

Wind Action Resistant Roofs

Introduction

During the storms in the summer of 2008, the wind damaged numerous roofs in Slovenia. The damage was caused on roofs with varied types of roofing. Even though many roofs were covered with lightweight sheet metal roof tiles, relatively few such roofs were damaged. The sponsor of this manual, Gerard Roofs, decided to publish this manual in order to decrease the scope of such damage in the future.

The manual discusses wooden roofs in accordance with **Figure 1**.

When designing, building and using the roofs in Slovenia, the European Standards on structures, in short Eurocodes, must be complied with. For wooden roofs, Eurocodes from the SIST EN 1990, 1991 and 1995 groups must be complied with. All guidelines in these instructions are adopted from these Eurocodes, which according to the rules on the Mechanical Resistance and Stability of Construction Works, are obligatory in the Republic of Slovenia.

The wind actions on roofs

To model the wind actions, we must know the nature of the wind, decide how the actions shall be presented and in what type of action shall we regard them. We must be familiar with the characteristic values of wind actions and finally, we must decide on the model for wind actions.

The wind actions are presented in simplified terms with a group of pressures or forces, the effects of which are equal to the extreme effects of turbulent wind.

The structure's reaction to wind actions depends on the size, shape and dynamic characteristics of the structure.

The wind velocity and pressure are composed of a mean and a fluctuating component.

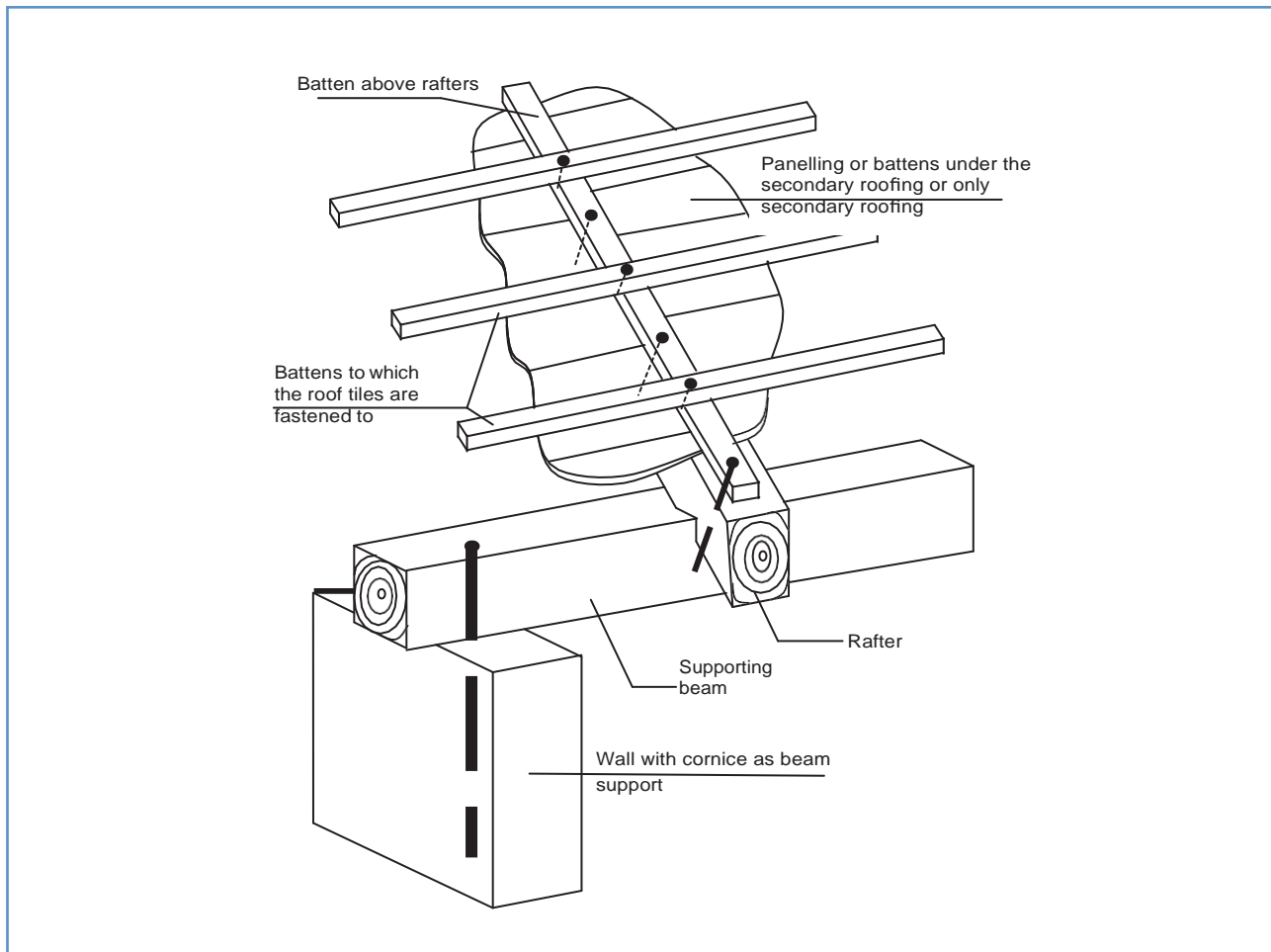


Figure 1 Structure of a Wooden Roof

The mean wind velocity v_m is determined from the basic wind velocity v_b which depends on the wind climate and the height variation of the wind (this is affected by the roughness and orography of the terrain and also by the neighbouring buildings). The fluctuating component of the wind velocity is determined by the turbulence intensity.

The fundamental value of the basic wind velocity $v_{b,0}$ is the 10 minute mean wind velocity, irrespective of direction and time of year, at 10 m above ground level in open country terrain with low vegetation (e.g. grass) and individual obstacles with a separation of at least 20 times the obstacle height (terrain category II). The basic wind velocity v_b at 10 m above the terrain category II is calculated from the fundamental value of the basic wind velocity $v_{b,0}$ while taking into account the wind direction and the effects of the season. The value is determined according to the map which is provided in the National Annex. The fundamental values of the basic wind velocity for various parts of Slovenia are provided in **Table 1**.

The mean wind velocity $v_m(z)$ at the height of z above ground level depends on terrain roughness ($c_r(z)$) and orography ($c_o(z)$) and larger and considerably higher neighbouring structures.

Wind turbulence at height z above ground level is measured with its intensity $I_t(z)$ which is expressed as the quotient between the standard turbulence deviation and the mean wind velocity. Wind turbulence is taken into account when determining peak velocity pressures.

The peak velocity pressure $q_p(z)$ at height z is calculated by taking into account the mean velocity and short-term wind velocity fluctuations.

Wind pressure acting on the external surfaces w_e and wind pressure acting on internal surfaces w_i is calculated from the relevant peak velocity pressure and the aerodynamic coefficients provided by Eurocodes.

Coefficients c_{pe} and c_{pi} can be positive or negative. The positive sign denotes pressure, the negative denotes suction. The net pressure on a surface that is exposed to external and internal pressures due to wind is the resultant of external and internal pressures **Figure 2**.

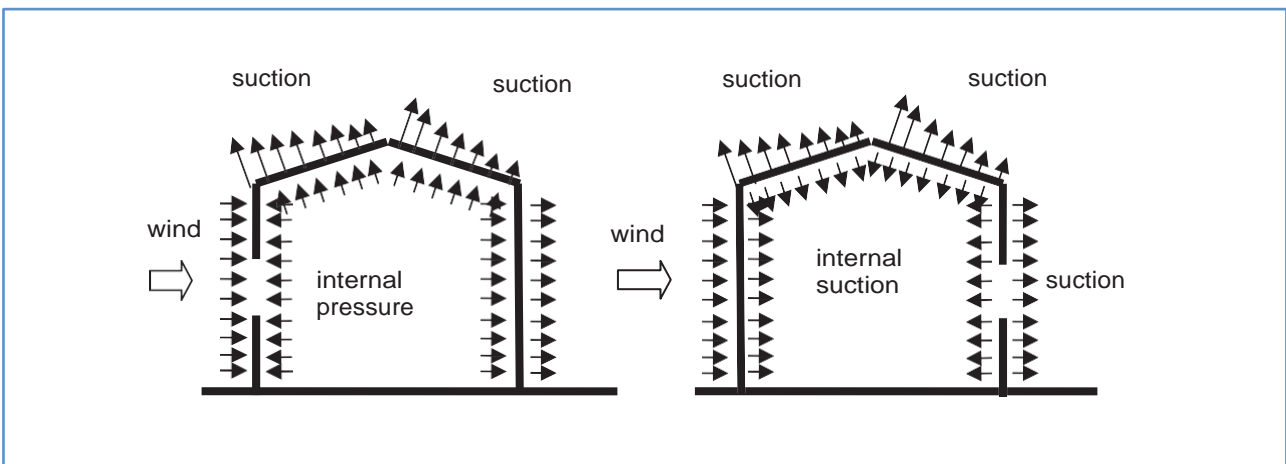


Figure 2 Examples of External and Internal Wind Pressures on the Surfaces of a Structures

External pressure coefficients c_{pe} for buildings and parts of buildings also depend on the size of the stressed surface A . The Eurocode provides coefficient $c_{pe,1}$ or $c_{pe,10}$ for surfaces of 1 m^2 or 10 m^2 . Coefficient $c_{pe,1}$ applies for surfaces smaller than 1 m^2 , and $c_{pe,10}$ applies for surfaces larger than 10 m^2 . Intermediate values between 1 and 10 m^2 are interpolated according to the equation in the Eurocode.

The coefficient values are provided for wind directions 0o, 90o and 180o. Provided are the least favourable values for directions $\pm 45o$ in terms of wind direction. For eaves, on the lower side of the eave, the pressure on the wall below the eave is taken into account.

Zone	Description	Altitude (m)	Mean wind velocity [m/s]
1	Majority of Slovenia	below 800	20
		800 - 1600	25
		1600 - 2000	30
		above 2000	40
2	Trnovski gozd, Notranjska and Karavanke	below 1600	25
		1600 - 2000	30
		above 2000	40
3	Primorje, Kras and a part of the Vipavska Valley	-	30

Table 1 Mean Wind Velocities in Relation to the Zone and Altitude

Roof structures

Lightweight sheet metal tiles are small, thin shells with complex geometry and variable supports depending on the direction of the stress. Due to the ribs in the direction from the ridge towards the eaves of the roof, the load capacity in the transversal direction in relation to the ribs can be ignored and the roof tile can be modelled as a freestanding support, supported by battens to which it is fastened. This applies when the load is pressing it onto the battens. But when the roof tile is exposed to suction, it is only supported where it is fastened to the battens.

Roof tiles are not checked when making calculations for the roof structure, because they have been tested before the serial production. These tests provide their load capacity together with the data on uniform surface load that they can withstand and the number of fixing points. Usually, the uniform surface load is not critical for roof tiles, but the concentrated load due to walking on the roof is. Usually, lightweight sheet metal roof tiles must only be walked upon certain places, otherwise the parts of the roof tile walked upon could collapse.

The calculation model for roof tiles must be provided so that the load of the battens, to which the tiles are fastened to, can be calculated.

Battens to which roof tiles are fastened to are freestanding supports or continuous supports reaching only across two, three or four fields. It is recommended to use shorter battens on the middle of the roof slopes. For battens to which roof tiles are fastened to, the load due to wind is taken into account as a uniform line load in the direction perpendicular to the surface of the roof slope.

The battens above the rafters can lie directly on the rafters or on the panelling or on the battens under the secondary roofing. Even in this case, they are relatively densely supported and their dimensions are determined by the required thickness of the aeration layer between the roofing. It is recommended that the loads of the battens, to which the roof tiles are fastened, are transferred through the battens above the rafters directly onto the rafters as much as possible. This can be achieved by e.g. making sure the wire nails for fixing the battens to which the roof tiles are fastened reach through the battens above the rafters into the rafters. For thicker battens above rafters or in the event that panelling (or battens) above the rafters, which support the secondary roofing, this is usually not possible; in this case, the fasteners between the battens above the rafters and the rafters themselves must be arranged at a suitable distance and provided separately. In this case, models similar to models in battens to which roof tiles are fastened should be used for a calculation model of the batten above the rafters. The wind load is taken into account as a concentrated force in the direction perpendicular to the surface of the roof slope. All the above only applies in the event of wind suction. If the wind causes pressure, all the junctions are pressed and the wind load is not critical.

Due to limited length of wood, the rafters are usually freestanding supports, freestanding supports with overhang, continuous supports across two fields or continuous supports across two fields with overhang. For battens, the wind load is taken into account only as a uniform line load in the direction perpendicular to the plane of the roof slope.

Supporting beams have similar calculation models as rafters. If the supporting beams are calculated separately, the wind load that is transferred onto them through battens and rafters can be taken into account simplified as a uniform load in the direction perpendicular to the roof slope plane. If the supporting beams are a part of the complete calculation model of the roof or even the structure, the forces between rafters and supporting beams are taken into account as concentrated forces. The wind load on the supporting beams acts in the direction that does not correspond to the main axes of the cross-section.

In complete calculation models of roof structures, attention has to be paid to modelling a continuous flow of individual elements through junctions and to the suitable blocking or releasing of the turning forces of elements along the longitudinal axes.

Due to wind, the roof tiles are stressed with a uniform surface load w which is calculated as the sum of external and internal pressures. Loads of roof tiles are calculated per unit of length in the direction of battens to which the roof tiles are fastened to.

If the forces are negative, it means the roof tiles have to be anchored. When calculating the anchoring, the decrease of the required supporting forces can be taken into account due to the component of the roof's weight.

The loads of battens to which the roof tiles are fastened to are somewhat larger on the second and the second to last support of an individual batten. If the forces are negative, it means the battens have to be anchored.

Due to the wind, battens above the rafters are burdened with loads of the battens to which the roof tiles are fastened to. In general, the stress on the battens above the rafters must be calculated with an appropriate calculation model. The dimensions of the battens are determined according to the rules of the Eurocodes while also taking into account the weight of the structure, the weight of the roofing and the snow load.

The loads of the battens above the rafters are somewhat larger on the second and the second to last support of an individual batten to which roof tiles are fastened to. If the forces are negative, it means the battens have to be anchored.

Due to wind, the rafters are burdened with the loads of the battens above the rafters. In general, the supporting forces and the loads on the rafters must be calculated with an appropriate calculation model. The dimensions of the rafters are determined according to the rules of the Eurocodes while also taking into account the structure's own weight, the weight of the roofing and the snow load.

Where the roof is also the ceiling above the attic, the weight of the ceiling lining and insulation layers should also be taken into account when designing the rafters.

Due to wind, the supporting beams are burdened with the loads of the battens above the rafters. In general, the supporting forces and the loads of the supporting beams must be calculated with an appropriate calculation model.

The dimensions of the supporting beams are determined according to the rules of the Eurocodes while also taking into account their own weight, the weight of the roofing, the weight of the battens to which roof tiles are fastened to, the battens above the rafters, the weight of the rafters and the snow load.

Where the roof is also the ceiling above the attic, the weight of the ceiling lining and insulation layers should also be taken into account when designing the supporting beams.

Various fasteners are used for connections between construction elements of the roof. The most often used are nails and screws. These instructions discuss those recommended by the manufacturers of lightweight sheet metal roof tiles.

The load capacity of fasteners can be determined with calculations directly from Eurocodes or with tests. Some of the tests for roofs with lightweight sheet metal roof tiles were carried out in New Zealand.

Lightweight sheet metal roof tiles are fastened to the battens with special nails with a diameter of 2.8 mm and length of 50 mm. They are nailed into the battens from the eaves side into the incline of the roof tile which is somewhat smaller than the incline of the roof slope. The nails are usually nailed at the distance of $e_z = 36$ cm.

The model of the resistance of nails for fastening the roof tiles is complex and should be determined with tests.

The battens to which the roof tiles are fastened to are fastened to the battens above the rafters with nails or screws. During wind loads, they are stressed axially, and their resistance is determined by the pulling force.

The battens above the rafters are fastened to the rafters with nails or screws. During wind loads, they are stressed axially, and their resistance is determined by the pulling force.

The rafters are fastened to the supporting beams with nails or screws. During wind loads, they are stressed axially, and their resistance is determined by the pulling force.

The beams are fastened to the support with screws that are anchored into the support. During wind loads, the screws are stressed axially, shear stressed or by bending stress.

Calculation example

The instructions show the calculation for fasteners on junctions between the elements of the roof structure according to figure 1 for the roof on a building according to figure 2. The building is constructed on terrain category III in the 2nd wind zone in the Gorenjska region at the altitude of 700 m.

The envisaged roofing is Gerard Heritage. Battens to which the roof tiles are fastened to at the axial distance of 36.9 cm have a cross-section of 5 x 4 cm. The battens above the rafters have a cross-section of 8 x 5 cm. A secondary roofing stretches across the rafters. The space between the roofing and the secondary roofing is aerated. The rafters at the axial distance of 80 cm have a cross-section of 10 x 16 cm, the ridge support beam has a cross section of 20 x 24 cm and the eaves support beams above the longitudinal wall have a cross-section of 16 x 20 cm. The strength class of the wood used is C24.

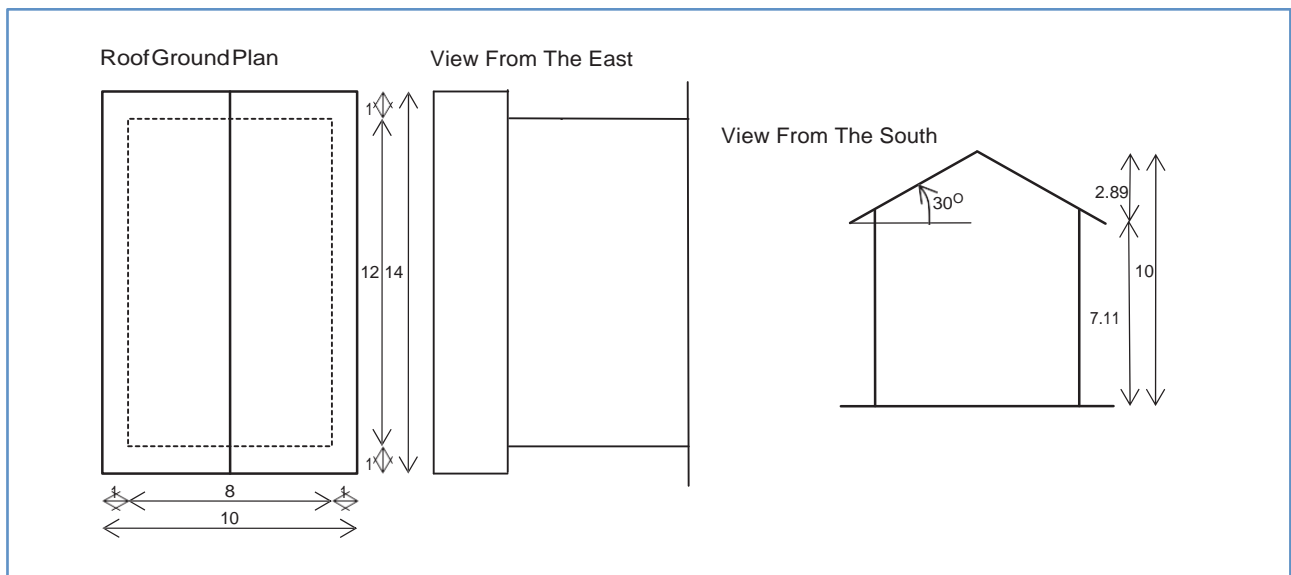


Figure 3 The Roof Ground Plan and the View on the Building From the East End

Wind load calculation

Mean wind velocity: $v_{b,0} = 25$ m/s (2nd zone, up to 1600 m of altitude).

Basic wind velocity: $v_b = 25$ m/s (for $c_{dir} = 1.0$ and $c_{season} = 1.0$).

Basic wind pressure: $q_b = 391$ Pa.

Upper roof surfaces

Reference height: $z = h = 10$ m.

Exposure factor: $c_e(z) = 1.71$.

Peak velocity pressure: $q_p(z) = 669$ Pa.

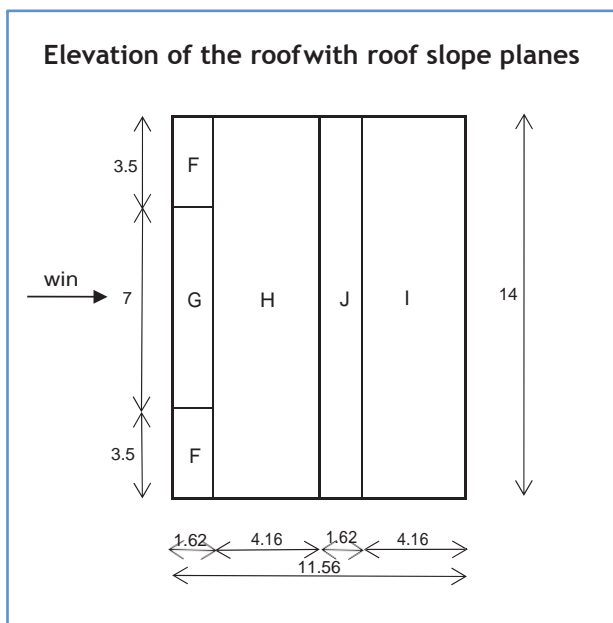


Figure 4 Division of the Upper Roof Surface Into Areas, Measured in Roof Slope Planes

Wind direction perpendicular to the ridge

Division of the roof surface into areas: $e = 14$ m (Figure 4).

External roof pressures, maximum suctions:

- F: $w_e = - 502$ Pa
- G and J: $w_e = - 335$ Pa
- H: $w_e = - 134$ Pa
- I: $w_e = - 268$ Pa

External roof pressures, maximum pressures:

- F and G: $w_e = 468$ Pa
- H: $w_e = 268$ Pa
- I and J: $w_e = 0$

For fasteners in which the influence surface is ≤ 1 m², the critical areas are F and G where the suction equals:

$w_e = - 1004$ Pa

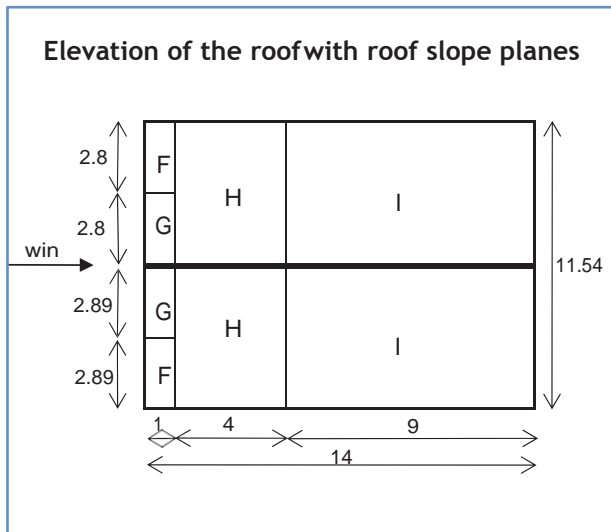


Figure 5 Division of the upper roof surface into areas, measured in roof slope planes

Wind direction perpendicular to the ridge

The south and north wall is divided into areas A and B, the west wall is area D and the east wall is area E.

External pressures on the wall:

- A: $w_e = - 803 \text{ Pa}$
- B: $w_e = - 535 \text{ Pa}$
- D: $w_e = 535 \text{ Pa}$
- E: $w_e = - 341 \text{ Pa}$

For fasteners where the influence surface is $\leq 1 \text{ m}^2$, critical area is D where the pressure that is added up with the suction on the upper roof surface equals:

$w_e = 669 \text{ Pa}$

Wind in the direction of the ridge

Division of the roof surface into areas: $e = 10 \text{ m}$ (Figure 5).

External pressures on the roof:

- F: $w_e = - 883 \text{ Pa}$
- G: $w_e = - 1150 \text{ Pa}$
- H: $w_e = - 535 \text{ Pa}$
- I: $w_e = - 335 \text{ Pa}$

For fasteners in which the influence surface is $\leq 1 \text{ m}^2$, the critical area is G where the suction equals:

$w_e = - 1338 \text{ Pa}$

The pressure on the lower roof surface equals the pressure on the wall below the overhang.

Wind in the direction of the ridge

External pressures on the wall :

- A: $w_e = - 803 \text{ Pa}$
- B: $w_e = - 535 \text{ Pa}$
- C: $w_e = - 334 \text{ Pa}$
- D: $w_e = 522 \text{ Pa}$
- E: $w_e = - 308 \text{ Pa}$

For fasteners where the influence surface is $\leq 1 \text{ m}^2$, critical area is D where the pressure that is added up with the suction on the upper roof surface equals:

$w_e = 669 \text{ Pa}$

Fasteners control

This section discusses only the fasteners and not the stresses on the elements of the roof structure.

The junction between roof tiles and battens

The wind direction in the direction perpendicular to the ridge is critical.

The resulting suction is 1673 Pa. The weight of the roof tiles is 64 N/m^2 , and its component in the direction perpendicular to the roof area is 55 N/m^2 . Due to the component, the resulting suction decreases to 1618 Pa.

The influence surface per one junction is $0.369 \times 0.36 = 0.133 \text{ m}^2$.

The designing value of the force on the junction equals 322 N.

The arrangement of the nails for fastening the roofing in the instructions is appropriate.

The junction between battens and the battens above the rafters

The influence surface for the junction between battens and the battens above the rafters is approximately 0.296 m^2 . For this junction, the same pressures can be applied as for the junctions between the roof tiles and the battens.

The design force due to wind suction at the junction is 716 N, by taking into account the weight of the batten it decreases to 711 N.

Data for the Paslode nails show that the permitted pulling forces are too small and that these nails cannot be used on the eaves area for fastening the battens onto the battens above the rafters.

The instructions for the SFS nails provide the characteristic values of resistance to pulling $R_{N,k}$. The design values of $R_{N,d}$ resistance is calculated in accordance with Eurocode 5.

The characteristic value $R_{N,k}$ must be at least 1027 N. A single 6 x 80 WFR screw, which has a $R_{N,k} = 1410 \text{ N}$, is suitable for fastening the batten to the batten above the rafters. When using these screws, the batten above the rafter must be fastened separately.

However, a single 6 x 130 WFR screw can be used to link the battens, the battens above the rafters and the rafters.

The junction between the battens above the rafters and the rafters

If the battens above the rafters are fastened to the rafters separately, it is best if they are fastened adjoining the intersection with the battens to which the roof tiles are fastened to. In this case, the junctions between the battens above the rafters and the rafters are burdened with approximately the same force as the junctions between the battens and the battens above the rafters. To ensure control and to ensure the nails or screws for fastening the batten are at an appropriate distance, it is recommended that this junction is executed so that the heads of the nails or screws for fastening the battens above the rafters are visible, namely that the battens for fastening the roof tiles do not cover them. Because the battens above the rafters are thicker than the battens, the nails or screws have to be longer.

A single 6 x 90 WFR screw can be used for the junction.

As mentioned above, this junction can be executed together with the junction between the batten and the batten above the rafters with a single 6 x 130 WFR screw.

The junction between rafters and beams

The rafters are burdened by wind differently depending on whether they are on the windward side or on the leeward side. At the windward side, the load is higher at the eaves; at the leeward side it is higher at the ridge. For the load at the eaves, the size of the influence surface between 1 and 10 m² should be taken into account. At overhangs, the load also acts on the lower side of the rafter. Suction acts along the entire length of the rafter at the windward side; on the leeward side, pressure occurs in the area of the eaves.

Besides the wind load, the beneficial influence of the roof's own weight, the battens, the battens above the rafters and the rafter should also be taken into account when the weight is equally distributed along the entire length of the rafter.

The design values of the supporting forces for determining the fasteners and the selection of screws:

$R_{1,d} = -2776$ N select the 12 x 240 WFC screw

$R_{2,d} = -596$ N select the 6 x 200 WFR screw

The junctions between the eaves support beams and the reinforced concrete cornice

Presuming that the eaves support beams are anchored at every 4 m and considering the load of the rafters as uniform, the design tensile force in the vertical anchor of the eaves beam equals:

$R_d = 10.3$ kN

A screw with 12 mm diameter and 4.6 quality is suitable for vertical anchoring of the beam.