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, combined 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**

<table>
<thead>
<tr>
<th>Material of wall</th>
<th>15</th>
<th>20</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>180</th>
<th>240</th>
<th>360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of units, mortar, grouping of units, including combined thickness if required, and density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wall thickness $t_F$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>row number</th>
<th>material properties:</th>
<th>Minimum wall thickness (mm) $t_w$ for fire resistance classification EI for time (minutes) $t_{d,d}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gross dry density $\rho$ [kg/m³]</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>1.1</td>
<td>Group 1S, 1, 2, 3 and 4</td>
<td></td>
</tr>
<tr>
<td>1.1.1</td>
<td>mortar: general purpose, thin layer, lightweight, $500 \leq \rho \leq 2400$</td>
<td>60/100</td>
</tr>
<tr>
<td>1.1.2</td>
<td>(50/70)</td>
<td>(50/70)</td>
</tr>
</tbody>
</table>
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 $\gamma_{\text{Global}}$ has to be applied to $N_{Rk}$ (and not $N_{E_k}$)
- Example
- $h = 2,75 \text{ m}, \ t = 175 \text{ mm}, \ f_b = 16 \text{ N/mm}^2, \ f_m = 5 \text{ N/mm}^2$
- Test load: 247 kN/m ($\alpha = 1,0$) (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

⇒ $\gamma_{Global}$ (applied on $N_{Rk}$) = $622/247 = 2.5$
TABULATED DATA (ANNEX B)

Vertical load level

Consequence

$\gamma_{\text{Global}}$ (applied on $N_{E_k}$) 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)

ärSurface finishes

ärFinishes 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

ärSand-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 $\alpha$-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)
  \[ N_{Ed} = 103 \text{ kN/m} \]
  \[ N_{Ed,fi} = 0.7 \times 103 \text{ kN/m} = 72 \text{ kN/m} \]
Worked example

Resistance

External wall

Group 2 unit, $f_b = 10 \text{ N/mm}^2$, Thin layer mortar

$f_k = 3.5 \text{ N/mm}^2$ (EN 1996-3, Annexe D)
Working example

- Resistance
- External wall

\[ N_{Rd} = 349 \, \text{kN/m} \]

Utilisation factor

\[ \alpha = \frac{N_{Ed}}{N_{Rd}} = \frac{103}{349} = 0.3 < 0.6 \]
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  
  (α ≤ 0,6) is 100 to 140 mm < 240 mm
- Verification o.k.
Worked example

Excerpt of table N.B.1.2

<table>
<thead>
<tr>
<th>Group 2 units</th>
<th>2.1 Mortar: general purpose, thin layer</th>
<th>2.1.1 $\alpha \leq 1,0$</th>
<th>2.1.2 $\alpha &gt; 1,0$</th>
<th>2.1.3 $\alpha \leq 0,6$</th>
<th>2.1.4 $\alpha &gt; 0,6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>90/100</td>
<td>90/100</td>
<td>90/100</td>
<td>90/100</td>
<td>100/140</td>
<td>190/240</td>
</tr>
<tr>
<td>(90/100)</td>
<td>(90/100)</td>
<td>(90/100)</td>
<td>(90/100)</td>
<td>(100/140)</td>
<td>(190/240)</td>
</tr>
<tr>
<td>140/240</td>
<td>190/240</td>
<td>190/240</td>
<td>190/240</td>
<td>190/240</td>
<td>190/240</td>
</tr>
</tbody>
</table>
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%) \( t = 215 \text{ mm} \)
- D (density > 800 kg/m\(^3\)) \( t = 175 \text{ mm} \)
- LUX and NL \( t = 130 \text{ mm} \)
- A \( t = 170 \text{ mm} \)
- I (circolare ministeriale) \( t = 200 \text{ mm} \)

✓ 240 mm is o.k. throughout the EC table NB1.2, line 2.1.3 \( t = 100/140 \text{ mm} \)
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

<table>
<thead>
<tr>
<th>row number</th>
<th>material properties</th>
<th>wall thickness [mm]</th>
<th>Minimum wall length (mm)</th>
<th>$l_F$ for fire resistance classification</th>
<th>R for time (minutes)</th>
<th>$f_{k,d}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>45</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>Group 2 units</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>mortar : general purpose, thin layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$5,0 \leq f_k \leq 35$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$800 &lt; \rho \leq 2,200$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$ct \geq 25%$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.12</td>
<td>$\alpha \leq 0,6$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.13</td>
<td></td>
<td></td>
<td>240</td>
<td>200</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>2.1.14</td>
<td></td>
<td></td>
<td>(170)</td>
<td>(170)</td>
<td>(170)</td>
<td>(170)</td>
</tr>
</tbody>
</table>
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) \( t = 175 \text{ mm} \)

\[
N_{Ed} = 123 \text{ kN/m} \\
N_{Ed,fi} = 0.7 \times 123 \text{ kN/m} = 86 \text{ kN/m}
\]
Worked example

Non-separating loadbearing
Worked example

⇒ Resistance

⇒ Internal wall

Group 2 unit, $f_b = 10 \text{ N/mm}^2$, Thin layer mortar

$f_k = 3.5 \text{ N/mm}^2$ (EN 1996-3, Annexe D)
Worked example

- Resistance
- Internal wall

\[ N_{Rd} = 193 \text{ kN/m} \]

Utilisation factor

\[ \alpha = \frac{N_{Ed}}{N_{Rd}} = \frac{123}{193} = 0.64 \approx 0.6 \]
Worked example

- Wall length ≥ 1,0 m
- REI, table N.B.1.3, line 2.1.4 (suitable plaster)
- The indicated value for R90 (α ≈ 0.6) is 100 mm < 175 mm
- “European” verification o.k.
Worked example

Excerpt of table N.B.1.3

<table>
<thead>
<tr>
<th>row number</th>
<th>material properties:</th>
<th>Minimum wall thickness or length (mm) $t_F$ for fire resistance classification $R$ for time (minutes) $t_{R,4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>unit strength $f_0$ [N/mm²]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>gross density $\rho$ [kg/m³]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>combined thickness $ct$ %</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Group 2 units</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>mortar: general purpose, thin layer</td>
<td></td>
</tr>
<tr>
<td>2.1.1</td>
<td>$5 \leq f_0 \leq 35$</td>
<td></td>
</tr>
<tr>
<td>2.1.2</td>
<td>$800 \leq \rho \leq 2200$</td>
<td></td>
</tr>
<tr>
<td>2.1.3</td>
<td>$ct \geq 25%$</td>
<td></td>
</tr>
<tr>
<td>2.1.4</td>
<td>$\alpha \leq 1.0$</td>
<td></td>
</tr>
<tr>
<td>2.1.4</td>
<td>$\alpha \leq 0.6$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$100$ (100)</td>
<td></td>
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<td></td>
<td>$100$ (100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$100$ (100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$240$ (100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$365$ (170)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$490$ (240)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>nvg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$100$ (100)</td>
<td></td>
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<tr>
<td></td>
<td>$100$ (100)</td>
<td></td>
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<tr>
<td></td>
<td>$100$ (100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$170$ (100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$240$ (100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$300$ (200)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>nvg</td>
<td></td>
</tr>
</tbody>
</table>
Minimum REI90 values in NA’s for plastered walls

- **UK** (perforation ≤ 40%)  \( t = 215 \text{ mm} \)
- **D** (density > 800 kg/m\(^3\))  \( t = 115 \text{ mm} \)
- **LUX**  \( t = 130 \text{ mm} \)
- **A**  \( t = 170 \text{ mm} \)
- **NL**  \( t = 120 \text{ mm} \)

✓ 175 mm is o.k. in central Europe

Table NB.1.3, line 2.1.4  \( t = 100 \text{ mm} \)
Worked example

Internal separating wall between flats
(group 3 unit for concrete infill)
t = 240 mm for acoustic reasons
\[ N_{Ed} = 123 \text{ kN/m} \]
\[ N_{Ed,fi} = 0.7 \times 123 \text{ kN/m} = 86 \text{ kN/m} \]
Worked example

Separating loadbearing

Separating loadbearing
Worked example

Excerpt of table N.B.1.2

<table>
<thead>
<tr>
<th>row number</th>
<th>material properties: unit strength $f_b$ [N/mm²]</th>
<th>gross density $\rho$ [kg/m³]</th>
<th>combined thickness $ct$ % of wall thickness</th>
<th>Minimum wall thickness (mm) $t_f$ for fire resistance classification REI for time (minutes)</th>
<th>$t_{f,4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Group 3 units</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mortar: general purpose, thin layer and lightweight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Walls in which holes in units are filled with mortar or concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>$10 \leq f_b \leq 35$</td>
<td>$500 \leq \rho \leq 1200$</td>
<td>$ct \geq 10%$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1.1</td>
<td>$\alpha \leq 1,0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1.3</td>
<td>$\alpha \leq 0,6$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>Wall type</th>
<th>Unit type</th>
<th>Wall thickness / utilisation</th>
<th>Table</th>
<th>Tabulated data</th>
</tr>
</thead>
<tbody>
<tr>
<td>External, separating</td>
<td>Group 2</td>
<td>240, $\alpha = 0.3$</td>
<td>NB 1.2, Line 2.1.3</td>
<td>100/140</td>
</tr>
<tr>
<td>External column</td>
<td>Group 2</td>
<td>240 x 500, $\alpha = 0.6$</td>
<td>NB 1.4, Line 2.1.13</td>
<td>240 x 500</td>
</tr>
<tr>
<td>Internal, non separating</td>
<td>Group 2</td>
<td>175, $\alpha = 0.6$</td>
<td>NB 1.3, Line 2.1.4</td>
<td>100</td>
</tr>
<tr>
<td>Internal, separating with infill</td>
<td>Group 3</td>
<td>240, $\alpha = 0.6$</td>
<td>NB 1.2, Line 4.1.4</td>
<td>100/140</td>
</tr>
</tbody>
</table>
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