LIGNOLOC®
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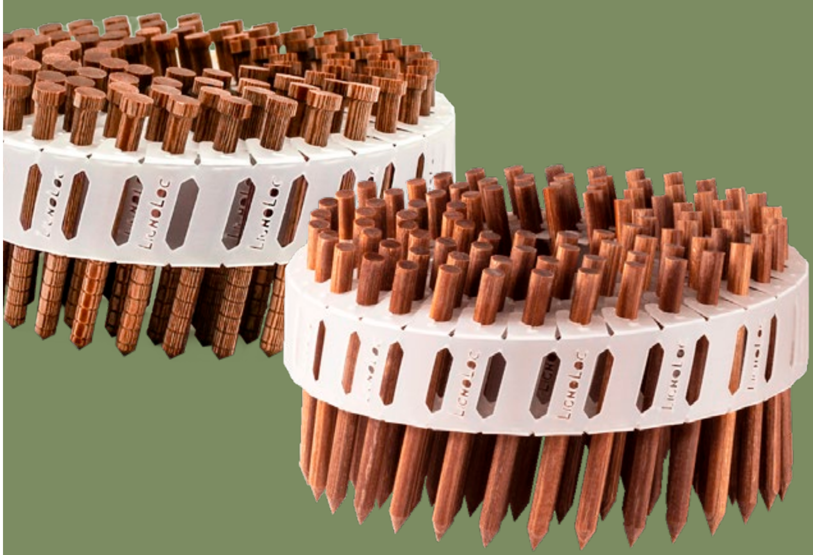
STRUCTURAL ANALYSIS

Fastening of a Rhombus Façade

with LIGNOLOC® wooden nails according to ETA-23/0330



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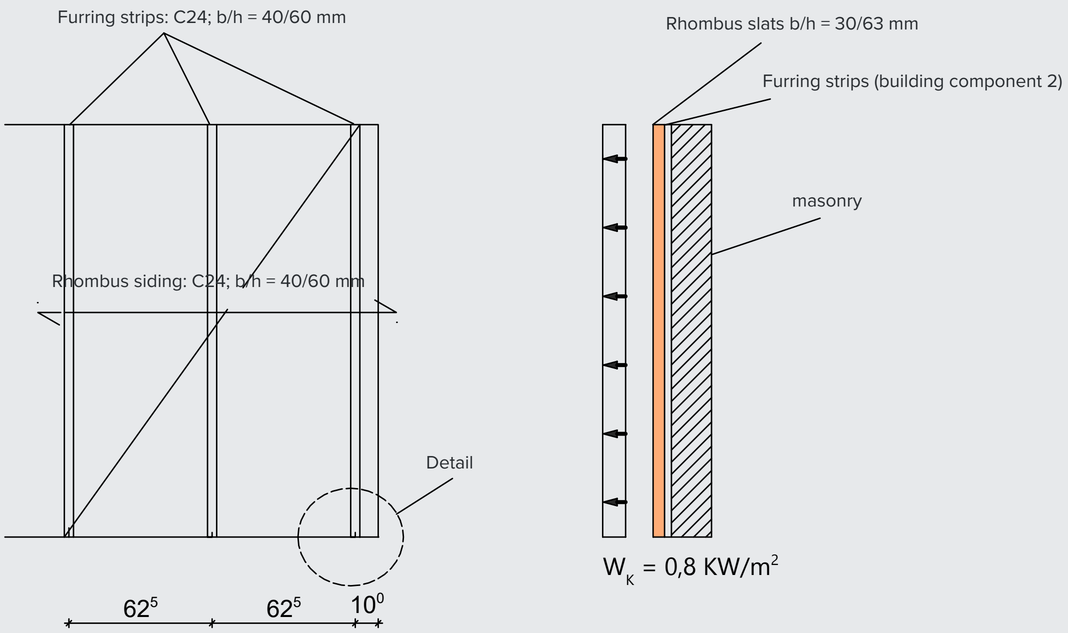
01 // System

A rhombus façade installed on a structural framework made of spruce timber is considered. Based on the local conditions, the façade can be assigned to Service Class 2.

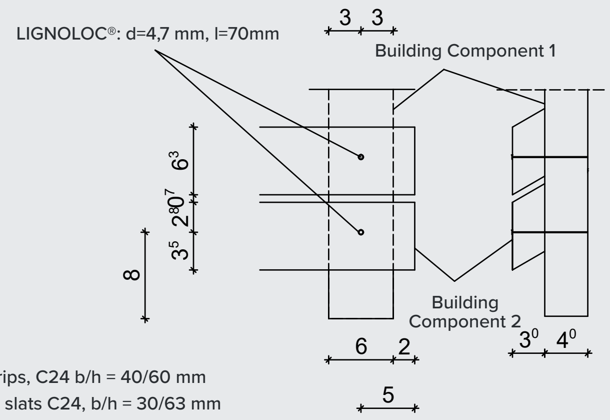
Furring strips: Softwood C24, b_{Ri} x h_{Ri} = 40 x 60 mm2, e = 625mm, NKL 2

Clapboard siding: Softwood C24, b_S x h_S = 30 x 63 mm2, NKL 2

Fastening: LIGNOLOC® wooden nail, d = 4,7 mm, L = 70 mm



Detail



Building Component 1: Furring strips, C24 b/h = 40/60 mm
Building Component 2: Rhombus slats C24, b/h = 30/63 mm

An analysis of the entire building resulted in a governing characteristic wind uplift action of 0.8 kN/m². For the rhombus profile slats, an average density of $\rho_{\text{mean, Timber}} = 4{,}2\ \text{kN/m}^2$ can be assumed.

02 // Verification of Minimum Clearances

Fasteners according to ETA-23/0041, analogous to non-pre-drilled nails in DIN EN 1995-1-1:2010-12

Are the minimum spacings in the rhombus slats (Component 2) met?

table 8.2

$$a_{1,min,VH} = (5 + 5 \cdot (\cos\alpha)) \cdot d = (5 + 5 \cdot (\cos 90^\circ)) \cdot 4{,}7 = 23{,}5 \text{ mm} \leq 625 \text{ mm} ✓$$

$$a_{3,c,min,VH} = 10 \cdot d = 10 \cdot 4{,}7 = 47{,}0 \text{ mm} \leq 50 \text{ mm} ✓$$

$$a_{4,t,min,VH} = (5 + 2 \cdot \sin\alpha) \cdot d = (5 + 2 \cdot (\sin 90^\circ)) \cdot 4{,}7 = 32{,}9 \text{ mm} \leq 35 \text{ mm} ✓$$

$$a_{4,c,min,VH} = 5 \cdot d = 5 \cdot 4{,}7 = 23{,}5 \text{ mm} \leq 28 \text{ mm} ✓$$

Are the minimum spacings in the furring strips (Component 2) met?

table 8.2

$$a_{1,min,VH} = (5 + 5 \cdot (\cos\alpha)) \cdot d = (5 + 5 \cdot (\cos 0^\circ)) \cdot 4{,}7 = 47 \text{ mm} \leq 70 \text{ mm} ✓$$

$$a_{3,t,min,VH} = (10 + 5 \cdot (\cos\alpha)) \cdot d = (10 + 5 \cdot (\cos 0^\circ)) \cdot 4{,}7 = 70{,}5 \text{ mm} \leq 80 \text{ mm} ✓$$

$$a_{4,c,min,VH} = 5 \cdot d = 5 \cdot 4{,}7 = 23{,}5 \text{ mm} \leq 30 \text{ mm} ✓$$

03 // Loads per Nail

From permanent load

$$F_{V,G,k} = \rho_{mean,\ Timber} \cdot b_S \cdot h_S \cdot e = 4{,}2 \tfrac{kN}{m^3} \cdot 0{,}03 \text{ m} \cdot 0{,}063 \text{ m} \cdot 0{,}625 \text{ m} = 5{,}0 \cdot 10^{-3} kN = 5{,}0 \text{ N}$$

Design level

$$F_{V,G,d} = F_{V,G,k} \cdot \gamma_G = 5{,}0 \text{ N} \cdot 1{,}35 = 6{,}75 \text{ N}$$

Wind load

$$F_{ax,W,k} = \underbrace{1{,}25}_{\text{continuity factor}} \cdot w_k \cdot h_S \cdot e = 1{,}25 \cdot 0{,}8 \tfrac{kN}{m^2} \cdot 0{,}063 \text{ m} \cdot 0{,}625 \text{ m} = 0{,}039 \text{ kN} = 39{,}4 \text{ N}$$

At the design level

$$F_{ax,W,d} = F_{ax,W,k} \cdot \gamma_Q = 39{,}4 \text{ N} \cdot 1{,}5 = 59{,}1 \text{ N}$$

04 // Verification of Permanent Load

Embedding strength of solid timber – nail head side (α_1=90°)

according to ETA

$$f_{h,1,k} = \frac{0{,}082 \cdot \rho_{k,1} \cdot d^{-0,3}}{(1{,}35+0{,}015 \cdot d) \cdot \sin^2\alpha_1 + \cos^2\alpha_1}$$

$$f_{h,1,k} = \frac{0{,}082 \cdot 350\ kg/m^3 \cdot 4{,}7^{-0,3}}{(1{,}35 + 0{,}015 \cdot 4{,}7) \cdot (\sin 90^\circ)^2 + (\cos 90^\circ)^2} = 12{,}70\ N/mm^2$$

according to DIN EN 1995-1-1, Tab. 3.1

$$k_{mod,1} = 0{,}6$$

$$f_{h,1,d} = \frac{f_{h,1,k} \cdot k_{mod,1}}{\gamma_{M,1}} = \frac{12{,}70 \cdot 0{,}6}{1{,}3} = 5{,}86\ N/mm^2$$

Embedding strength of solid timber – nail tip side (α_2 = 0°)

according to ETA

$$f_{h,2,k} = \frac{0{,}082 \cdot \rho_{k,2} \cdot d^{-0,3}}{(1{,}35 + 0{,}015 \cdot d) \cdot \sin^2\alpha_2 + \cos^2\alpha_2} =$$

$$f_{h,2,k} = \frac{0{,}082 \cdot 350\ kg/m^3 \cdot 4{,}7^{-0,3}}{(1{,}35 + 0{,}015 \cdot 4{,}7) \cdot (\sin 0^\circ)^2 + (\cos 0^\circ)^2} = 18{,}04\ N/mm^2$$

according to DIN EN 1995-1-1, Tab. 3.1

$$k_{mod,2} = 0{,}6$$

$$f_{h,2,d} = \frac{f_{h,2,k} \cdot k_{mod,2}}{\gamma_{M,2}} = \frac{18{,}04 \cdot 0{,}6}{1{,}3} = 8{,}33\ N/mm^2$$

$$\beta = \frac{f_{h,2,d}}{f_{h,1,d}} = \frac{8{,}33\ N/mm^2}{5{,}86\ N/mm^2} = 1{,}42$$

Design value of the yield moment

ETA-table B.1

$$M_{u,k} = 1800\ Nmm$$

$$M_{u,d} = M_{u,k} \cdot \frac{k_{mod,M}}{\gamma_M} = 1800\,Nmm \cdot \frac{0{,}35}{1{,}3} = 485\,Nmm$$

Required minimum embedment depth 1 – nail head side

according to ETA

$$t_{1,req} = \left(\sqrt{\frac{\beta}{1+\beta}} + 1\right) \cdot \sqrt{\frac{4 \cdot M_{u,d}}{0{,}75 \cdot f_{h,1,d} \cdot d}} = \left(\sqrt{\frac{1{,}42}{1+1{,}42}} + 1\right) \cdot \sqrt{\frac{4 \cdot 485\,Nmm}{0{,}75 \cdot 5{,}86\,\frac{N}{mm^2} \cdot 4{,}7}} = 17{,}11\,mm$$

$$t_{1,req} = 17{,}11\,mm \leq t_{1,vorh} = 30{,}0\,mm\ \checkmark$$

Required minimum embedment depth 2 – nail tip side

according to ETA

$$t_{2,req} = \left(\sqrt{\frac{1}{1+\beta}} + 1\right) \cdot \sqrt{\frac{4 \cdot M_{u,d}}{0{,}75 \cdot f_{h,2,d} \cdot d}} = \left(\sqrt{\frac{1}{1+1{,}42}} + 1\right) \cdot \sqrt{\frac{4 \cdot 485\,\text{Nmm}}{0{,}75 \cdot 8{,}33\,\frac{\text{N}}{\text{mm}^2} \cdot 4{,}7}} = 13{,}35\,\text{mm}$$

$$t_{1,req} = 13{,}35\,\text{mm} \leq t_{1,vorh} = 40{,}0\,\text{mm}\ ✓$$

Design of the load-bearing capacity in shear per nail

$$F_{v,Rd,Na} = \sqrt{\frac{2 \cdot \beta}{1+\beta}} \cdot \sqrt{1{,}5 \cdot M_{u,d} \cdot f_{h,1,d} \cdot d}$$

$$F_{v,Rd,Na} = \sqrt{\frac{2 \cdot 1{,}42}{1+1{,}42}} \cdot \sqrt{1{,}5 \cdot 485\ \text{Nmm} \cdot 5{,}86\ \text{N/mm}^2 \cdot 4{,}7\ \text{mm}}$$

$$F_{v,Rd,Na} = 153{,}32\ \text{N}$$

Nachweis:

$$\eta = \frac{F_{V,G,d}}{F_{v,Rd,Na}} = \frac{6{,}75\,\text{N}}{153{,}32\,\text{N}} = 0{,}04 < 1{,}0\ \text{(utilization ratio 4 \%)}$$

05 // Verification of permanent and temporary loads

Embedding strength of solid timber – nail head side (α_1 = 90°)

according to ETA

$$f_{h,1,k} = \frac{0{,}082 \cdot \rho_{k,1} \cdot d^{-0{,}3}}{(1{,}35 + 0{,}015 \cdot d) \cdot \sin^2\alpha_1 + \cos^2\alpha_1}$$

$$f_{h,1,k} = \frac{0{,}082 \cdot 350\,\text{kg/m}^3 \cdot 4{,}7^{-0{,}3}}{(1{,}35 + 0{,}015 \cdot 4{,}7) \cdot (\sin 90^\circ)^2 + (\cos 90^\circ)^2} = 12{,}70\,\text{N/mm}^2$$

$$k_{mod,1} = 1{,}0$$

$$f_{h,1,d} = \frac{f_{h,1,k} \cdot k_{mod,1}}{\gamma_{M,1}} = \frac{12{,}70 \cdot 1{,}0}{1{,}3} = 9{,}77\,\frac{\text{N}}{\text{mm}^2}$$

Embedding strength of solid timber – nail tip side (α_2=0°)

according to ETA

$$f_{h,2,k} = \frac{0{,}082 \cdot \rho_{k,2} \cdot d^{-0{,}3}}{(1{,}35+0{,}015 \cdot d) \cdot \sin^2\alpha_2 + \cos^2\alpha_2} =$$

$$f_{h,2,k} = \frac{0{,}082 \cdot 350\,\text{kg/m}^3 \cdot 4{,}7^{-0{,}3}}{(1{,}35+0{,}015 \cdot 4{,}7) \cdot (\sin 0^\circ)^2 + (\cos 0^\circ)^2} = 18{,}04\,\text{N/mm}^2$$

$k_{mod,2} = 1{,}0$ (Load duration class: medium, between short-term and very short-term)

according to DIN EN 1995-1-1, Tab. 3.1

$$f_{h,2,d} = \frac{f_{h,2,k} \cdot k_{mod,2}}{\gamma_{M,2}} = \frac{18{,}04 \cdot 1{,}0}{1{,}3} = 13{,}88\,\text{N/mm}^2$$

$$\beta = \frac{f_{h,2,d}}{f_{h,1,d}} = \frac{13{,}88\,\text{Nmm}^2}{9{,}77\,\text{Nmm}^2} = 1{,}42$$

Design value of the yield moment

ETA-table B.1

$$M_{u,k} = 1800\ \text{Nmm}$$

To remain on the safe side, the load duration class “short-term” is assumed for the wind action.

$$M_{u,d} = M_{u,k} \cdot \frac{k_{mod,M}}{\gamma_M} = 1800\,Nmm \cdot \frac{0{,}60}{1{,}3} = 831\,Nmm$$

Required minimum embedment deph 1 – nail head side

according to ETA

$$t_{1,req} = \left(\sqrt{\frac{\beta}{1+\beta}} + 1\right) \cdot \sqrt{\frac{4 \cdot M_{u,d}}{0{,}75 \cdot f_{h,1,d} \cdot d}} = \left(\sqrt{\frac{1{,}42}{1+1{,}42}} + 1\right) \cdot \sqrt{\frac{4 \cdot 831\,\text{Nmm}}{0{,}75 \cdot 9{,}77\,\frac{N}{mm^2} \cdot 4{,}7}} = 17{,}35\,\text{mm}$$

$$t_{1,req} = 17{,}35\,\text{mm} \leq t_{1,vorh} = 30{,}0\,\text{mm}\ ✓$$

Required minimum embedment deph 2 – nail tip side

according to ETA

$$t_{2,req} = \left(\sqrt{\frac{1}{1+\beta}} + 1\right) \cdot \sqrt{\frac{4 \cdot M_{u,d}}{0{,}75 \cdot f_{h,2,d} \cdot d}} = \left(\sqrt{\frac{1}{1+1{,}42}} + 1\right) \cdot \sqrt{\frac{4 \cdot 831\,\text{Nmm}}{0{,}75 \cdot 13{,}88\,\frac{N}{mm^2} \cdot 4{,}7}} = 13{,}54\,\text{mm}$$

$$t_{2,req} = 15{,}54\,\text{mm} \leq t_{2,vorh} = 40{,}0\,\text{mm}\ ✓$$

Design of the load-bearing capacity in shear per nail

$$F_{v,Rd,Na} = \sqrt{\frac{2 \cdot \beta}{1+\beta}} \cdot \sqrt{1{,}5 \cdot M_{u,d} \cdot f_{h,1,d} \cdot d}$$

$$F_{v,Rd,Na} = \sqrt{\frac{2 \cdot 1{,}42}{1+1{,}42}} \cdot \sqrt{1{,}5 \cdot 831\ \text{Nmm} \cdot 9{,}77\ \text{N/mm}^2 \cdot 4{,}7\ \text{mm}}$$

$$F_{v,Rd,Na} = 259\ \text{N}$$

Determination of the withdrawal capacity

Verification of the minimum penetration depth in component 2 – nail tip side:

$$t_{pen,min,2} = 8 \cdot d = 8 \cdot 4{,}7 = 37{,}6\ \text{mm}$$

$$t_{pen,min,2} = 37{,}6\ \text{mm} \leq t_{pen,vorh,2} = 40{,}0\ \text{mm}\ ✓$$

Withdrawal capacity on the nail head side – component 1:

$$F_{ax,l,Rd,1} = \min\left\{\begin{matrix} 1 \\ \frac{t_{pen,1}}{8 \cdot d} \end{matrix}\right\} \cdot \frac{f_{ax,k} \cdot k_{mod,ax}}{\gamma_{M,1}} \cdot d \cdot t_{pen,1} \cdot \left(\frac{\rho_{k,1}}{350}\right)^{0.8} =$$

$$F_{ax,l,Rd,1} = \min\left\{\begin{matrix} 1 \\ \frac{30}{8 \cdot 4{,}7} \end{matrix}\right\} \cdot \frac{7{,}0\frac{N}{mm^2} \cdot 0{,}5}{1{,}3} \cdot 4{,}7 \cdot 30\text{mm} \cdot \left(\frac{350}{350}\right)^{0{,}8} =$$

$$F_{ax,l,Rd,1} = 0{,}80 \cdot \frac{7{,}0\frac{N}{mm^2} \cdot 0{,}5}{1{,}3} \cdot 4{,}7 \cdot 30\ \text{mm} \cdot 1{,}0 = 303\text{N}$$

Head pull-through capacity – component 1:

$$F_{ax,\alpha,Rd,1} = \frac{f_{head} \cdot k_{mod,M}}{\gamma_{M,1}} \cdot d_h^2 \cdot \left(\frac{\rho_{k,1}}{350}\right)^{0,8}$$

$$F_{ax,\alpha,Rd,1} = \frac{12\ N/mm^2 \cdot 0,6}{1,3} \cdot (6,3mm)^2 \cdot \left(\frac{350}{350}\right)^{0,8} = 220N$$

Withdrawal capacity on the nail head side – component 1:

$$F_{ax,Rd,1} = \max\begin{Bmatrix} F_{ax,l,Rd,1} \\ F_{ax,\alpha,Rd,1} \end{Bmatrix} = \max\begin{Bmatrix} 303\ N \\ 220\ N \end{Bmatrix} = 303\ N$$

Withdrawal capacity on the nail tip side – component 2:

$$F_{ax,Rd,2} = \min\begin{Bmatrix} 1 \\ \frac{t_{pen,2}}{8 \cdot d} \end{Bmatrix} \cdot \frac{f_{ax,k} \cdot k_{mod,ax}}{\gamma_{M,2}} \cdot d \cdot t_{pen,2} \cdot \left(\frac{\rho_{k,2}}{350}\right)^{0,8}$$

$$F_{ax,Rd,2} = \min\begin{Bmatrix} 1 \\ \frac{40}{8 \cdot 4,7} \end{Bmatrix} \cdot \frac{7,0 \cdot \frac{N}{mm^2} \cdot 0,5}{1,3} \cdot 3,7 \cdot 40mm \cdot \left(\frac{350}{350}\right)^{0,8} =$$

$$F_{ax,Rd,2} = 1,0 \cdot \frac{7,0\ \frac{N}{mm^2} \cdot 0,5}{1,3} \cdot 4,7 \cdot 40\ mm \cdot 1,0 = 506\ N$$

Withdrawal resistance:

$$F_{ax,Rd} = \min\begin{Bmatrix} F_{ax,Rd,1} \\ F_{ax,Rd,2} \end{Bmatrix} = \min\begin{Bmatrix} 303\ N \\ 506\ N \end{Bmatrix} = 303\ N$$

Verification (combined verification)

$$\eta = \frac{F_{V,G,d}}{F_{v,Rd,Na}} + \frac{F_{ax,W,d}}{F_{ax,Rd}} = \frac{6,75\ N}{259\ N} + \frac{59,1\ N}{303\ N} = 0,22 < 1,0\ \left(\text{utilization ratio 22 \%}\right)$$

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Version 11/25 EN