Eurocode 8
Timber and Masonry structures

E C Carvalho, Chairman TC250/SC8

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

Structural material		Unit mass ρ (kg/m³)	Strength f Range of values (MPa)	Ratio f/ρ (10^{-3} MPa / kg/m³)
Wood	Compression and tension	550	20 – 30	**35 – 55**
Structural steel	Compression and tension	7800	275 - 355	35 - 45
Concrete	Compression	2400	25 - 80	10 - 30
	Tension	2400	2 – 3,5	0,8 - 1,5
Reinforced concrete	Bending	2500	10 - 25	4 - 10
Masonry	Compression	2100	4 - 8	1,9 – 3,8
	Tension	2100	0,3 – 0,5	0,1 - 02

The **good performance** of wood is reflect by its range of **values** *f/ρ* 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**

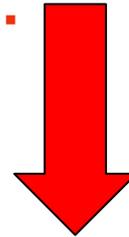- **Timber elements should respond linearly**

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)
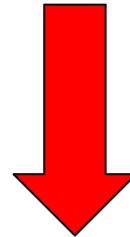
Stable mechanism with large hysteretic cycles

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

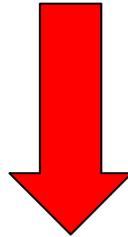### Ductility Class Medium (DCM)

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)

- **<u>Additional</u> requirements for DCM and DCH**

  Glued joints may not be considered dissipative

  Density of particle board panels $\geq$ 650 kg/m^3

  Thickness of particle board and fibre board panels $\geq$ 13 mm

  Thickness of plywood sheating $\geq$ 9 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)

Structural types	DCM	DCH
Wall panels with **glued diaphragms** connected with nails and bolts	**Glued** panels $q = 2,0$	**Nailed** panels $q = 3,0$
Wall panels with **nailed diaphragms** connected with nails and bolts	-	**Nailed** panels $q = 5,0$ ($q = 4,0$)
Trusses	**Doweled** and **bolted** joints $q = 2,0$	**Nailed** joints $q = 3,0$
Mixed structures with timber framing and non-load bearing infills	$q = 2,0$	-
Hyperstatic portal frame with doweled and bolted joints	$\mu \geq 4$ $q = 2,5$	$\mu \geq 6$ $q = 4,0$ ($q = 2,5$)

( ) 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:

- μ = 4 for DCM

- μ = 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:** $d \leq 12$ **mm**

In shear walls and diaphragms:

- **Wood-based material**
- **Slenderness of nails:** $t/d \geq 4$ **(or 3)**
- **Nail diameter:** $d \leq 3,1$ **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

- ## <u>Connections</u>

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 sheating 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 $a_g\, S \geq 0,2\ g$ (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

- ## <u>DCL</u>

  Partial factors $\gamma_{\mathbf{M}}$ as for the fundamental load combination

- ## <u>DCM and DCH</u>

  Partial factors $\gamma_{\mathbf{M}} = 1,0$ 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

Structural material		Unit mass ρ (kg/m^3)	Strength f Range of values (MPa)	Ratio f/ρ (10^{-3} MPa / kg/m^3)
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The specific problems of the seismic performance of masonry is reflect by the low of values *f/ρ* 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 $a_g\,S > 0{,}20\,g$ (recommended NDP that should depend on the requirements for materials properties)*

Materials and bonding patterns

- **General requirements as in EN 1996-1-1**

- **<u>Additional</u> requirements (all recommended NDPs)**

  Minimum strength of units

  > **Normal to bed face:** $f_b \geq 5 \ N/mm^2$
  > **Parallel to bed face:** $f_b \geq 2 \ N/mm^2$

  Minimum strength of mortar

  > **Unreinforced and confined:** $f_m \geq 5 \ N/mm^2$
  > **Reinforced:** $f_m \geq 10 \ N/mm^2$

  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)

Type of construction	Q
Unreinforced masonry in accordance with EN 1996 alone	1,5
Unreinforced masonry in accordance with EN 1998	**1,5** – 2,5
Confined masonry	**2,0** – 3,0
Reinforced masonry	**2,5** – 3,0

Structural analysis

- **Uncracked or cracked** *(recommended)* **stiffness**

- **Cracked stiffness approx. 50%**

- **If appropriate** *(existance 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 $t_{ef,min}$

  Maximum height to thickness ratio $(h_{ef}/t_{ef})_{max}$

  Minimum length to height ratio $(l/h)_{min}$

Geometric requirements for shear walls

Masonry type	$t_{ef,min}$ (mm)	$(h_{ef}/t_{ef})_{max}$	$(l/h)_{min}$
Unreinforced, with natural stone units	350	9	0,5
Unreinforced, with any other type of units	240	12	0,4
Unreinforced, with any other type of units, in cases of low seismicity	170	15	0,35
Confined masonry	240	15	0,3
Reinforced masonry	240	15	No restriction

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 cm^2**

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 cm^2 or 1% of cross sectional area**

- **Stirrups d ≥ 5 mm spaced ≤ 150 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 m^2

    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 γ_m for masonry and γ_s for steel to be defined as NDPs

Recommended values:

For masonry:
γ_m = 2/3 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)