Eurocode 8
Timber and Masonry structures

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EN 1998-1
Section 8
Specific rules for timber structures
Timber is generally considered to be a good structural material for construction in seismic areas due to its:

• Light weight
• Reasonable strength in tension and in compression

both being relevant properties for the seismic performance of structures
### Typical values of unit mass and strength for various structural materials and corresponding ratios

<table>
<thead>
<tr>
<th>Structural material</th>
<th>Unit mass $\rho$ (kg/m$^3$)</th>
<th>Strength $f$ Range of values (MPa)</th>
<th>Ratio $f/\rho$ ($10^{-3}$ MPa / kg/m$^3$)</th>
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</table>
|                           | Tension                        | 2100                              | 0,3 – 0,5                                | 0,1 - 02}
The good performance of wood is reflected by its range of values $f/\rho$ similar to structural steel.

but

• Timber elements do not present large deformational ductility.

• Response of timber elements up to failure is approximately linear elastic.

• Collapse is sudden, mostly associated with defects inherent to the natural origin of timber.
For timber structures EN 1998-1 distinguishes between **dissipative** and **low-dissipative structural behaviour** (as for concrete, steel and composite).

However, in view of the **limited ability** of timber to behave nonlinearly:

- Energy dissipation should be mostly in connections
- Timber elements should respond linearly

*Some (little) NL behaviour in compression perpendicular to grain may be expected.*

*Tension perpendicular to grain markedly brittle.*
Distinction between dissipative and low-dissipative structures depends mostly on the

Nature of the connections:

Basic distinction in EN1998-1 between:

• Semi-rigid joints
• Rigid joints
Dissipation of energy in connections:

Two main sources:

1. **Cyclic yielding** of metallic (normally steel) dowel type fasteners of the connections (nails, staples, screws, dowels or bolts)

   *Stable mechanism with large hysteretic cycles*

2. **Crushing** of the wood fibres bearing against the dowel

   *Thin hysteretic loops with significant degradation (due to the cavity being formed in front of the dowel)*
Response of the connections depends mostly on the interaction between the two mechanisms

Achieve good dissipative behaviour with proper balance between:

- Wood crushing
- Dowel yielding

More significant parameter:

*Slenderness of the dowel type element*
Ductility Classes

Dissipative structures

Ductility Class Medium (DCM)
Ductility Class High (DCH)

Low-dissipative structures

Ductility Class Low (DCL)

Choice of the DCs left to the designer but National Authorities may limit the use of the various DCs
Ductility classification depends mostly on:

- Structural type/redundancy
- Nature of structural connections

Determine properties of dissipative zones by testing (prEN 12512)
or
Use deemed to satisfy rules (in EN 1998-1)
Materials and properties of dissipative zones:

- **General requirements as in EN 1995-1-1**
  (and EN 1993-1 for steel elements)

- **Additional requirements for DCM and DCH**
  - Glued joints may not be considered dissipative
  - Density of particle board panels $\geq 650 \text{ kg/m}^3$
  - Thickness of particle board and fibre board panels $\geq 13 \text{ mm}$
  - Thickness of plywood sheathing $\geq 9 \text{ mm}$

  *Nailed shear panel systems superior to conventional bracing*
  *Avoid pull out of nails under transverse loading (avoid smooth nails or apply provisions against withdrawal)*
## Behaviour factors DCM and DCH  \((q = 1.5\) for DCL\)

<table>
<thead>
<tr>
<th>Structural types</th>
<th>DCM</th>
<th>DCH</th>
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<tr>
<td>Wall panels with <strong>glued diaphragms</strong> connected with nails and bolts</td>
<td><strong>Glued panels</strong></td>
<td><strong>Nailed panels</strong></td>
</tr>
<tr>
<td></td>
<td>(q = 2.0)</td>
<td>(q = 3.0)</td>
</tr>
<tr>
<td>Wall panels with <strong>nailed diaphragms</strong> connected with nails and bolts</td>
<td>-</td>
<td><strong>Nailed panels</strong></td>
</tr>
<tr>
<td></td>
<td>(q = 5.0)</td>
<td>(q = 4.0)</td>
</tr>
<tr>
<td>Trusses</td>
<td><strong>Doweled and bolted joints</strong></td>
<td><strong>Nailed joints</strong></td>
</tr>
<tr>
<td></td>
<td>(q = 2.0)</td>
<td>(q = 3.0)</td>
</tr>
<tr>
<td>Mixed structures with timber framing and non-load bearing infills</td>
<td>(q = 2.0)</td>
<td>-</td>
</tr>
<tr>
<td>Hyperstatic portal frame with doweled and bolted joints</td>
<td>(\mu \geq 4)</td>
<td>(\mu \geq 6)</td>
</tr>
<tr>
<td></td>
<td>(q = 2.5)</td>
<td>(q = 4.0)</td>
</tr>
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<td></td>
<td></td>
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</table>

( ) for lower slenderness dowels
Underlying requirements for the allowed $q$ factors for timber structures:

**Buildings regular in elevation** (if non-regular, reduce by 20% the values indicated for $q$)

**Dissipative zones able to sustain, without strength degradation larger than 20%, 3 fully reversed cycles** at ductility demand of:

- $\mu = 4$ for DCM
- $\mu = 6$ for DCH

*Rotational ductility in portal frames or distortional displacement ductility in shear panels*
Deemed to satisfy rules for dissipative zones

Fasteners in doweled, bolted and nailed timber-to-timber and steel-to-timber joints:

- Slenderness: \( t/d \geq 10 \) (or 8)
- Diameter: \( d \leq 12 \text{ mm} \)

In shear walls and diaphragms:

- Wood-based material
- Slenderness of nails: \( t/d \geq 4 \) (or 3)
- Nail diameter: \( d \leq 3,1 \text{ mm} \)

More demanding than EN 1995 (allows dowels and bolts up to 30 mm)
Allowance for lower slenderness (values) with reduction of the \( q \) factor
Detailing for DCM and DCH

*Dissipative zones in parts of the structure not affecting its overall stability*

• **Connections**

Connections in compression members *prevented from separating*

Tight fitted bolts and dowels in pre-drilled holes.

**Maximum diameter of bolts and dowels: 16 mm** (larger diameters allowed with toothed ring connectors for confinement)

**Dowels, smooth nails and staples with provisions against withdrawal**

**Provisions against splitting** (metal or plywood plates)
Detailing for DCM and DCH

*Increase the effectiveness of the sheathing material and edge connections*

- **Diaphragms** (rules more demanding than EN 1995-1-1)
  
  Disregard allowance in EN1995-1-1 for increased resistance and increased spacing of edge connectors

**Continuity of beams**

*Height-to-width ratio (slenderness) of beams: $t/d \leq 4$* (in the absence of transverse blocking)

*Reduce spacing of fasteners if $a_g \cdot S \geq 0,2 \cdot g$* (respect minimum spacing of EN 1995-1-1; provide «generous» size of timber elements to allow space for nailing)
Safety verifications

*Resistance models in accordance with EN 1995-1-1 with $k_{mod}$ values for instantaneous loading*

- **DCL**
  
  Partial factors $\gamma_M$ as for the *fundamental* load combination

- **DCM and DCH**
  
  Partial factors $\gamma_M = 1,0$ as for the *accidental load combination* (important difference from concrete, steel and timber)

Provide sufficient overstrength to elements connected to dissipative zones

*Increase partial factors by 1,3 in carpenter joints* (to avoid brittle failures)
EN 1998-1
Section 9
Specific rules for masonry structures
Masonry is generally considered to present specific problems for construction in seismic areas due to its:

- Weight
- Poor strength in tension
- Brittle response in tension and compression

all being relevant properties for the seismic performance of structures
Typical values of **unit mass** and **strength** for various structural materials and corresponding ratios

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<td>35 – 55</td>
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<td>0,8 - 1,5</td>
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<td></td>
<td></td>
</tr>
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<td>4 - 8</td>
<td>1,9 – 3,8</td>
</tr>
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<td>0,1 - 02</td>
</tr>
</tbody>
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The specific problems of the seismic performance of masonry is reflect by the low of values $f/\rho$ both in compression and tension

however

Masonry structures may present:

- **Densely distributed walls**
- **Good robustness** (if all elements are appropriately tied together)
- **Dissipation of energy in a distributed fashion by widespread cracking** (which has to be controlled either by tying or by distributed reinforcement)

Hence the seismic behaviour of masonry structures may be very much influenced by design
For masonry structures EN 1998-1 distinguishes between:

- **Unreinforced** masonry construction
- **Confined** masonry construction
- **Reinforced** masonry construction

**Unreinforced** masonry akin to the concept of Low-Dissipative structures

Use of unreinforced masonry (**EN1996**) is recommended **only** for Low seismicity cases (recommended NDP)

**Unreinforced** masonry (**EN1998-1**) may **not be used** if \( a_g \cdot S > 0.2 \text{ g} \) (recommended NDP that should depend on the requirements for materials properties)
Materials and bonding patterns

- General requirements as in EN 1996-1-1
- **Additional requirements** (all recommended NDPs)

**Minimum strength of units**
- Normal to bed face: $f_b \geq 5 \text{ N/mm}^2$
- Parallel to bed face: $f_b \geq 2 \text{ N/mm}^2$

**Minimum strength of mortar**
- Unreinforced and confined: $f_m \geq 5 \text{ N/mm}^2$
- Reinforced: $f_m \geq 10 \text{ N/mm}^2$

Masonry **bond** for perpend joints
- Fully grouted joints with mortar
- Ungrouted joints
- Ungrouted with mechanical interlocking

*Large number of NDPs reflect and is intended to accommodate the large variety of materials and construction practices for masonry across Europe*
Upper limits of behaviour factors (recommended NDPs)

<table>
<thead>
<tr>
<th>Type of construction</th>
<th>$Q$</th>
</tr>
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<tr>
<td>Unreinforced masonry in accordance with EN 1996 alone</td>
<td>1,5</td>
</tr>
<tr>
<td>Unreinforced masonry in accordance with EN 1998</td>
<td>1,5 – 2,5</td>
</tr>
<tr>
<td>Confined masonry</td>
<td>2,0 – 3,0</td>
</tr>
<tr>
<td>Reinforced masonry</td>
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Structural analysis

- Uncracked or cracked (*recommended*) stiffness
- Cracked stiffness approx. 50%
- If appropriate (*existence of coupling beams/spandrels*) a frame analysis may be used
- Redistribution of base shear among walls
Construction rules and geometric conditions

• **General**
  Connections between floors and walls
  Floor continuity and effective diaphragm effect
  **Shear walls in two orthogonal directions**

• **Shear walls**
  Minimum effective thickness $t_{ef,\text{min}}$
  Maximum height to thickness ratio $(h_{ef}/t_{ef})_{\text{max}}$
  Minimum length to height ratio $(l/h)_{\text{min}}$
# Geometric requirements for shear walls

<table>
<thead>
<tr>
<th>Masonry type</th>
<th>$t_{ef,\text{min}}$ (mm)</th>
<th>$(h_{ef}/t_{ef})_{\text{max}}$</th>
<th>$(l/h)_{\text{min}}$</th>
</tr>
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<tr>
<td>Unreinforced, with natural stone units</td>
<td>350</td>
<td>9</td>
<td>0,5</td>
</tr>
<tr>
<td>Unreinforced, with any other type of units</td>
<td>240</td>
<td>12</td>
<td>0,4</td>
</tr>
<tr>
<td>Unreinforced, with any other type of units, in cases of low seismicity</td>
<td>170</td>
<td>15</td>
<td>0,35</td>
</tr>
<tr>
<td>Confined masonry</td>
<td>240</td>
<td>15</td>
<td>0,3</td>
</tr>
<tr>
<td>Reinforced masonry</td>
<td>240</td>
<td>15</td>
<td>No restriction</td>
</tr>
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$t_{ef}$  thickness of the wall (EN 1996-1-1);  
$h_{ef}$  effective height of the wall (EN 1996-1-1);  
$h$  greater clear height of the openings adjacent to the wall;  
$l$  length of the wall.
Additional requirements for unreinforced masonry

• Horizontal concrete beams or steel ties at floor levels in all walls

• Concrete beams reinforcement with at least 2 cm²

All beams (or ties) interconnected

Peripheral beams essential
Additional requirements for confined masonry

• Horizontal and vertical **confining elements** bonded together and cast against the masonry

• Confining elements larger than **150 mm** (interconnect the two masonry leaves in case of double-leaf masonry)

• Longitudinal **reinforcement** of confining elements with at least **3 cm²** or 1% of cross sectional area

• **Stirrups** \( d \geq 5 \text{ mm} \) spaced \( \leq 150 \text{ mm} \)

• Reinforcing steel **Class B or C** (EN 1992-1-1)

• **Lap splices** longer than **60 diameters**
Additional requirements for confined masonry (cont.)

• **Vertical** confining elements:
  
  At both **edges** of walls
  
  At both sides of **openings** larger than 1,5 m²
  
  Within wall **spaced**, at most, 5 m
  
  At **wall intersections** more than 1,5 from other confining element

• **Horizontal** confining elements:
  
  At **every floor level**
  
  With **vertical spacing** not larger than 4 m
Additional requirements for reinforced masonry

• **Horizontal reinforcement in bed joints spaced** not more than 600 mm

• Reinforcing steel not less than 4 mm in diameter, bent around bars at edges of walls

• **Horizontal reinforcement not less than 0.05% of cross sectional area of wall**

• **Vertical reinforcement (in pockets or holes in the units) not less than 0.08% of cross sectional area of wall**

• Reinforcing steel **Class B or C** (EN 1992-1-1)

• **Lap splices longer than 60 diameters**
Additional requirements for reinforced masonry (cont.)

- **Vertical** reinforcement not less than 200 mm\(^2\) and provided with 5 mm **stirrups** at 150 mm spacing:
  
  At both free edges of all walls
  
  At every wall intersection
  
  Within wall spaced, at most, 5 m
Safety verifications

Resistance models in accordance with EN 1996-1-1

Specific partial factor $\gamma_m$ for masonry and $\gamma_s$ for steel to be defined as NDPs

Recommended values:

For masonry:

$$\gamma_m = \frac{2}{3} \text{ of the value from EN 1996-1-1, but not less than 1.5}$$

For steel:

$$\gamma_s = 1.0$$
“Simple masonry buildings”

Concept applicable only for Importance Classes I and II

Explicit safety verification not mandatory

Safety verification implicit with the fulfilment of some geometrical conditions
“Simple masonry buildings” conditions:

Maximum number of storeys and minimum relative area of walls depending on $a_g S$ and type of masonry

Regularity in plan

Compact in plan shape

Shear walls in both orthogonal directions and approximately symmetrical

Two parallel walls in both orthogonal directions, placed close to the edges of the building

75% of weight supported by shear walls

Variation of mass and wall area between adjacent storeys limited to 20% (recommended NDP)