EUROCODE 6

Design of masonry structures

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Scope of Eurocode 6

Design of buildings and civil engineering works in

- unreinforced
- reinforced
- prestressed
- confined

masonry.

Concerns the requirements for

- resistance
- serviceability
- durability

(requirements related to the so-called essential requirements ER1 'Strength and Stability' and ER2 'Resistance to Fire')

Execution is only covered to the extent that is necessary to indicate

- the quality of the construction materials and products that should be used
- the standard of workmanship on site needed to comply with the assumptions made in the design rules

EN 1996 series consists of 4 parts:

EN 1996-1-1	General - Rules for reinforced and unreinforced masonry
EN 1996-1-2	General rules - Structural fire design
EN 1996-2	Design considerations, selection of materials and execution of masonry
EN 1996-3	Simplified calculation methods for unreinforced masonry structures

Character of code / standard

Partial factor design code

- design values for loads – loads multiplied with a load factor (EN 1991-series)
- design values for resistance – material strength divided by a material factor (EN 1996-1-1)

Limit state design

- Ultimate limit state (ULS)
  - collapse
  - loss of equilibrium,
  - buckling
  - loss of stability
- Serviceability limit state (SLS)
  - deflection
  - cracking

Performance based approach

- Minimum dimensions are based on calculation
- Certain practical limits e.g. slenderness of load bearing walls

Distinction between principle and application rules

Principles:

- general statements and definitions for which there is no alternative
- requirements and analytical models for which no alternative is permitted
- Paragraphs numbers indicated with “P”

Application rules:

- generally recognised rules which comply with the principles and satisfy their requirements
- instances where no applications rules are given after a principle freedom what is chosen for meeting the principle (!)
- permissible to use alternative rules provided that the alternatives are equivalent with regards to:
  - structural safety
  - serviceability
  - durability

Assumptions

The assumptions given in 1.3 of EN 1990:2002 apply:

- the choice of the structural system and the design of the structure is made by appropriately qualified and experienced personnel;
- execution is carried out by personnel having the appropriate skill and experience;
- adequate supervision and quality control is provided during execution of the work, i.e. in design offices, factories, plants, and on site;
- the construction materials and products are used as specified in EN 1990 or in EN 1991 to EN 1999 or in the relevant execution standards, or reference material or product specifications;
- the structure will be adequately maintained;
- the structure will be used in accordance with the design assumptions.

- NOTE There may be cases when the above assumptions need to be supplemented.

EN 1996-1-1 Scope

The basis for the design of buildings and civil engineering works in masonry:

unreinforced masonry

reinforced masonry where reinforcement is added to provide

- ductility,
- strength
- improved serviceability

The principles of the design of:

prestressed masonry

confined masonry

Not valid for masonry with a plan area of less than 0,04 m^2.

The principles and application rules given in this EN may be applicable for

types of structures not covered entirely

for new structural uses for established materials,

for new materials, or

where actions and other influences outside normal experience have to be resisted

but may need to be supplemented.

Detailed rules which are mainly applicable to ordinary buildings

The applicability of these rules may be limited, for practical reasons or due to simplifications; any limits of applicability are given in the text where necessary.

EN 1996-1-1 Scope

Masonry made with the following masonry units:

- clay masonry units
- calcium silicate units
- aggregate concrete units (dense and lightweight aggregate)
- autoclaved aerated concrete units
- manufactured stone units
- dimensioned natural stone units

laid in:

- general purpose mortar
- lightweight mortar
- thin layer mortar

EN 1996-1-1 Sections

Contents of EN 1996-1-1 (Standard arrangement of sections in Material Eurocodes)

Foreword
1. General
2. Basis of Design
3. Materials
4. Durability
5. Structural analysis
6. Ultimate Limit State
7. Serviceability Limit State
8. Detailing
9. Execution

Annexes (normative & informative)

Additionally Eurocode 6 part 2 (EN 1996-2) gives basic rules for:

- design considerations related to selection of materials
- execution to comply with design assumption in part 1-1

EN 1996-1-1 Foreword and Section 1 General

Foreword

Background to the Eurocode programme
Status and field of application of Eurocodes
National Standards implementing Eurocodes
Links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products
National Annex for EN 1996-1-1

- Overview of clauses for which a National choice is allowed in EN 1996-1-1

Section 1

Scope
Normative references
Assumptions
Distinction between principles and application rules
Terms and Definitions
Symbols

EN 1996-1-1 Section 2 Basis of Design

2.1 Basic requirements

2.1.1 General

(1)P The design of masonry structures shall be in accordance with the general rules given in EN 1990.

(3) The basic requirements of EN 1990 Section 2 are deemed to be satisfied for masonry structures when the following are applied:

- limit state design in conjunction with the partial factor method described in EN 1990;
- actions given in EN 1991;
- combination rules given in EN 1990;
- the principles and rules of application given in this EN 1996-1-1.

2.3.3 Material and product properties

(1) Properties of materials and construction products and geometrical data to be used for design should be those specified in the relevant ENs, hENs or ETAs, unless otherwise indicated in this EN 1996-1-1.

EN 1996-1-1 Section 2 Basis of Design

2.4 Verification by the partial factor method

2.4.1 Design values of material properties

(1)P The design value for a material property is obtained by dividing its characteristic value by the relevant partial factor for materials, γ_M.

2.4.3 Ultimate limit states

(1)P The relevant values of the partial factor for materials γ_M shall be used for the ultimate limit state for ordinary and accidental situations. When analysing the structure for accidental actions, the probability of the accidental action being present shall be taken into account.

NOTE The numerical values to be ascribed to the symbol γ_M for use in a country may be found in its National Annex. Recommended values, given as classes that may be related to execution control (see also Annex A) according to national choice, are given in the table below.

EN 1996-1-1 Section 2 Basis of Design

Material		γ_M				
		Class				
		1	2	3	4	5
	Masonry made with:					
A	Units of Category I, designed mortar[a]	1,5	1,7	2,0	2,2	2,5
B	Units of Category I, prescribed mortar[b]	1,7	2,0	2,2	2,5	2,7
C	Units of Category II, any mortar[a, b, e]	2,0	2,2	2,5	2,7	3,0
D	Anchorage of reinforcing steel	1,7	2,0	2,2	2,5	2,7
E	Reinforcing steel and prestressing steel	1,15				
F	Ancillary components[c, d]	1,7	2,0	2,2	2,5	2,7
G	Lintels according to EN 845-2	1,5 to 2,5				

[a] Requirements for designed mortars are given in EN 998-2 and EN 1996-2.

[b] Requirements for prescribed mortars are given in EN 998-2 and EN 1996-2.

[c] Declared values are mean values.

[d] Damp proof courses are assumed to be covered by masonry γ_M.

[e] When the coefficient of variation for Category II units is not greater than 25 %.

EN 1996-1-1 Section 2 Basis of Design

UK			Class of execution	
	URM in compression	cat I	2.3	2.7
		cat II	2.6	3.0
	URM in flexural tension	cat II	2.3	2.7

NL Materials A, B & C $\gamma_M = 1.7$

DK $\gamma_M = \gamma_1 \gamma_2 \gamma_3 \gamma_4$

γ_1	type of failure
γ_2	uncertainty related to the design model
γ_3	inspection level for factory made mortar and mortar on side
γ_4	the variation of the strength parameter/measured resistance

EN 1996-1-1 Section 2 Basis of Design

2.4.4 Serviceability limit states

(1) Where simplified rules are given in the relevant clauses dealing with serviceability limit states, detailed calculations using combinations of actions are not required. When needed, the partial factor for materials, for the serviceability limit state, is γ_M.

NOTE Recommended value for $\gamma_M = 1.0$ (PART of NA)

2.5 Design assisted by testing

(1) Structural properties of masonry may be determined by testing.

NOTE Annex D (informative) of EN 1990 gives recommendations for design assisted by testing.

EN 1996-1-1 Section 3 Materials

3.1 Masonry units

3.1.1 Types and grouping of masonry units

(1) P Masonry units shall comply with any of the following types:

- clay units in accordance with EN 771-1.
- calcium silicate units in accordance with EN 771-2.
- aggregate concrete units (dense and lightweight aggregate) in accordance with EN 771-3.
- autoclaved aerated concrete units in accordance with EN 771-4.
- manufactured stone units in accordance with EN 771-5.
- dimensioned natural stone units in accordance with EN 771-6.

(2) Masonry units may be Category I of II

- category I
  units with a declared compressive strength with a probability of failure to reach it not exceeding 5 %
- category II
  lower confidence level than for I

EN 1996-1-1 Section 3 Materials

3.1 Masonry units

(3) Masonry units should be grouped as Group 1, Group 2, Group 3 or Group 4, for the purposes of 3.6.1.2 (2), (3), (4), (5) and (6), and 3.6.1.3 and where grouping is referred to in other clauses

Grouping is defined in Table 3.1 with limits on:

- volume of all holes
- volume of any hole
    - multiple holes
    - gripholes
- declared value of thickness of web and shells
- declared value of combined thickness of web and shells

Disadvantage

- always units that will not fit!

EN 1996-1-1 Section 3 Materials

3.1.2 Properties of masonry units – compressive strength

(1)P The compressive strength of masonry units, to be used in design, shall be the normalised mean compressive strength, f_b

f_b compressive strength of masonry units converted to the air dry compressive strength of an equivalent 100 mm wide × 100 mm high masonry unit – see product standards and Annex A of EN 772-1.

3..2 Mortar

3.2.1 Types of masonry mortar

- Application
  - general purpose,
  - thin layer,
  - lightweight
- Method of specification
  - designed
  - prescribed
- Method of production (all in accordance with EN 998-2!)
  - factory made
  - semi-finished factory made
  - site made mortars

3.2.2. Specification of masonry mortar

- designed: M10
- prescribed: M5 1:1:6

EN 1996-1-1 Section 3 Materials

3..2 Mortar

3.2.3 Properties of mortar

3.2.3.1 Compressive strength f_{m} according EN 105-11

- mean value of a 40 x 40 “mm “cube” remaining from a prism (160 x 40 x 40 mm^3) tested in flexure
- reinforced masonry: > 4 N/mm^2

3.2.3.2 Adhesion between units and mortar

- (1)P The adhesion between the mortar and the masonry units shall be adequate for the intended use.

EN 1996-1-1 Section 3 Materials

3.3 Concrete Infill

3.3.1 General: f_{ck}, (concrete strength class) in accordance with EN 206

3.3.2 Specification for concrete infill

- Minimum strength class C12/15
- Advise on workability
- Maximum aggregate size

3.3.3 Properties of concrete infill

- Values for compressive strength and shear strength of infill are give in Table 3.2

3.4 Reinforcing steel

3.4.1 General

- in accordance with EN 10080
- Detailed information on the properties of reinforcing steel is to be found in EN 1992-1-1.

3.4.2 Properties of reinforcing steel bars

- Characteristic strength f_{yk}, shall be in accordance with annex C of EN 1992-1-1

3.4.3 Properties of prefabricated bed joint reinforcement

- in accordance with EN 845-3

3.5 Prestressing steel

- Properties should be obtained from EN 1992-1-1

3.6.1 Characteristic compressive strength of masonry

Principle: determination by test

3.6.1.2 Characteristic compressive strength of masonry other than shell bedded

- Alternative i: based on test acc. EN 1052-1 by project / database
  - in table format or
  - in formula format: $f_k = K\, f_b^{\alpha}\, f_m^{\beta}$ with K, α and β to be given in the NA
- Alternative ii: formulae as given:

$f_k = K \cdot f_b^{0,7} \cdot f_m^{0,3}$ (3.2) masonry with general purpose mortar

$f_k = K\, f_b^{0,85}$ (3.3) thin bed masonry with CS and AAC units

$f_k = K\, f_b^{0,7}$ (3.4) thin bed with group 2 and 3 clay blocs

  - with limits on values for f_b and f_m

– Choice for alternative i or ii: PART OF NA

3.6.1.2 Characteristic compressive strength of masonry National Annex

DK

- method (i) in EN1996-1-1 may be used provided that documentation for the parameters of equation 3.1 is given.
- method (ii) may be used without further documentation.

NL

- method (i) with tabled values on K, α and β (ENV values)
- distinction between units based on volume of voids and not on grouping

UK

- follows method (i) in the spirit of method (ii)
- own limits on f_b and f_m
- no values for group 3 and 4 units

3.6.2 Characteristic shear strength of masonry

Shear strength

- Principle: determination by test, but no test available

Initial shear strength f_{vko}

- Principle: determination by test.
- EN 1052-3 (masonry)
- EN 1052-4 (dpc layers)

Shear strength of masonry will filled head joints

- $f_{\text{vk}} = f_{\text{vko}} + 0{,}4\,\sigma_{\text{d}}$
- $f_{\text{vk}} \leq 0{,}065\, f_{\text{b}}$ or $f_{\text{vk}} \leq f_{\text{vlt}}$ CHOICE: PART OF NA

Shear strength of masonry with unfilled head joints

- $f_{\text{vk}} = 0{,}5\, f_{\text{vko}} + 0{,}4\,\sigma_{\text{d}}$
- $f_{\text{vk}} \leq 0{,}045\, f_{\text{b}}$ or $f_{\text{vk}} \leq f_{\text{vlt}}$ CHOICE: PART OF NA

Shear strength of shell bedded masonry

- $f_{\text{vk}} = \frac{g}{t} f_{\text{vko}} + 0{,}4\,\sigma_{\text{d}}$
- Not greater than with unfilled bed joint

3.6.2 Characteristic shear strength of masonry

Initial shear strength f_{vko} may be obtained from:

- evaluation of database on test results
- from Table 3.4 *provided that general purpose mortars do not contain admixtures or additives*

CHOICE: PART OF NA

Vertical shear resistance of the junction of two masonry walls

- from suitable test or evaluation of test data
- equal to f_{vko} when detailing is according 8.5.2.1
  - in bond
  - with connectors or reinforcement extending into each wall

3.6.2 Characteristic shear strength of masonry

DK

- Recommended values

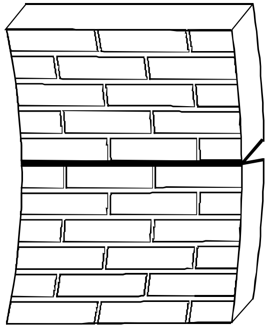
UK

- Tabulated values, same as in Eurocode 6, but with slightly adapted mortar strength classes

NL

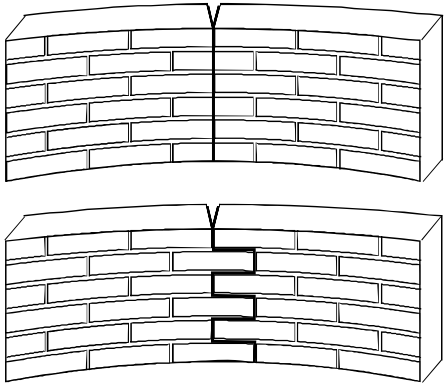
- Minimum demand on values to be achieved
  (based on Nat. Masonry Standard)

3.6.3 Characteristic flexural strength of masonry (out-of-plane)



Two directions

- plane of failure parallel to bed joints, f_{xk1}



- plane of failure perpendicular to bed joints, f_{xk2}

Principle: determination by test.

- EN 1052-2
- Evaluation of test data
- Proposed values are given in a Note

CHOICE: PART OF NA

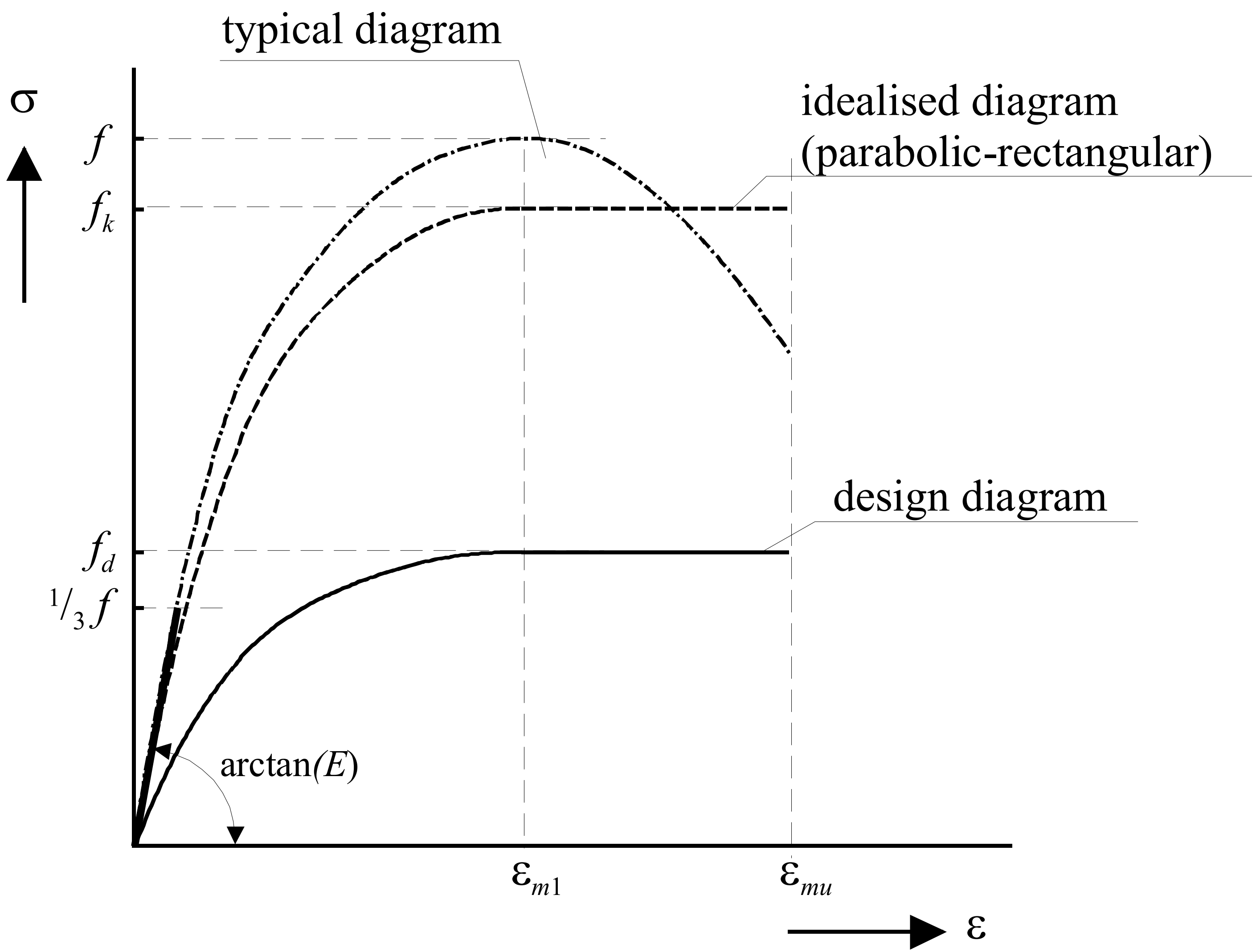
3.6.4 Characteristic anchorage strength of reinforcement

Principle: determination by test

- No test method available
- May be based on an evaluation of test data
- Tabulated values for f_{bok}
    - differentiation between plain and high-bond steel
    - in concrete infill with dimensions $\geq$ 150 mm (Table 3.5)
    - in mortar and concrete infill with dimensions < 150 mm (Table 3.6)
- Prefabricated bed joint reinforcement
    - by test in accordance with EN 846-2
    - based on longitudinal wires via table 3.6

3.7 Deformation properties of masonry

3.7.1 Stress-strain relationship



3.7 Deformation properties of masonry

3.7.2 Modulus of elasticity

- $E = K_E \cdot f_k$
- K_E
  - recommended value = 1000

CHOICE: PART OF NA

3.7.3 Shear modulus

- $G = 0.4E$

3.7.4 Creep, moisture expansion or shrinkage and thermal expansion

- Principle: determination by test
- No test method available
- Ranges of values given in a table in a note

CHOICE: PART OF NA

3.8 Ancillary components

3.8.1 Damp proof courses

- shall resist the passage of water

3.8.2 Wall ties

- according EN 845-1

3.8.3 Straps, hangers and brackets

- according EN 845-1

3.8.4 Prefabricated lintels

- according EN 845-2

3.8.5 Prestressing devices

- in accordance with requirements of EN 1992-1-1

EN 1996-1-1 Section 4 Durability

4.1 General

Principle: Must be durable for the intended use taking into account the relevant environmental conditions

4.2. Classification of environmental conditions

The classification of environmental conditions should be in accordance with EN 1996-2

- MX1 - dry
- MX2 - moisture or wetting
- etc.

4.3 Durability of masonry

Selection of materials is related to the exposure class
Detailing is an important element
EN 1996-2 gives requirements for the durability of ancillary components

EN 1996-1-1 Section 4 Durability

4.3.3 Reinforcing steel

Steel

- selection based on exposure class
- relation between material choice and exposure class
- table with recommended values is given in Note

CHOISE: PART OF NA

Cover

- for unprotected carbon steel minimum cover c_{nom}
- table with recommended values is given in Note

CHOICE: PART OF NA

4.4 Masonry below ground

resistant to ground conditions or
suitable protected
protection against chemicals if present and harmful

EN 1996-1-1 Section 5 Structural Analysis

5.1 General

Principles

- For each relevant limit state a calculation model shall be established
- The general arrangement of the structure and the interaction and connection of its various parts shall be such as to give appropriate stability and robustness during construction and use

Response of structure shall be calculated using

- linear theory
- non-linear theory (using stress-strain relation of 3.7.1)

5.2 Structural behaviour in accidental situations (other than earthquakes and fire)

Principle

- In addition to designing the structure to support loads arising from normal use, it shall be ensured that there is a reasonable probability that it will not be damaged under the effect of misuse or accident to an extent disproportionate to the original cause

Consideration of structural behaviour under accidental situations by one of the following methods:

- members designed to resist the effects of accidental actions given in EN 1991-1-7;
- the hypothetical removal of essential loadbearing members in turn
- use of a tie-ing system;
- reducing the risk of accidental actions, such as the use of impact barriers against vehicle impact.

EN 1996-1-1 Section 5 Structural Analysis

5.3 Imperfections

Structure is supposed to be inclined under an angle $\upsilon = \frac{1}{\left(100\sqrt{h_{\text{tot}}}\right)}$

The resulting horizontal action should be added to the other actions

5.4 Second order effects

No influence when:

$$h_{\text{tot}}\sqrt{\frac{N_{\text{Ed}}}{\sum EI}} \quad \begin{array}{ll} \leq 0{,}6 & \text{for } n \geq 4 \\ \leq 0{,}2 + 0{,}1\,n & \text{for } 1 \leq n \leq 4 \end{array}$$

When the stiffness is not large enough: calculation (e.g. by Annex B)

5.5 Analysis of structural members

5.5.1 Masonry walls subjected to vertical loading

- calculation method of bending moments, according simplified method of Annex C
- initial eccentricity = h_{ef} / 450
- calculation of effective height of a wall depending on several boundary conditions e.g. floors and intersecting stiffening walls

$$h_{\mathrm{ef}} = \rho_{\mathrm{n}}\, h$$

- ρ_{n} is a reduction factor depending on the edge restraint or stiffening of the wall
- detailed demands for stiffened and stiffening walls
  - stiffening wall has approx. similar deformation behaviour
  - stiffening wall is approx. evenly loaded
  - connection by bonding or other suitable means
  - length of stiffening wall ≥ 1/5 of clear height
  - etc.

5.5 Analysis of structural members

5.5.1 Masonry walls subjected to vertical loading

- calculation of effective thickness of a wall
  - $t_{ef} = t$ for a
    - single leaf wall
    - double-leaf wall
    - faced wall
    - shell bedded wall
    - grouted cavity wall
  - $t_{ef} = \rho_t \, t$ for a wall stiffened by piers
    - ρ_t value depends on the geometrical arrangement of the piers (see Table 5.1 and Figure 5.2)
  - $t_{ef} = \sqrt[3]{k_{tef} t_1^3 + t_2^3}$ for cavity wall connected with wall ties
    - k_{tef} factor for stiffnesses (defined as E_1 / E_2)

      CHOICE FOR THE NA recommended value ≤ 2

5.5 Analysis of structural members

5.5.1 Masonry walls subjected to vertical loading

- slenderness ratio
  - effective height / effective thickness
  - ≤ 27

5.5 Analysis of structural members

5.5.2 Reinforced masonry members subjected to vertical loading

- slenderness ratio
  - for a grouted cavity only 100 mm of the grouted cavity may be used
  - ≤ 27
- effective span of masonry (deep) beams
- redistribution of internal forces
- limiting span of reinforced masonry members (similar to slenderness ratio), see table 5.2

	Ratio of effective span to effective depth (l_{ef}/d) or effective thickness (l_{ef}/t_{ef})	
	Wall subjected to out-of-plane bending	Beam
Simply supported	35	20
Continuous	45	26
Spanning in two directions	45	-
Cantilever	18	7

NOTE For free-standing walls not forming part of a building and subjected predominantly to wind loads, the ratios may be increased by 30 %, provided such walls have no applied finish which may be damaged by deflections.

5.5 Analysis of structural members

5.5.3 Masonry shear walls subjected to shear loading

- influence of intersecting walls (flanges)
- rigid floors as distribution for horizontal forces to shear walls in ratio to their stiffness
- distribution of vertical forces
  - two way spanning equally over the supporting walls
  - one way spanning: 45^0 spread of the load to under laying non load bearing walls

5.5.4 Reinforced masonry members subjected to shear loading

- maximum shear load occurs at a distance of $d/2$ from the face of the support under several conditions

5.5 Analysis of structural members

5.5.5 Masonry walls subjected to lateral loading

- several rules for determining the support conditions
- bending moments for both directions

$$M_{\mathrm{Ed2}} = \alpha_2 \, W_{\mathrm{Ed}} \, l^2 \quad M_{\mathrm{Ed1}} = \alpha_1 \, W_{\mathrm{Ed}} \, l^2$$

  - bending moment coefficients α_1, α_2 from any suitable theory
  - Annex E gives coefficients based o yield line theory, taking the orthogonal strength ratio into account
- limiting dimensions for laterally loaded walls according to annex F

EN 1996-1-1 Section 6 Ultimate Limit State

6.1 Unreinforced masonry walls subjected to mainly vertical loading

6.1.1 General

- plane sections remain plane;
- the tensile strength of masonry perpendicular to bed joints is zero

6.1.2 Verification of unreinforced masonry walls subjected to mainly vertical loading

- Resistance $N_{\mathrm{Rd}} = \Phi\, t\, f_{\mathrm{d}}$
- Φ is the capacity reduction factor allowing for
  - slenderness
  - eccentricity of loading
  - at the top or bottom of the wall
  - in the middle of the wall
- f_{d} is the design compressive strength
  - reduced when gross sectional area < 0.1 m^2 with factpr (0.7 + 3 A)
- each leaf of a cavity wall should be considered separately (using the effective thickness)
- chases larger than specified in 8.6 should be taken into account

EN 1996-1-1 Section 6 Ultimate Limit State

6.1.2 Verification of unreinforced masonry walls subjected to mainly vertical loading

- Φ at the top and the bottom of the wall

$$\Phi_i = 1 - 2\,\frac{e_i}{t}$$

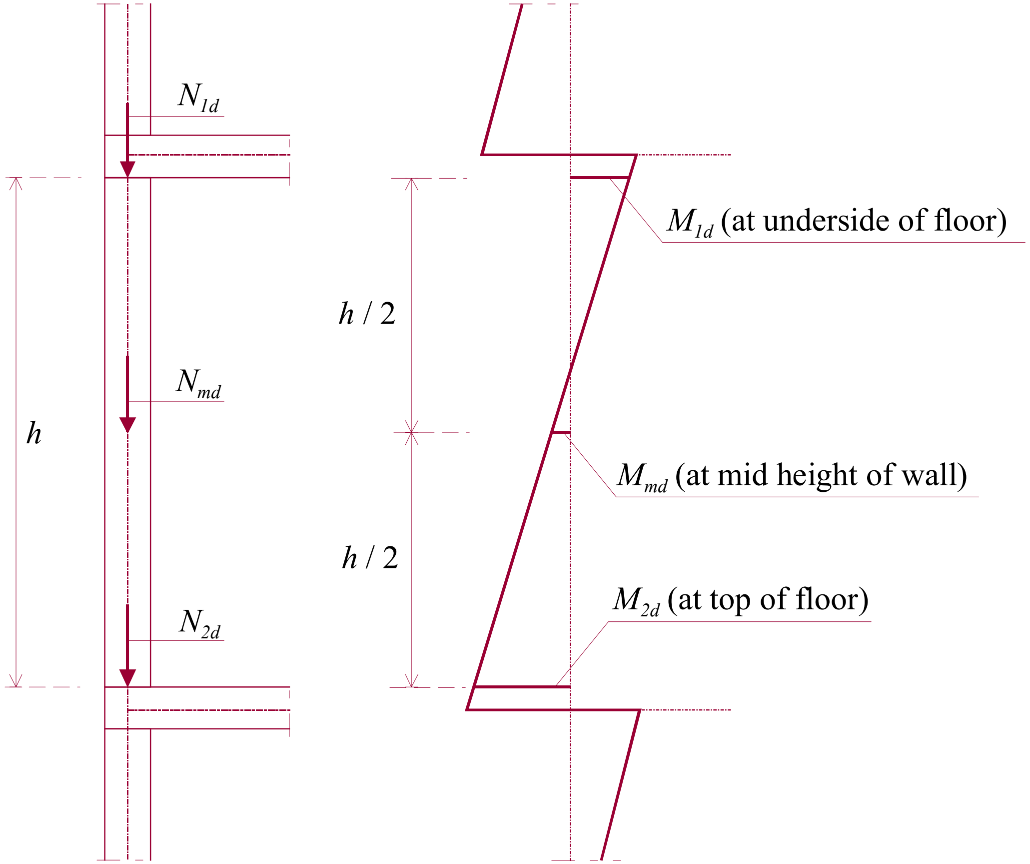
$$e_i = \frac{M_{id}}{N_{id}} + e_{he} + e_{init} \geq 0{,}05\,t$$

- Φ at the middle of the wall
- may be determined from Annex G, using e_{mk}

$$e_{mk} = e_m + e_k \geq 0{,}05\,t$$

$$e_m = \frac{M_{md}}{N_{md}} + e_{hm} \pm e_{init}$$

$$e_k = 0{,}002\,\phi_\infty\,\frac{h_{ef}}{t_{ef}}\sqrt{t\,e_m}$$



- if slenderness ≤ $\lambda_{c:}$ than the creep eccentricity can be neglected
- recommended value is 15

PART OF NA

EN 1996-1-1 Section 6 Ultimate Limit State

6.1 Unreinforced masonry walls subjected to mainly vertical loading

6.1.3 Walls subjected to concentrated loads

- resistance $N_{\mathrm{Rdc}} = \beta\, A_{\mathrm{b}}\, f_{\mathrm{d}}$
- β is an enhancement factor
- several limits on use:
  - eccentricity of the load ≤ t / 4
  - not valid for group 2, 3 and 4 units (β = 1)
  - not valid for shell bedded masonry (β = 1)
- with a spreader beam the area A_{b} can be increased, using the enhancement of the strength under the beam

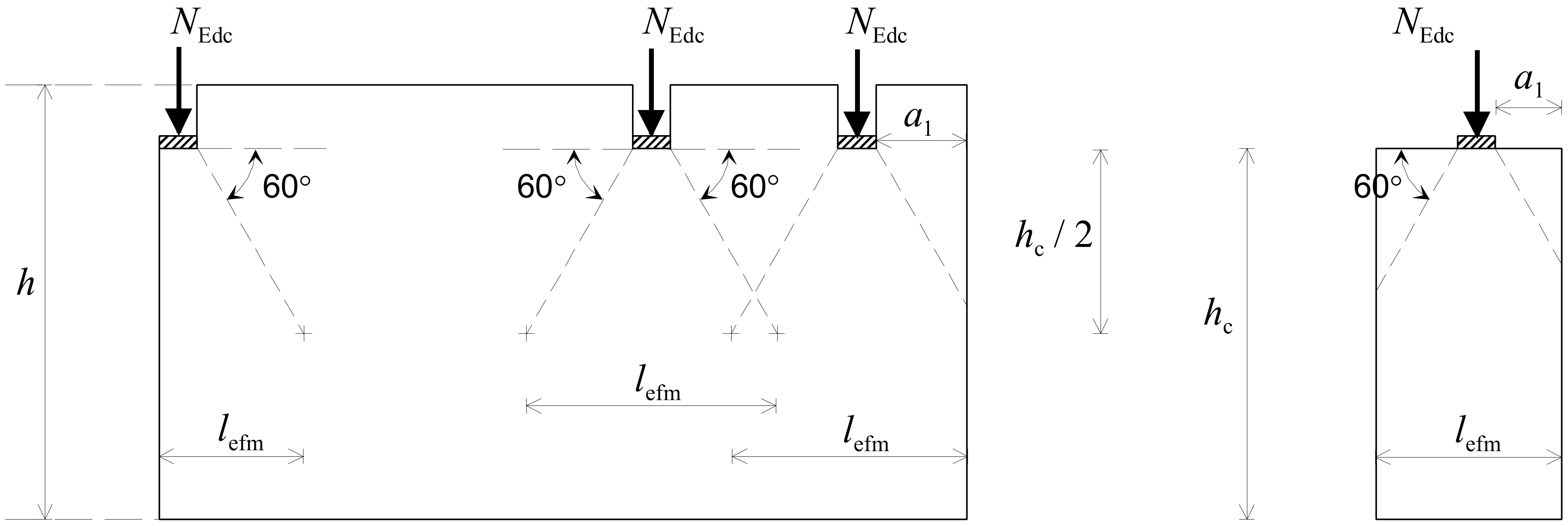
EN 1996-1-1 Section 6 Ultimate Limit State

6.1.3 Walls subjected to concentrated loads

- $1.0 \le \beta \le 1.5$

$$\beta = \left(1 + 0{,}3\,\frac{a_1}{h_c}\right)\left(1{,}5 - 1{,}1\,\frac{A_b}{A_{ef}}\right) \qquad \frac{A_b}{A_{ef}} \le 0.45$$

$$\beta \le 1{,}25 + \frac{a_1}{2\,h_c}$$



EN 1996-1-1 Section 6 Ultimate Limit State

6.2 Unreinforced masonry walls subjected to shear loading

- resistance: $V_{\mathrm{Rd}} = f_{\mathrm{vd}}\, t\, l_{\mathrm{c}}$
- l_{c} is the compressed part of the wall
- connection between shear wall and flanges shall be verified for vertical shear
- compressed part should be verified for the vertical loading

6.3 Unreinforced masonry walls subjected to lateral loading

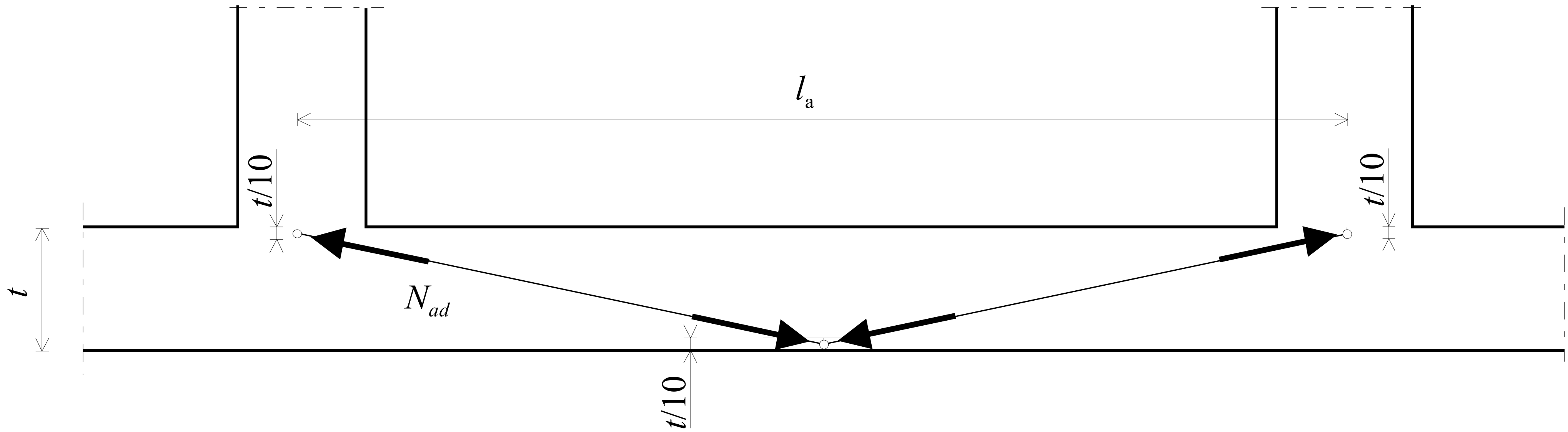
6.3.1 General

- resistance: $M_{\mathrm{Rd}} = f_{\mathrm{xd}} \, Z$
- f_{xd} design flexural strength
  - from chapter 3
  - enhanced by the vertical stress if present
    - $f_{\mathrm{xd1,app}} = f_{\mathrm{xd1}} + \sigma_{\mathrm{d}}$
    - using an enhanced Φ_{fl} factor in the vertical resistance (not given, may part of NCCI))
  - enhanced by reinforcement if designed tot resist lateral loading - 6.6.2 (9)
  - influence of enhanced strength on orthogonal stress ratio should be taken into account
- section modulus Z can be influenced by
  - piers with outstanding length of the flange from the face of the pier as the lesser of:
    - h / 10 for walls spanning vertically between restraints
    - h / 5 for cantilever walls
    - half the clear distance between the piers
  - chases and recesses outside the limits of 8.6
- distribution of load between the leaves in a cavity wall
  - in proportion to their strength or
  - in proportion to their stiffness

6.3 Unreinforced masonry walls subjected to lateral loading

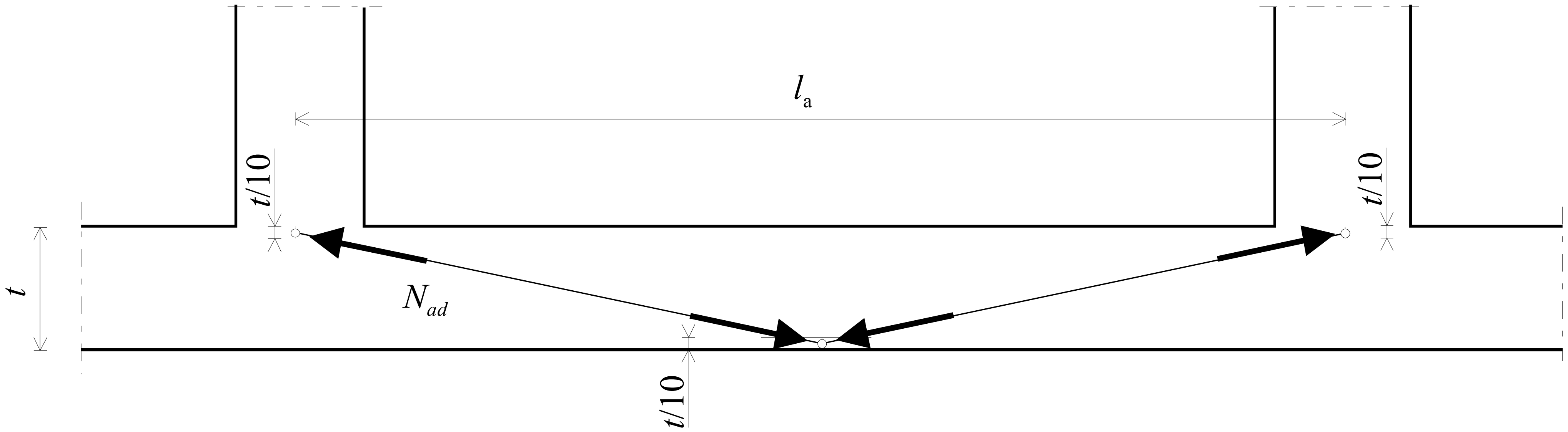
6.3.2 Walls arching between supports

- resistance:
  - design load resistance under arch action
  - design strength of the support
  - analysis may be based on a three-pin arch



6.3 Unreinforced masonry walls subjected to lateral loading

6.3.2 Walls arching between supports



- arch rise: $r = 0{,}9\,t - d_a$
- maximum design arch thrust per unit length: $N_{ad} = 1{,}5\, f_d \dfrac{t}{10}$
- with small lateral deflection: $q_{lat,d} = f_d \left(\dfrac{t}{l_a}\right)^2$
  - design value of vertical stress ≥ 0,1 N/mm^2
  - slenderness ratio ≤ 20

6.3 Unreinforced masonry walls subjected to lateral loading

6.3.3 Walls subjected to wind loading
6.3.4 Walls subjected to lateral loading from earth and water
6.3.5 Walls subjected to lateral loading from accidental situations

Indication of relevant clauses with respect to the loading cases

6.4 Unreinforced masonry walls subjected to combined vertical and lateral loading

Verification either according

- formula (6.2) using a modified Φ factor: Φ_{fl} (not available)
- apparent flexural strength
- equivalent bending moment coefficient according Annex I

EN 1996-1-1 Section 6 Ultimate Limit State

6.5 Ties

For calculation consider:

- differential movement due to
    - temperature differences
    - changes of moisture content
    - actions
- horizontal wind action
- forces due interaction in cavity leaves
- deviation from straightness
- impairment due to handling during execution
- minimum number of ties per unit area: $n_\text{t} \geq \dfrac{W_\text{Ed}}{F_\text{d}}$
    - declared strength acc. EN 845-1
      is not a design value!

6.6 Reinforced masonry members subjected to bending, bending and axial loading, or axial loading

6.6.1 General

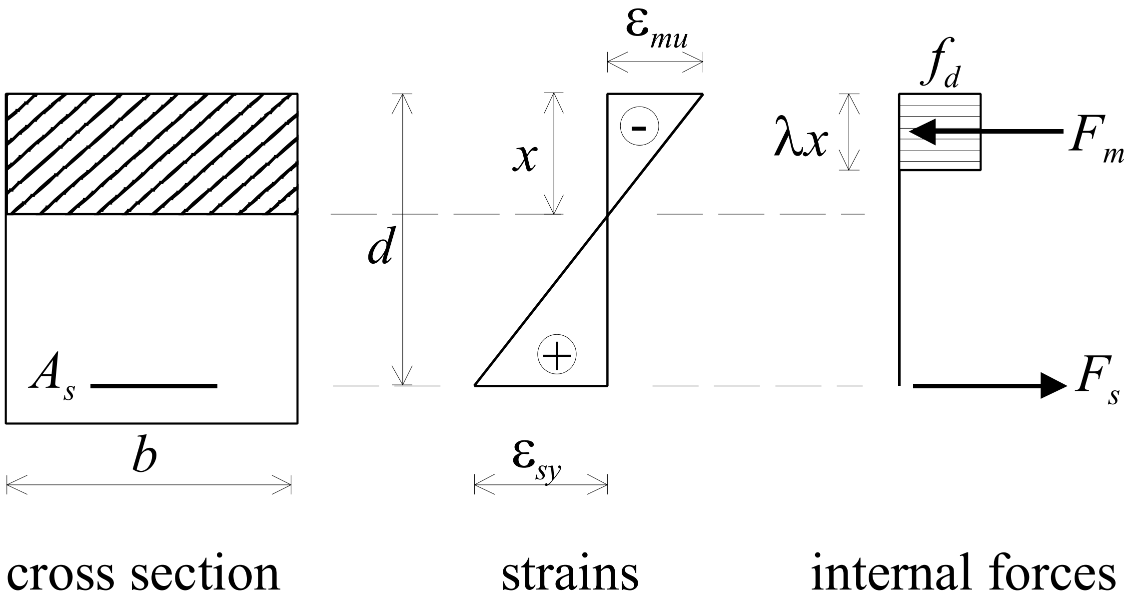
- plane sections remain plane;
- the tensile strength of the masonry is taken to be zero;
- for cross-sections not fully in compression
  - group 1: $\varepsilon_{mu} \leq 0{,}0035$
  - other groups: $\varepsilon_{mu} \leq 0{,}002$
- the σ–ε diagram of masonry may be linear, parabolic, parabolic rectangular or rectangular (see 3.7.1);
- the σ–ε diagram of the reinforcement is obtained from EN 1992-1-1;
- the deformation properties of concrete infill shall be assumed to be as for masonry.
- when a compression zone contains both masonry and concrete infill, the compressive strength should be calculated using a stress block based on the compressive strength of the weakest material.

EN 1996-1-1 Section 6 Ultimate Limit State

6.6.2 Verification of reinforced masonry members subjected to bending and/or axial loading

resistance

- based on general assumptions
- tensile strain of reinforcement ≤ 0.01
- rectangular stress bloc may be assumed



$$M_{\mathrm{Rd}} = A_{\mathrm{s}}\, f_{\mathrm{yd}}\, z$$

$$z = d\left(1 - 0{,}5\,\frac{A_{\mathrm{s}}\, f_{\mathrm{yd}}}{b\, d\, f_{\mathrm{d}}}\right) \leq 0{,}95\, d$$

for group 1 units other than lightweight aggregate units:

$$M_{\mathrm{Rd}} \leq 0.4\, f_{\mathrm{d}}\, b\, d^2$$

for group 2,3,4 and group 1 lightweight aggregate units:

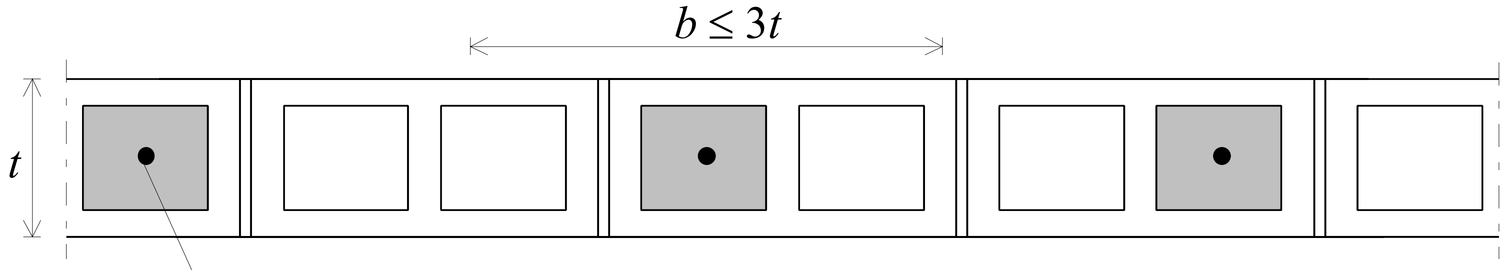
$$M_{\mathrm{Rd}} \leq 0.3\, f_{\mathrm{d}}\, b\, d^2$$

EN 1996-1-1 Section 6 Ultimate Limit State

6.6.2 Verification of reinforced masonry members subjected to bending and/or axial loading

other points to consider

- limitation of reinforced section in case of concentrated reinforcement



- additional moment taking second order effect into account when considered as unreinforced member mainly subjected to vertical loading

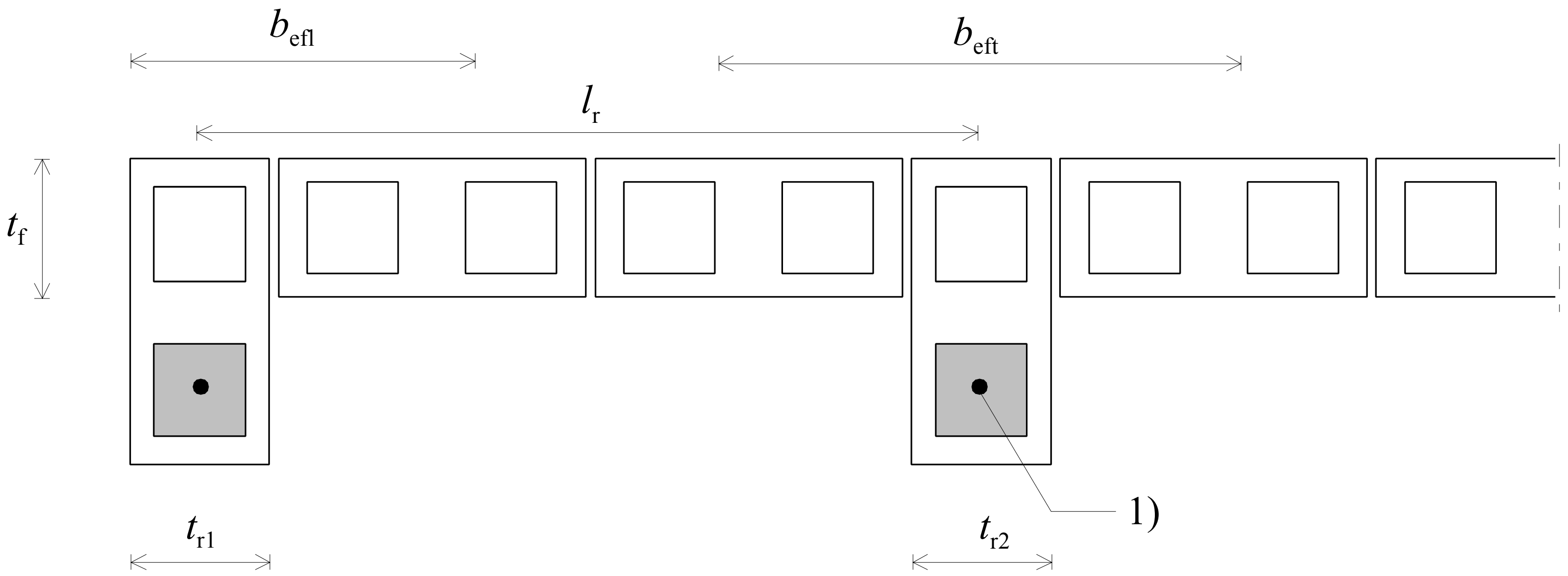
$$M_{\mathrm{ad}} = \frac{N_{\mathrm{Ed}}\, h_{\mathrm{ef}}^{\;2}}{2\,000 \cdot t}$$

- design for bending only is allowed when $\sigma_{\mathrm{d}} \leq 0{,}3\, f_{\mathrm{d}}$

6.6.3 Flanged Reinforced Members

- rules to determine the sectional area

$$b_{\mathrm{efl}} = \text{the lesser of} \begin{cases} t_{\mathrm{r1}} + 6\,t_{\mathrm{f}} \\ l_{\mathrm{r}}/2 \\ h/6 \\ \text{actual width of flange} \end{cases} \qquad b_{\mathrm{eft}} = \text{the lesser of} \begin{cases} t_{\mathrm{r2}} + 12\,t_{\mathrm{f}} \\ l_{\mathrm{r}} \\ h/3 \\ \text{actual width of flange} \end{cases}$$



- limit on bending moment resistance $M_{\mathrm{Rd}} \leq f_{\mathrm{d}}\, b_{\mathrm{ef}}\, t_{\mathrm{f}} \left(d - 0{,}5\, t_{\mathrm{f}}\right)$

EN 1996-1-1 Section 6 Ultimate Limit State

6.6.4 Deep beams

- resistance: according ordinary beams with
- rules for lever arm z that are given
- limit on bending moment same as for ordinary beams
- additional reinforcement needed above main reinforcement to avoid large cracks
- resistance of the compression zone if unrestrained, should be verified against buckling according 6.1.2.

6.6.5 Composite lintels

- design may be based on 6.6.4 when
  - stiffness of prefab part is limited
  - sufficient bearing length ≥ 100 m is provided

EN 1996-1-1 Section 6 Ultimate Limit State

6.7 Reinforced masonry members subjected to shear loading

6.7.1 General

Resistance

- ignoring the contribution of the reinforcement or
- taking the contribution into account when the minimum area according 8.2.3.(5) (0.05%) is provided

6.7 Reinforced masonry members subjected to shear loading

6.7.2 Verification of reinforced masonry walls subjected to horizontal loads in the plane of the wall

resistance

- for walls containing vertical reinforcement $V_{\mathrm{Rd1}} = f_{\mathrm{vd}}\, t\, l$
- for walls containing vertical reinforcement with horizontal shear reinforcement additional resistance: $V_{\mathrm{Rd2}} = 0{,}9\, A_{\mathrm{sw}}\, f_{\mathrm{yd}}$;
- limit on shear resistance: $\dfrac{V_{\mathrm{Rd1}} + V_{\mathrm{Rd2}}}{t\, l} \le 2{,}0\ \mathrm{N/mm^2}$

EN 1996-1-1 Section 6 Ultimate Limit State

6.7 Reinforced masonry members subjected to shear loading

6.7.3 Verification of reinforced masonry beams subjected to shear loading

resistance ignoring the contribution of shear reinforcement: $V_{\mathrm{Rd1}} = f_{\mathrm{vd}}\, b\, d$

- may be increased for presence of longitudinal reinforcement according Annex J
- may be increased near the face of a support with

$$\frac{2\,d}{\alpha_x} \leq 4 \;\; \text{with } f_{\mathrm{vd}} \leq 0.3\mathrm{N/mm}^2$$

6.7 Reinforced masonry members subjected to shear loading

6.7.3 Verification of reinforced masonry beams subjected to shear loading

resistance taking the shear reinforcement into account: $V_{\mathrm{Rd1}} + V_{\mathrm{Rd2}}$

- additional resistance: $V_{\mathrm{Rd2}} = 0{,}9\, d\, \frac{A_{\mathrm{sw}}}{\mathrm{s}}\, f_{\mathrm{yd}} \left(1 + \cot \alpha\right) \sin \alpha$
- total shear resistance is limited: $V_{\mathrm{Rd1}} + V_{\mathrm{Rd2}} \leq 0{,}25\, f_{\mathrm{d}}\, b\, d$

6.7.4 Verification of deep beams subjected to shear loading

- as for ordinary members
- effective depth d = 1.3·z

EN 1996-1-1 Section 6 Ultimate Limit State

6.8 Prestressed masonry

- Principles of EN 1992-1-1 apply
- Design requirements and properties according sections 3, 5 and 6 of EN 1996-1-1
- General guidance

6.9 Confined masonry

Design shall be based on similar assumptions as for unreinforced and reinforced masonry

Verification of confined members

- bending and/or axial loading
  - according assumptions for reinforced masonry
  - reinforcement in compression should be ignored
- shear
  - resistance is the sum of the masonry and the concrete of confining elements
  - for the masonry part the rules for unreinforced masonry applies (using l_c !)
  - reinforcement in the confining elements should not be taken into account
- lateral loading
  - contribution of reinforcement of confining elements may be considered

EN 1996-1-1 Section 7 Serviceability Limit State

7.2 Unreinforced masonry walls

- the SLS need not to be checked when the ULS is satisfied
- allowance difference in properties of masonry where they are interconnected
- damages due to stresses from restraints should be avoided by proper specification and detailing

7.3 Reinforced masonry members

- Deflections will be acceptable when the dimension are with the limits given in 5.5.2.5
- Cracking of reinforced masonry members subjected to bending will be limited so as to satisfy the SLS when the limiting dimensions in 5.5.2.5 and the detailing requirements in section 8 are followed.

EN 1996-1-1 Section 7 Serviceability Limit State

7.5 Confined masonry members

Verification of the SLS shall be based on the assumptions given for reinforced masonry

7.6 Walls subjected to concentrated loads

Bearings that satisfy the ULS may be deemed to satisfy the SLS

EN 1996-1-1 Section 8 Detailing

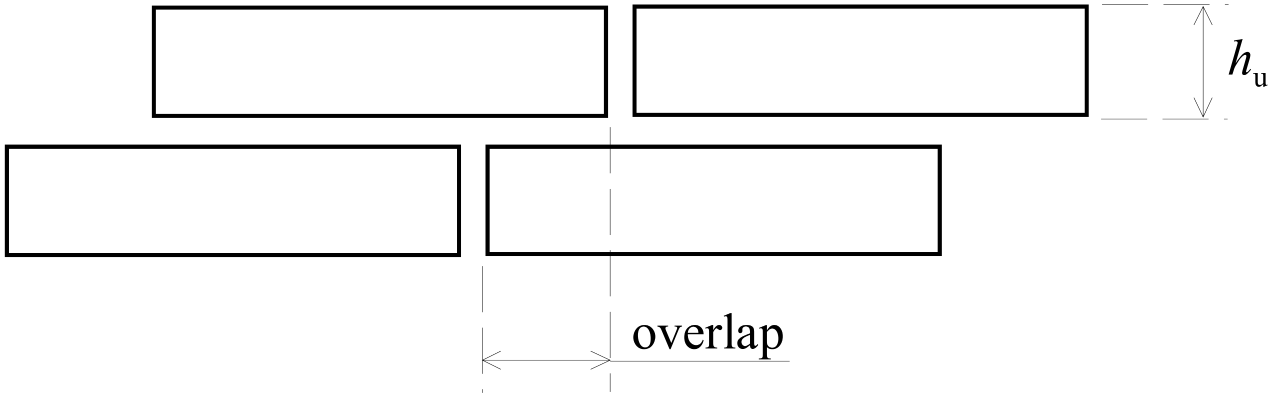
8.1 Masonry details

- Mortar in masonry reinforced with bars should be stronger than M5
- Mortar in masonry with prefabricated bed joint reinforcement should be stronger than M2.5
- Minimum thickness t_{min} of a wall ≥ Outcome of calculation
  - Choice t_{min} may be found in the NA
- Minimum net area of a loadbearing wall 0.04 m^2

EN 1996-1-1 Section 8 Detailing

8.1 Masonry details

- Bonding: minimum overlap:



$$\text{overlap}\begin{cases}\text{when } h_u \le 250\text{ mm: overlap} \ge 0{,}4h_u \text{ or } 40\text{ mm, whichever is the greater}\\ \text{when } h_u > 250\text{ mm: overlap} \ge 0{,}2h_u \text{ or } 100\text{ mm, whichever is the greater}\end{cases}$$

- Bonding arrangements not meeting the minimum overlap may be reinforced where experience exist or experimental data is available

EN 1996-1-1 Section 8 Detailing

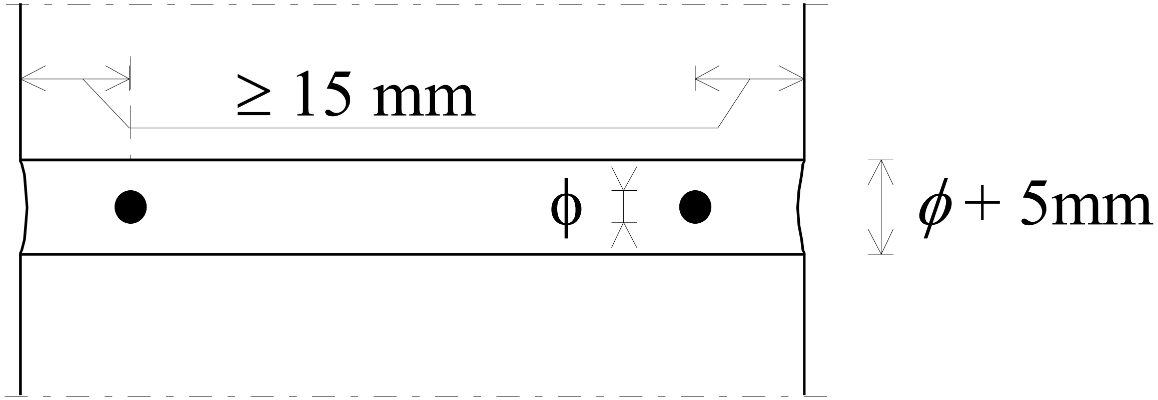
8.1 Masonry details

- Mortar joints
  - General purpose mortar: between 6 and 15 mm
  - Thin layer mortar: between 0.5 and 3 mm
  - NOTE: Joint between 3 and 6 mm can be used with specially developed mortars, the design may be based on the use of general purpose mortar
  - mortar pockets: perpend joint should be filled over full height and 40% of width
  - reinforced masonry subjected to bending and shear: perpend joints fully filled

- Bearing under concentrated loads
  - minimum length of 90 mm

8.2 Reinforcement details

- Cover (for bond strength!)



- Minimum area of reinforcement
  - strength enhancement general: 0.05%
  - strength enhancement for out-of-plane lateral loading 0.03% (0.015% per face)
  - crack control: 0.03%
  - grouted cavity: in the secondary direction 0.05%
  - shear reinforcement in beams (acc. 6.7.3): 0.05%

- Rules for anchorage length, lapping, spacing are also given

8.3 Prestressing details

- see EN 1992-1-1

8.4 Confined masonry details

- top and side elements are to be cats after the masonry has been built
- confining elements should be provide at:
  - every floor level
  - every interception between walls
  - at both sides of openings larger than 1.5 m^2
- minimum area of an element: 0.02 m^2
- minimum dimension of an element: 150 mm
- minimum area of reinforcement
  - 0.8% but not less than 200 mm^2
- stirrups
  - minimum diameter 6 mm
  - maximum distance 300 mm
- bonding of masonry units not fulfilled
  - reinforcement > 6mm distance < 300 mm

8.5 Connection of walls

8.5.1 Connection of walls to floors and roofs

- transfer of lateral loads to the bracing elements should be made by
  - the floor or roof structure, provided the floor or roof structure is capable of developing diaphragm action
  - a ring beam capable of transferring the resulting shear and bending action effects.

- the loads may be transferred by
  - frictional resistance of the bearing of structural members on masonry walls
  - metal straps
    - anchorage in a lightly loaded wall - length of the strap!
    - spacing

      ≤ 2m for building up to 4 storeys, ≤ 1.25 m for higher buildings
  - ring beams
    - in the floor or directly below
    - made of reinforced concrete/masonry, steel or wood
    - be able to resist a direct tensile force of 45 kN
    - reinforced concrete beams at least two bars of 150 mm^2

8.5 Connection of walls

8.5.2 Connection between walls

- Intersections
  - masonry bond
  - connectors or reinforcement extending into each wall
- Cavity and veneer walls
  - minimum number of ties n_{tmin} choice: part of NA recommended value is 2
  - not less than calculated
- Double-leaf walls
  - minimum number of ties j choice: part of NA recommended value is 2
  - not less than calculated

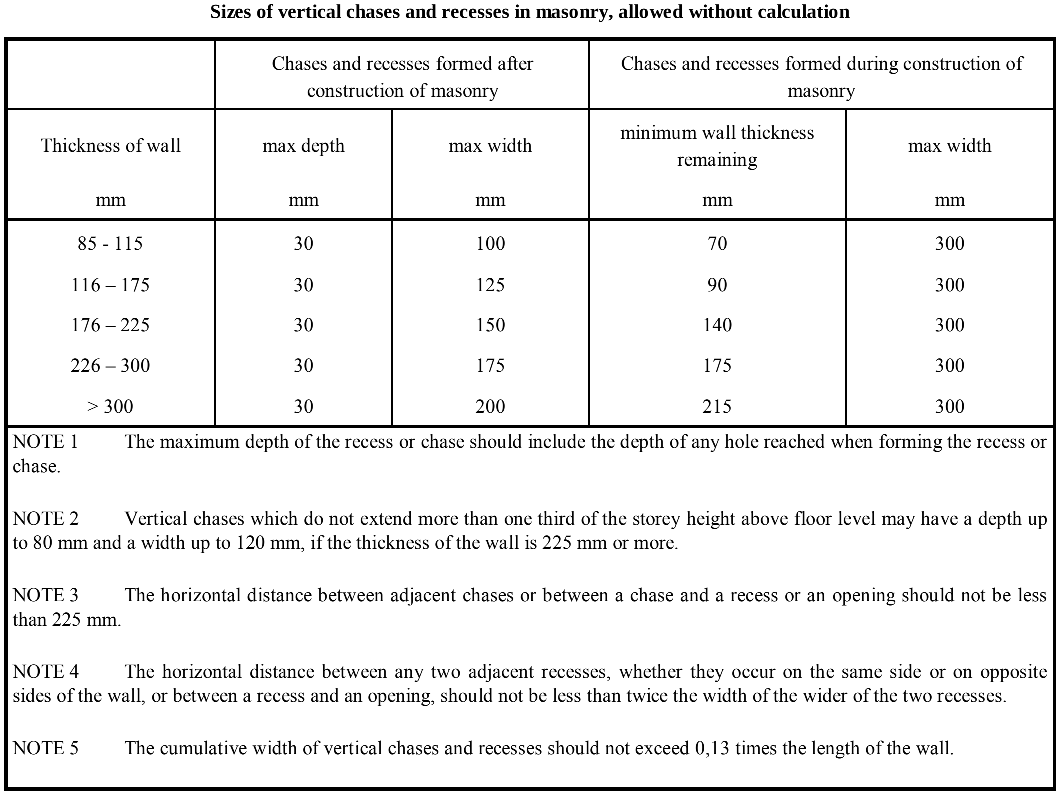
8.6 Chases and recesses on walls

8.6.1 General

- should not pas through lintels
- should not be allowed in a reinforced wall unless designed for

8.6.2 Vertical chases and recesses

- to be neglected if not deeper than $t_{ch,v}$ choice: part of NA



Sizes of vertical chases and recesses in masonry, allowed without calculation

	Chases and recesses formed after construction of masonry		Chases and recesses formed during construction of masonry	
Thickness of wall mm	max depth mm	max width mm	minimum wall thickness remaining mm	max width mm
85 - 115	30	100	70	300
116 – 175	30	125	90	300
176 – 225	30	150	140	300
226 – 300	30	175	175	300
> 300	30	200	215	300

NOTE 1 The maximum depth of the recess or chase should include the depth of any hole reached when forming the recess or chase.

NOTE 2 Vertical chases which do not extend more than one third of the storey height above floor level may have a depth up to 80 mm and a width up to 120 mm, if the thickness of the wall is 225 mm or more.

NOTE 3 The horizontal distance between adjacent chases or between a chase and a recess or an opening should not be less than 225 mm.

NOTE 4 The horizontal distance between any two adjacent recesses, whether they occur on the same side or on opposite sides of the wall, or between a recess and an opening, should not be less than twice the width of the wider of the two recesses.

NOTE 5 The cumulative width of vertical chases and recesses should not exceed 0,13 times the length of the wall.

8.6 Chases and recesses on walls

8.6.3 Horizontal and inclined chases

- should be positioned within one eighth of the clear height of the wall, above or below a floor
- to be neglected if
  - eccentricity ≤ t / 3
  - not deeper than $t_{ch,h}$ choice: part of NA

Sizes of horizontal and inclined chases in masonry, allowed without calculation

Thickness of wall mm	Maximum depth mm	
	Unlimited length	Length ≤ 1 250 mm
85 - 115	0	0
116 - 175	0	15
176 - 225	10	20
226 - 300	15	25
over 300	20	30

NOTE 1 The maximum depth of the chase should include the depth of any hole reached when forming the chase.

NOTE 2 The horizontal distance between the end of a chase and an opening should not be less than 500 mm.

NOTE 3 The horizontal distance between adjacent chases of limited length, whether they occur on the same side or on opposite sides of the wall, should be not less than twice the length of the longest chase.

NOTE 4 In walls of thickness greater than 175 mm, the permitted depth of the chase may be increased by 10 mm if the chase is machine cut accurately to the required depth. If machine cuts are used, chases up to 10 mm deep may be cut in both sides of walls of thickness not less than 225 mm.

NOTE 5 The width of chase should not exceed half the residual thickness of the wall.

EN 1996-1-1 Section 9 Execution

9.1 General

(1)P All work shall be constructed in accordance with the specified details within permissible deviations.

(2)P All work shall be executed by appropriately skilled and experienced personnel.

(3) If the requirements of EN 1996-2 are followed, it can be assumed that (1)P and (2)P are satisfied.

9.2 Design of structural members

(1) The overall stability of the structure or of individual walls during construction should be considered; if special precautions are needed for the site work, they should be specified.

9.3 Loading of masonry

(1)P Masonry shall not be subjected to load until it has achieved adequate strength to resist the load without damage.

(2) Backfilling against retaining walls should not be carried out until the wall is capable of resisting loads from the filling operation, taking account of any compacting forces or vibrations.

(3) Attention should be paid to walls which are temporarily unrestrained during construction, but which may be subjected to wind loads or construction loads, and temporary shoring should be provided, if necessary, to maintain stability.

Consideration of partial factors relating to Execution

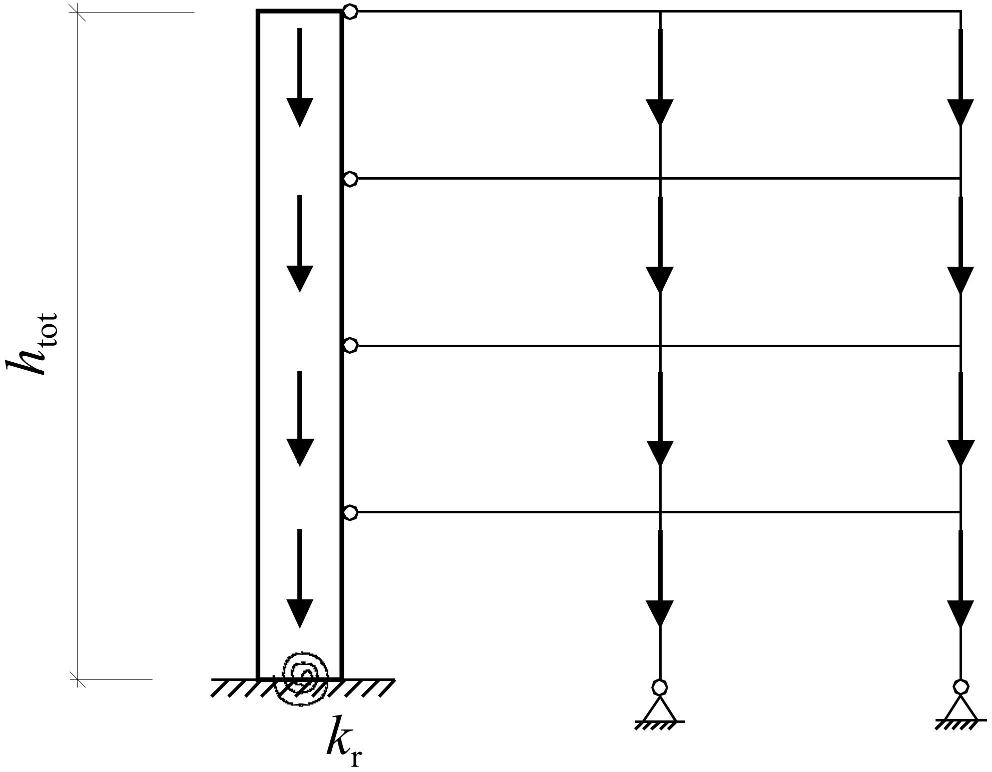
Classes of execution should consider

- appropriately qualified and experienced personnel, employed by the contractor, for supervision of the work;
- appropriately qualified and experienced personnel, independent of the contractor's staff, for the inspection of the work;
- assessment of the site properties of the mortar and concrete infill;
- the way in which mortars are mixed and the constituents are batched

Method for calculating the eccentricity of a stability core

Method

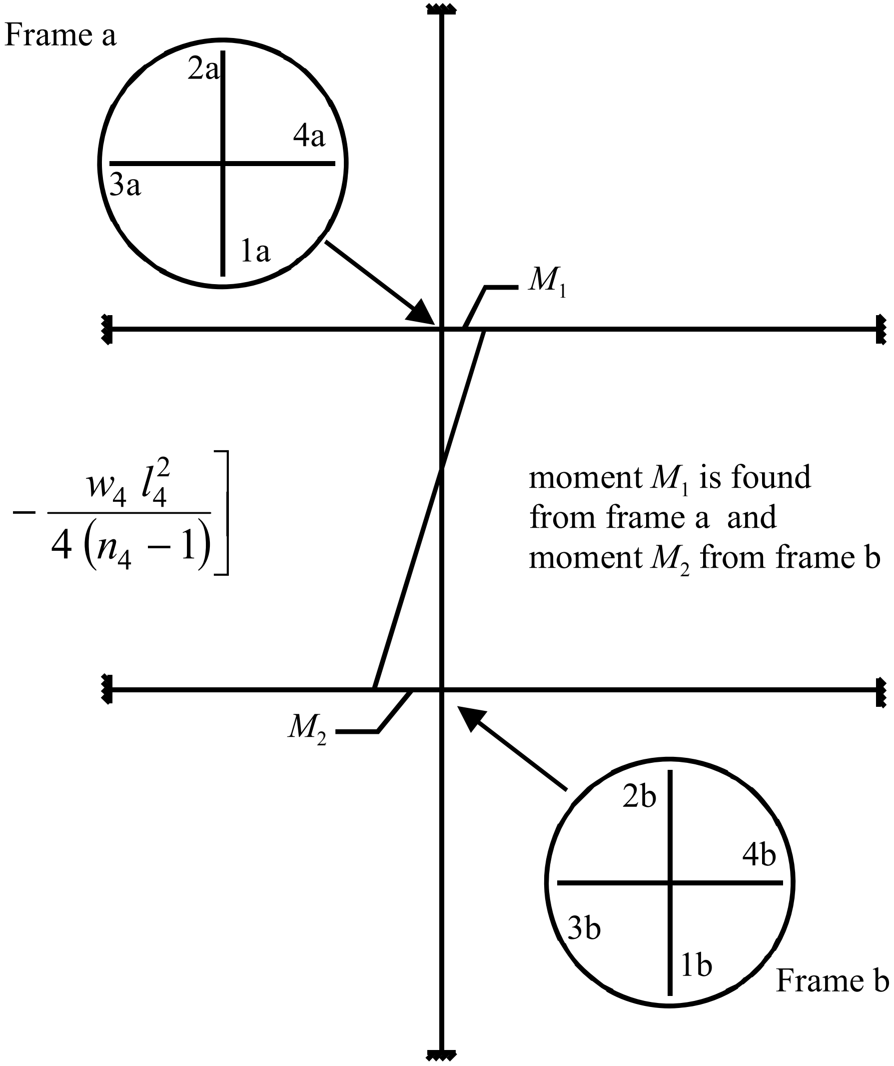
- originates form the Dutch masonry code
- is based on non-linear behaviour of masonry with $\sigma-\varepsilon$ diagram according 3.7.1



A simplified method for calculating the out-of-plane eccentricity of loading on walls

(2) Simplified joint analysis

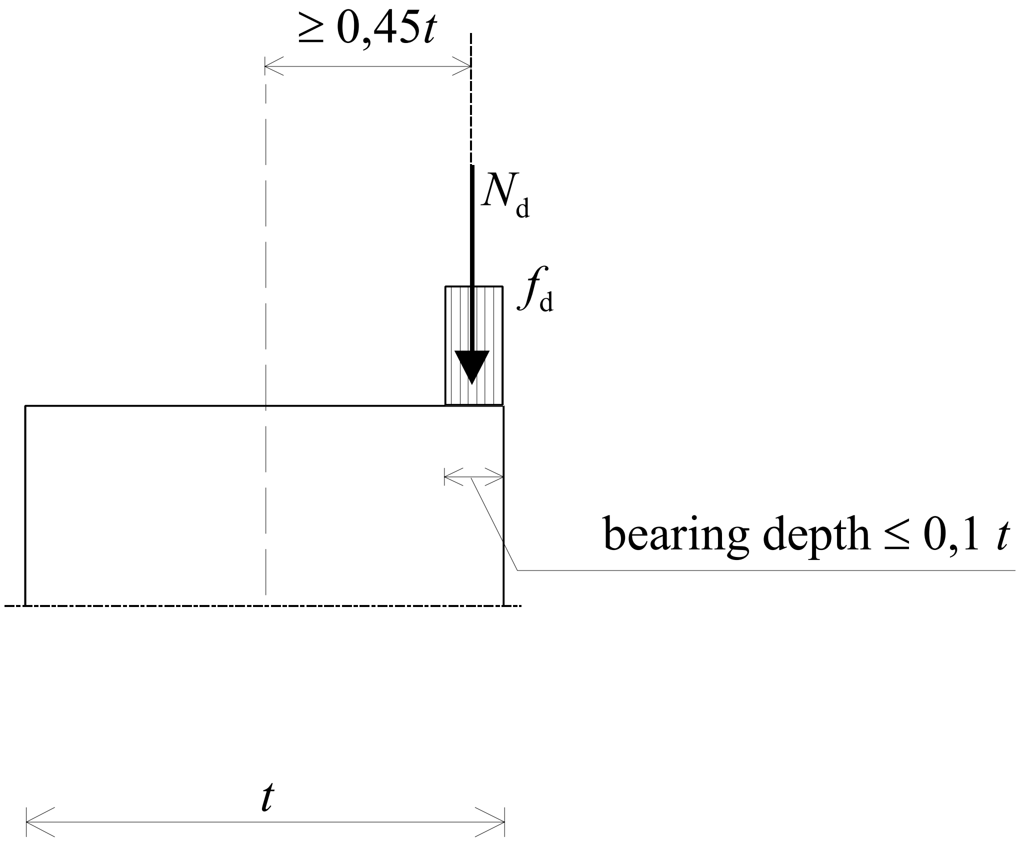
$$M_1 = \frac{\frac{n_1 E_1 I_1}{h_1}}{\frac{n_1 E_1 I_1}{h_1} + \frac{n_2 E_2 I_2}{h_2} + \frac{n_3 E_3 I_3}{l_3} + \frac{n_4 E_4 I_4}{l_4}} \left[\frac{w_3 l_3^2}{4(n_3 - 1)} - \frac{w_4 l_4^2}{4(n_4 - 1)} \right]$$



moment M_1 is found from frame a and moment M_2 from frame b

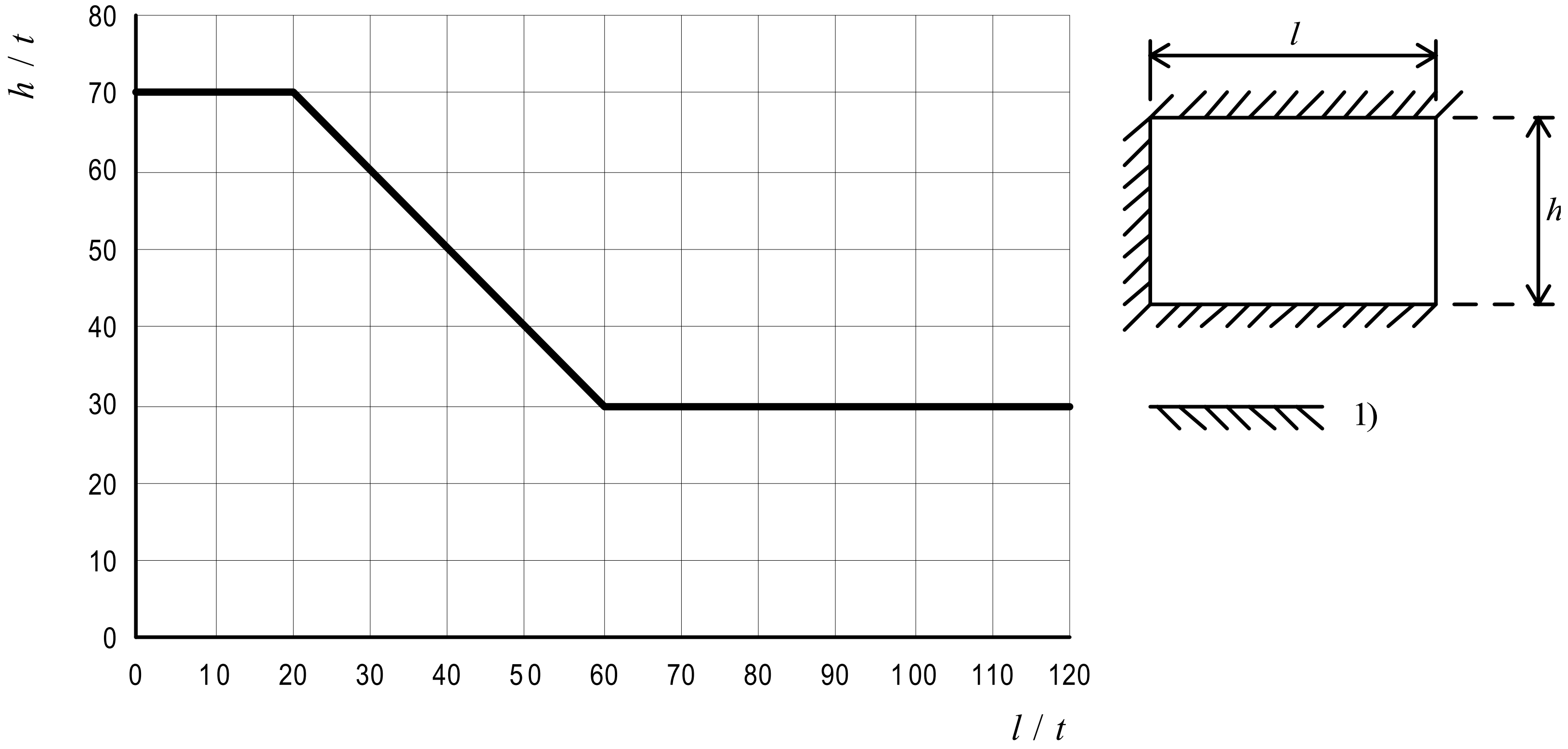
EN 1996-1-1 Annex C (informative)

(5) The eccentricity of loading to be used in design may be based on the load being resisted by the minimum required bearing depth, not taken to be more than 0,1 times the wall thickness, at the face of the wall, stressed to the appropriate design strength of the material (see figure C.2).



Limiting height and length to thickness ratios for walls under the serviceability limit state

Maximum dimensions with respect to SLS for several support conditions



1) simply supported or with full continuity

Reduction factor for slenderness and eccentricity

(in the middle height of the wall)

$$\Phi_m = A_1 \, e^{-\frac{u^2}{2}}$$

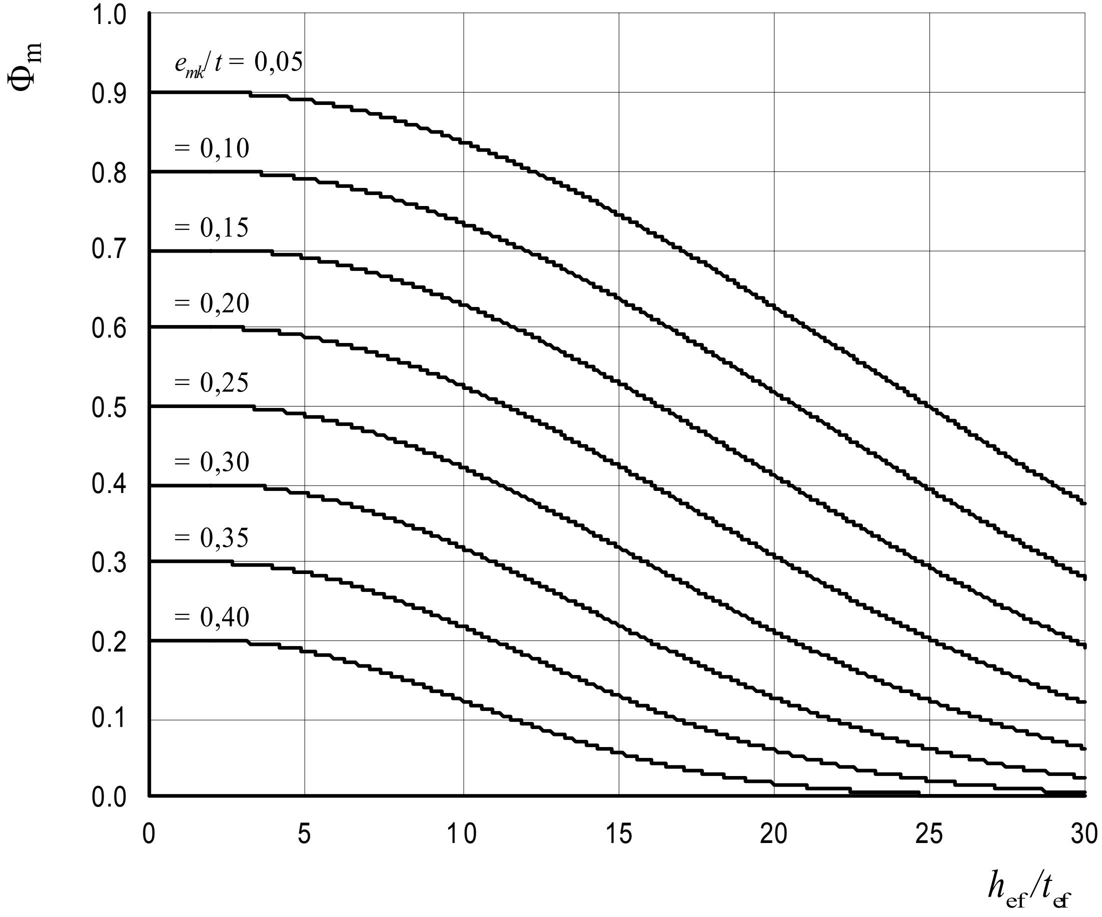


Figure G.1 — Values of Φ_m against slenderness ratio for different eccentricities, based on an E of 1 000 f_k

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Eurocode for Masonry, EN 1996-1-1 and EN 1996-2:
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