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Eurocodes?!



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Background to Eurocode program

- Eliminate technical barriers to trade through harmonisation of technical standards and specifications
- Setting up of harmonised technical rules for design of construction works
 - Initially as alternatives and finally to replace National Standards and specifications
- First generation Eurocodes arrived in 1980s
- Commission and Member States' decision in 1989 to transfer preparation and publication to CEN

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Aim

- To give consistent recommendations in a standard style
- Enabling easy use across materials
 - Calculation flow from roof to foundation, irrespective of materials

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Some Eurocode Definitions

- Packages
- Coexistence
- Nationally determined parameters (NDP)
- Principles and application rules – (P)
- Normative and informative

CPD

- Essential requirements
 - **ER1:** Mechanical resistance and stability
 - **ER2:** Safety in case of fire
 - **ER3:** Hygiene, health and the environment
 - **ER4:** Safety in use
 - **ER5:** Protection against noise
 - **ER6:** Energy, economy and heat retention
- CE mark

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National Standards

as of 2010

- Comprise full text of Eurocodes as published by CEN
- Most have a national title page, national foreword and a national annex
- National annex may only contain information on
 - Values and/or clauses where alternatives are given in Eurocodes
 - Values to be used where a symbol only is given in Eurocodes
 - Country specific data (geographic, climatic, etc)
 - Procedures to be used where alternatives are given or allowed in Eurocodes
 - Decision on application of informative annexes
 - Reference to non-contradictory complementary information (NCCI)

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Eurocode Parts

- EN 1990, Eurocode: Basis of structural design
- EN 1991, Eurocode 1: Actions on structures
- EN 1992, Eurocode 2: Design of concrete structures
- EN 1993, Eurocode 3: Design of steel structures
- EN 1994, Eurocode 4: Design of composite steel and concrete structures
- EN 1995, Eurocode 5: Design of timber structures
- **EN 1996, Eurocode 6: Design of masonry structures**
- EN 1997, Eurocode 7: Geotechnical design
- EN 1998, Eurocode 8: Design of structures for earthquake resistance
- EN 1999, Eurocode 9: Design of aluminium structures

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EN 1996, Eurocode 6

Design of masonry structures

Masonry Product Standards

- EN 771, Specification for masonry units
 - Part 1: Clay masonry units
 - Part 2: Calcium silicate masonry units
 - Part 3: Aggregate concrete masonry units
 - Part 4: Autoclaved aerated concrete units
 - Part 5: Manufactured stone masonry units
 - Part 6: Natural stone masonry units

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Test Standards

- EN 772, Methods of test for masonry units
 - Part 1: Determination of compressive strength
 - Part 2: Determination of percentage of voids...
 - ...
 - ...
 - Part 20: Determination of flatness of faces of masonry units
 - Part 22: Determination of freeze/thaw resistance of clay masonry units

Other Associated Standards

- EN 845 series: Specifications for ancillary components; ties, straps, lintels etc
- EN 998 series: Specification for mortars for masonry
- EN 1015 series: Methods of tests for mortar for masonry
- EN 1052 series: Methods of tests for masonry; compressive, flexural and shear strengths

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BS EN 1996

- Part 1-1: General – Rules for reinforced and unreinforced masonry
- Part 1-2: General rules – Structural fire design
- Part 2: Design consideration, selection of materials and execution of masonry
- Part 3: Simplified calculation methods for unreinforced masonry structures

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Masonry Units

- Categories
- Declared values
- Normalised mean compressive strength
- Grouping

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- Categories

- I: probability of not reaching declared compressive strength < 5%
- II: not intended to comply with category I level of confidence

- Declared values

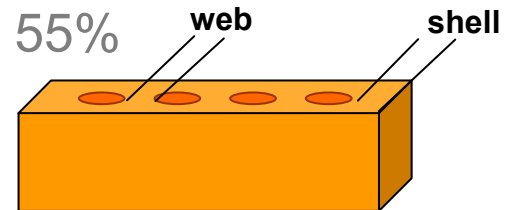
- The mean value of a test sample must not be less than the declared value
- E.g. declared compressive strength for clay units
 - Mean compressive strength of 10 units must be greater than the declared value
 - Any individual result must not be less than 80% of the declared value

- Normalised mean compressive strength
 - Conditioning regimes
 - Air dry and 6% mc – used as reference method
 - Oven dry – x 0.8
 - Immersion in water – x 1.2
 - Shape factor
 - Applied to specimens other than 100mm wide x 100mm high, 0.85 for UK bricks

- Grouping

- Based on geometric requirements

- % holes
- Orientation of holes – vertical or horizontal
- Thickness of webs and shells
- Etc
- UK bricks are Group 1 or 2
 - Group 1 holes $\leq 25\%$
 - Group 2 holes $> 25\% \leq 55\%$



Workmanship or Class of Execution

- There are 5 in EC6
- Classes are described in National Annex
- UK values

	Category of masonry unit	Category of execution control	
		1	2
Compression, γ_m	I	2.3	2.7
	II	2.6	3.0
Flexure, γ_m	I, II	2.3	2.7
Shear, γ_m	I, II	2.5	2.5

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Design Principles

- Based on limit state principles
 - Ultimate
 - Serviceability
- Durability

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Basis of Design

$$E_d \leq R_d$$
$$R_d = R_k / \gamma_m$$

E_d = Design value of effect

R_d = Design value of resistance

R_k = Characteristic value of resistance

γ_m = Material partial safety factor

Mortars

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Compressive strength class	Prescribed mortars				Mortar designations
	cement: lime: sand	cement: sand	masonry cement ^a : sand	masonry cement ^b : sand	
M12	1:0 to ¼: 3	1:3	not suitable	not suitable	(i)
M6	1: ½ :4: 4 ½	1:3 to 4	1:2 ½ to 3 ½	1:3	(ii)
M4	1:1:5 to 6	1:5 to 6	1:4 to 5	1:3 ½ to 4	(iii)
M2	1:2:8 to 9	1:7 to 8	1:5 ½ to 6 ½	1:4 ½	(iv)

a masonry cement without lime

b masonry cement with lime

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Durability

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BS 3921	EN 771-1	
	Freeze/thaw resistance	Active soluble salt content
FL	F2	S2
FN	F2	S1
ML	F1	S2
MN	F1	S1
OL	F0	S2
ON	F0	S1

Characteristic compressive strength

$$f_k = K f_b^\alpha f_m^\beta$$

f_k = characteristic compressive strength of masonry, N/mm²

K = constant, 0.5 for Group1 clay units, 0.4 for Group2 clay units in general purpose mortar, reduced by 20% for construction thicker than 1 unit

α, β = constants, 0.7 and 0.3 respectively for general purpose mortar

f_b = normalised mean comp. strength of unit, N/mm²

f_m = comp. strength of mortar, N/mm²

Wall Geometry

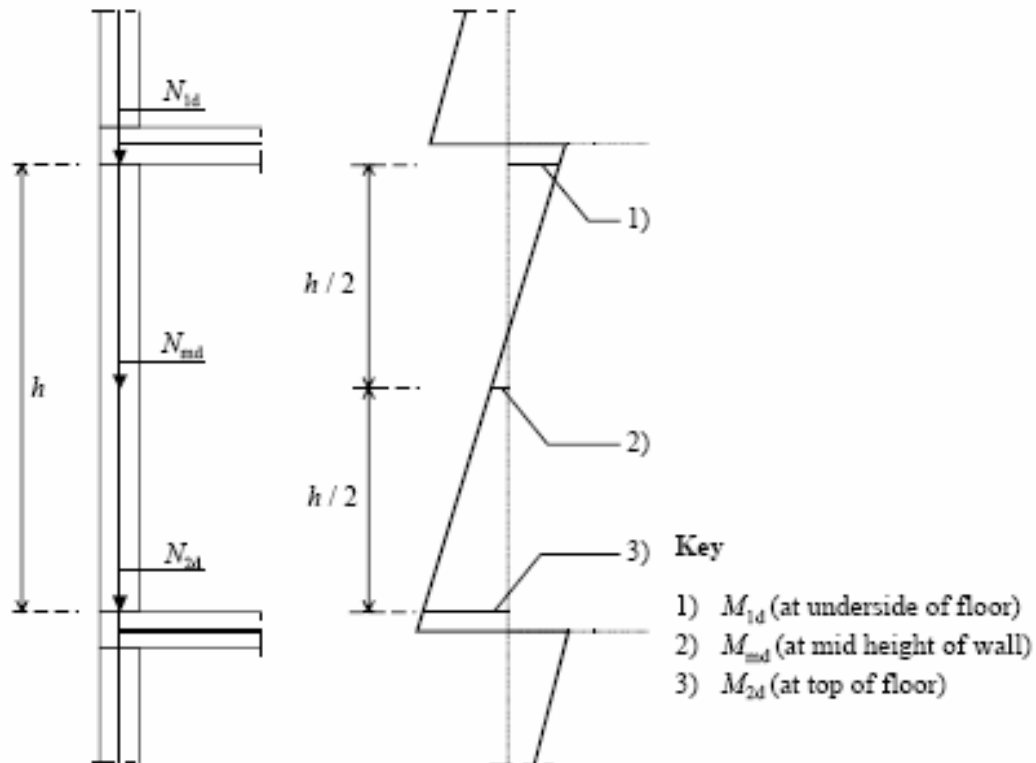
- Effective height, h_{ef}
 - $h_{ef} = \rho_n h$, $\rho_n = 0.75$ or 1.0 depending on top and bottom restraints, further reductions are permitted for vertical restraints
- Effective thickness, t_{ef}
 - $t_{ef} = (t_1^3 + t_2^3)^{1/3}$, t_1 and t_2 are actual thickness of each leaf
- Slenderness ratio
 - $h_{ef} / t_{ef} \leq 27$



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Eccentricity

- Assessed at top, middle and bottom of wall using a sub-frame analysis



Eccentricity - continued

- At top or bottom of wall
 - $e_i = \frac{M_{id}}{N_{id}} + e_{he} + e_{init} \geq 0.05t$
 - M_{id} = design moment at top or bottom of wall
 - N_{id} = design vertical load at top or bottom of wall
 - e_{he} = load related eccentricity at top or bottom of wall from lateral loads
 - $e_{init} = h_{ef}/450$ when $SR \leq 27$

Eccentricity - continued

- Middle of wall

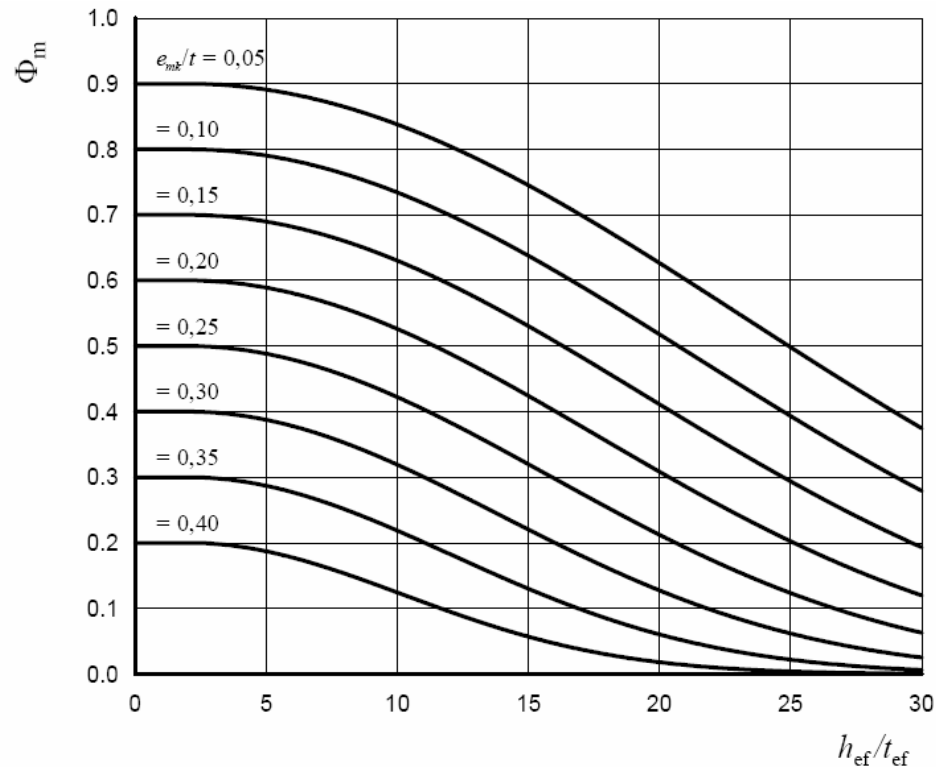
- $e_{mk} = e_m + e_k \geq 0.05t$

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

- $e_k = 0.002\Phi_{\infty} \frac{h_{ef}}{t_{ef}} \sqrt{te_m}$
 - Usually taken as 0

Capacity Reduction Factor, Φ

- $\Phi_i = 1 - 2e_i/t$ top or bottom of wall
- $\Phi_m =$ use graphs



Vertical Load Resistance

- $N_{RD} = \Phi t f_d$
– $f_d = f_k / \gamma_m$

- Therefore

- $N_{RD} = \Phi t f_k / \gamma_m$ - EC6
= $\beta t f_k / \gamma_m$ - BS 5628 -1

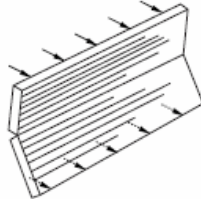
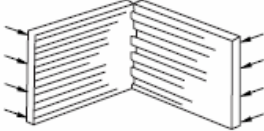
Characteristic Shear Strength

- $f_{vk} = f_{vko} + 0.4\sigma_d$
 - $f_{vk} \leq 0.065 \text{ N/mm}^2$ for filled perpend
 $\leq 0.045 \text{ N/mm}^2$ for unfilled perpend
 - f_{vko} – for clay masonry in GP mortar
 - 0.30 N/mm^2 in M12
 - 0.20 N/mm^2 in M4 and M6
 - 0.10 N/mm^2 in M2

Characteristic Flexural Strength

- Same approach as BS 5628
- f_{xk1} and f_{xk2} in NA same as BS 5628

Table NA.6 Characteristic flexural strength of masonry, f_{xk1} and f_{xk2} , in N/mm²

	Values of f_{xk1} Plane of failure parallel to bed joints			Values of f_{xk2} Plane of failure perpendicular to bed joints		
						
Mortar strength class:	M12	M6 and M4	M2	M12	M6 and M4	M 2
Clay masonry units of groups 1 and 2 having a water absorption (see Note 1) of:						
less than 7%	0,7	0,5	0,4	2,0	1,5	1,2
between 7% and 12%	0,5	0,4	0,35	1,5	1,1	1,0
over 12%	0,4	0,3	0,25	1,1	0,9	0,8

Design Examples

Example 1

- Design parameters:
 - Clay masonry units
 - Declared mean comp. strength = 50 N/mm^2 , Category II
 - Conditioned by air drying
 - Size: 215mm long x 102.5mm wide x 65mm high, Group 1
 - Mortar strength class M4
 - 3000mm high single leaf wall restrained by concrete slabs top and bottom
- Required: concentric load bearing capacity in class 2 execution.

Solution

- Normalised compressive strength of clay unit, f_b = conditioning factor x shape factor x declared mean compressive strength
 - $f_b = 1,0 \times 0,85 \times 50 = 42,5 \text{ N/mm}^2$
- $f_k = K f_b^\alpha f_m^\beta = 0,5 \times 42,5^{0,7} \times 4^{0,3}$
 $= 10,5 \text{ N/mm}^2$
- $h_{ef} = \rho_n h = 0,75 \times 3000 = 2250 \text{ mm}$
- $t_{ef} = t = 102,5 \text{ mm}$
- $h_{ef}/t_{ef} = 2250/102,5 = 22 < 27$ **ok**
- Eccentricities
 - Top and bottom of wall, $e_i = (M_{id}/N_{id}) + e_{he} \pm e_{init} \geq 0,05t$
 - $M_{id}/N_{id} = 0$, concentric load capacity required
 - $e_{he} = 0$, no horizontal loads
 - $e_{init} = h_{ef}/450 = 2250/450 = 5 \text{ mm}$
 - $e_i = 0 + 0 + 5 = 5 \text{ mm} < 0,05t = 5,12 \text{ mm}$ therefore **$e_i = 0,05t$**
 - $\Phi_i = 1 - 2(e_i/t) = 1 - 2(0,05) = 0,9$
 - Middle of wall, $e_m = (M_{md}/N_{md}) + e_{hm} \pm e_{init} \geq 0,05t$
 - $M_{md}/N_{md} = 0$
 - $e_{hm} = 0$, no horizontal loads
 - $e_{init} = h_{ef}/450 = 2250/450 = 5 \text{ mm}$
 - $e_{mk} = 0 + 0 + 5 = 5 \text{ mm} < 0,05t = 5,12 \text{ mm}$ therefore **$e_{mk} = 0,05t$**
 - $\Phi_m = 0,58$, from design curves – **governs design**
- Vertical load capacity = $\Phi t f_k / \gamma_m = 0,58 \times 102,5 \times 10,5 / 3 = 208 \text{ kN/m run}$

Example 2

- Design parameters
 - Clay masonry units
 - Category 1, Group 1
 - 215mm long x 102.5mm wide x 65mm high,
 - Mortar strength class M4
 - 3000mm high cavity wall, both leaves brick, restrained by concrete slabs top and bottom
- 3000mm high inner leaf, restrained by concrete slabs top and bottom
- Required: brick strength for inner leaf to carry a concentric design load of 150 kN/m run in addition to 30 kN/m run at t/3 eccentricity at top of wall. Assume class 1 execution.

Solution

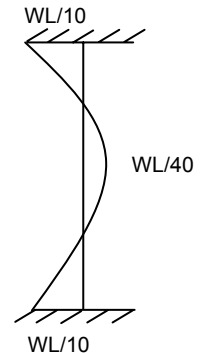
- $t_{ef} = (t_1^3 + t_2^3)^{1/3} = (102,5^3 + 102,5^3)^{1/3} = 129\text{mm}$
- $h_{ef} = 0,75 \times h = 0,75 \times 3000 = 2250\text{mm}$
- $h_{ef}/t_{ef} = 2250/129 = 17,4 < 27$ ok
- Eccentricities
 - Top and bottom of wall, $e_i = (M_{id}/N_{id}) + e_{he} \pm e_{init} \geq 0,05t$
 - $M_{id}/N_{id} = (30 \times t)/3(150 + 30) = 6,2\text{mm}$
 - $e_{he} = 0$, no horizontal loads
 - $e_{init} = h_{ef}/450 = 2250/450 = 5\text{mm}$
 - $e_i = 6,2 + 0 + 5 = 11,2\text{mm} = 0,11t > 0,05t = 5,12\text{mm}$ therefore $e_i = 0,11t$
 - $\Phi_i = 1 - 2(e_i/t) = 1 - 2(0,11) = 0,78$
 - Middle of wall, $e_m = (M_{md}/N_{md}) + e_{hm} \pm e_{init} \geq 0,05t$
 - $M_{md}/N_{md} = 0$
 - $e_{hm} = 0$, no horizontal loads
 - $e_{init} = h_{ef}/450 = 2250/450 = 5\text{mm}$
 - $e_m = 0 + 0 + 5 = 5\text{mm} < 0,05t = 5,12\text{mm}$ therefore $e_m = 0,05t$
 - $\Phi_m = 0,69$, from design curves – **governs design**
 - $N_{Rd} = \Phi t f_d$, $f_d = f_k/\gamma_m$
 - $N_{Rd} = \Phi t f_k/\gamma_m$
 - $f_k = (\gamma_m N_{Rd}) / (\Phi t)$
 - $f_k = (2,3 \times 180) / (0,69 \times 102,5) = 5,85 \text{ N/mm}^2$
 - $f_k = K f_b^\alpha f_m^\beta = 0,5 f_b^{0,7} \times 4^{0,3}$
 - $f_b = (5,85 / (0,5 \times 1,51))^{1/0,7} = 18,6 \text{ N/mm}^2$ – normalised mean value

Example 3

- Design parameters
 - Assume example 1.
- Required: Suitability of the original units to carry a design wind load of 1kN/m^2 in addition to a concentric design vertical load of 180 kN/m run.

Solution

- Normalised compressive strength of clay unit, f_b = conditioning factor x shape factor x declared mean compressive strength
 - $f_b = 1,0 \times 0,85 \times 50 = 42,5 \text{ N/mm}^2$
- $f_k = K f_b^\alpha f_m^\beta = 0,5 \times 42,5^{0,7} \times 4^{0,3} = 10,5 \text{ N/mm}^2$
- $h_{ef} = \rho_n h = 0,75 \times 3000 = 2250 \text{ mm}$
- $t_{ef} = t = 102,5 \text{ mm}$
- $h_{ef}/t_{ef} = 2250/102,5 = 22 < 27$ **ok**
- Eccentricities
 - Top and bottom of wall, $e_i = (M_{id}/N_{id}) + e_{he} \pm e_{init} \geq 0,05t$
 - $M_{id}/N_{id} = 0$, concentric load
 - $e_{he} = (WL/10)/N_{id} = (1 \times 3 \times 3000)/(10 \times 180) = 5 \text{ mm}$
 - $e_{init} = h_{ef}/450 = 2250/450 = 5 \text{ mm}$
 - $e_i = 0 + 5 + 5 = 10 \text{ mm} > 0,05t = 5,12 \text{ mm}$ therefore $e_i = 0,1t$
 - $\Phi_i = 1 - 2(e_i/t) = 1 - 2(0,1) = 0,8$
 - Middle of wall, $e_m = (M_{md}/N_{md}) + e_{hm} \pm e_{init} \geq 0,05t$
 - $M_{md}/N_{md} = 0$
 - $e_{hm} = (WL/40)/N_{md} = (1 \times 3 \times 3000)/(40 \times 180) = 1,3 \text{ mm}$
 - $e_{init} = h_{ef}/450 = 2250/450 = 5 \text{ mm}$
 - $e_{mk} = 0 + 1,3 + 5 = 6,3 \text{ mm} > 0,05t = 5,12 \text{ mm}$ therefore $e_{mk} = 0,06t$
 - $\Phi_m = 0,55$, from design curves – **governs design**
- Vertical load capacity = $\Phi t f_k / \gamma_m = 0,55 \times 102,5 \times 10,5 / 3 = 197 \text{ kN/m run}$



Example 4

Masonry infill to framed structures

- Design parameters
 - Cavity wall construction in brickwork, water absorption between 7% and 12 %, in mortar strength class M4, category II units in class 2 execution
 - Characteristic wind load = 1,0 kN/m²
- Required: Assess suitability of a wall panel 6m long x 3m high to sustain lateral load assuming simple supports top and bottom and continuous supports either side



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Solution using Annex E of 1996-1-1

- Design wind load = $1,5 \times 1,0 = 1,5 \text{ kN/m}^2$ – leading variable action
- $f_{xk1} = 0,4 \text{ N/mm}^2$, $f_{xk2} = 1,1$
- $\mu = 0,4/1,1 = 0,36$
- $h/l = 3000/6000 = 0,5$
- $\alpha_1 = 0,025$
- $M_{Rd} = f_{xd} Z$
 $= (1,1)/(2,7) \times 102,5^2 \times 10^{-3} / 6 = 0,71$
kNm/m – each leaf, 1.43 kNm/m - both leaves
- $M_{ed} = 0,025 \times 1,5 \times 6000^2 / 10^6 = 1.35 \text{ kNm/m} < 1.43 \text{ kNm/m}$ - ok

Further Information

- Eurocode expert
 - www.eurocodes.org.uk
- International Masonry Society
 - www.masonry.org.uk
- The Brick Development Association
 - www.brick.org.uk
- Eurocode 6 website
 - www.eurocode6.org
- BSI

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