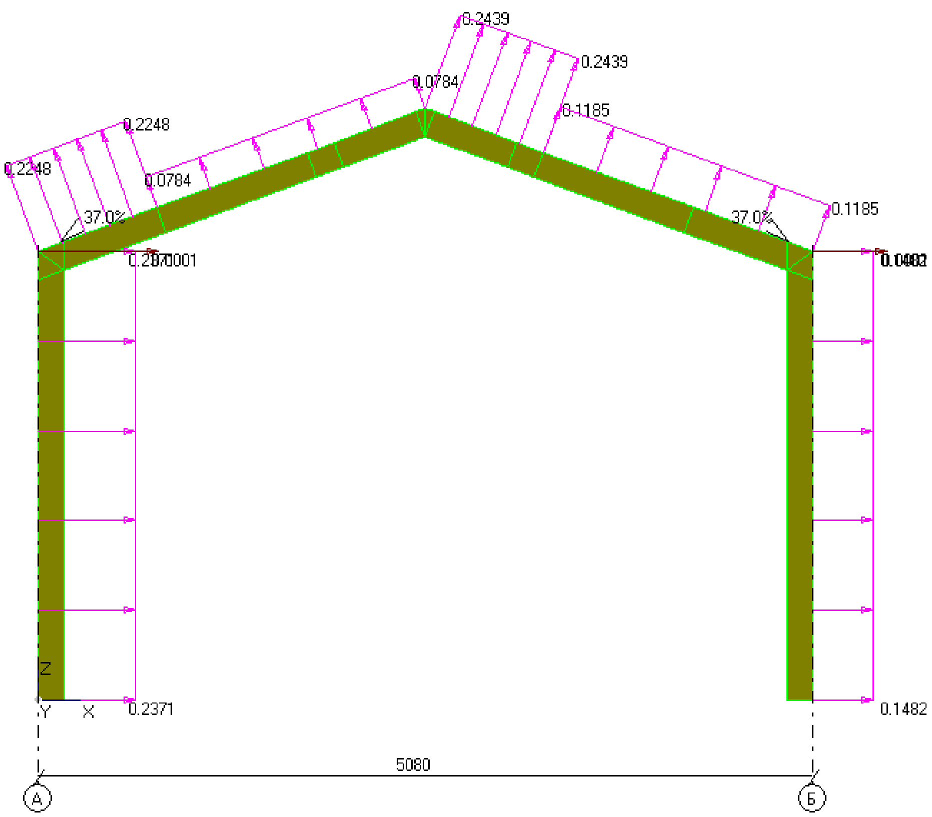

Fig. 8. The design wind load is the wind from the left, acting normal to the surface, kN/m^2

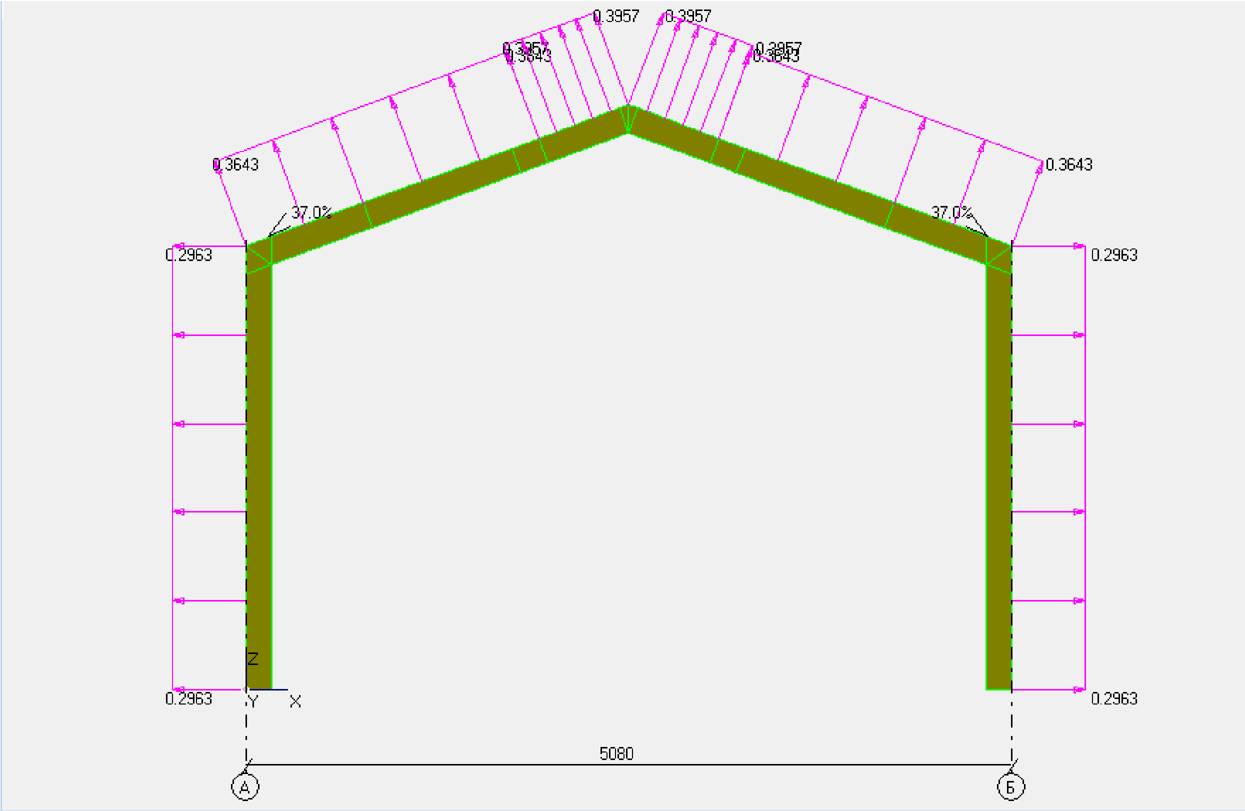

Fig. 9. Design wind load, wind at the end, acting normal to the surface, kN/m^2

1.5 Seismic loads

2 Horizontal action in the direction of the transverse axis (**Quake X**);

3 Horizontal impact in the direction of the longitudinal axis (**Quake Y**);

4 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_ψ = 1.3 - factor that takes into account the ability of a building to dissipate vibration energy under horizontal impact, taken from table 5.
- $A = 4$ 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. 6.

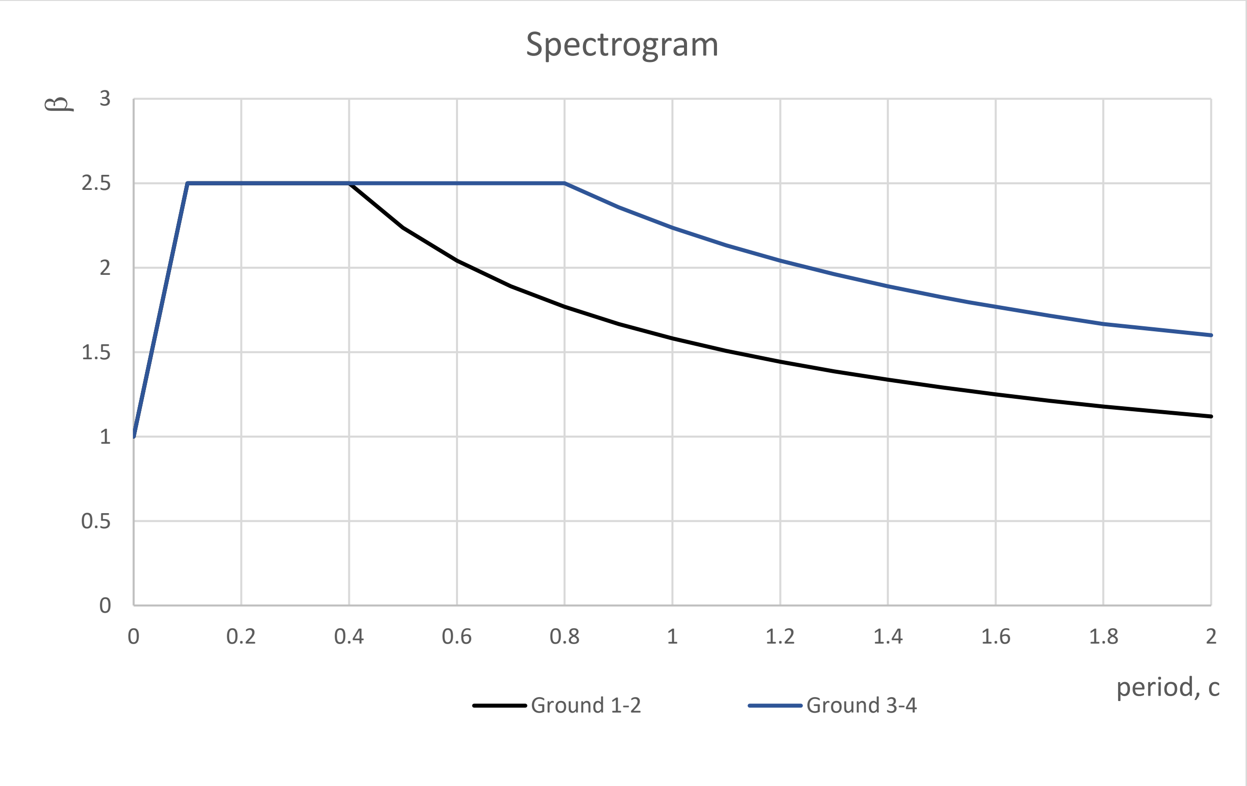

Fig. 10. The spectrogram of dynamic coefficients

1.5 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]

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

1.6 Assigning loads and constrains

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

g = -9810*1.2=-11770 mm/c2, (considering γ_{Gf} = 1.2) along the Z coordinate axis.

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

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 F A SHED-ROOF BUILDING

2.1 Frame design models

The FINHA building design models are shown in Fig. 11-13.

Frames and longitudinal beams are modeled using Beam elements of the appropriate cross-section. Joints between beams and struts are assumed to be moment joints.

Connectors are modeled using two-dimensional Plate elements. Planks at the joints are modeled using solid elements.

Bolts connecting the connectors to the mullions and beams are modeled using one-dimensional Beam elements.

Frictional contact conditions are specified between the connectors and planks. The friction coefficient is assumed to be *f* = 0.5.

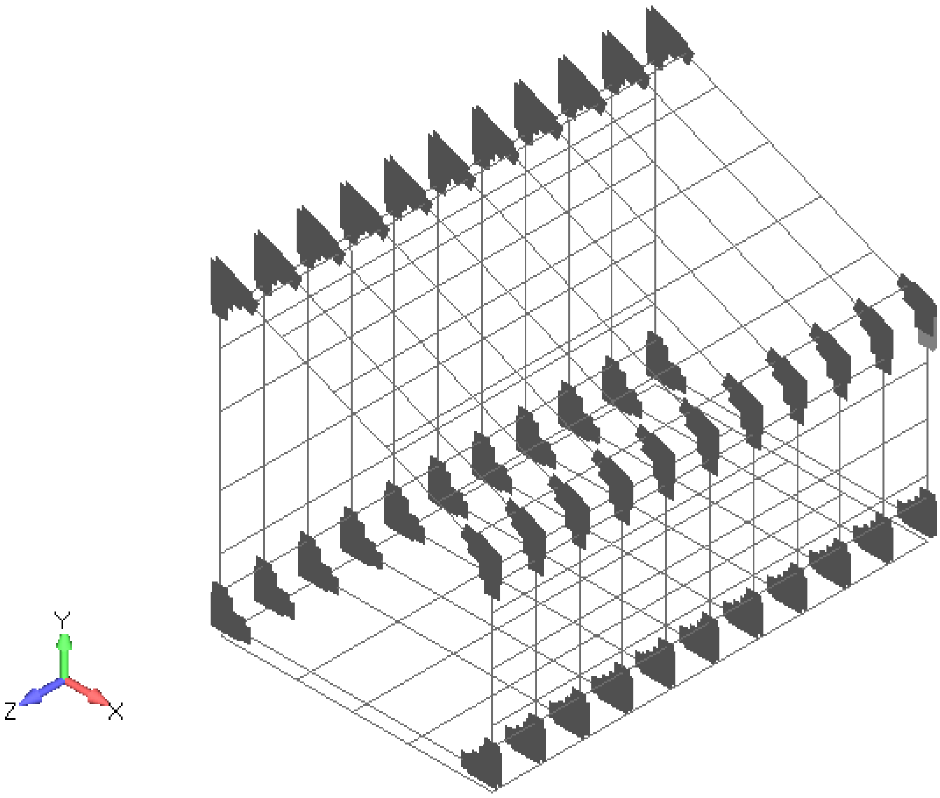

Fig. 11. Finite element model of a shed-roof building

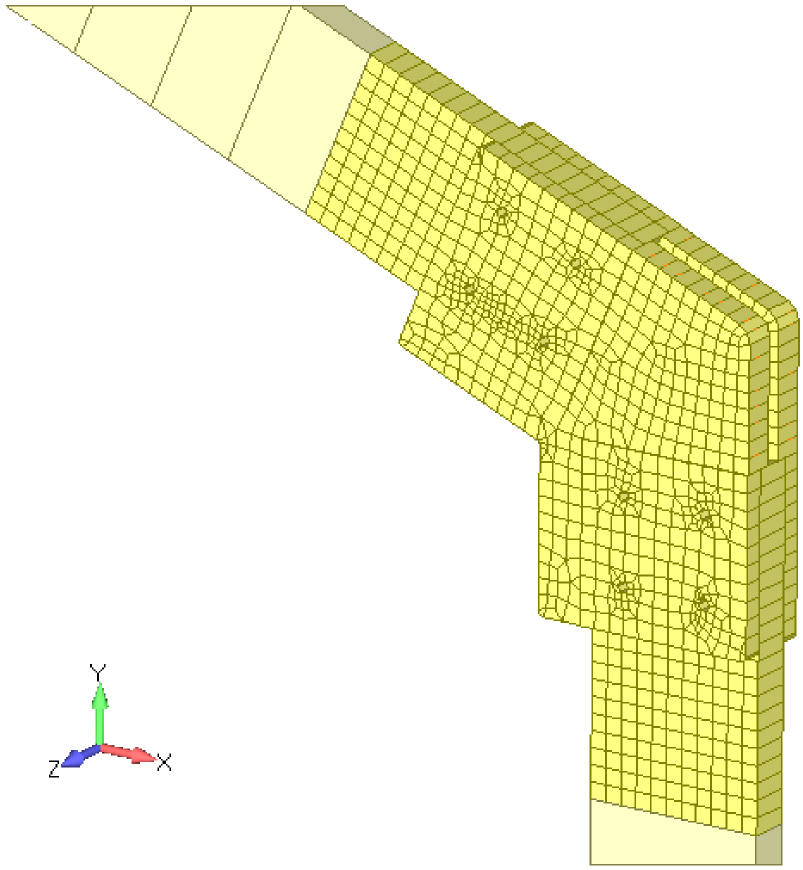

Fig. 12. Finite element model of the joint of beam boards with connectors, angle 112.5 deg.

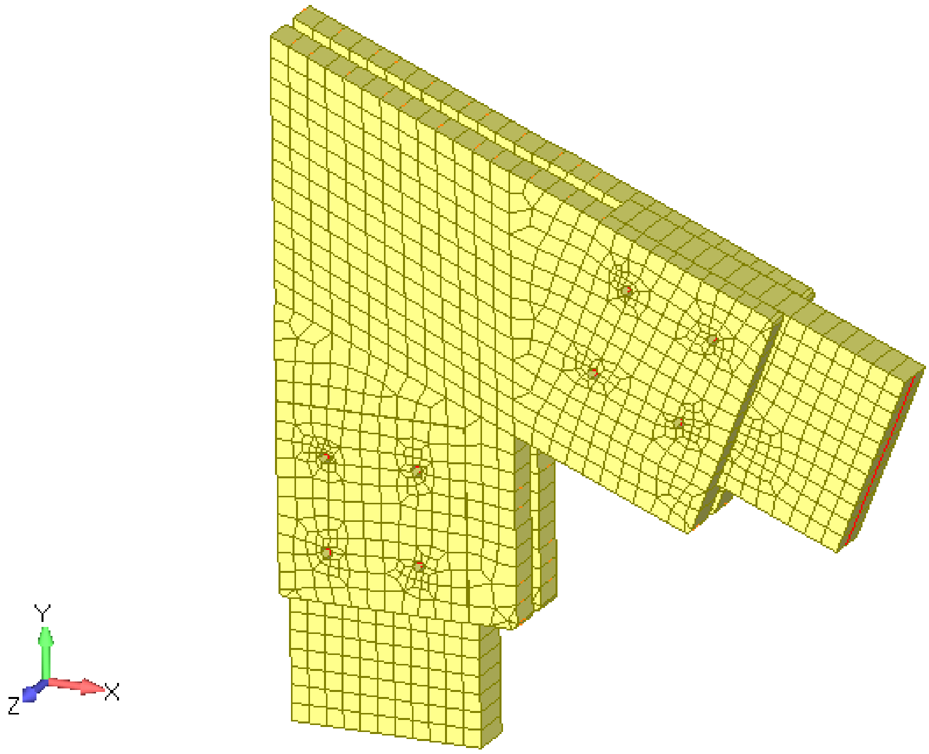

Fig. 13. Finite element model of the junction of a post with a beam of a shed-roof building using connectors

2.2 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.

Frames

Maximum bending stresses in frame elements: σmax = 10.8 MPa, fig. 15,

- Factor of safety η= $R_{p}^{A} / \sigma_{\max} = 14/10.8$ = **1.3**
- Utilization rate f=1/η = **0.77**

Crossbars

The maximum bending stresses are in the struts: σmax = 3.7 MPa, fig. 16,

- Factor of safety η= $R_{p}^{A} / \sigma_{\max} = 14/3.7$ > **2.0**

Posts and beams in the joint

The maximum stresses in the elements of the posts and beams are in the joint area: σmax = 10 MPa caused by bending, fig. 17,

- Factor of safety $R_{bend}^{A} / \sigma_{\max} = 14/12$ = **1.17**
- Utilization rate f=1/η = **0.86**.

Connectors

The maximum stresses in the connectors: σmax =12 MPa, fig. 17, 18

- Factor of safety $R_{bend}^{A}/\sigma_{max} = 14/12 =$ **1.17**
- Utilization rate f=1/η = **0.86**

Bolt hole crushing strength

Figure 19 shows the shear forces in the bolts (N) acting on a 22.5 mm thick connector wall loaded with its own weight and snow loads for Region VIII.

The sum of these forces acts on the board from the bolt side.

The maximum resulting force on the connector is P1shear = 2294 N.

The force from the bolt on the second connector is P2shear = 1970 N

Ultimate bearing force [Pcm] = Rcm * Fcm,

where Rcm is the permissible bearing stress;

Fcm is the bearing area;

Connector bearing strength.

For plywood (birch), Rcm = 12 MPa (SNiP Wooden Structures. 2017, Table 3):

Bolt diameter D = 14 mm;

Crush area Fcm = t*D=22.5*14=315 mm2

Therefore, [Pcm]=12*315=3780 N.

Factor of safety η=[Psm]/ Pshear=3811/2294= **1.66**

Board crush strength.

Ultimate bearing stress at a 45-degree angle Rcm45 = 8.0 MPa;

Maximum bearing force Pshear = P1shear + P2shear = 4264 N

Bearing area Fsm = t * D = 45 * 14 = 630 mm^2

Therefore, [Psm] = 8 * 630 = 5040 N

Factor of safety η=[Psm]/ Pshear=5040/4264 > **1.18**

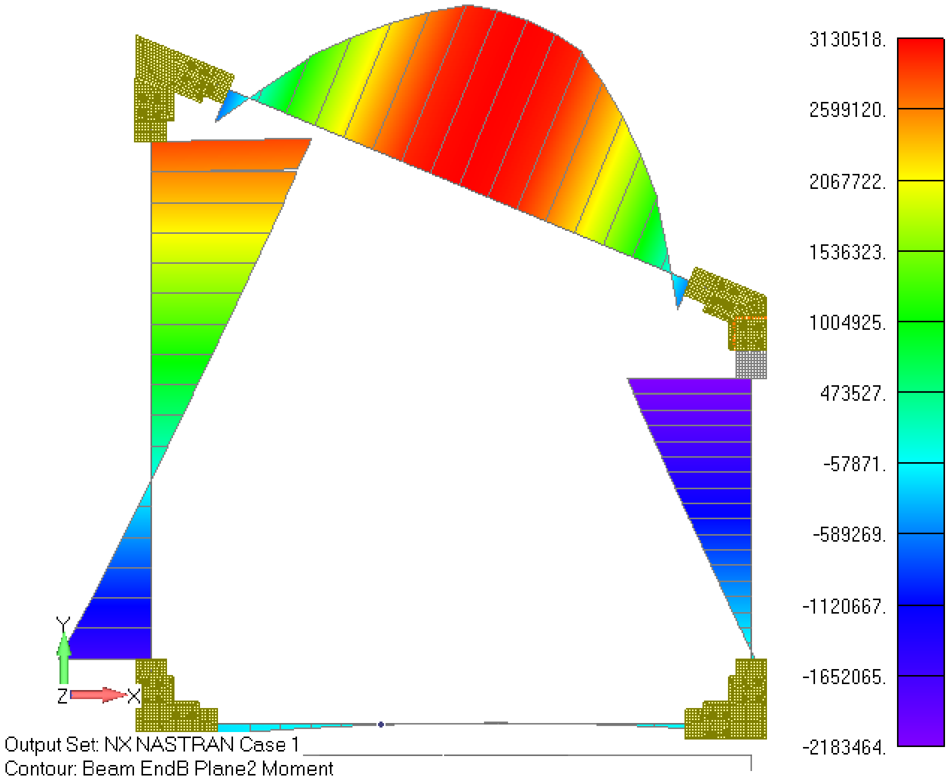

Fig. 14. Basic combinations. Bending moments in posts and beams, N*mm.

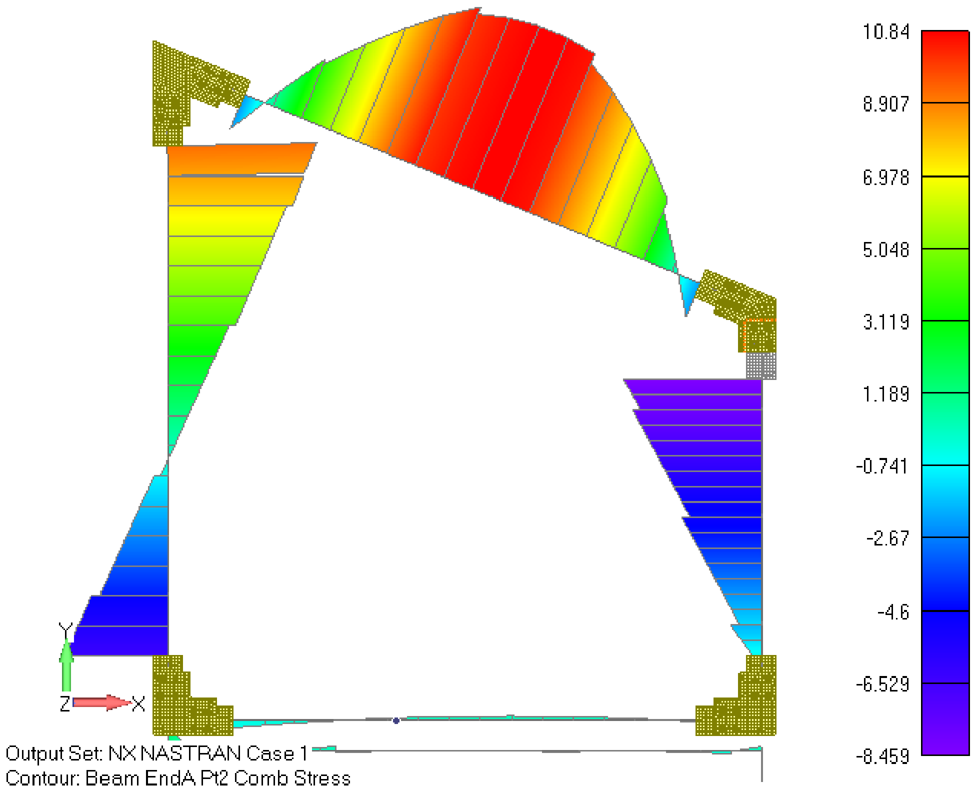

Fig. 15. Basic combinations. Maximum bending stress in frames, MPa

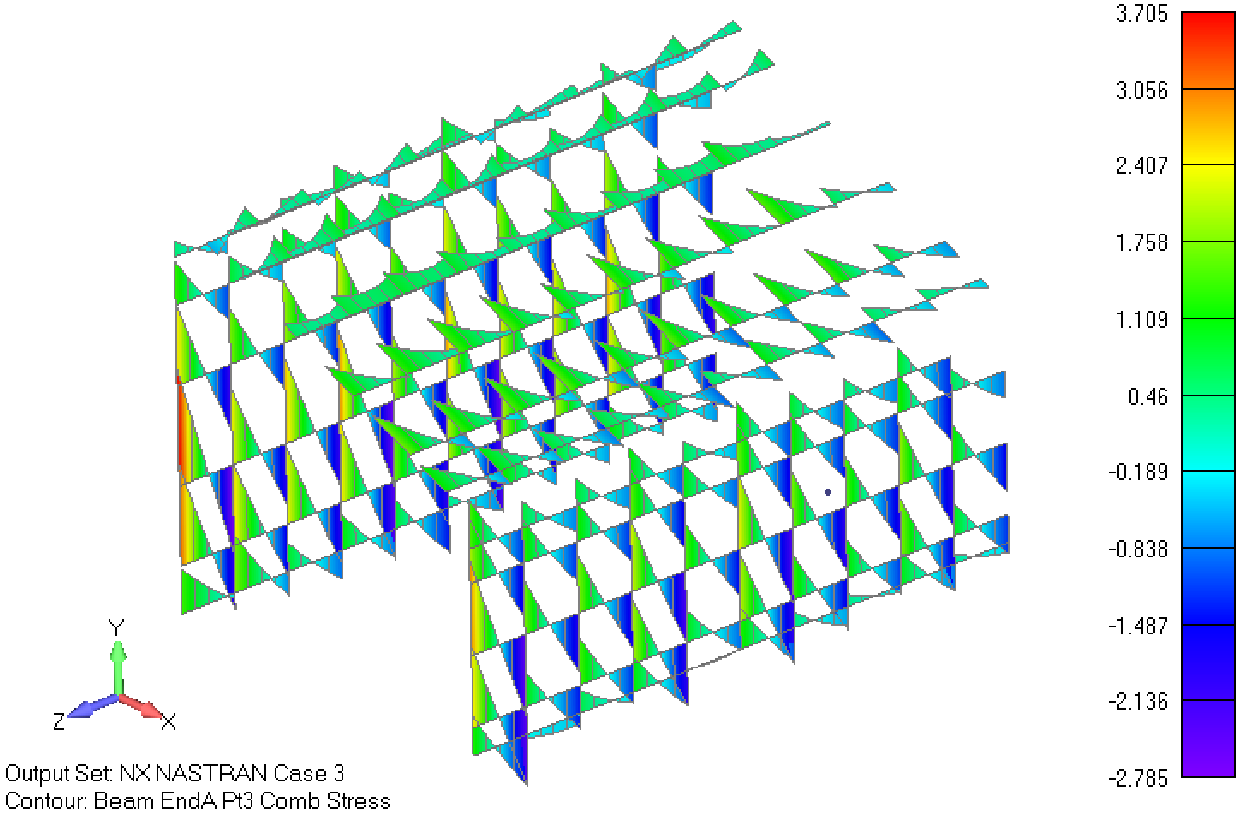

Fig. 16. Basic combinations. Maximum stresses in struts, MPa

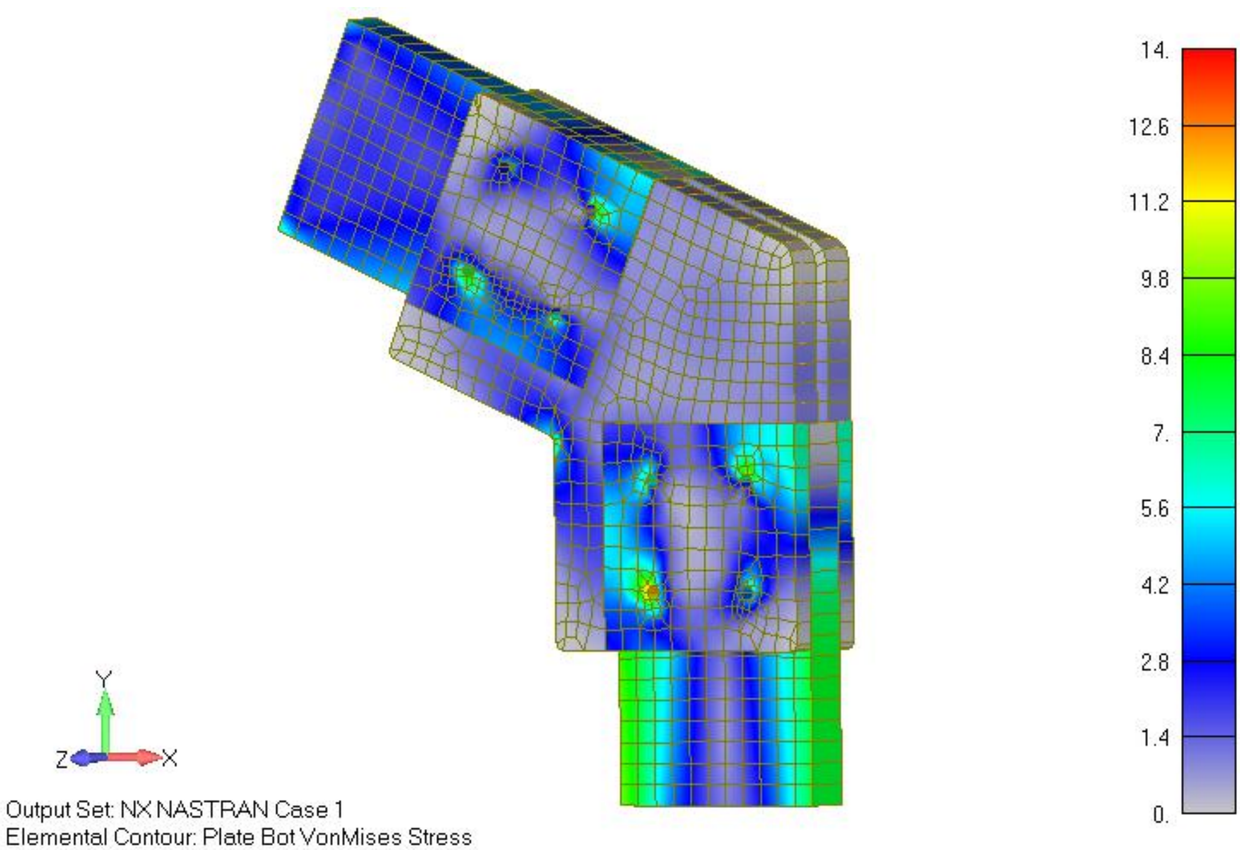

Fig. 17 Basic combinations. Maximum stresses in the connection of posts and beams with connectors, MPa.

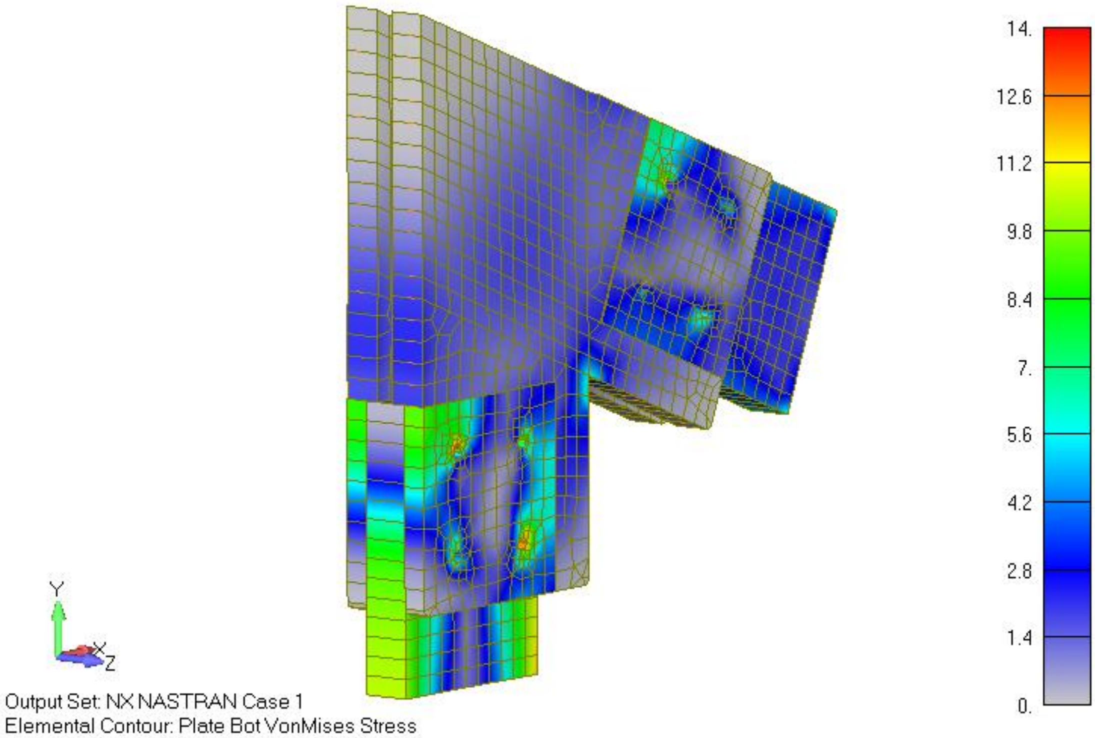

Fig. 18. Basic combinations. Maximum stresses in the connection of posts and beams with connectors, MPa.

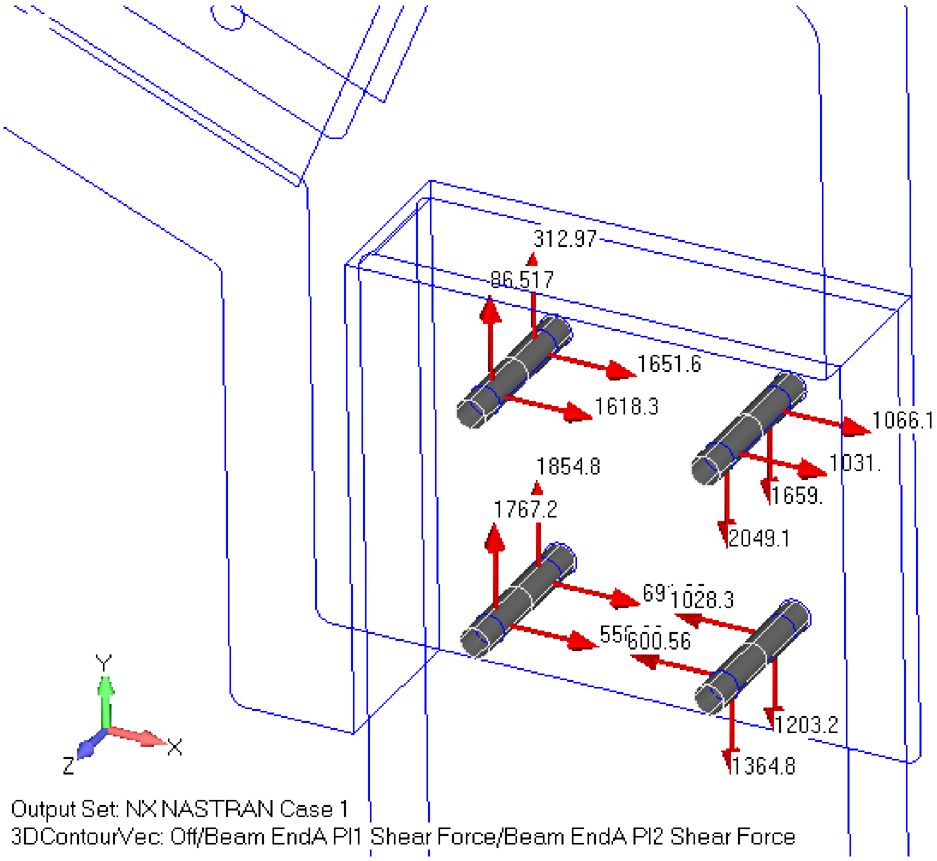

Fig. 19. Basic combinations. Maximum forces in bolts fastening boards to connectors, N

2.3 Special load combination

Design value of resistance to bending and compression:

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

Frames

The maximum bending stresses in frame elements: σmax = 10.8 MPa, fig. 20,

- Factor of safety $\eta = R_{p}^{A} / \sigma_{max} = 20/10.4 =$ **1.92**
- Utilization rate $f = 1/\eta$ = **0.52**

Crossbars

The maximum bending stresses are in the struts: σmax = 3.7 MPa, fig. 22,

- Factor of safety $\eta = R_{p}^{A} / \sigma_{max} = 20/13$ **= 1.54**

Posts and beams in the joint

The maximum stresses in the elements of the posts and beams are in the joint area: σmax = 10 MPa caused by bending, fig. 23,

- Factor of safety $R_{bend}^{A} / \sigma_{max} = 20/14 =$ **1.42**
- Utilization rate $f = 1/\eta$ = **0.7**.

Connectors

The maximum stress in the connectors: σmax =12 MPa, fig. 23, 24

- Factor of safety $R_{bend}^{A} / \sigma_{max} = 20/14 =$ **1.42**
- Utilization rate $f = 1/\eta$ = **0.7**

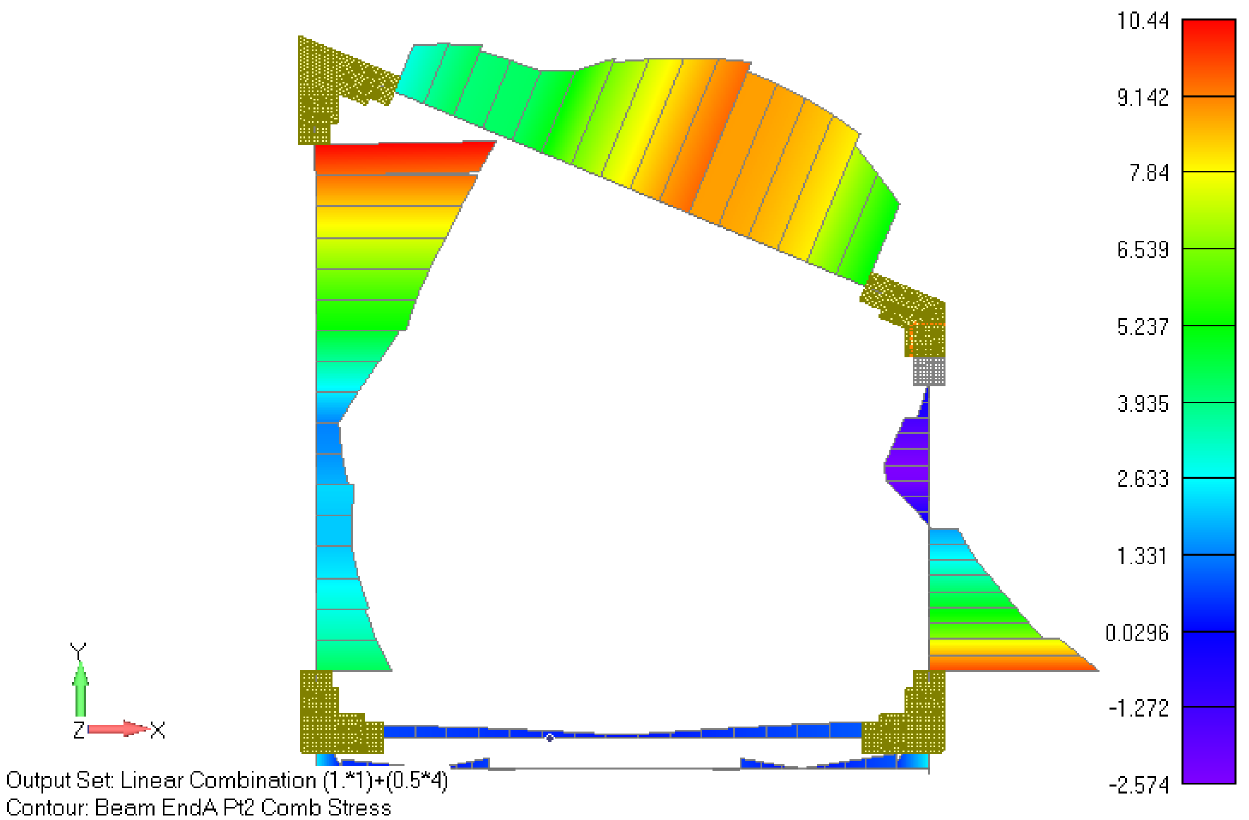

Fig. 20. Special combinations. Maximum stresses in frames, MPa.

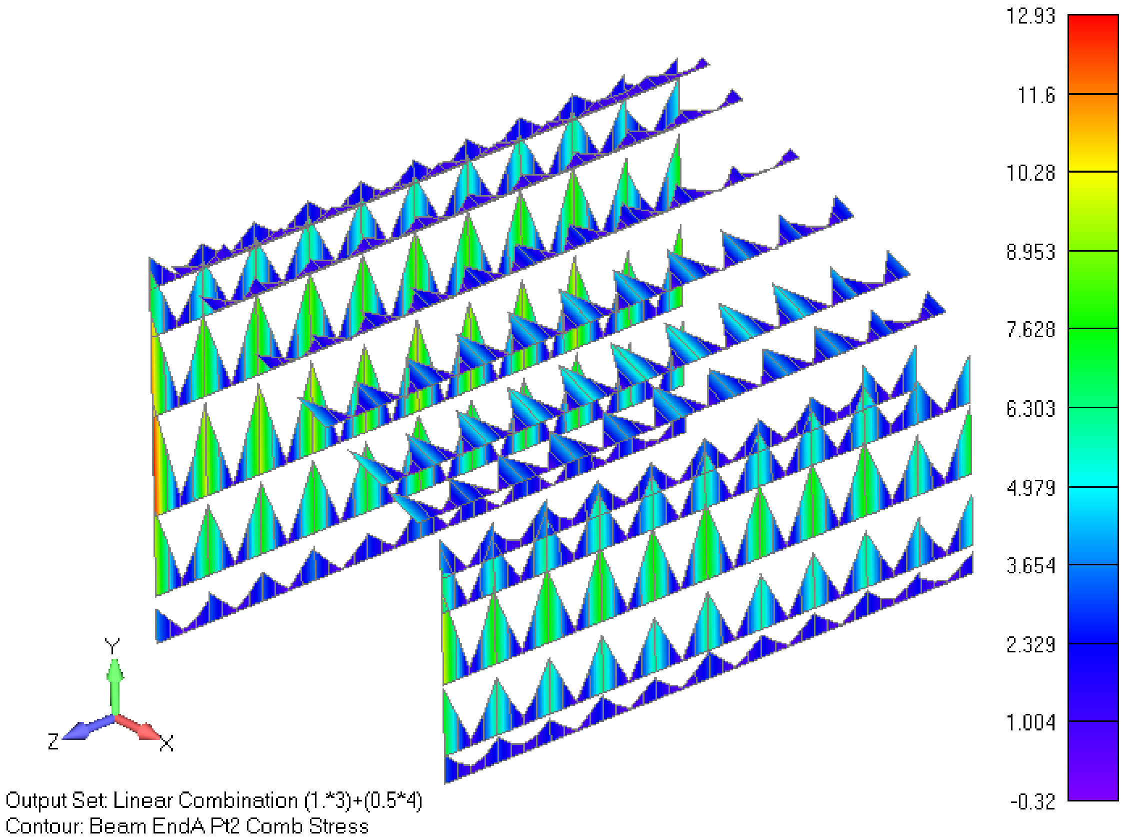

Fig. 21. Special combinations. Maximum stresses in struts, MPa.

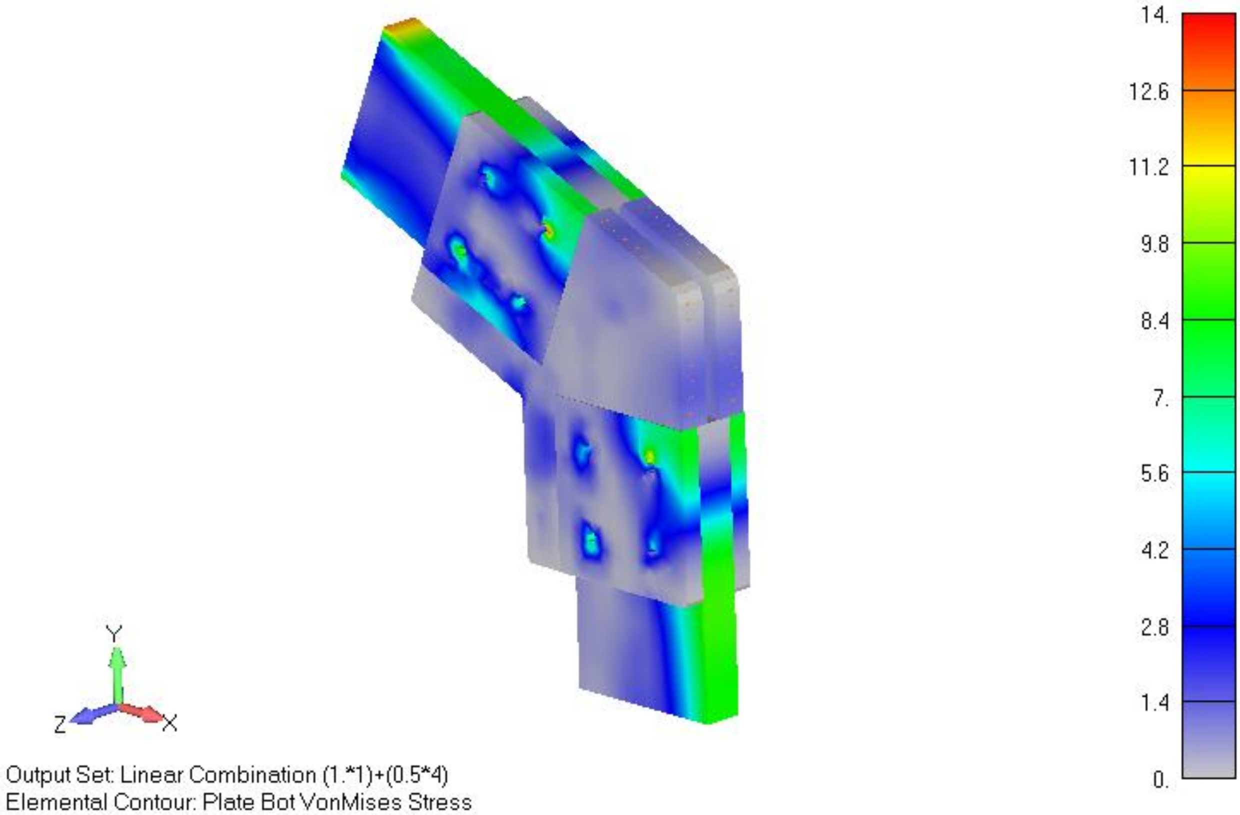

Fig. 22. Special combinations. Maximum stresses in the connection of posts and beams with connectors, MPa

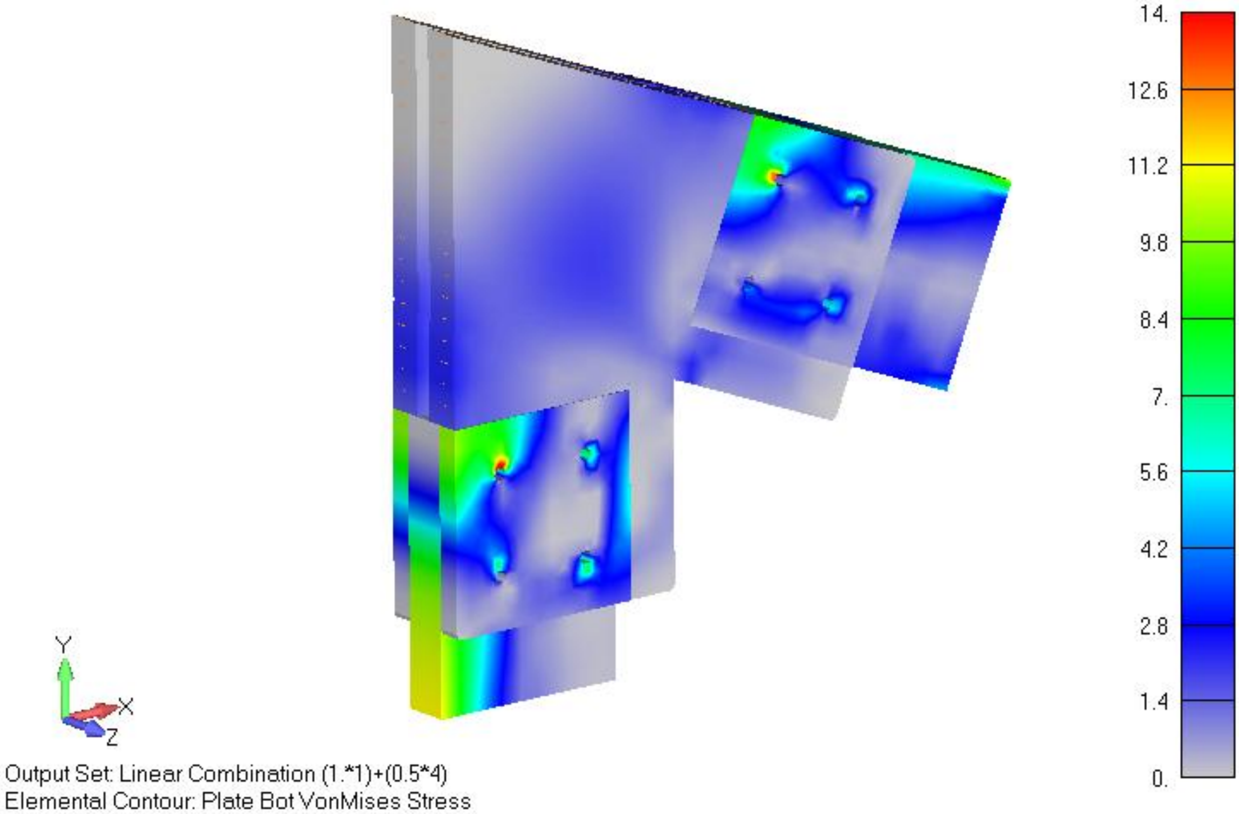

Fig. 23. Special combinations. Maximum stresses in the connection of posts and beams with connectors, MPa

2.4 Summary of safety factors for a shed-roof building

Table 2

#	Name	Minimum safety margin, η	Maximum utilization rate
1	Frames	1.3	0.77
2	Crossbars	>2.0	<0.5
3	Posts and beams in the joint	1.17	0.86
4	Connectors	1.17	0.86
5	Strength of boards (holes) against crushing	1.18	0.85

3 STRENGTH ANALYSIS OF A 5-M SPAN GABLE ROOF BUILDING

3 Finite element model

The building's design model is shown in Fig. 24-25.

Frames and longitudinal beams are modeled using Beam elements of the appropriate cross-section. Joints between beams and struts are assumed to be moment joints.

Connectors and planks at the joints are modeled using Solid elements. The bolts connecting the Connectors to the mullions and beams are modeled using one-dimensional Bush or Beam elements.

Frictional contact conditions are specified between the connectors and planks. The friction coefficient is assumed to be f = 0.5.

The elements modeling the bolts are weakened in the transverse direction, so bending moments in the joint are transmitted primarily by contact forces and partially by friction.

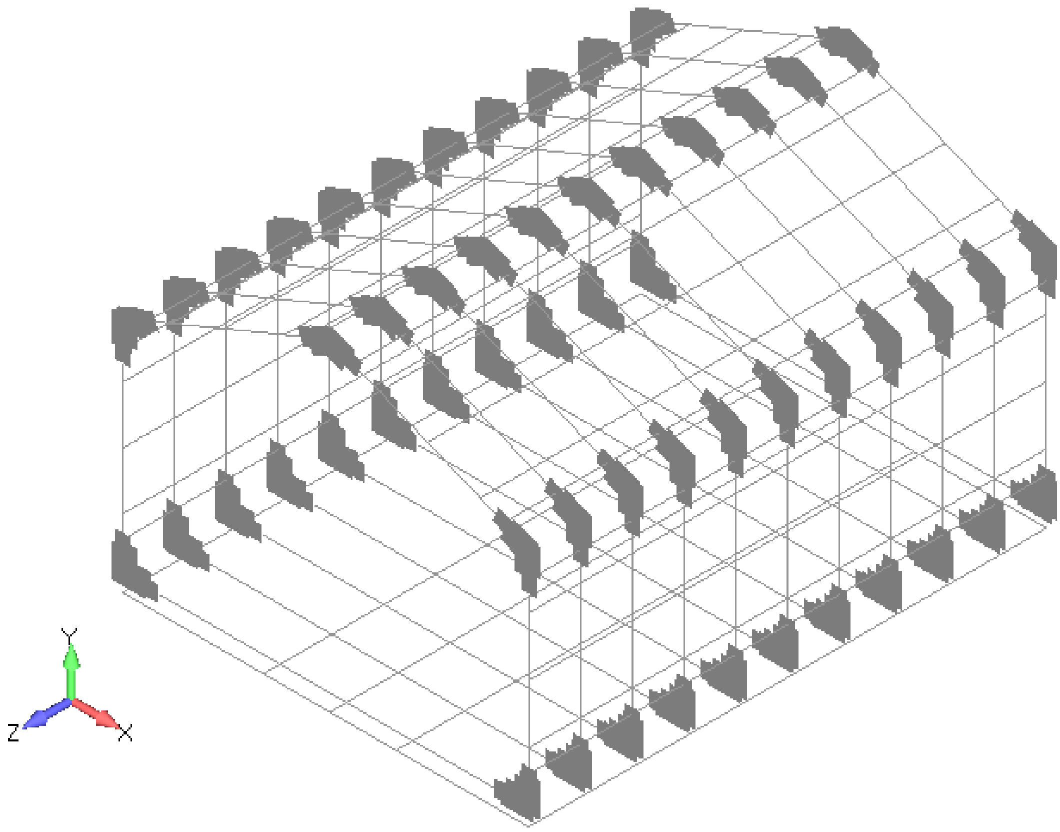

Fig. 24. Finite element model of gable roof building

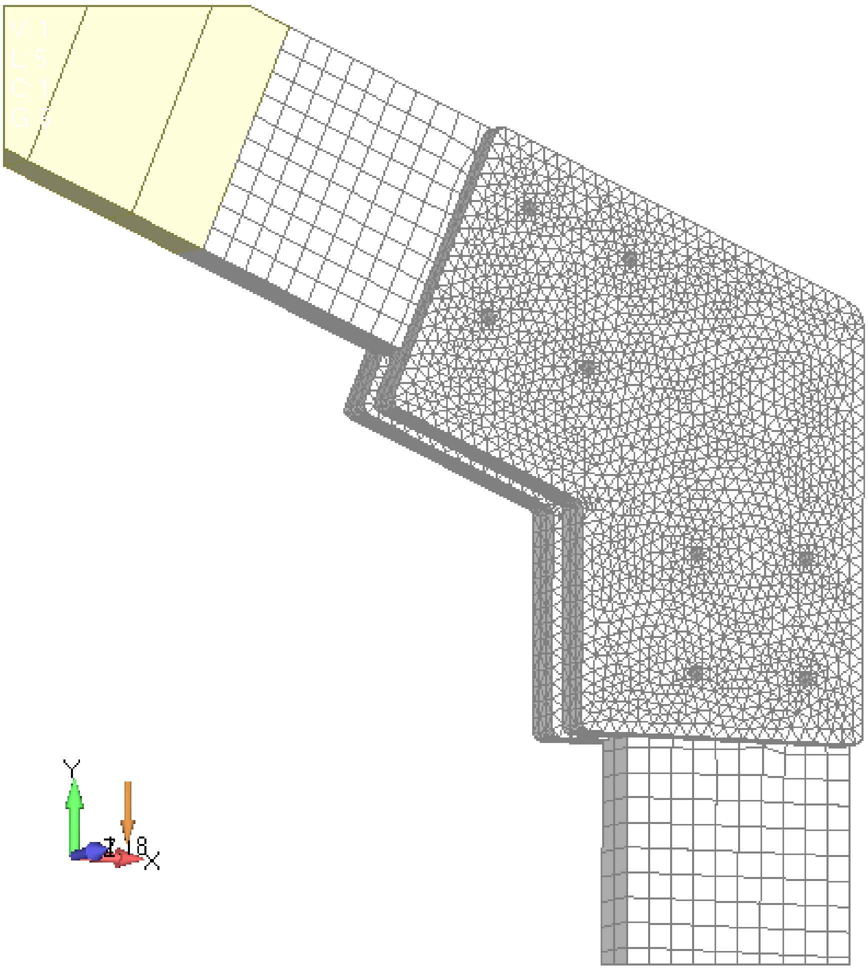

Fig. 25. Finite element model of the joint of beam boards with connectors

3.1 Basic load combinations

Design value of resistance to bending and compression:

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

Frames

Maximum bending stresses in frame elements: σmax = 8.2 MPa, fig. 26:

- Factor of safety $\eta = R^{A}_{p} / \sigma_{max} = 14/8.2 =$ **1.7**
- Utilization rate $f = 1/\eta$ = **0.59**

Crossbars

The maximum bending stresses are in the struts: σmax = 1.7 MPa, fig. 27:

- Factor of safety $\eta = R^{A}_{p} / \sigma_{max} = 14/1.7 >$ **2.0**

Posts and beams in the joint

The maximum stresses in the elements of the posts and beams are in the joint area: σmax = 14 MPa caused by bending, fig. 28,

- Factor of safety $R^{A}_{bend} / \sigma_{max} = 14/14 =$ **1.0**
- Utilization rate $f = 1/\eta$ = **1.0**.

Connectors

The maximum stress in the connectors: σmax =13 MPa, fig. 29, 30

- Factor of safety $R^{A}_{bend} / \sigma_{max}$ = 14/13 = **1.08**
- Utilization rate f=1/η = **0.93**

Bolt hole crushing strength

Fig. 31 shows the shear forces in the bolts (N) acting on a 22.5 mm thick connector wall under dead weight and snow loads for Region VIII. Most of the load is transferred through contact forces between the board and the connector.

The sum of these forces acts on the board from the bolt side.

The maximum resulting force on the connector is P1 shear = 210 N.

The force from the bolt side on the second connector is P2 shear = 210 N.

Ultimate bearing force [Psm] = Rsm * Fsm,

where Rsm is the permissible bearing stress;

Fsm is the bearing area.;

Connector crush strength.

For plywood (birch), Rcm = 12 MPa (SNiP Wooden Structures. 2017, Table 3):

Bolt diameter D = 14 mm;

Crushing area Fsm = t * D = 22.5*14 = 315 mm^2

Therefore, [Psm=12*315=3780 N.

Factor of safety η=[Psm]/ Pshear=3811/210 > **10**

Board crush strength.

Ultimate bearing stress at a 45-degree angle Rcm45 = 8.0 MPa;

Maximum bearing force Pshear = P1shear + P2shear = 420 N

Bearing area Fsm = t * D = 45 * 14 = 630 mm^2

Therefore, [Psm] = 8 * 630 = 5040 N

Factor of safety η=[Psm]/ Pshear=5040/420 > **10**

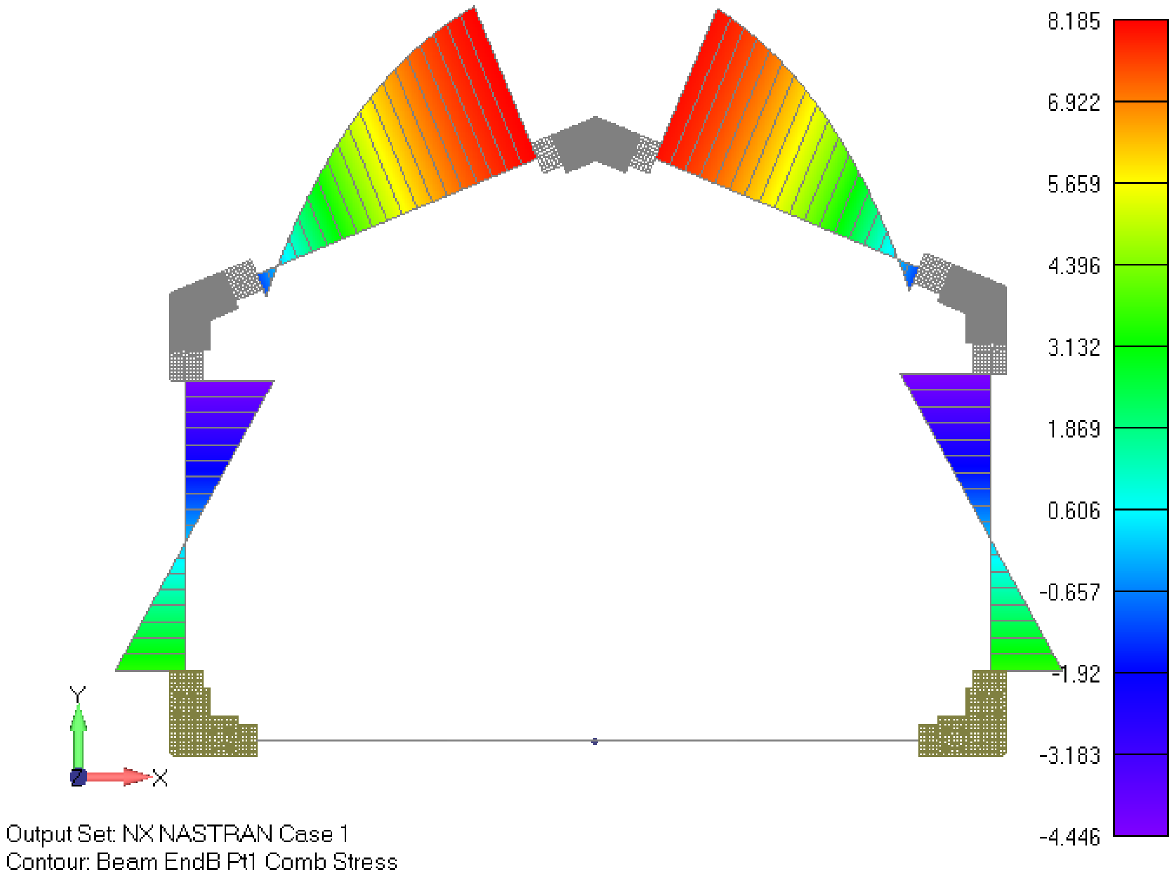

Fig. 26. Basic combinations. Maximum bending stress in frames, MPa

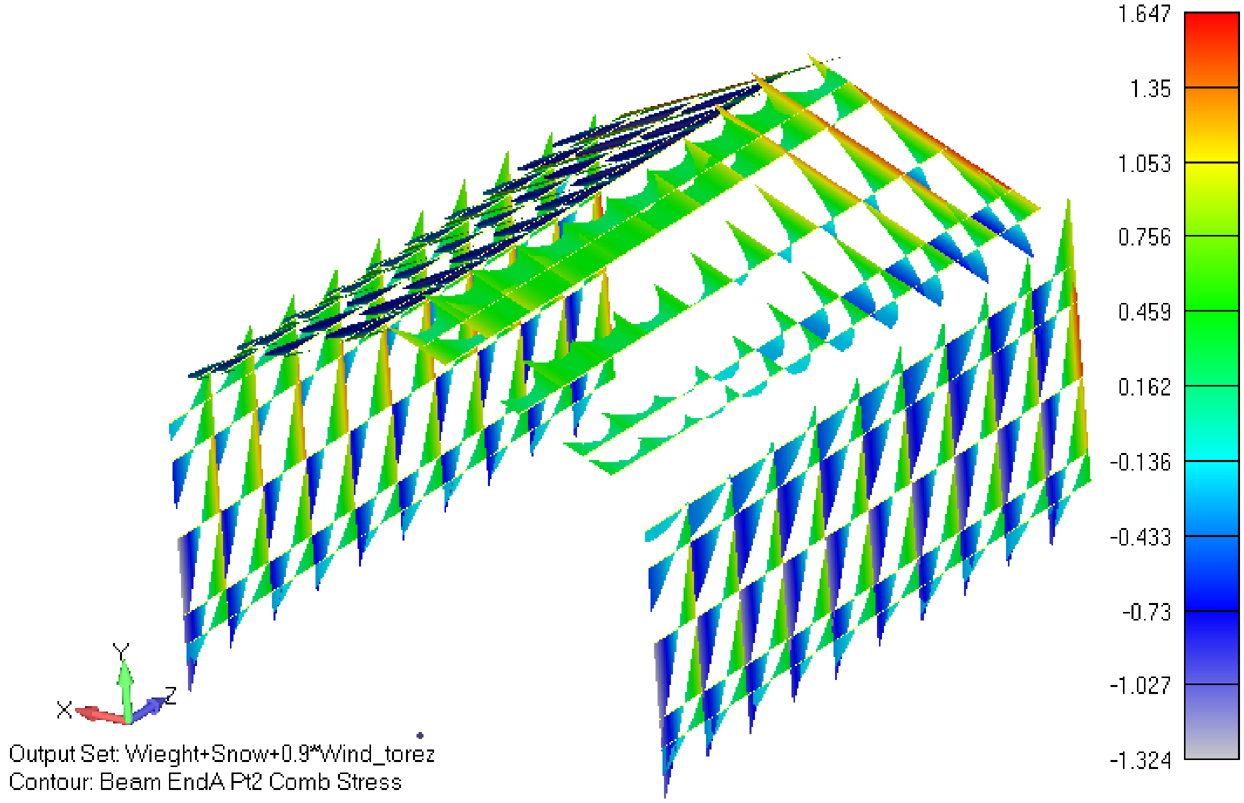

Fig. 27Basic combinations. Maximum stresses in crossbars, MPa

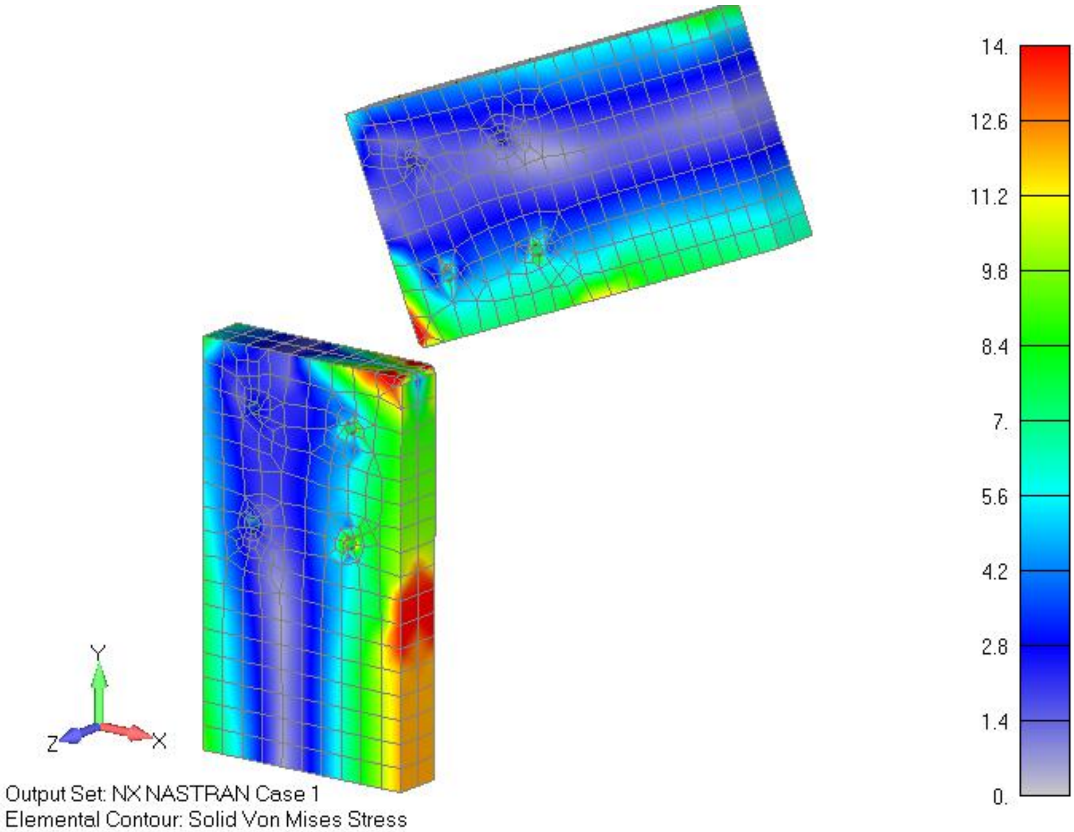

Fig. 28. Basic combinations. Maximum stresses in post and beam boards, MPa

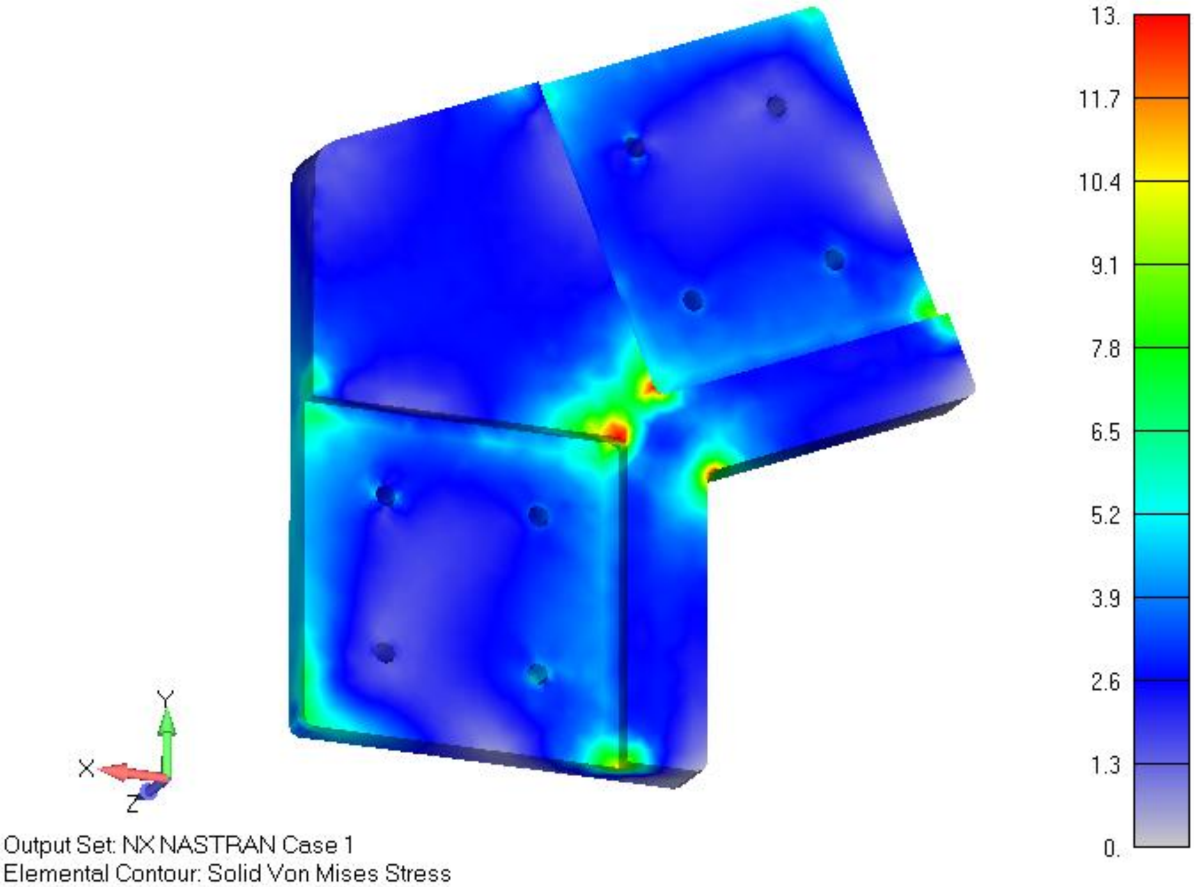

Fig. 29. Basic combinations. Maximum stresses in the pillar-to-beam connector, MPa

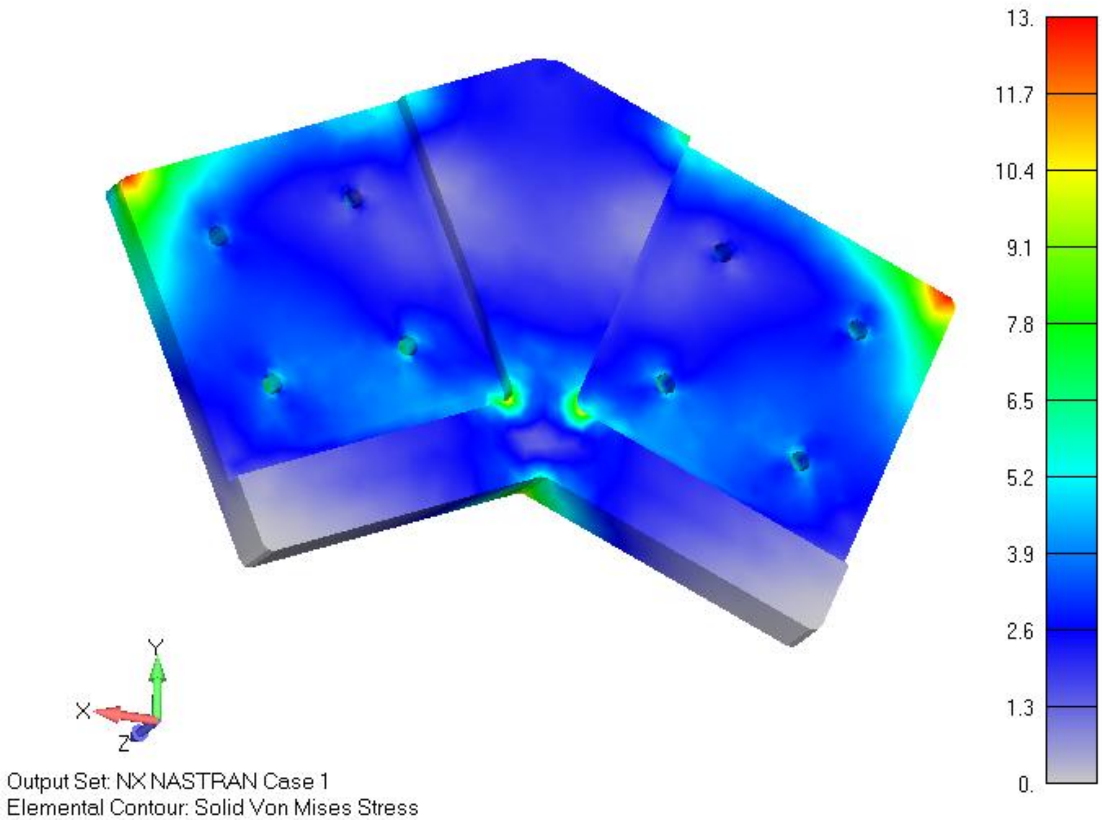

Fig. 30. Basic combinations. Maximum stresses in the beam connector, MPa

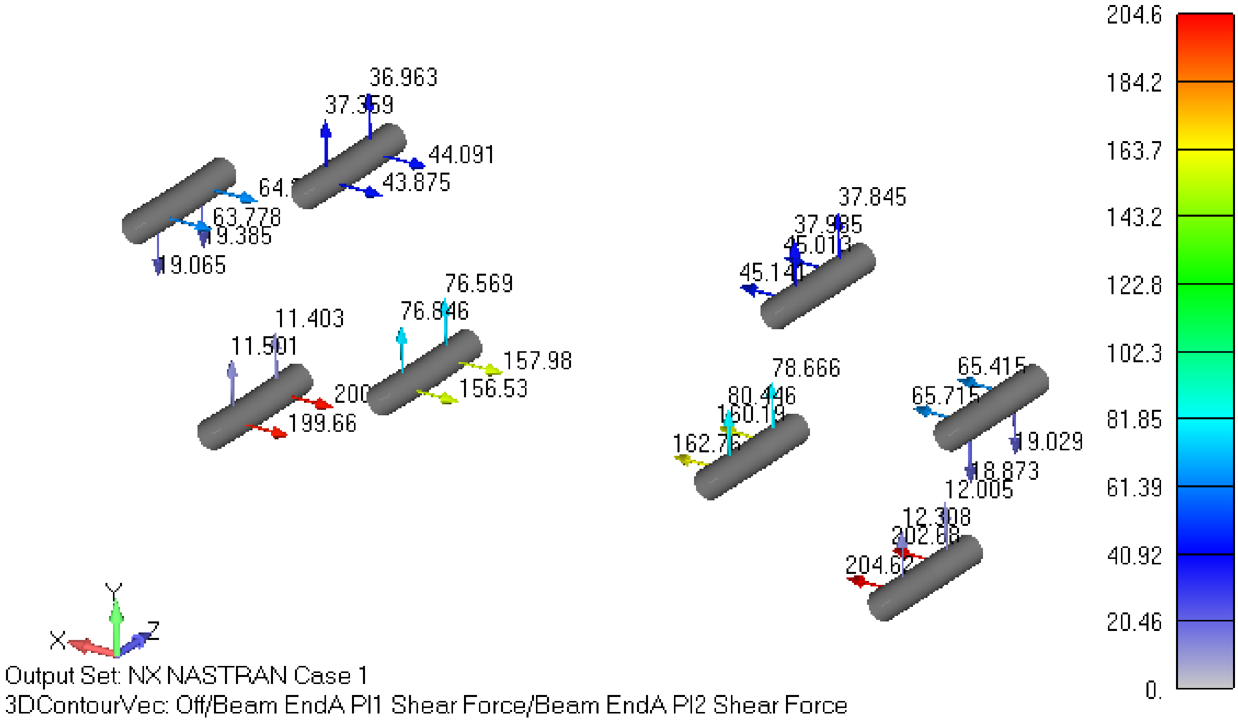

Fig. 31. Basic combinations. Maximum bolt forces, N

3.2 Special combinations

Design value of resistance to bending and compression:

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

Frames

The maximum bending stresses in frame elements: σmax = 15.5 MPa, fig. 32,

- Factor of safety $\eta = R^{A}_{p} / \sigma_{max} = 20/15.5 =$ **1.29**
- Utilization rate $f = 1/\eta$ = **0.78**

Crossbars

The maximum bending stresses are in the crossbar: σmax = 11.6 MPa, fig. 33,

- Factor of safety $\eta = R^{A}_{p} / \sigma_{max} = 20/11.6$ **= 1.72**
- Utilization rate $f = 1/\eta$ = **0.58**

Posts and beams in the joint

The maximum stresses in the elements of the studs and beams are in the joint area: σmax = 15 MPa caused by bending, fig. 34,

- Factor of safety $R^{A}_{bend} / \sigma_{max} = 20/15$ = **1.33**
- Utilization rate $f = 1/\eta$ = **0.75**

Connectors

The maximum stress in the connectors: σmax =15 MPa, fig. 34

- Factor of safety $R^{A}_{bend} / \sigma_{max} = 20/15 =$ **1.33**
- Utilization rate $f = 1/\eta$ = **0.75**

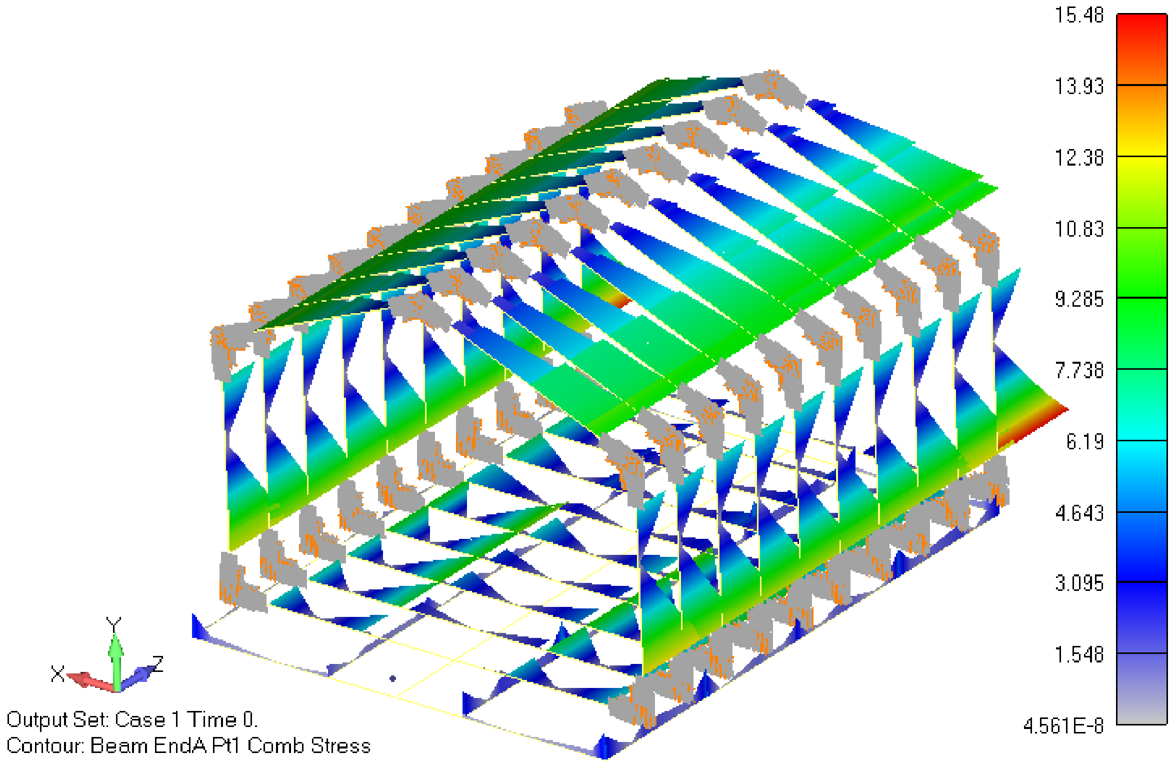

Fig. 32. Special combinations. Maximum stresses in frames, MPa.

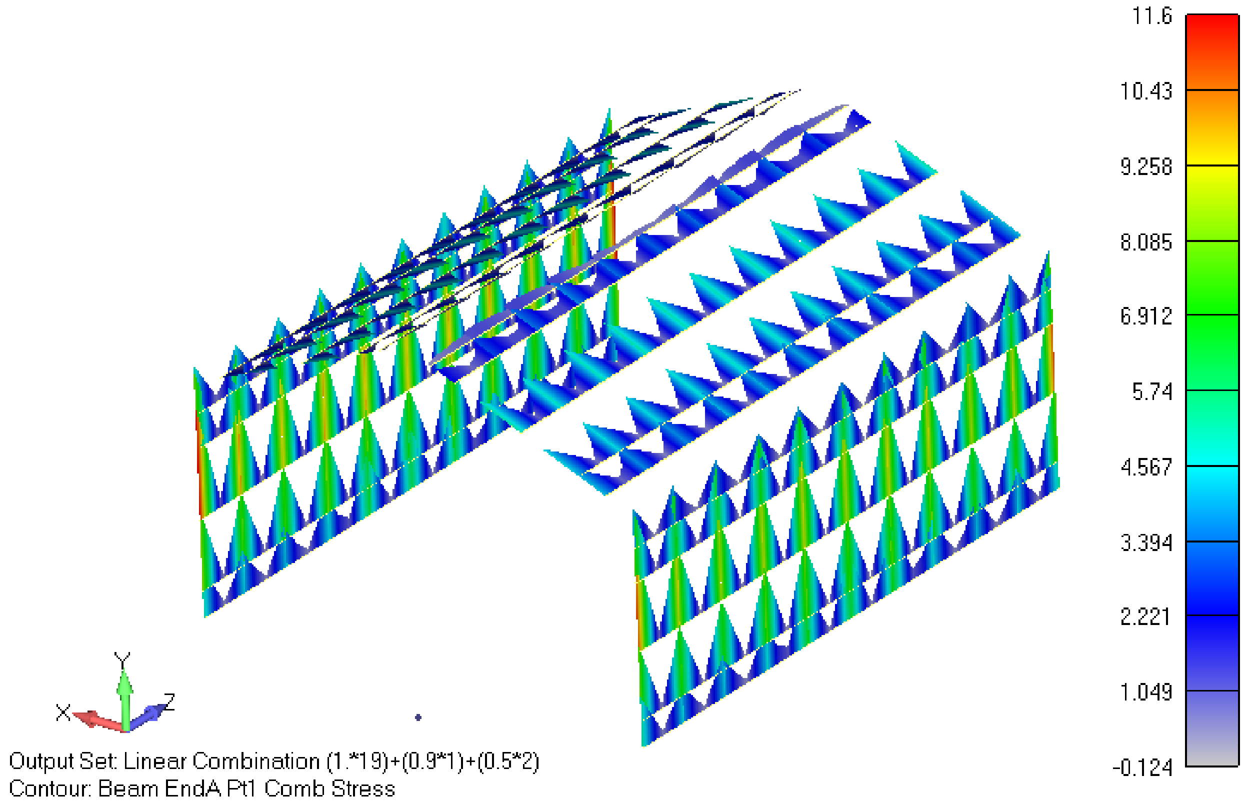

Fig. 33. Special combinations. Maximum stresses in crossbars, MPa.

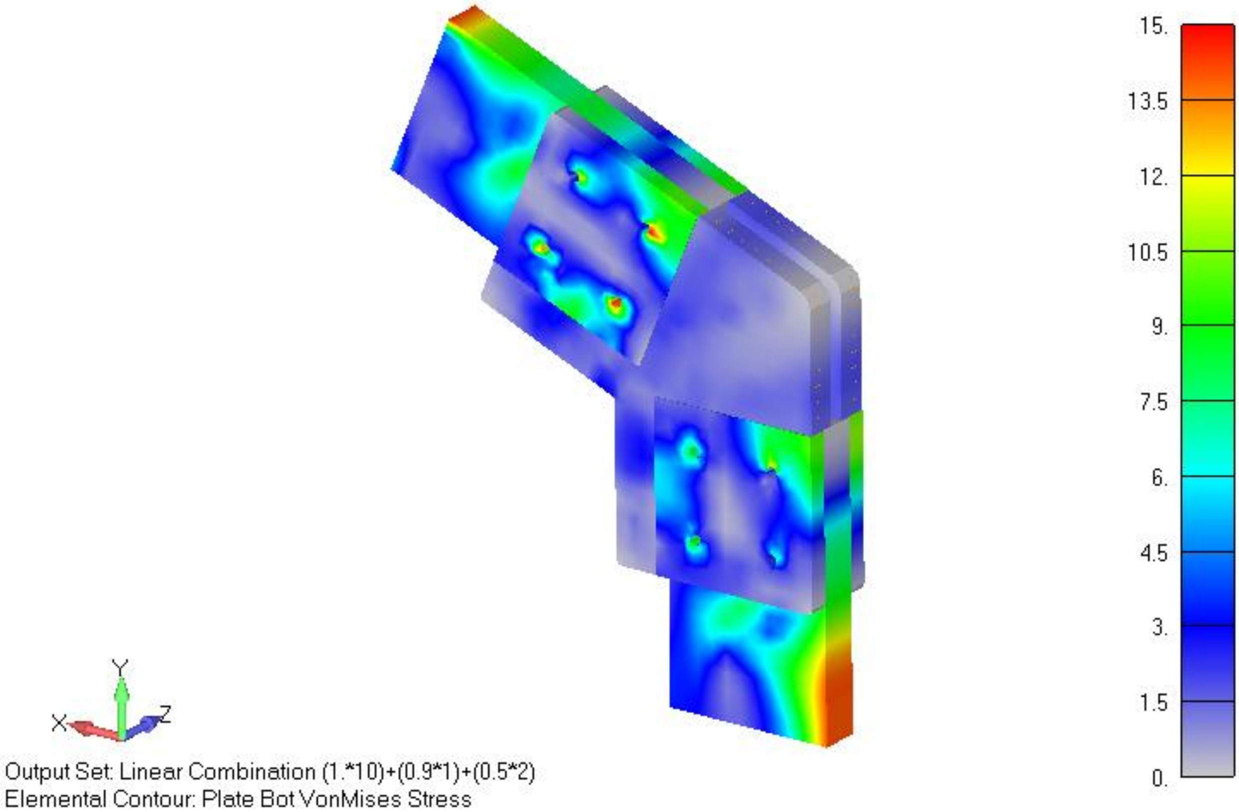

Fig. 34. Special combinations. Maximum stresses in the connection of studs and beams with connectors, MPa

3.3 Summary of safety factors and utilization factors for a gable-roof building

Table 3

#	Name	Minimum safety margin, η	Maximum utilization rate
1	Frames	1.29	0.78
2	Crossbars	1.72	0.58
3	Posts and beams in the joint	1.0	1.0
4	Connectors	1.08	0.93
5	Strength of boards (holes) against crushing	>2	<0.5

4 STRENGTH ANALYSIS OF A 6-SLOPE BUILDING, SPAN 6 M, SLOPE 45 DEG.

4.1 Finite element model

5 The building's design model is shown in Fig. 35-36.

6 Frames and longitudinal beams are modeled using Beam elements of the appropriate cross-section. Joints between beams and struts are assumed to be moment joints.

7 Connectors and planks at the joints are modeled using Solid elements. The bolts connecting the Connectors to the mullions and beams are modeled using one-dimensional Bush or Beam elements.

8 Frictional contact conditions are specified between the connectors and planks. The friction coefficient is assumed to be f = 0.5.

9 The elements modeling the bolts are weakened in the transverse direction, so bending moments in the joint are transmitted primarily by contact forces and partially by friction.

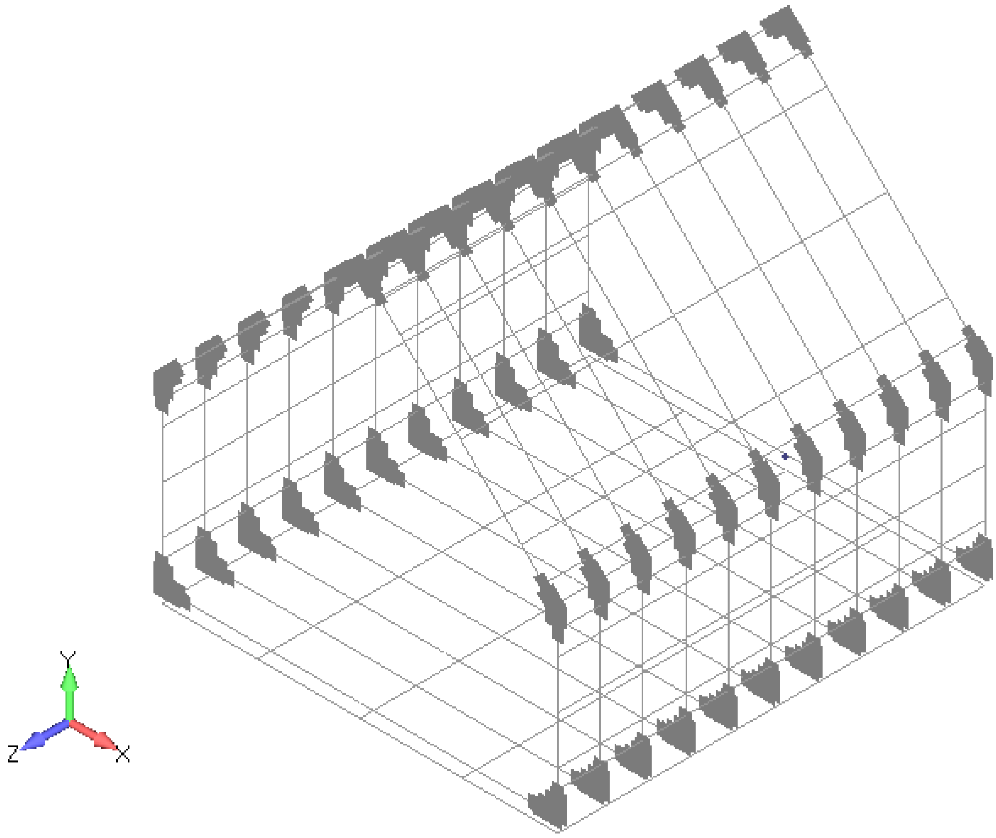

Fig. 35. Finite element model of gable roof building with a roof pitch of 45 deg.

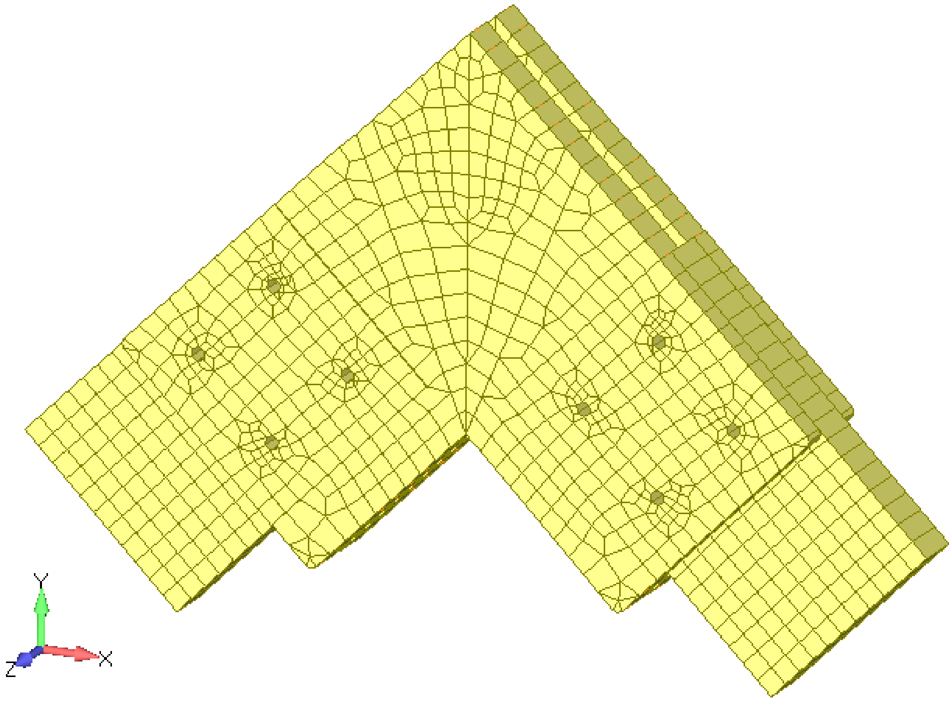

Fig. 36. Finite element model of the joint of beam boards with connectors, angle 90 deg.

4.2 Basic load combinations

Design value of resistance to bending and compression:

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

Frames

The maximum bending stresses in frame elements: σmax = 8.4 MPa, fig. 37,

- Factor of safety $\eta = R^{A}_{p} / \sigma_{\max} = 14/8.4$ = **1.67**
- Utilization rate $f=1/\eta$ = **0.6**

Crossbars

The maximum bending stresses are in the struts: σmax = 1.7 MPa, fig. 38,

- Factor of safety $\eta = R^{A}_{p} / \sigma_{\max} = 14/1.7 >$ **2.0**

Posts and beams in the joint

The maximum stresses in the elements of the posts and beams are in the joint area: σmax = 9.6 MPa caused by bending, fig. 39,

- Factor of safety $R^{A}_{bend} / \sigma_{\max} = 14/9.6$ = **1.46**
- Utilization rate $f=1/\eta$ = **0.69**

Connectors

The maximum stress in the connectors: σmax =9.6 MPa, fig. 40

- Factor of safety $R^{A}_{изг} / \sigma_{\max} = 14/9.6 =$ **1.46**
- Utilization rate *f*=1/η = **0.69**

Bolt hole crushing strength

Fig. 41 shows the shear forces in the bolts (N) acting on a 22.5 mm thick connector wall loaded with its own weight and snow loads for Region VIII.

The sum of these forces acts on the board from the bolt side.

The maximum resulting force on the connector is P1shear = 2300 N.

The force from the bolt side on the second connector is P2shear = 2300 N

Ultimate bearing force [Psm] = Rsm * Fsm,

where Rsm is the permissible bearing stress;

Fcm is the bearing area;

Connector bearing strength.

For plywood (birch), Rcm = 12 MPa (SNiP Wooden Structures. 2017, Table 3):

Bolt diameter D = 14 mm;

Fsm = t*D=22.5*14=315 mm2

Therefore, [Psm]=12*315=3780 N.

Safety factor ⍰=[Psm]/Pshear=3811/2300 = 1.66

Board compressive strength.

Ultimate compressive stress at a 45-degree angle Rcm45 = 8.0 MPa;

Maximum compressive force Pshear = P1shear + P2shear = 4600 N

Fcm = t*D=45*14=630 mm2

Therefore, [Psm]=8*630=5040 N

Safety factor ⍰=[Psm]/Pshear=5040/4600= 1.1

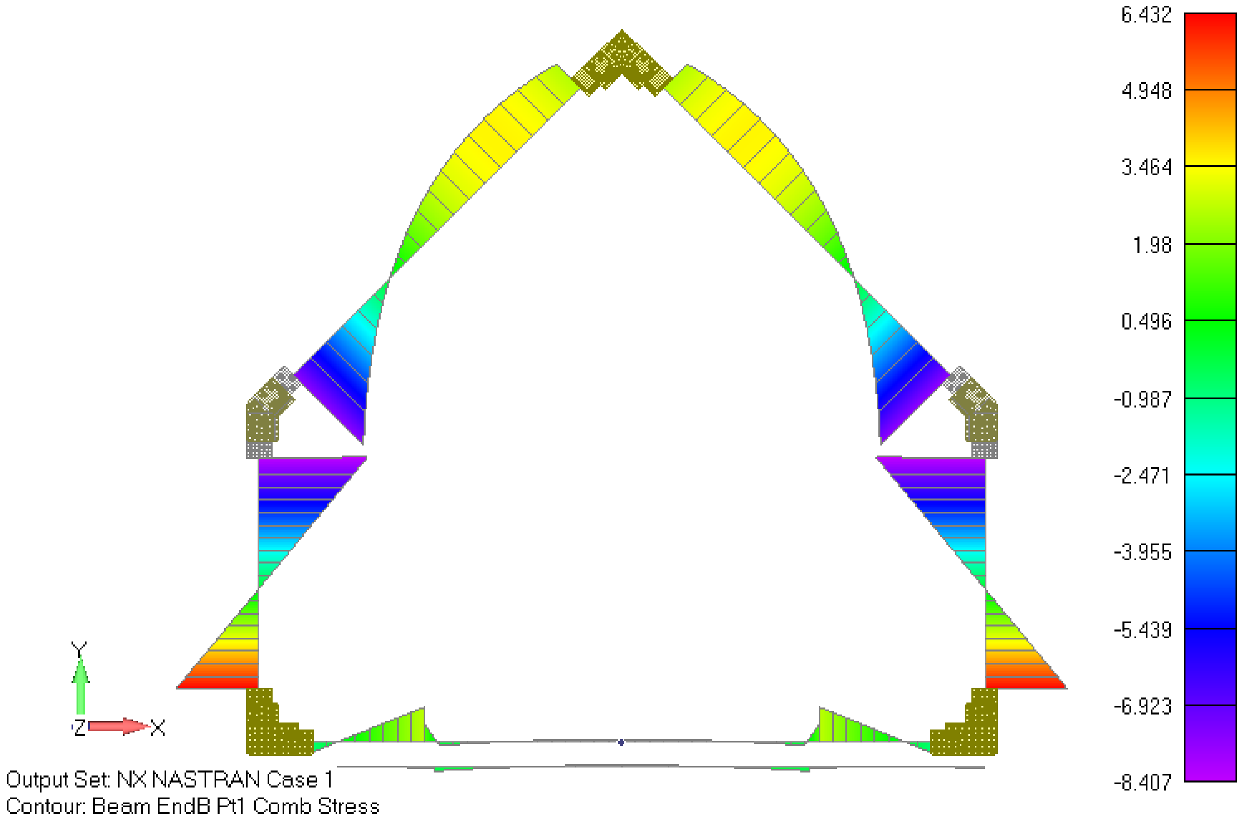

Fig. 37. Basic combinations. Maximum bending stresses in frames, MPa

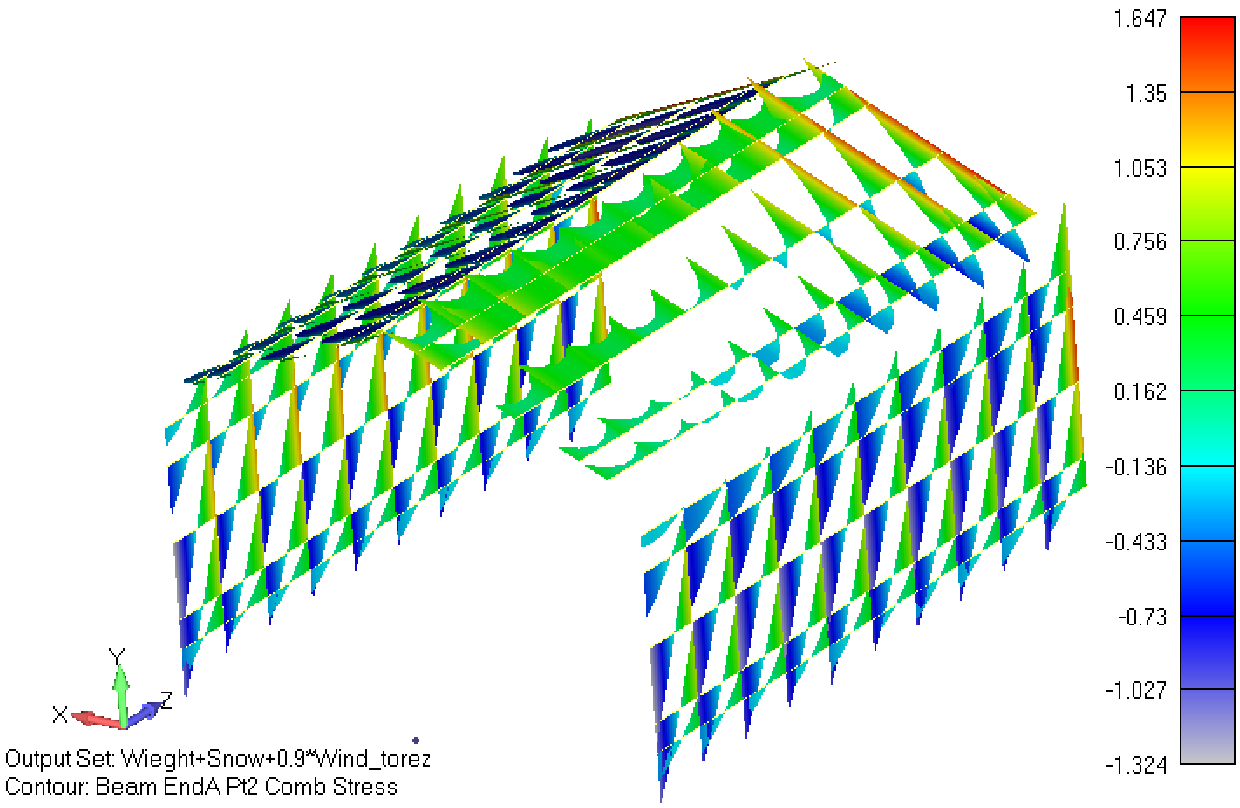

Fig. 38. Basic combinations. Maximum bending stresses in crossbars, MPa

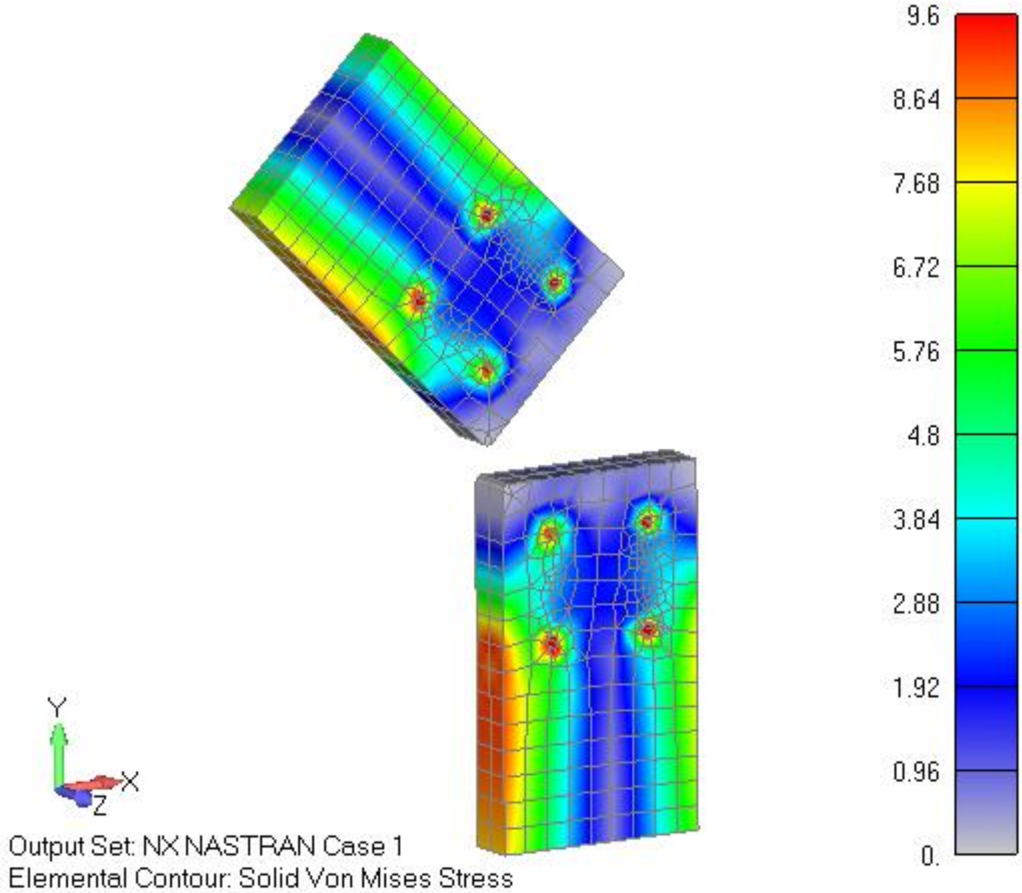

Fig. 39. Basic combinations. Maximum stresses in post and beam boards, MPa.

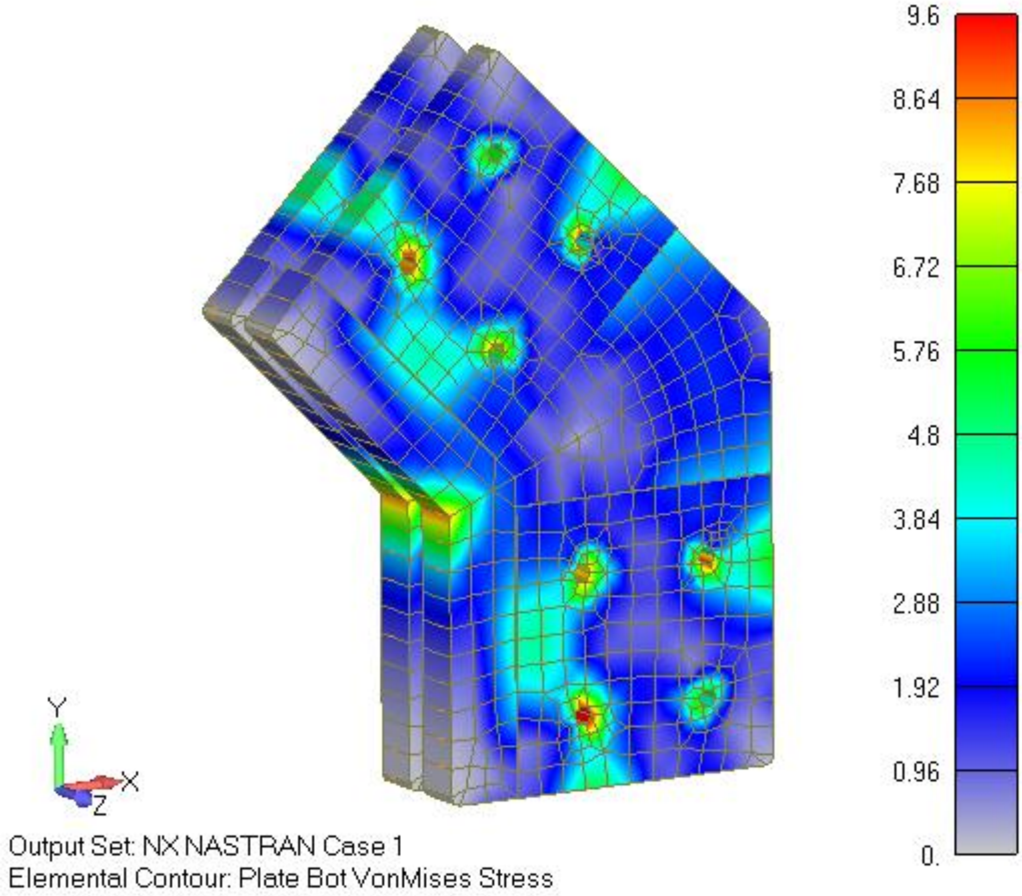

Fig. 40. Basic combinations. Maximum stresses in the stud-to-beam connector, MPa.

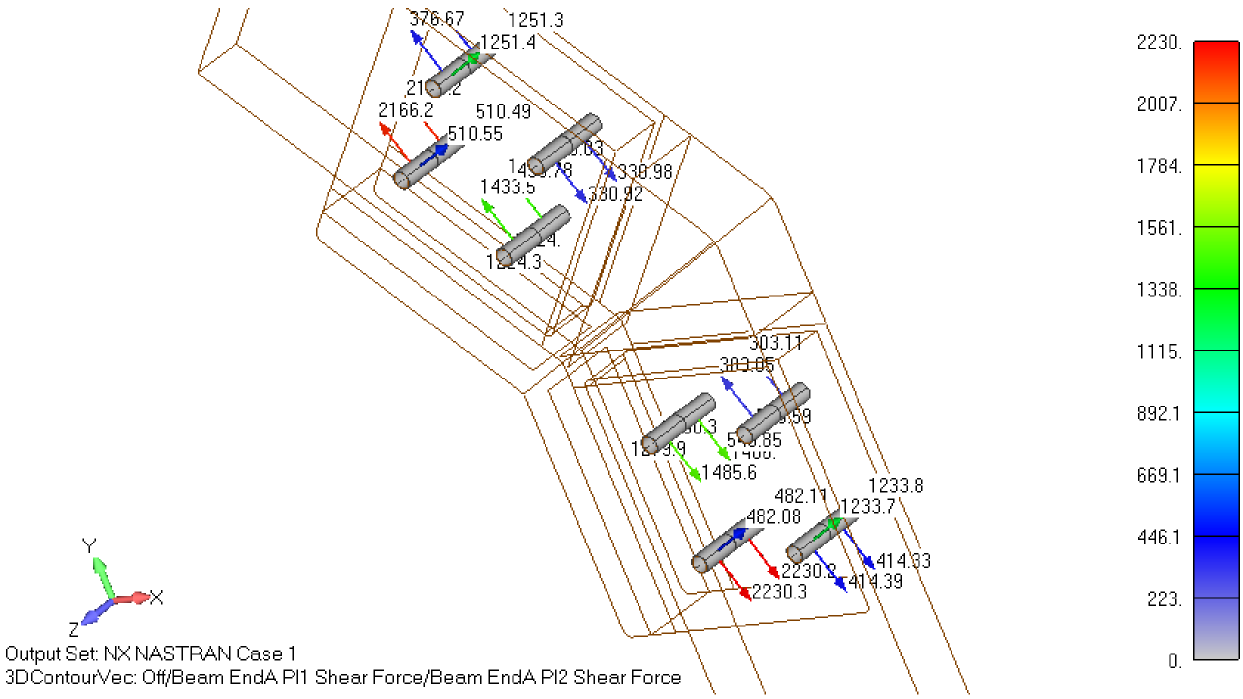

Fig. 41. Basic Combinations. Maximum bolt forces, H

4.3 Special combinations

Design value of resistance to bending and compression:

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

Frames

The maximum bending stresses in frame elements: σmax = 19 MPa, fig. 42,

- Factor of safety $\eta = R_p^A / \sigma_{max} = 20/19 =$ **1.05**
- Utilization rate $f = 1/\eta$ = **0.95**

Crossbars

The maximum bending stresses are in the struts: σmax = 17.5 MPa, fig. 43,

- Factor of safety $\eta = R_p^A / \sigma_{max} = 20/17.5 =$ **1.14**
- Utilization rate $f = 1/\eta$ = **0.88**

Posts and beams in the joint

The maximum stresses in the elements of the posts and beams are in the joint area: σmax = 17.1 MPa caused by bending, fig. 44,

- Factor of safety $R_{bend}^{A} / \sigma_{max} = 20/17.1 =$ **1.17**
- Utilization rate $f = 1/\eta$ = **0.86**

Connectors

The maximum stress in the connectors: σmax =13 MPa, fig. 45

- Factor of safety $R_{bend}^{A} / \sigma_{max} = 20/13 =$ **1.54**
- Utilization rate $f = 1/\eta$ = **0.65**

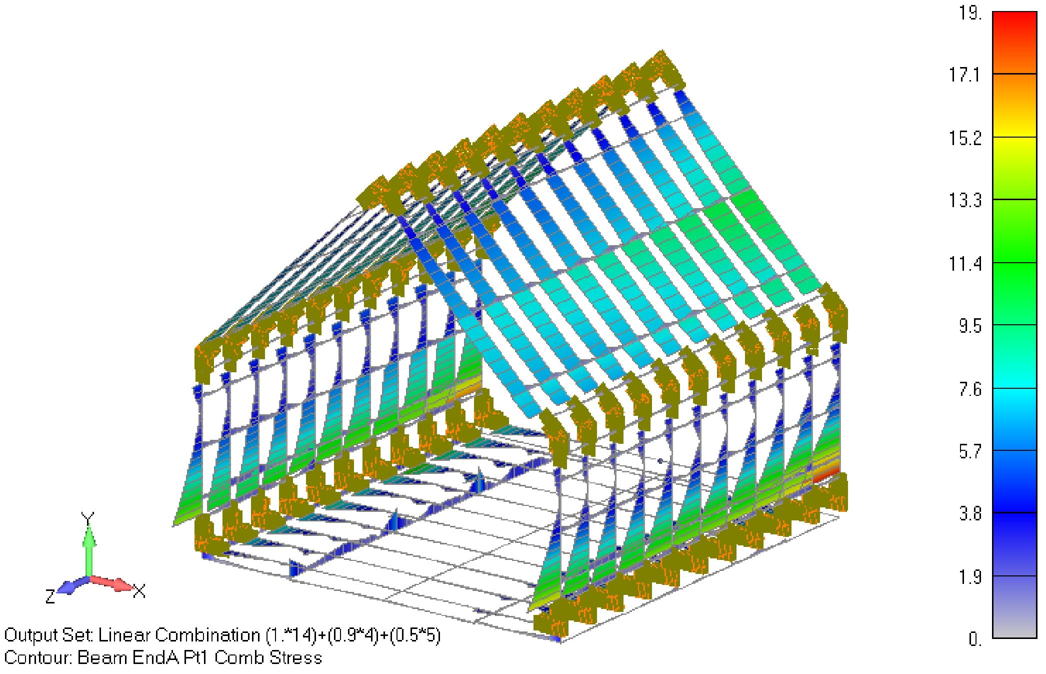

Fig. 42. Special combinations. Maximum stresses in frames, MPa.

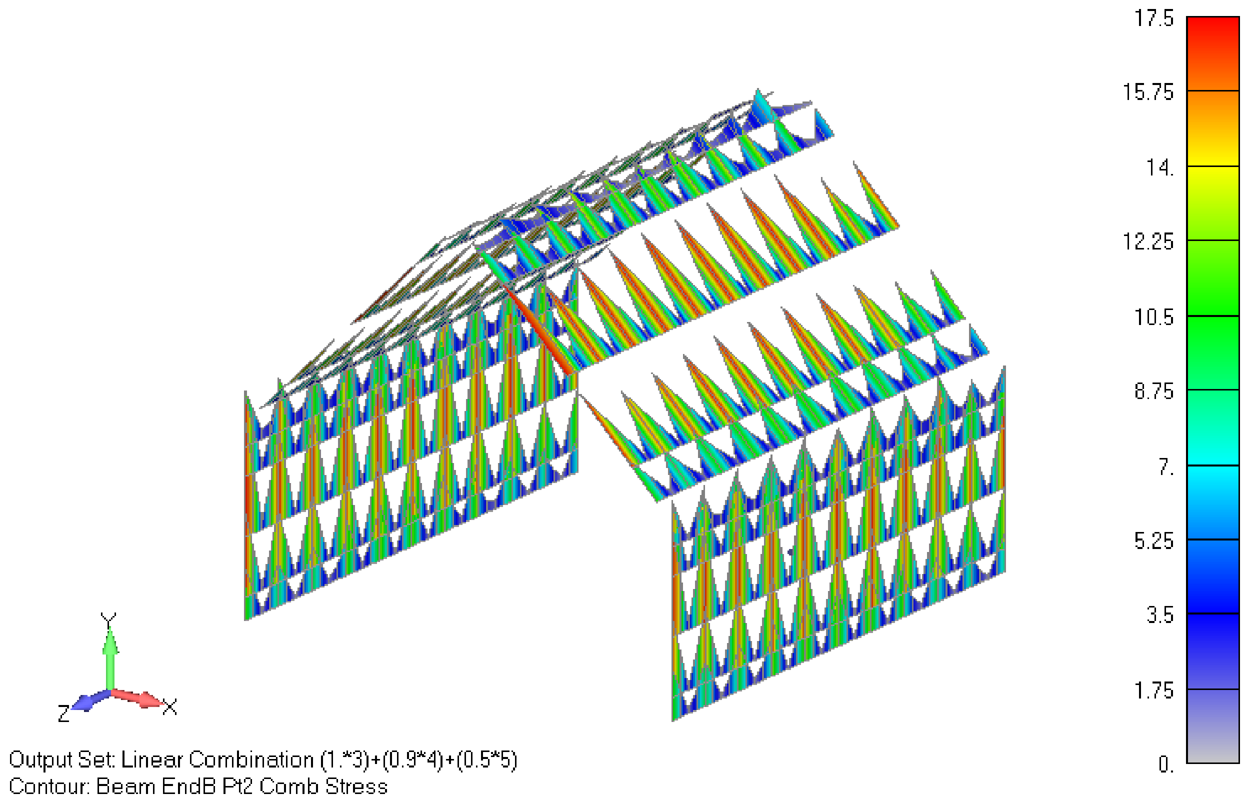

Fig. 43. Special combinations. Maximum stresses in crossbars, MPa.

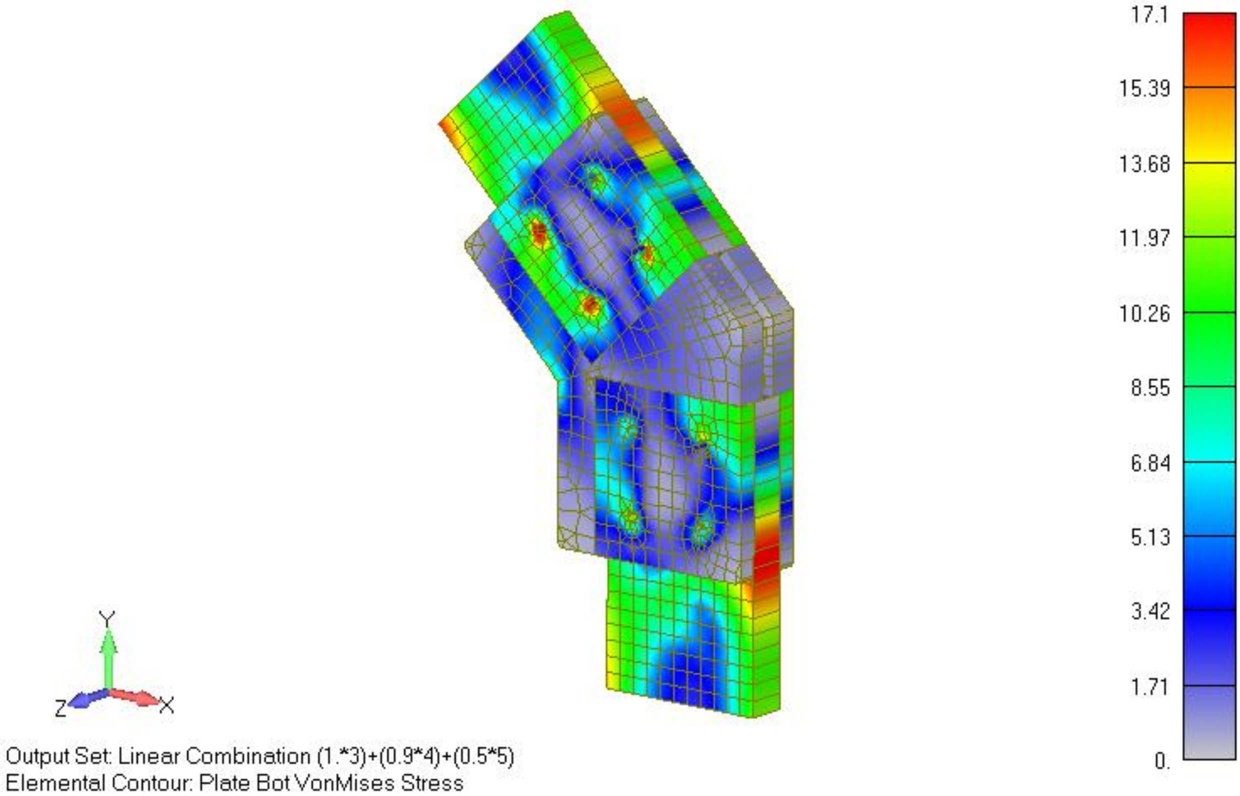

Fig. 44. Special combinations. Maximum stresses in the connection of studs and beams with connectors, MPa

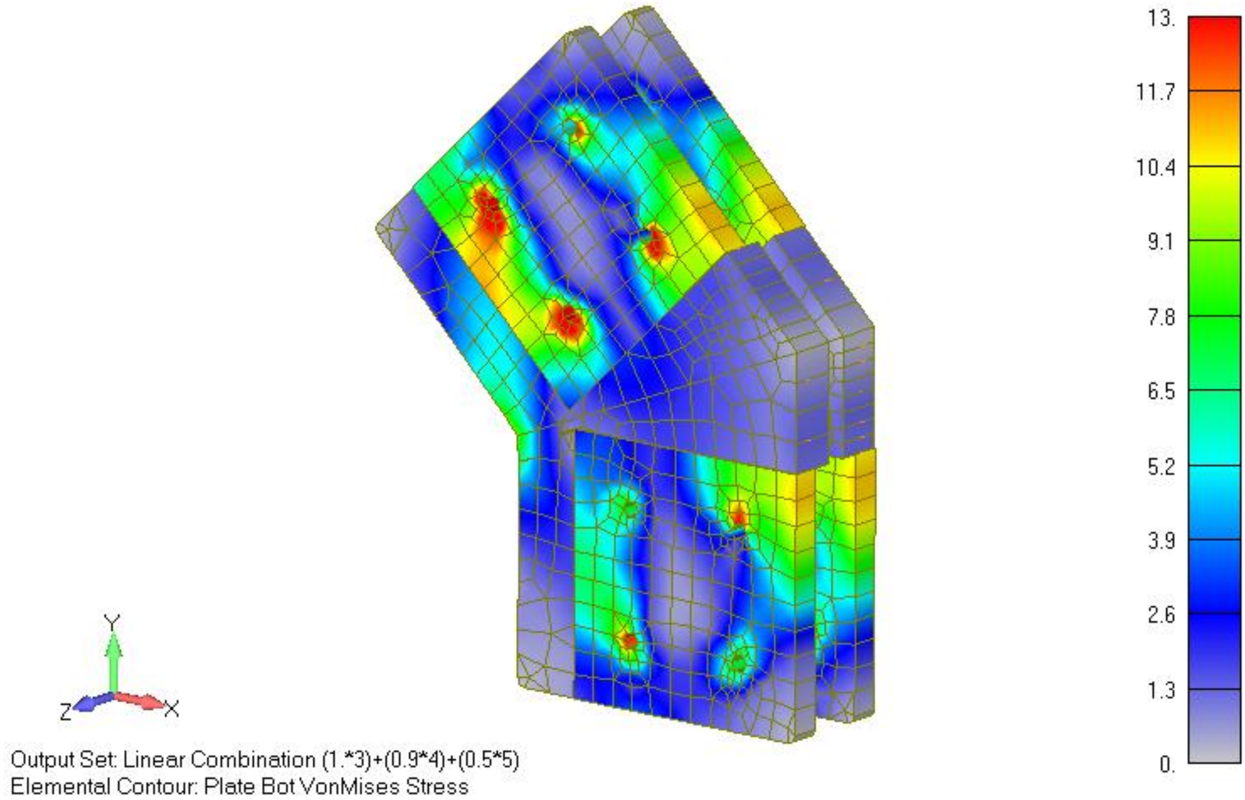

Fig. 45. Special combinations. Maximum streses in connectors, MPa

4.4 Summary of safety factors and utilization factors for a gable-roof building with SLOPE 45 DEG.

Table 4

#	Name	Minimum safety margin, η	Maximum utilization rate
1	Frames	1.05	0.95
2	Crossbars	1.14	0.88
3	Studs and beams in the joint	1.17	0.86
4	Connectors	1.46	0.69
5	Strength of boards (holes) against crushing	1.1	0.91

CONCLUSION

Calculations for extreme operating conditions showed that the FINHA building structure, with stud and beam connections using connectors, meets the requirements of the building code SP 64.13330.2017 "SNiP II-25-80. Wooden Structures."

The required safety factor is met, $\eta \geq 1$.

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

The calculations were performed using the maximum possible snow load—the estimated snow cover weight = 5.6 kN/m² = 570 kg/m², snow zone VIII.

The maximum estimated seismicity of the region was assumed to be 9 points.

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