Fire resistance assessment of masonry structures

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Contents

- General information on EN 1996-1-2
- Assessment methods in EN 1996-1-2
- Tabulated data for masonry walls
- Application of EN 1996-1-2 design on a multi-storey building (worked example)

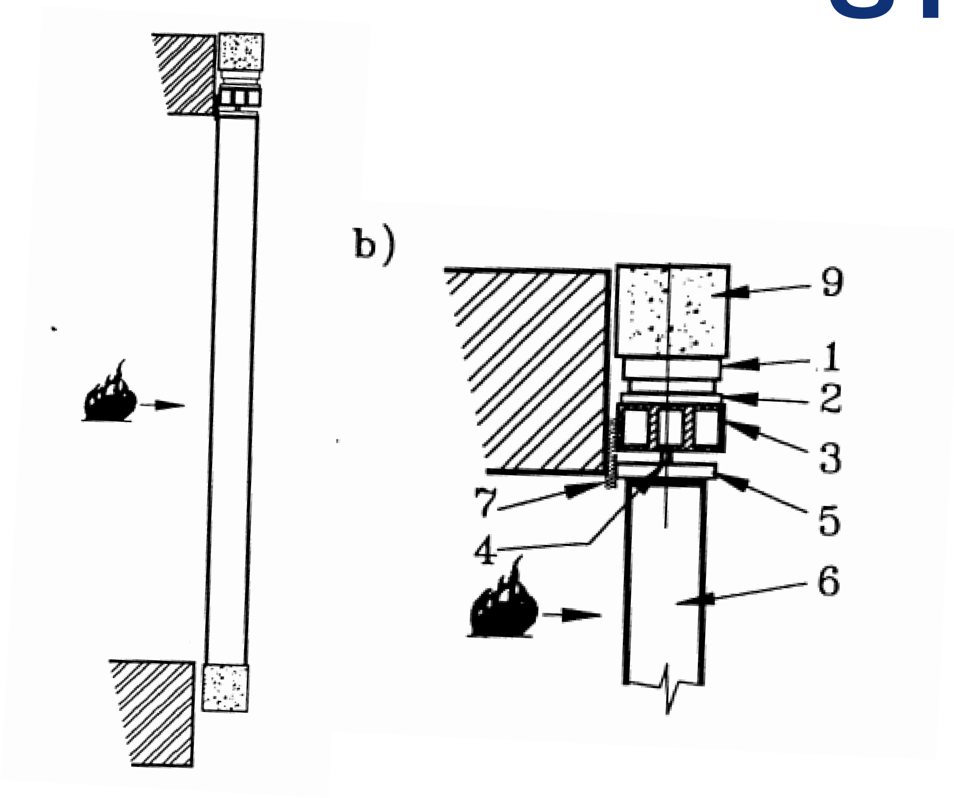
General information on EN 1996-1-2

- ⇨EN 1996-1-2 was the last part of the Eurocodes to be finished in 2006
- ⇨Rather limited number (10) of national determined parameters (NDP)
- ⇨All relevant material properties and tabulated data are NDP

Methods for Classification of Fire Resistance in EN 1996-1-2

- Tests according to EN 1364 and EN 1365 series and classification according to EN 13501-2
- Tabulated data from Annex B
- Calculation methods

TESTS ACCORDING TO EN STANDARDS

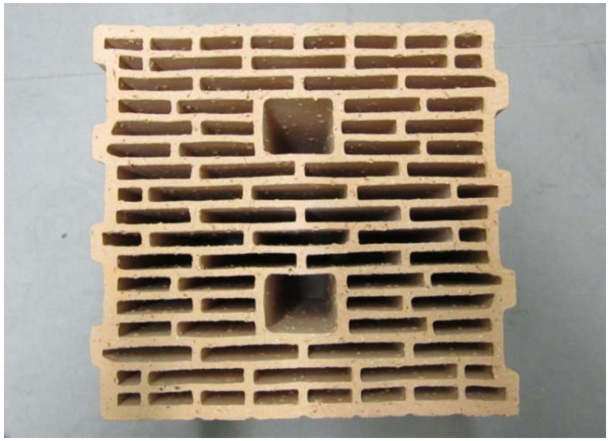


TESTS ACCORDING TO EN STANDARDS

- To allow for extended application, additional measurements required in EN 15254-2 (non-loadbearing) and EN 15080-12 (loadbearing) should be carried out

ADDITIONAL MEASUREMENTS FOR EXAP

- Deflection of the specimen, at least in mid-height
- Gross density, compressive strength, moisture content, percentage of voids, web and shell thickness, com-bined thickness of units



ADDITIONAL MEASUREMENTS FOR EXAP

- Gross density and compressive strength of masonry mortar
- Thickness of unfilled perpend joints in unplastered walls
- Thickness and type of plaster in plastered walls (not required but useful: gross density of plaster)

BASIS FOR TABULATED DATA

A significant number of tests on load-bearing masonry walls were available as basis for the recommendation, mainly from Belgium, Germany and the UK

Definition of wall thicknesses providing a specified fire resistance is problematic due to differences in national and European test methods and procedures

Tests were often not carried out until failure, but up to a specific time of resistance (requirement aimed to be met)

TABULATED DATA (ANNEX B)

These different types of walls may react significantly different to fire

- ⇨ **Non-loadbearing separating walls** (EI) show the highest resistance
- ⇨ **Loadbearing separating walls (REI)** (fire from one side) may develop significant differences depending on the load level

TABULATED DATA (ANNEX B)

These different types of walls may react significantly different to fire

⇨**Loadbearing non-separating walls (R)** (fire from all sides) may perform better (lower deflection) or worse (deterioration from all sides) than separating walls

TABULATED DATA (ANNEX B)

Different tables to be defined for

⇨ Non-loadbearing separating walls (Criterion EI)
⇨ Loadbearing separating walls (Criterion REI)
⇨ Loadbearing non-separating walls (Criterion R)
⇨ Short loadbearing non-separating walls (Criterion R)
⇨ fire walls (loadbearing or not, single or double leaf, Criterion REI-M, EI-M)
⇨ Loadbearing cavity walls with one leaf loaded (REI)

TABULATED DATA (ANNEX B)

Table B.1 Minimum thickness of non-loadbearing separating walls (Criteria EI) for fire resistance classifications

Material of wall	Minimum wall thickness (mm) t_F for fire resistance classification EI for time (minutes) $t_{fi,d}$									
	15	20	30	45	60	90	120	180	240	360
Type of units, mortar, grouping of units, including combined thickness if required, and density	Wall thickness t_F									

TABULATED DATA (ANNEX B)

- A final agreement on tabulated data was not possible at European level mainly due to different views about the test methods and limited documentation about boundary conditions in the tests
- Ranges of possible values were defined at last
- Recommendations for wall thicknesses meeting a specified criterion are given only in a note

TABULATED DATA (ANNEX B)

N.B.1 Clay masonry

Clay units conforming to EN 771-1

Table N.B.1.1 Clay Masonry Minimum thickness of separating non-loadbearing ~~separating~~ walls (Criterion EI) for fire resistance classifications

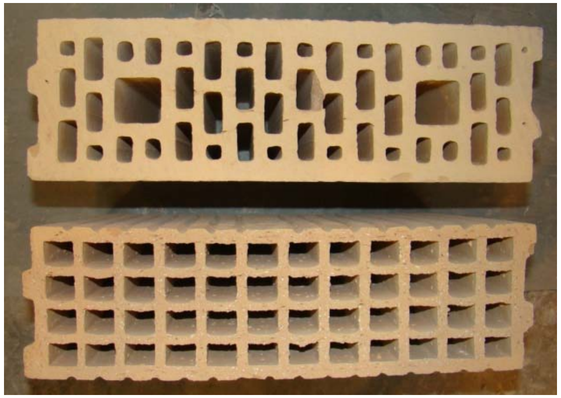
row number	material properties: gross dry density ρ [kg/m³]	Minimum wall thickness (mm) t_F for fire resistance classification EI for time (minutes) $t_{fi,d}$						
		30	45	60	90	120	180	240
1.	**Group 1S, 1, 2, 3 and 4**							
1.1	mortar : general purpose, thin layer, lightweight $500 \leq \rho \leq 2\ 400$							
1.1.1 1.1.2		60/100 (50/70)	90/100 (50/70)	90/100 (60/70)	100/140 (70/100)	100/170 (90/140)	160/190 (110/140)	190/210 (170)

TABULATED DATA (ANNEX B)

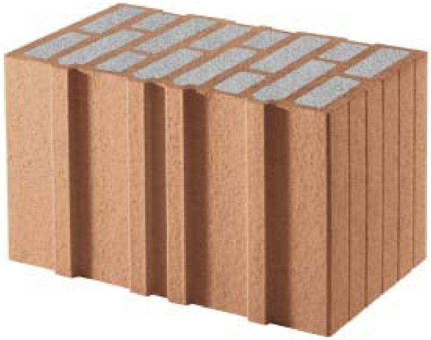
- Types of units, see EN 1996-1-1, table 3.1 (examples in clay)

Group 1

Group 2



Group 3



TABULATED DATA (ANNEX B)

- ⇨Differentiation for types of units, utilisation factor and applied surface finishes
- ⇨Every member state is free to choose periods of fire resistance, materials and load levels according to its needs in the national annex
- ⇨Definitions may be based on existing data, experience or testing

TABULATED DATA (ANNEX B)

Vertical load level

- Misunderstanding in the definition in EN 1996-1-2, §4.5 (3)
- The factor γ_{Global} has to be applied to N_{Rk} (and not N_{Ek})
- Example
- h = 2,75 m, t = 175 mm, f_b = 16 N/mm², f_m = 5 N/mm²
- Test load: 247 kN/m (α = 1,0) (from global safety concept)

TABULATED DATA (ANNEX B)

Vertical load level

⇨ Test load: 247 kN/m

⇨ Characteristic load N_{Rk}:

⇨ $N_{Rk} = \phi_s \times f_k \times A = 0{,}7 \times 5{,}1 \times 175 = 622$ kN/m

⇨ γ_{Global} (applied on N_{Rk}) = 622/247 = 2,5

TABULATED DATA (ANNEX B)

Vertical load level

⇨ Consequence

⇨ γ_{Global} (applied on N_{Ek}) should be taken as approx. 1

⇨ German NA chooses a different approach taking into account the different buckling equations and the defined f_k values, leading to the same practical result

TABULATED DATA (ANNEX B)

⇨Surface finishes

⇨Finishes enhancing the fire resistance of walls are

- gypsum premixed plaster in accordance with EN 13279-1
- plaster type LW or T in accordance with EN 998-1

⇨Sand-cement mortars do not normally increase the fire resistance to the same extent than the mortars mentioned above

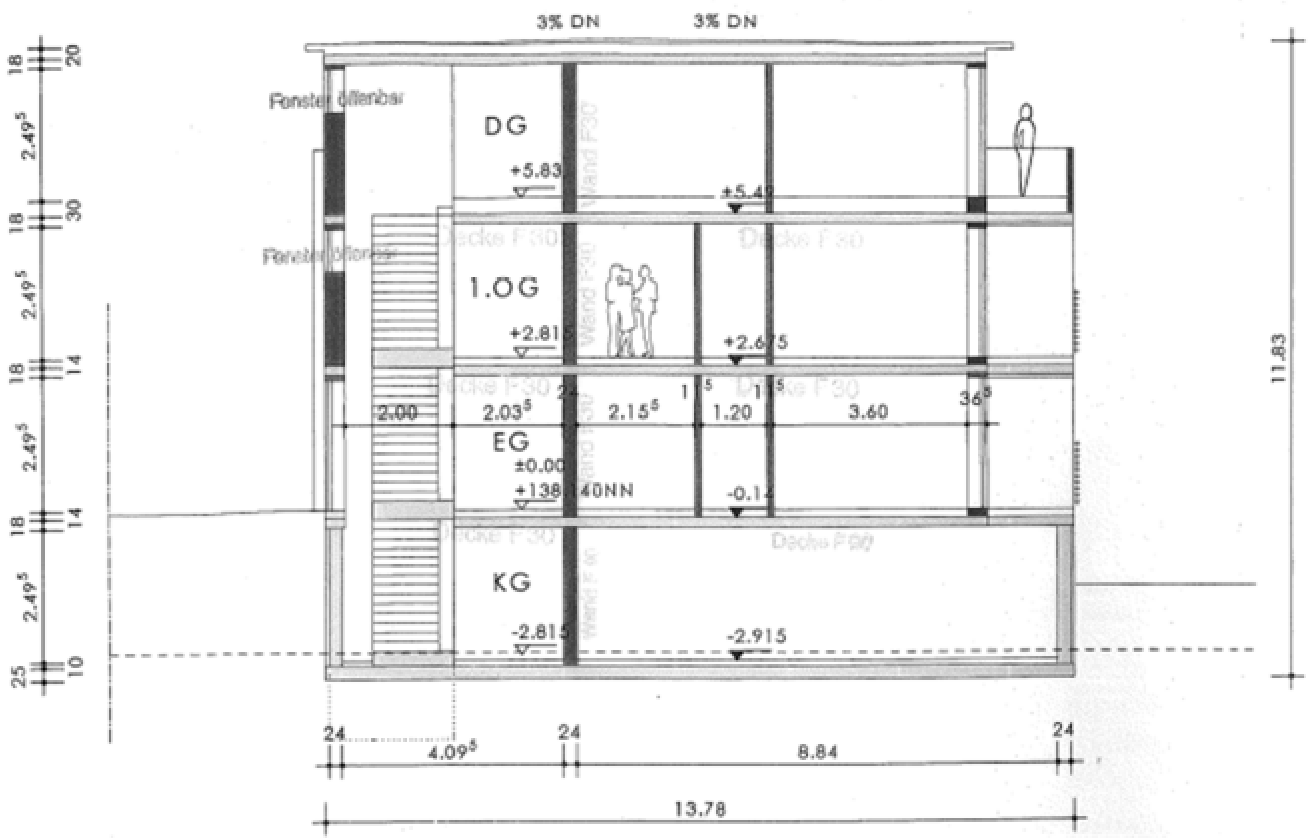
Calculation methods

- ⇨ Two different methods proposed
- ⇨ Material parameters for a very limited range of materials and based on very limited data
- ⇨ **Practically not applicable**
- ⇨ Excluded in most national annexes

Worked example

- 3-storey building with basement in south-west Germany
- Clay unit masonry with additional thermal insulation
- Fire design based on tabulated data (supported by test evidence)

Worked example



Worked example

Worked example

Worked example

- Typical wall thicknesses
- External: 240 mm + insulation
- Internal:

  separating loadbearing 240 mm

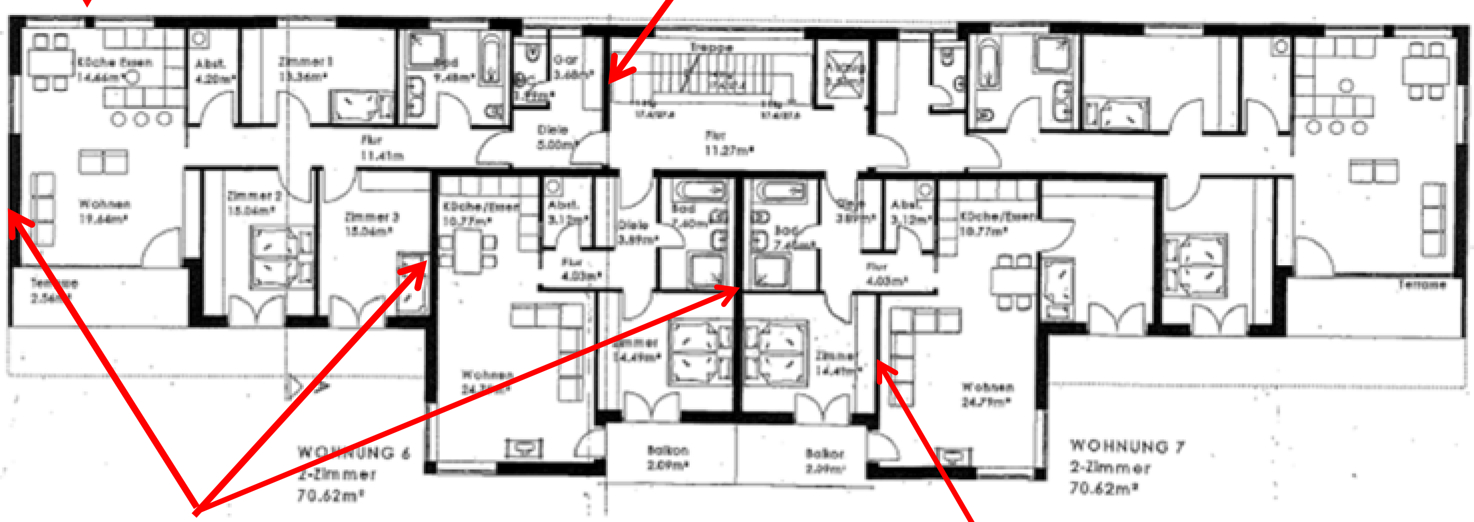
  non-separating loadbearing 175 mm

  non-loadbearing 115 mm

Worked example

Non-separating loadbearing

Separating loadbearing



Separating loadbearing

Non-separating loadbearing

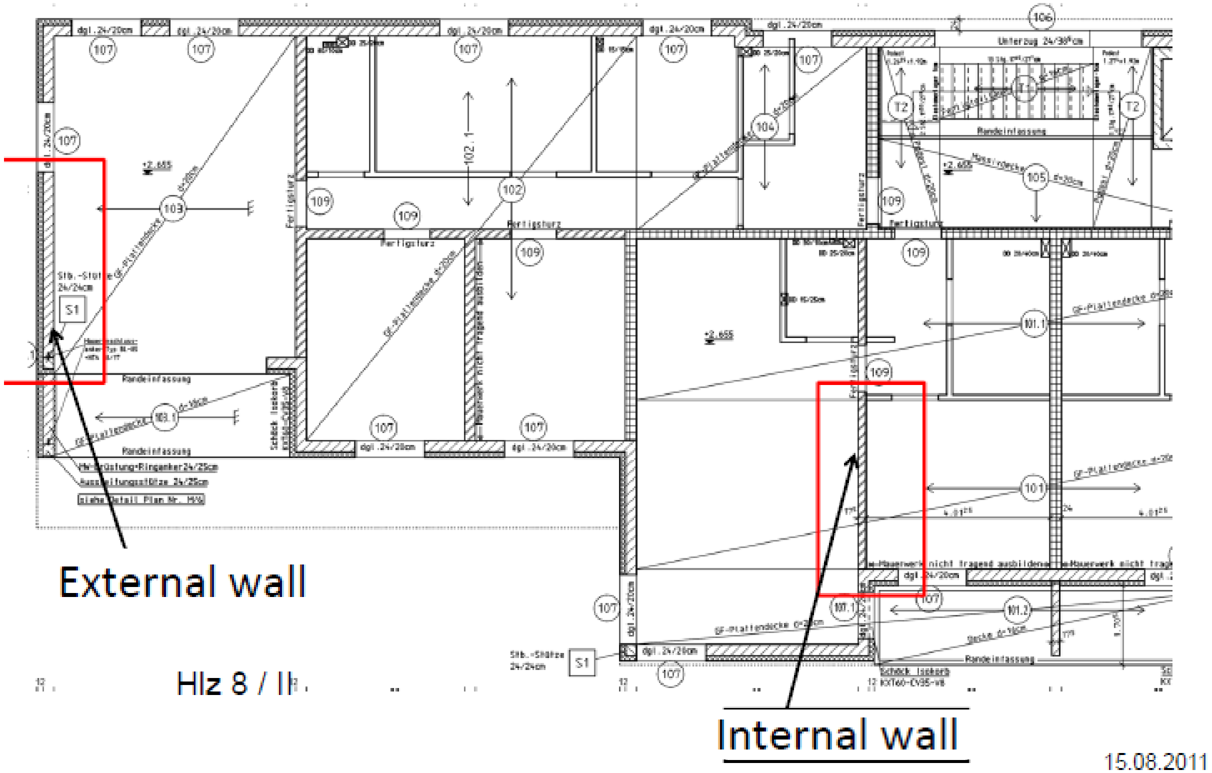
Worked example

- ⇨Typical design process
- ⇨Identification of the critical external and internal walls in cold design
- ⇨Determination of the corresponding α-values
- ⇨Identification of walls with fire resistance requirements

Worked example

- ⇨Fire resistance requirements depend on national regulations
- ⇨In multi-storey buildings often for:
- ⇨External walls
- ⇨Separating walls between flats and walls separating staircases
- ⇨For slabs see presentations on concrete and timber structures

Worked example



Worked example

- Design loads
- External wall (t = 240 mm)

  N_{Ed} = 103 kN/m

  $N_{Ed,fi}$ = 0,7 * 103 kN/m = 72 kN/m

Worked example

- Resistance
- External wall

Group 2 unit, f_b = 10 N/mm², Thin layer mortar

f_k = 3,5 N/mm² (EN 1996-3, Annexe D)

Worked example

- Resistance
- External wall

N_{Rd} = 349 kN/m

Utilisation factor

$\alpha = N_{Ed}/N_{Rd} = 103/349 = 0,3 < 0,6$

Worked example

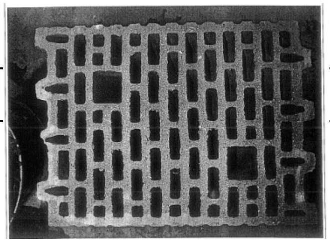
- German requirement for loadbearing external walls is "fire-resistant" which means REI 90
- Tabulated data in a note in EN 1996-1-2, annex B

Worked example

- Wall length ≥ 1,0 m
- Separating, loadbearing wall
- REI, table N.B.1.2, line 2.1.3 (combustible thermal insulation)
- The indicated range for REI90 ($\alpha \leq 0{,}6$) is 100 to 140 mm < 240 mm
- Verification o.k.

Worked example

⇨ Excerpt of table N.B.1.2



2	**Group 2 units**							
2.1	Mortar:general purpose, thin layer $5 \leq f_b \leq 35$ $800 < \rho \leq 2\,200$ $ct \geq 25\%$							
2.1.1 2.1.2	$\alpha \leq 1{,}0$	90/100 (90/100)	90/100 (90/100)	90/100 (90/100)	100/170 (100/140)	140/240 (140)	190/240 (190/240)	190/240 (190/240)
2.1.3 2.1.4	$\alpha \leq 0{,}6$	90/100 (90)	90/100 (90)	90/100 (90/100)	100/140 (100/140)	190/240 (100/140)	190/240 (140/190)	190/240 (190)

Worked example

- REI90 classification in some national annexes
- Group 2 clay units with thin layer mortar in loadbearing separating walls

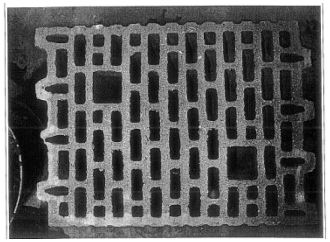
Minimum REI90 values in NA's

- ⇨UK (perforation ≤ 40%) t = 215 mm
- ⇨D (density > 800 kg/m³) t = 175 mm
- ⇨LUX and NL t = 130 mm
- ⇨A t = 170 mm
- ⇨I (circolare ministeriale) t = 200 mm

✓ **240 mm is o.k. throughout the EC**

table NB1.2, line 2.1.3 t = 100/140 mm

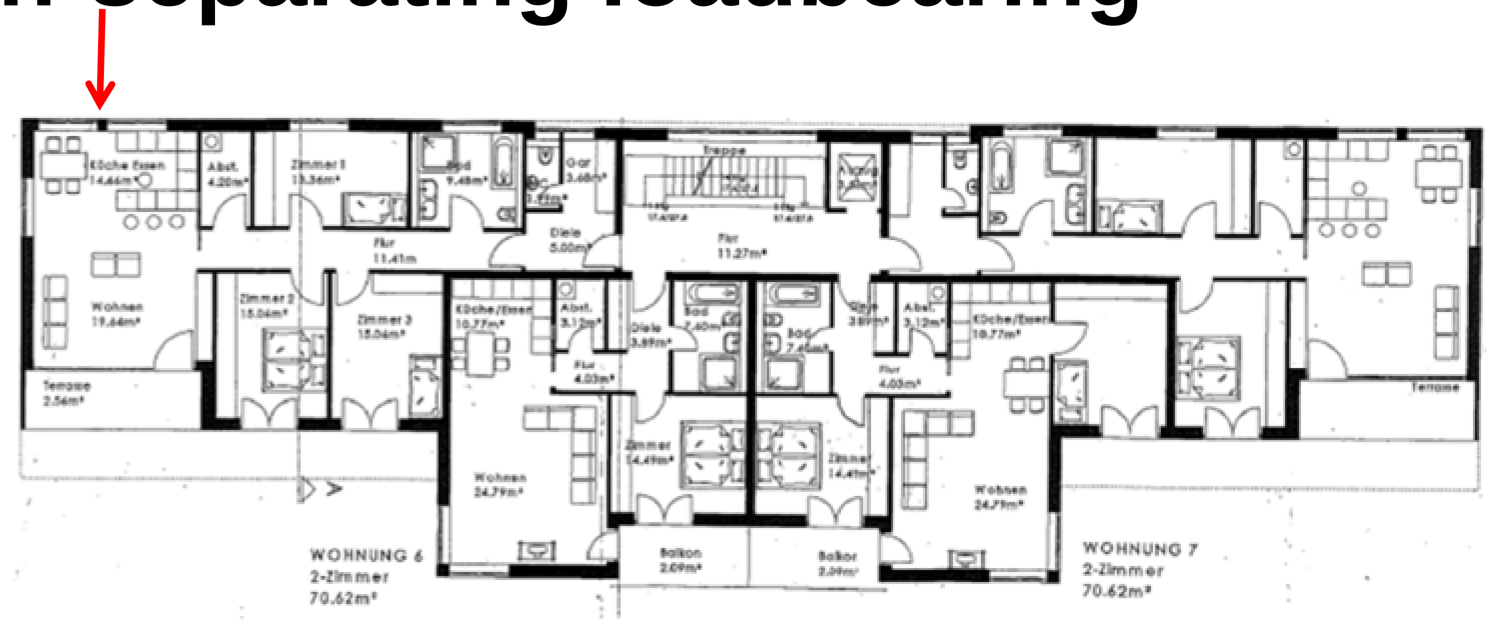
Comparison with test according to EN 1365-1



- 235 mm clay unit wall with thin-layer mortar without finish
- Mean compressive strength 12,2 N/mm²
- Mean gross density 900 kg/m³
- Applied load 77 kN/m (eccentricity t/6)
- **Classification REI-M 90**

Worked example

Non-separating loadbearing



Worked example

- External non-separating column
- t = 240 mm, l = 490 mm

Worked example

- Wall length 0,49 m < 1,0 m
- R, table N.B.1.4, line 2.1.13 (combustible thermal insulation)
- The minimum wall length for R90 is 300 mm (wall thickness 240 mm)
- Verification o.k.

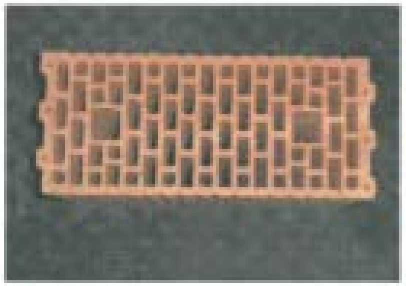
Worked example

⇨ Excerpt of table N.B.1.4

row number	material properties unit strength f_b [N/mm²] gross density ρ [kg/m³] combined thickness ct % of wall thickness	wall thickness [mm]	Minimum wall length (mm) l_F for fire resistance classification R for time (minutes) $t_{fi,d}$						
			30	45	60	90	120	180	240
2	**Group 2 units**								
2.1	mortar : general purpose, thin layer $5{,}0 \leq f_b \leq 35$ $800 < \rho \leq 2\,200$ $ct \geq 25\%$								
2.1.12	$\alpha \leq 0{,}6$		(240)	(240)	(240)	(240)	(300)	nvg	nvg
2.1.13		240	200	240	240	300	365	490	nvg
2.1.14			(170)	(170)	(170)	(170)	(240)	(300)	nvg

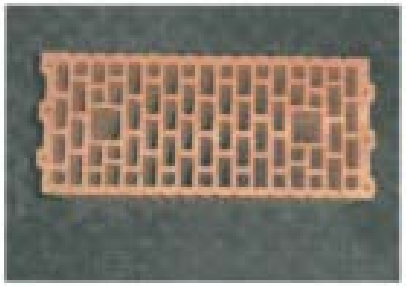
Comparison with test according to EN 1365-4

- 175 x 373 mm clay unit column with thin-layer mortar + applied finish
- Mean compressive strength 11,6 N/mm²
- Mean gross density 900 kg/m³
- Applied load 55 kN
- **Classification R 120**



Comparison with test according to EN 1365-4

- ⇨175 x 497 mm clay unit column with thin-layer mortar
- ⇨Mean compressive strength 10,9 N/mm²
- ⇨Mean gross density 1020 kg/m³
- ⇨Applied load 85 kN
- ⇨**Classification R 120**



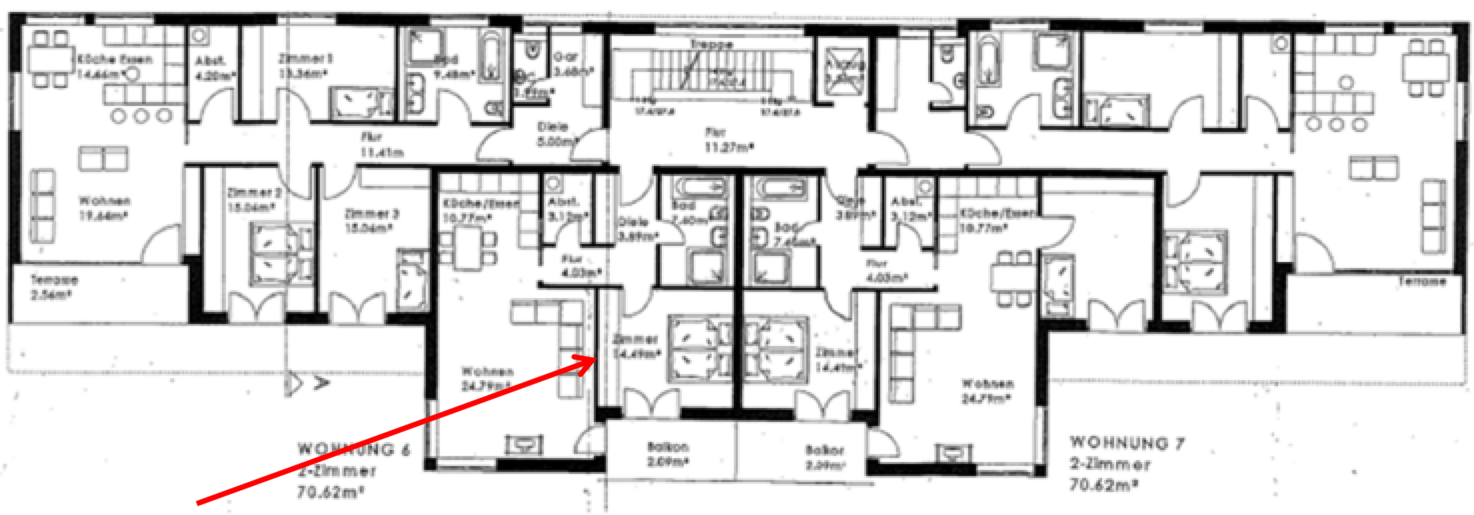
Worked example

- ⇨Design loads
- ⇨Internal non-separating wall within a flat (group 2) t = 175 mm

N_{Ed} = 123 kN/m

$N_{Ed,fi}$ = 0,7 * 123 kN/m = 86 kN/m

Worked example



Non-separating loadbearing

Worked example

- Resistance
- Internal wall

Group 2 unit, f_b = 10 N/mm², Thin layer mortar

f_k = 3,5 N/mm² (EN 1996-3, Annexe D)

Worked example

- Resistance
- Internal wall

N_{Rd} = 193 kN/m

Utilisation factor

$\alpha = N_{Ed}/N_{Rd} = 123/193 = 0{,}64 \cong 0{,}6$

Worked example

- Wall length ≥ 1,0 m
- REI, table N.B.1.3, line 2.1.4 (suitable plaster)
- The indicated value for R90 ($\alpha \cong 0{,}6$) is 100 mm < 175 mm
- "European" verification o.k.

Worked example

⇨ Excerpt of table N.B.1.3

row number	material properties: unit strength f_b [N/mm²] gross density ρ [kg/m³] combined thickness ct % of wall thickness	Minimum wall thickness or length (mm) t_F for fire resistance classification R for time (minutes) $t_{fi,d}$						
		30	45	60	90	120	180	240
2	**Group 2 units**							
2.1	mortar: general purpose, thin layer $5 \leq f_b \leq 35$ $800 \leq \rho \leq 2\,200$ $ct \geq 25\%$							
2.1.1 2.1.2	$\alpha \leq 1{,}0$	100 (100)	100 (100)	100 (100)	240 (100)	365 (170)	490 (240)	nvg
2.1.3 2.1.4	$\alpha \leq 0{,}6$	100 (100)	100 (100)	100 (100)	170 (100)	240 (100)	300 (200)	nvg

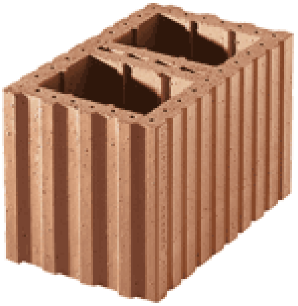
Minimum REI90 values in NA's for plastered walls

- ⇨ UK (perforation ≤ 40%) t = 215 mm
- ⇨ D (density > 800 kg/m³) t = 115 mm
- ⇨ LUX t = 130 mm
- ⇨ A t = 170 mm
- ⇨ NL t = 120 mm

✓ **175 mm is o.k. in central Europe**

Table NB.1.3, line 2.1.4 t = 100 mm

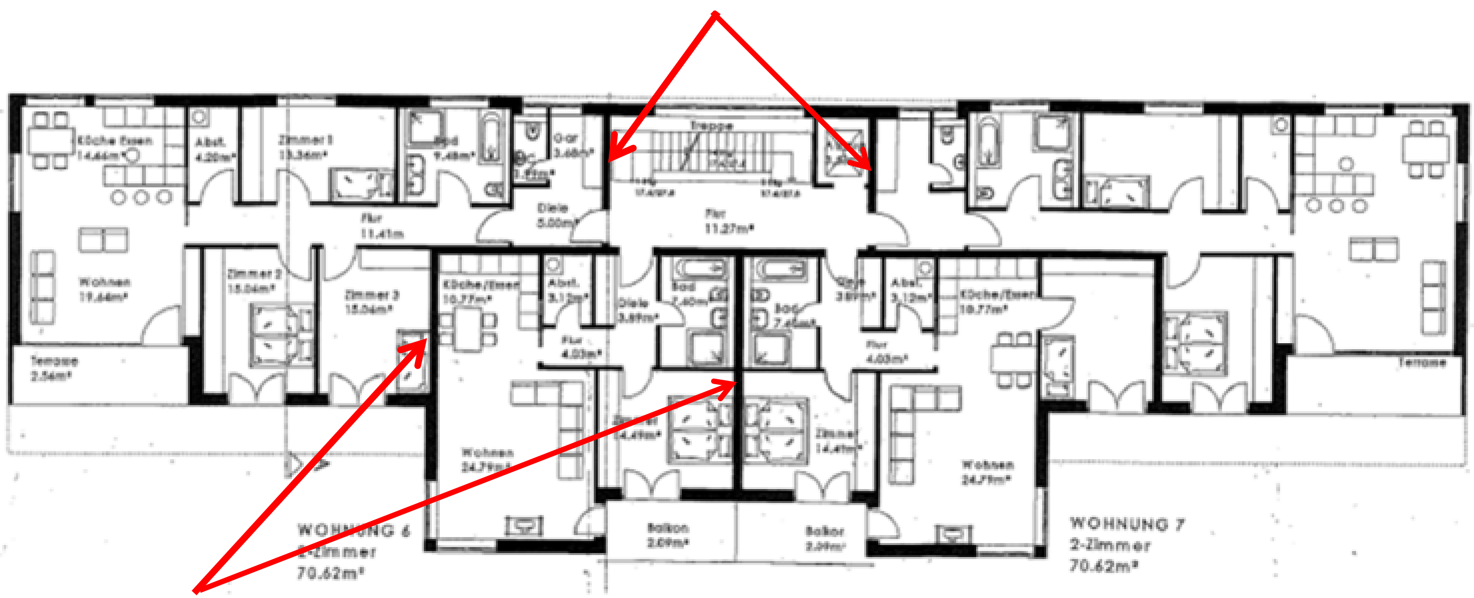
Worked example



- Internal separating wall between flats (group 3 unit for concrete infill)
  t = 240 mm for acoustic reasons
  N_{Ed} = 123 kN/m
  $N_{Ed,fi}$ = 0,7 * 123 kN/m = 86 kN/m

Worked example

Separating loadbearing



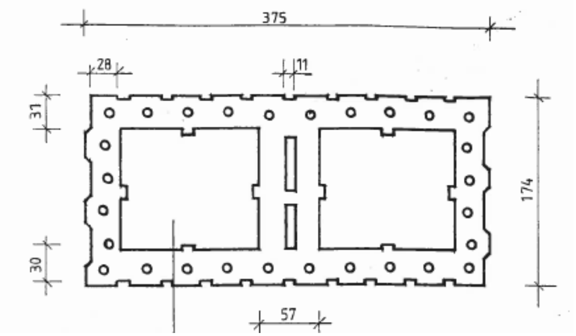
Separating loadbearing

Worked example

⇨ Excerpt of table N.B.1.2

row number	material properties: unit strength f_b [N/mm²] gross density ρ [kg/m³] combined thickness ct % of wall thickness	Minimum wall thickness (mm) t_F for fire resistance classification REI for time (minutes) $t_{fi,d}$						
		30	45	60	90	120	180	240
3	**Group 3 units** mortar: general purpose, thin layer and lightweight							
4	**Walls in which holes in units are filled with mortar or concrete** mortar: general purpose, thin layer							
4.1	$10 \leq f_b \leq 35$ $500 \leq \rho \leq 1\,200$ $ct \geq 10\%$							
4.1.1 4.1.2	$\alpha \leq 1{,}0$	90/100 (100)	90/100 (100)	90/100 (100)	140/170 (100)	140/240 (140)	170/240 (170/190)	190/240 (190)
4.1.3 4.1.4	$\alpha \leq 0{,}6$	90/100 (90/100)	90/100 (100)	90/100 (90/100)	100/140 (100/140)	100/170 (100/140)	140/240 (140/190)	190/240 (190)

Comparison with test according to EN 1365-1



- 175 mm clay unit wall with thin-layer mortar and applied finish
- Mean compressive strength 10,5 N/mm²
- Applied load 149 kN/m (eccentricity t/6)
- **Classification REI-M 90**

Worked example summary

Wall type	Unit type	Wall thickness / utilisation	Table	Tabulated data
External, separating	Group 2	240, $\alpha = 0{,}3$	NB 1.2, Line 2.1.3	100/140
External column	Group 2	240 x 500 $\alpha = 0{,}6$	NB 1.4, Line 2.1.13	240 x 500
Internal, non separating	Group 2	175, $\alpha = 0{,}6$	NB 1.3, Line 2.1.4	100
Internal, separating	Group 3 with infill	240 $\alpha = 0{,}6$	NB 1.2, Line 4.1.4	100/140

Worked example conclusion

- Fire resistance requirements for masonry walls are normally met by the wall thicknesses necessary due to static, acoustic or thermal-insulating requirements

Worked example conclusion

- Tabulated data in Annex B provide a reliable and quick design guideline for unreinforced masonry walls
- Differences in the national annexes may be minimized in a revision