Technical guideline for masonry walls with Perinsul HL thermal break units

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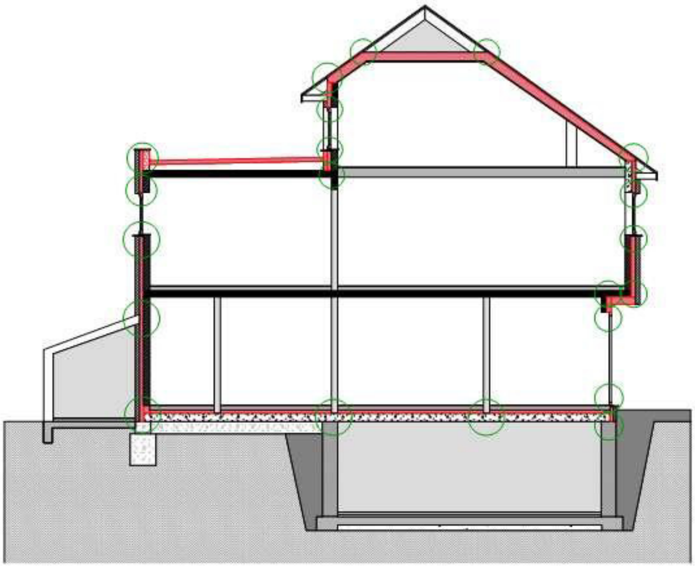
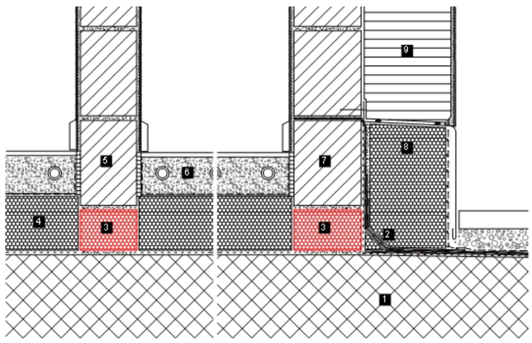
The following design guideline is based on Eurocode 6 (EN 1996-1-1) and refers to ETA 13-0163 "Perinsul HL". For application in a specific country, the appropriate National Annex to Eurocode 6 shall be considered as well.

The load-bearing capacity of masonry walls shall be determined according to the rules adopted in Eurocode 6. Unfortunately, no rules are given for inhomogeneous walls like walls with thermal break units at the bottom. In order to develop design rules for such load-bearing walls, a comprehensive test campaign on Perinsul HL units and masonry in combination with Perinsul HL units has been carried out at Eindhoven University of Technology. The results of these tests were used to get the European Technical Approval ETA13-0163.

In this document the procedure for the determination of the load-bearing capacity at the bottom of the wall is described. The load-bearing capacity at the top and at mid-height of the wall shall be determined according to the rules of Eurocode 6, section 6.1 'Unreinforced masonry walls subjected to mainly vertical loading'.





1. First step: calculation of loads

A first step comprises the calculation of the design values of the vertical load N_{Ed}, the eccentricity e_t and the shear force V_{Ed} acting at the bottom of the wall. This may be done according to the general rules given in Eurocode 6, section 5.5.1 Masonry walls subjected to vertical loading.

The vertical load N_{Ed} and bending moment M_{Ed} result from the calculation of all vertical loads which act on the wall and may be determined using theory of linear elasticity according to Eurocode 6, Section 5.1 Structural Analysis. Based on the values of the stress resultants, the eccentricity at the bottom of the wall shall be calculated as follows (see Figure 1):

$$e_t = \frac{M_{2d}}{N_{2d}} + e_{he} + e_{init} \geq 0.05\,t$$

where

e_t is the eccentricity at the bottom of the wall

M_{2d} is the design value of the bending moment at the bottom of the wall resulting from the eccentricity of the floor load at the support, analysed according to 5.5.1.

N_{2d} is the design value of the vertical load at the top or bottom of the wall

e_{he} is the eccentricity at the bottom of the wall resulting from horizontal loads (for example wind)

e_{init} is the initial eccentricity which may be assumed to be $h_{ef}/450$, where h_{ef} is the effective height of the wall calculated from 5.5.1.2 in Eurocode 6

t is the thickness of the wall

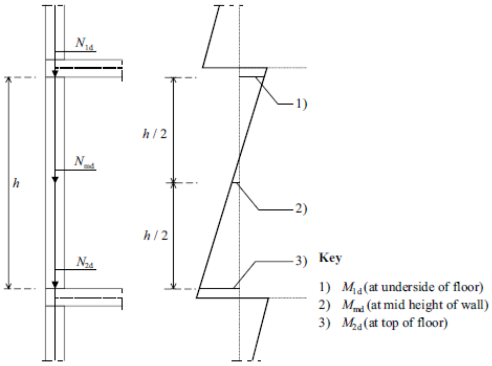


Figure 1 Bending moments in vertically loaded masonry wall

The design value of the shear force at the bottom of the wall due to eccentric vertical and horizontal actions shall be calculated using appropriate theory of structural analysis.

2. Second step: calculation of load-bearing capacity

2.1 Vertical loading

In the second step the load-bearing capacity at the bottom of the wall shall be determined. The general procedure described in Eurocode 6 shall be used:

$$N_{Rd} = \Phi . t . f_d$$

where

N_{Rd} is the design value of the vertical resistance of a single wall per unit length at the bottom of the masonry wall with thermal break unit

Φ is the capacity reduction factor at the bottom of the wall allowing for the effects of eccentricity of loading

t is the wall thickness

f_d is the design value of the compressive strength of the masonry with thermal break based on data from experiments (see ETA 13-0163 and report on compression tests according to EN 1052-1)

From eccentric loading tests on Perinsul HL (see Figure 2) specimens it was concluded that the influence of eccentric loading may be determined assuming linear elastic behaviour, which is more conservative than the rectangular stress block approach adopted in Eurocode 6. As a result the capacity reduction factor shall be calculated as follows:

$$e_t < \frac{t}{6} \qquad \phi = \frac{1}{1 + 6 \cdot \frac{e_t}{t}}$$

$$e_t > \frac{t}{6} \qquad \phi = \frac{3}{4} \cdot \left(1 - 2\frac{e_t}{t}\right)$$

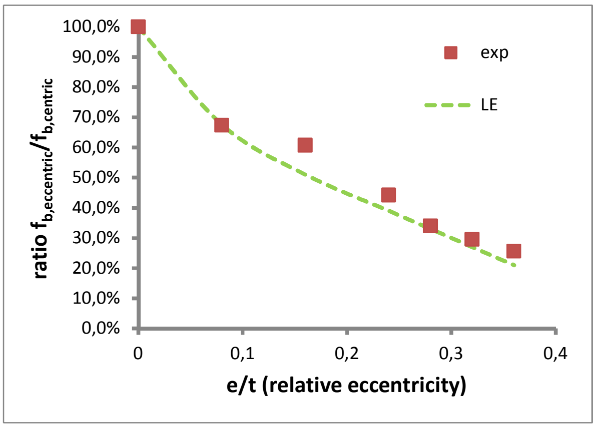


Figure 2 Capacity reduction factor for masonry with Perinsul HL thermal break unit

The determination of the design value of the compressive strength of the masonry with Perinsul HL thermal break unit at the bottom of the wall f_d shall be based on the declared characteristic values f_k given in the ETA 13-0163 document:

Values of f_k for PERINSUL®HL with compressive strength $f_{b,tb}$ = 2.9 N/mm² (MPa)

Masonry units	f_b N/mm² (MPa)	General Purpose Mortar	f_m N/mm² (MPa)	f_k N/mm² (MPa)
Calcium Silicate units; Group 1	12	M10	10	**1.8**
Clay units; Group 1	15	M10	10	**1.6**
Clay units; Group 2	17.5	M10	10	**1.5**

where

- $f_{b,tb}$ is the normalized mean compressive strength of masonry units, in the direction of the applied action effect according to EN 771-1, in N/mm^2
- f_b is the normalized mean compressive strength of the masonry units, in the direction of the applied action effect according to EN 772-1, in N/mm^2
- f_m is the compressive strength of the mortar according to EN 1015-11 in N/mm^2
- f_k is the characteristic compressive strength of the masonry with the thermal break included according to EN 1052-1 in N/mm^2.

The design value f_d shall be calculated as follows:

$$f_d = \frac{f_k}{\gamma_M \cdot \gamma_{M;b}}$$

where

f_k is the characteristic value of the compressive strength of the masonry with thermal break unit (declared value according to ETA 13-0163)

γ_M is the partial safety factor determined according to Eurocode 0 (EN 1990)

$\gamma_{M;b}$ is the partial safety factor taking into account the brittle behaviour of the thermal break unit

The numerical values γ_M and $\gamma_{M;b}$ for use in a country may be found in its National Annex to Eurocode 6. The value for γ_M takes into account the possibility of an unfavourable deviation of a material from its characteristic value and the effect of the conversion factor which accounts for the volume and scale effects, the effects of moisture and temperature, the uncertainty of the resistance model, the not modelled geometric deviations and any other relevant parameters. Since no explicit reduction factor is adopted for strength reduction due to long term behaviour, this effect shall be incorporated in the value of the γ_M-factor.

The $\gamma_{M;b}$-factor accounts for the brittle behaviour of the thermal break unit and may be found in the National Annex of each country. The value of 1.2 for the $\gamma_{M;b}$-factor, which is frequently used for unreinforced concrete structures, may be recommended.

Information about long term behaviour

From creep tests on Perinsul HL with liner under constant compressive loading of 0,8 MPa during 1 year, an extrapolated creep strain after 50 years of 2.093% was calculated. For a thermal break unit with a height of 65 mm, this creep strain corresponds to a total deformation of 1.36 mm after 50 years. This value should be considered as a safe upper bound value since, in practice, the constant compressive loading will always be lower than 0.8 MPa. Assuming an f_k-value of 1.8 MPa (largest value in ETA 13-0163), a Φ-factor of 0.9, a load factor γ_F of 1.35, a partial material factor γ_M of 1.7 (which is the lowest value in Europe) and a partial factor for brittle materials $\gamma_{M;b}$ of 1.2, the maximum value of the compressive loading in serviceability situation σ_s may be calculated as follows:

$$\gamma_F \,.\, t \,.\, \sigma_s < \Phi \,.\, t \,.\, f_d$$

$$\sigma_s = \frac{\Phi \,. f_k}{\gamma_F \cdot \gamma_M \cdot \gamma_{M;b}} = \frac{1.8}{1.35 * 1.7 * 1.2} = \frac{1.8}{2.75} = 0.65\ MPa < 0.8\ \text{MPa}$$

As a result, the deformation of the thermal break after 50 years will be less than 1.1 mm, which is of the same order as the long term deformation of a 3 m high masonry wall loaded in compression of 0.65 MPa. It may be concluded that the deformation of the thermal break unit will not affect the overall behaviour of the masonry structure.

2.2 Horizontal loading

The next step consists of checking the shear resistance of the wall. This verification shall be carried out according to Eurocode 6, 3.6.2 Characteristic shear strength of masonry and 6.2 'Unreinforced masonry walls subjected to shear loading' with the following equations:

$$V_{Ed} < V_{Rd}$$

$$V_{Rd} = f_{vd} \,.\, t \,.\, l_c$$

$$f_{vd} = \frac{f_{vk}}{\gamma_M}$$

$f_{vk} = f_{vk0} + \mu\, \sigma_d$, but not greater than 0.065 f_b or f_{vlt}

where

V_{Ed}	the design value of the shear load applied to the masonry walls at the bottom
V_{Rd}	the design value of the shear resistance of the masonry wall with thermal break unit
f_{vd}	the design value of the shear strength of the masonry with thermal break unit, based on the average of the vertical stresses over the compressed part of the wall that is providing the shear resistance
f_{vk}	the characteristic shear strength of the masonry with thermal break unit & general purpose mortar
f_{vk0}	the characteristic initial shear strength under zero compressive stress
f_{vlt}	a limit to the value of f_{vk}
f_b	the normalised compressive strength of the masonry units, as described in clause 3.1.2.1 of Eurocode 6 for the direction of the load on the test specimens being perpendicular to the bed face
γ_M	the partial safety factor determined according to Eurocode 0 (EN 1990)
σ_d	the design compressive stress perpendicular to the shear in the member at the level under consideration, using appropriate load combination based on the average vertical stress over the compressed part of the wall in providing shear resistance
t	the thickness of the wall resisting the shear
l_c	the length of the compressed part of the wall ignoring any part of the wall that is in tension
μ	the coefficient of friction

The value of f_{vk} shall be determined according to the declared values for f_{vk0} and μ given in the ETA 13-0163 document:

Values of f_{vk0} and μ for PERINSUL®HL with compressive strength $f_{b,tb}$ = 2.9 N/mm² (MPa)

Masonry units	f_b N/mm² (MPa)	General Purpose Mortar	f_m N/mm² (MPa)	f_{vk0} N/mm² (MPa)	μ -
Calcium Silicate units; Group 1	12	M10	10	**0.16**	**0.12**
Clay units; Group 1	15	M10	10	**0.13**	**0.35**
Clay units; Group 2	17.5	M10	10	**0.18**	**0.25**

where

- f_b is the normalized mean compressive strength of masonry units, in the direction of the applied action effect according to EN 771-1, in N/mm²
- f_m is the compressive strength of the mortar according to EN 1015-11 in N/mm²
- f_{vk0} is the characteristic initial shear strength of the masonry with the thermal break included according to EN 1052-3 in N/mm².
- μ is the characteristic value of the coefficient of friction according to EN 1052-3.
- $f_{b,tb}$ is the normalized mean compressive strength of the thermal break units, in the direction of the applied action effect according to EN 771-1, in N/mm²

In its National Annex to Eurocode 6 each country may determine the value of f_{vlt}, while the value of f_b shall be based on test results of declared values by the manufacturer.

For the calculation of the design value of the shear strength, only a γ_M -value should be taken into account since shear failure in the shear tests was not brittle. The γ_M -value may be determined by each country in its National Annex to Eurocode 6.

The length of the compressed part of the wall l_c should be calculated assuming a linear stress distribution of the compressive stresses. Any portion of the wall subjected to vertical tensile stresses should not be used in calculating the area of the wall to resist shear: see Figure 3.

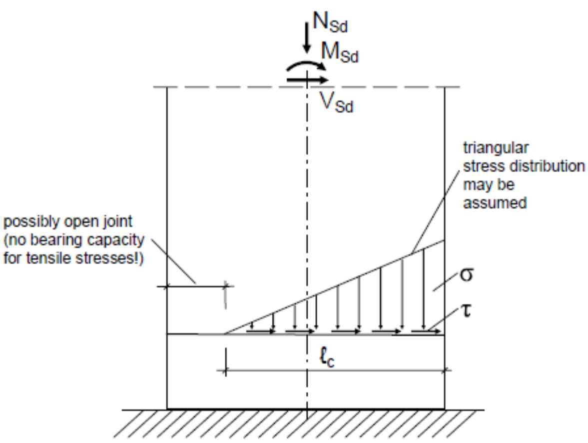


Figure 3.Determination of the compressed part of the wall

3. Worked example: clay brick masonry wall with Perinsul HL at the bottom

Consider a masonry wall made of group 1 clay units (t = 140 mm – solid clay bricks without any holes) with Perinsul HL thermal break (h= 65 mm) unit at the bottom. The height of the wall is 3000 mm.

3.1 Design loads

The following stress resultants act at the bottom of the wall, assuming a design value of the wind loading of 2.0 kN/m^2:

N_{E2d} = 70 kN/m
e_t = 0.05 t = 7 mm
V_{E2d} = 2 kN/m^2 * 3 m /2 = 3.0 kN/m

In the National Annex of the country where the walls are built the following values are adopted:

γ_M = 2.0
$\gamma_{M;b}$ = 1.2
f_{vlt} = 0.5 MPa

3.2 Vertical compression

The verification of the resistance of the wall under vertical compression may be carried out as follows:

e_t/t = 0.05 < t/6:

$$\phi = \frac{1}{1+6\cdot\frac{e_t}{t}} = \frac{1}{1+0.3} = 0.77$$

$$f_d = \frac{f_k}{\gamma_M \cdot \gamma_{M;b}} = \frac{1.6}{2.0*1.2} = 0.67\ MPa$$

$$N_{Rd} = \Phi.t.f_d = 0.77*140mm*0.67MPa$$ = **72.2 kN/m** > N_{E2d} = **70 kN/m**

Hence, in the ultimate limit state, the masonry wall with thermal break can resist the vertical load at the bottom of the wall. Verification at the top and mid-height of the wall has to be performed according to Eurocode 6 rules.

3.3 Shear loading

The verification of the resistance of the masonry wall loaded by the lateral shear load, may be carried out as follows:

e_t = 0.05 t = 7 mm < t/6 (fully compressed cross-section)
lc = 140 mm

For the calculation of the shear resistance the minimum design value of the compressive loading should be taken into account. Assuming f_d = 30 kN/m yields:

$$f_{vk} = f_{vk0} + \mu\,\sigma_d = 0.13 + 0.35 * \frac{30\ N/mm}{140mm} = 0.205MPa$$

$$f_{vd} = \frac{f_{vk}}{\gamma_M} = \frac{0.205}{2.0} = 0.10MPa$$ < f_{vlt} = 0.5 MPa

V_{Rd} = f_{vd} . t . l_c = 0.10 MPa . 1000 mm . 140 mm = 14 000 N = **14.0 kN/m** > V_{E2d} = **3.0 kN/m**

Hence, in the ultimate limit state, the masonry wall with thermal break can resist the lateral shear load at the bottom of the wall due to the wind loading.

3.4 Conclusion

The load-bearing capacity of the wall with Perinsul HL at the bottom is assured:

Vertical resistance N_{Rd} 72.2 kN/m > vertical load N_{Ed} 70 kN/m

Shear resistance V_{Rd} 14,0 kN/m > shear load V_{Ed} 3.0 kN/m

4. References

[1] EN 1996-1-1 (Eurocode 6)
[2] ETA 13-0163 'Perinsul HL