EN 1996 DESIGN OF MASONRY STRUCTURES

- REINFORCED AND PRESTRESSED MASONRY -

2 and 3 April 2009 - Brussels

Presented by Peter Watt

Charlwood Partnership Ltd

EN 1996-1-1 Design

Reinforced	**-**	**Principles**	**Yes**
	-	**Application Rules**	**Yes**
Prestressed	**-**	**Principles**	**Yes**
	-	**Application Rules**	**None**

Mortars

Mortars

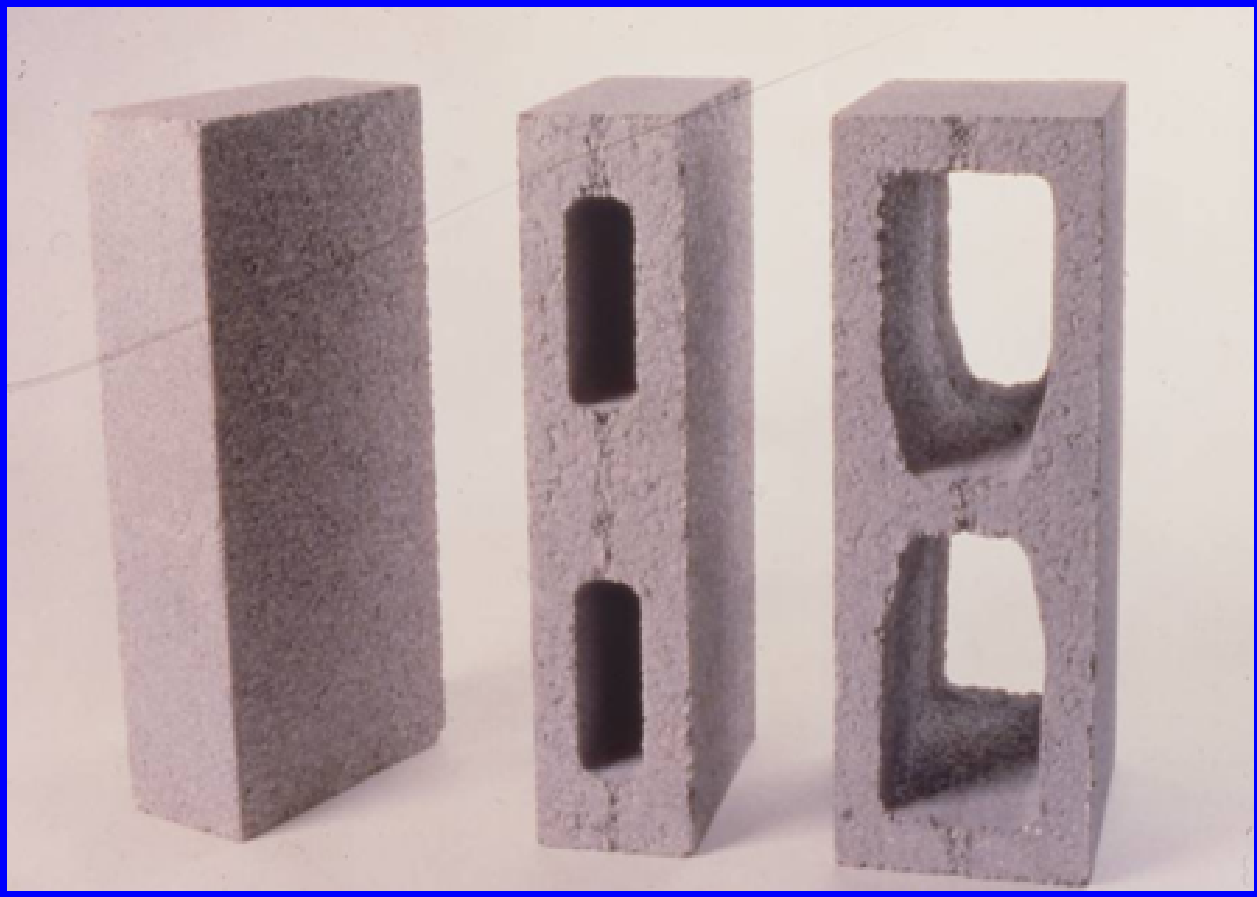
EC6 Mortars and Their Uses

M4 minimum strength class for reinforced/pre-stressed work

M2 minimum strength class for bed joint reinforced walls to – enhance resistance to lateral loads

Thin layer mortars and lightweight mortars "could" be used – BUT lightweight mortars are not advised in this type of work

Masonry Units



Masonry Units

EC6 Masonry Units

No specific minimum unit compressive strength required

Some National Standards have minimum masonry unit - compressive strength requirements; for example 7 N/mm^2 - in British design code BS5628 Part 2

EN 1990 Basis of Structural Design (Actions)

- $\gamma_{Gj,sup}G_{kj,sup} + \gamma_{Q,1}Q_{k,1} + \gamma_{Q,i}\Psi_{0,i}Q_{k,i}$ is EN1990 general form

UK National Annex to EN1990 has adopted :

$$1.35G_k + 1.50Q_{k,1} + \Psi Q_{k,i} \text{ etc}$$

with $1.5Q_{k,1}$ as leading variable action

PARTIAL SAFETY FACTORS γ – ULS
dead and imposed actions - dead & imposed other than wind

Load type	G_k	Q_k	Comment
EC6 UK N/A	1.35 *1.0 fav.*	1.50 leading variable action	1.43 mean (-5% diff.)
BS5628	1.40 *0.9 fav.*	1.60	1.50 mean

PARTIAL SAFETY FACTORS γ – ULS
dead and imposed actions – wind actions on panels

Load type	G_k	Q_k	Comment
EC6 UK N/A	1.35	1.50 leading variable action	1.50 (+25% diff.)
BS5628	1.40	1.20 *1.40 stab.*	1.20

PARTIAL SAFETY FACTORS γ – ULS
dead and imposed actions – earth walls

Load type	G_k	Q_k	Comment
EC6 UK N/A	1.35	1.50 1.35 as permanent action	1.50 (+4% eff. diff.) 1.35 (-6% eff. diff.)
BS5628	1.40	1.20 E_u	1.44 eff.

PARTIAL SAFETY FACTORS γ_m – ULS
compression, shear, bond, steel

	EC6 UK N/A	EC6 DE N/A
Compression strength Cat I	2.0	1.76
Compression strength Cat II	2.3	---
Shear strength	2.0	1.5
Bond strength	1.5	1.5
Steel strength	1.15	1.15

Partial Safety Factors γ_m - ULS

BUT :

- $f_k = K f_b^{\alpha} f_m^{\beta}$
- $f_d = f_k / \gamma_m$

where K , α , β and γ_m are all NDP values to be nationally - selected on safety basis

COMPARISON OF f_k VALUES
Group 1 clay brick masonry – standard format - 102.5mm wide wall

Comp. Strength f_b	EC6 UK N/A f_k		BS5628 f_k		% Difference	
	M12	*M2*	M12	*M2*		
7	3.7	*2.1*	3.6	*2.8*	+3 &	*-25*
20	7.7	*4.5*	7.4	*4.7*	+4 &	*-4*
40	12.4	*7.3*	11.5	*7.0*	+8 &	*+4*
60	16.5	*9.7*	15.0	*9.0*	+10 &	*+8*
80	20.2	*11.8*	18.2	*10.7*	+11 &	*+10*
100	23.6	*13.8*	21.0	*12.1*	+12 &	*+14*

COMPARISON OF f_k VALUES
Group 1 clay brick masonry – standard format - 328mm wide wall

Comp. Strength f_b	EC6 UK N/A f_k		BS5628 f_k		% Difference
	M12	*M2*	M12	*M2*	
7 5.95	2.9	*1.7*	3.2	*2.4*	-9 & *-29*
20 17.00	6.1	*3.6*	6.4	*4.1*	-5 & *-12*
40 34.00	10.0	*5.8*	10.0	*6.1*	0 & *-5*
60 51.00	13.2	*7.7*	13.0	*7.9*	+2 & *-3*
80 68.00	16.2	*9.4*	15.8	*9.3*	+3 & *+1*
100 85.00	18.9	*11.0*	18.3	*10.5*	+3 & *+5*

COMPARISON OF f_k VALUES
Group 1 concrete block masonry – 215 by 100mm – 100mm wide wall

Comp. Strength f_b		EC6 UK N/A f_k		BS5628 f_k		% Difference
		M12	*M2*	M12	*M2*	
2.9	4.40	3.0	*1.9*	2.8	*2.8*	+7 & *-32*
3.6	5.46	3.7	*2.2*	3.5	*3.5*	+6 & *-37*
5.2	7.89	4.9	*2.9*	5.0	*4.4*	-2 & *-34*
7.3	11.08	6.2	*3.6*	6.8	*5.6*	-9 & *-36*
10.4	15.79	8.0	*4.7*	8.8	*7.0*	-9 & *-33*
22.5	34.16	13.7	*8.0*	15.0	*10.5*	-9 & *-24*

REINFORCED MASONRY

EC6 Bending Elements

- **Straightforward singly reinforced sections achievable as :**
  - **Beams simple span or continuous spans**
  - **Grouted cavity walls**
  - **Hollow blockwork walls**
  - **Grouted pocket walls**
  - **Quetta bond walls**
  - **Deep beams etc.**

EC6 Bending Elements

- EC6 enables :
  - Compression block check
  - Calculation of tensile steel area
  - Check shear capacity and size/calculate shear links
  - Flanged sections are included
  - Verify serviceability by span/depth ratios

Does not directly deal with doubly reinforced sections

EC6 Bending Elements

AND

- **For beams compression capacity = $0.27 f_d\, bd^2$**
- **For cantilever walls compression capacity = $0.40 f_d\, bd^2$**

  Or = $0.30 f_d\, bd^2$ for Groups 2, 3 & 4 and L. Agg. Units

for flanged section :

- **$M_{Rd} = f_d\, b_{ef}\, t_f\, (d - 0.5 t_f)$ is design compression capacity**

EC6 Bending Elements

Where :

- $M_{Rd} = A_s f_{yd} z$ is the section design moment capacity
- $z = d\{1 - 0.5(A_s f_{yd} / bd f_d)\} \leq 0.95d$ is the lever arm

No user friendly interaction curves or simplified equations to - directly deduce lever arm depth

EC6 Bending Elements

- **Shear and shear span enhancement as :**
  - **For beams shear capacity = f_{vd} bd for unreinforced section**

    with shear span enhancement to f_{vd} of $2d/a_x \leq 4$ applicable

    And = f_{vd} bd + $(0.9d\ A_{sw}\ f_{yd}/s)(1 + \cot\alpha)\sin\alpha$ for reinforced - section (links)

    where reinforced section shear capacity is $0.25f_d$ bd limiting

EC6 Bending Elements

- Shear and shear span enhancement of f_{vd} as :

  - Annex "J" modifies f_{vd} to $(0.35N/mm^2 + 17.5\rho) / \gamma_M$ - and revised shear span enhancement for concrete - grouted reinforcement in beams and walls without - designed shear reinforcement (Annex is Informative)

  BUT

  - EC6 does allow M4 mortars which are not compatible - with $0.35N/mm^2$ initial shear strength (high). National - Annex material required or NCCI material

LIMITING SPAN TO DEPTH RATIOS - SERVICEABILITY
Reinforced masonry members subjected to bending

	Effective Span to Wall – out of plane bending	Depth Ratio Max. Beam
Simply supported	35	20
Continuous	45	26
Spanning two directions	45	-
Cantilever	18	7

EC6 Bending Elements

- Deep beam design and design equations included :

- For beams compression capacity = $0.40 f_d\, bd^2$

  Or = $0.30 f_d\, bd^2$ for Groups 2, 3 & 4 and L. Agg. Units

  where z the lever arm is lesser of:

  $0.7 l_{ef}$ and $0.4h + 0.2 l_{ef}$

  and d = 1.3z by EC6 definition

EC6 Column (Strut) Elements

- **Principles included :**
  - **Short and slender columns design**
  - **Axial and combined axial/bending effects design**
  - **Includes additional moment equation for slender columns**
  - **No interaction equations for combined axial/bending design**
  - **Steel strength f_{yd} not modified by 0.83 as in British design - standard BS5628 Pt. 2 for compression part of section**

EC6 Column (Strut) Elements

Some Application Rules missing from EC6 for reinforced design

e.g. combined vertical load and bending equation forms :

$$N_{Rd} = f_d\, b\, d_{cm} + f_{s1}\, A_{s1}/\gamma_m - f_{s2}\, A_{s2}/\gamma_m$$ - vertical load capacity

$$M_{Rd} = 0.5 f_d\, d_{cm}\, (t_o - d_{cm}) + 0.83\, f_{yd}\, A_{s1}\, (0.5 t_o - d_1) + f_{s2}\, A_{s2}\, (0.5 t_o - d_2)/\gamma_m$$ - moment capacity

where: γ_m is the steel partial safety factor in this case

EC6 Racking Wall Elements

- **Principles and Application Rules included :**

  - For walls shear capacity = $f_{vd}\, tl$ for unreinforced section

    And = $f_{vd}\, tl + 0.9 A_{sw}\, f_{yd}$ for reinforced section

    where $(f_{vd}\, tl + 0.9 A_{sw}\, f_{yd}) / tl$ is $2.0 N/mm^2$ limiting

EC6 Bed Joint Reinforced Walls

- Principles and Application Rules included :
  - Basic singly reinforced section in EC6
  - Modified orthogonal ratio method included
  - No serviceability over-ride (as in BS5628 Part 2)
  - No separate limiting panel dimensions given

EC6 Anchorage Bond and Lap

- Principles and Application Rules included :
  - Tables 3.5 and 3.6 give f_{bok} values
  - Bond length calculation as ø $f_{yd}/4\ f_{bod}$ (as EC6 amendment)
  - Reinforcement cut off calculations given
  - Hooks, bends effective anchorage lengths set out to - develop anchorage lengths
  - Detailing requirements on straight laps quite onerous

EC6 Anchorage Bond Calculation

- $l_b = \phi f_{yd} / 4 f_{bod}$

  Minimum straight lap detailing :

  = l_b for tension/compression bars where < 30% - bars are lapped and ≥ 10 bar ø's between bars

  = 1.4 l_b for tension bars where ≥ 30% bars are - lapped or < 10 bar ø's between bars

  = 2 l_b for tension bars where ≥ 30% bars are - lapped and < 10 bar ø's between bars

Durability

- **Principles and Application Rules included :**
  - **There are 5 MX durability classes**
  - **Concrete mixes/covers table given (NDP values)**
  - **Extensive guidance given on bed joint reinforcement - requirements; and cover to bed joint reinforcement in - mortar**

Summary of Differences EC6/BS5628 Pt. 2

- Partial load factors γ_f are only about ±5% different - except laterally loaded wind panels +25%
- Partial material factors γ_m are same
- Many design equations (Application Rules) are - same or very similar with few exceptions shown
- Otherwise dependant upon any real differences in - material characteristic strength values such as f_k

PRESTRESSED MASONRY

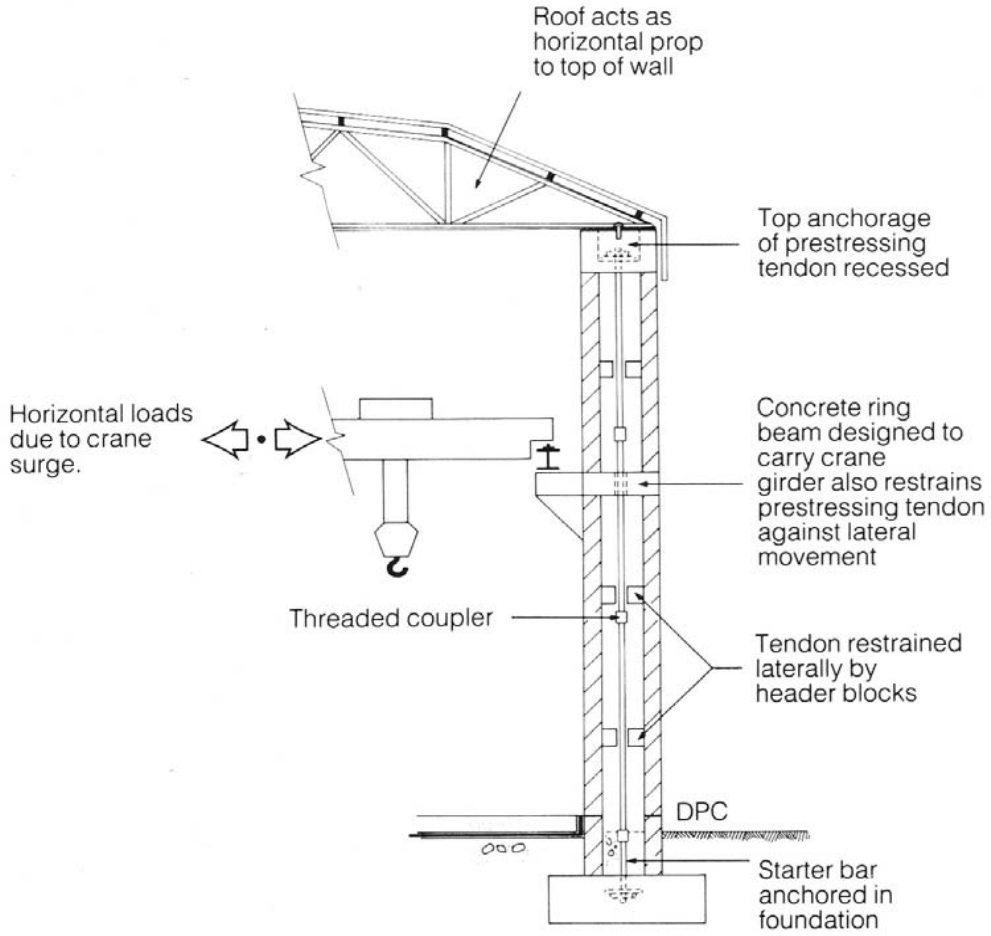


Figure **Prestressed blockwork diaphragm wall to tall industrial building.**

No Application Rules in EC6 for prestressed design resistance

Actions, materials and partial safety factors same as reinforced

Bending, shear, compression and losses equations not included,

e.g. :

- $M_u = f_{pb} A_{ps} z$ for basic bending capacity missing
- $V_u = \nu d_0 b$ for basic shear capacity missing
- $l_t = K_t \phi_t / \sqrt{f_{ci}}$ for transmission length missing

Up to each country's NCCI's to deal with

REINFORCED MASONRY DESIGN GUIDANCE

EC6 Design Guidance Worked Examples

- 3 No. fully worked design examples as :
  - Reinforced pocket wall
  - Reinforced short and slender columns with - axial and bending actions
  - Reinforced simple spanning beam element

*Provided in delegates packs

EC6 Design Guidance Worked Examples

- **Reinforced pocket wall :**
  - **Limiting moment does not effect design output - or masonry section thickness/pocket centres**
  - **Tensile reinforcement same bar size/number; - IMS Guide interaction curve / ”c” factor used**
  - **Shear not restrictive**
  - **Serviceability same limiting conditions**
  - **Concrete infill/cover required same**
  - **Straight lap length for lapped bars doubled - (40% increase for most grouted cavity walls)**

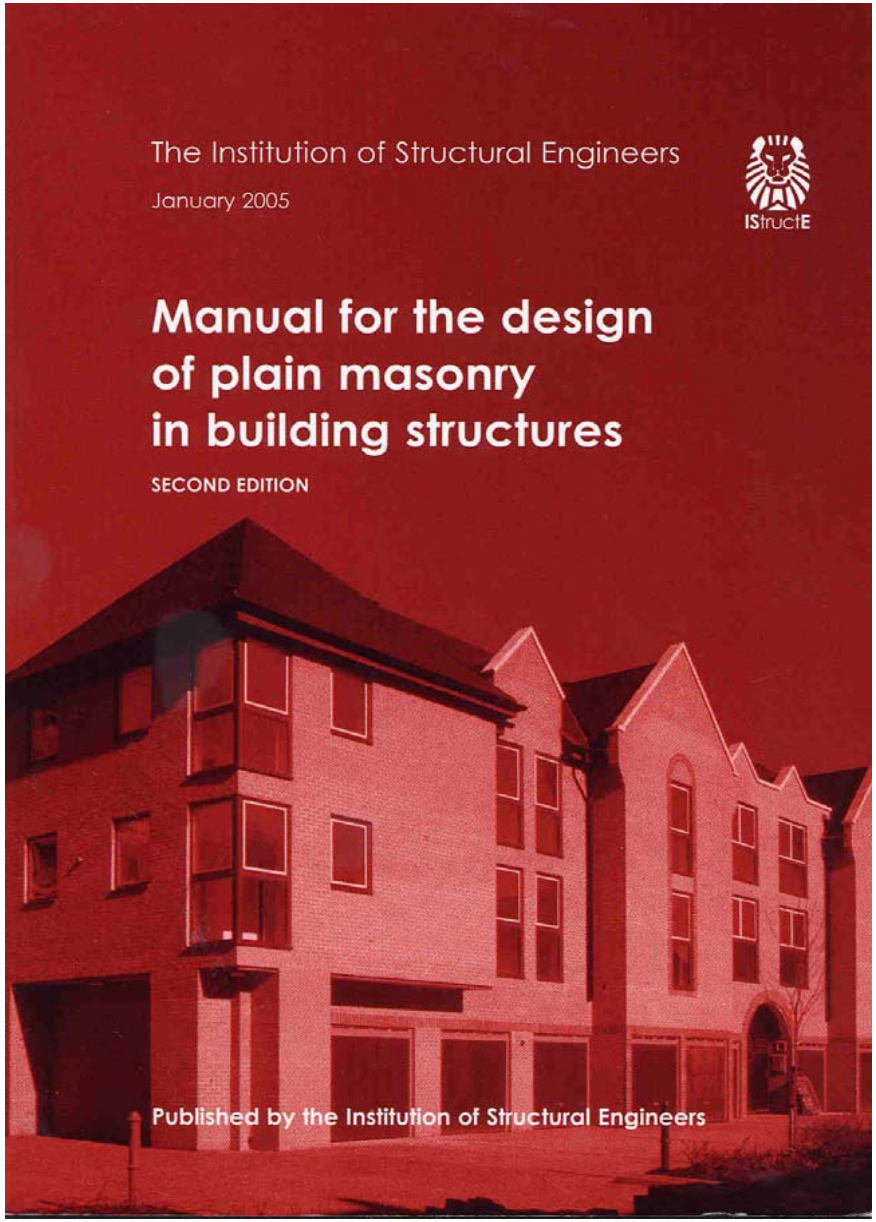
EC6 Design Guidance Worked Examples

- **Reinforced short and slender columns :**
  - **In examples $\sigma_d = 0.81f_d > 0.30f_d$ so - design axial load cannot be ignored with section - just being treated as simple bending member**
  - **Designs use BS5628 Pt. 2 interaction equations - for axially loaded + moment conditions**
  - **0.83 applied to steel compressive f_{yd} as BS5628**
  - **Reinforcement output same incl. shear links**

EC6 Design Guidance Worked Examples

- **Reinforced simple spanning beam :**
  - **Compression limited to $0.27f_d\,bd^2$ Does not change original design size**
  - **Tensile reinforcement output does not change**
  - **Designed shear links just needed. No change**
  - **Serviceability same limiting conditions**
  - **Buckling limiting span $250b_c^2/d$ seems odd!**
  - **Concrete infill/cover required same**

Does not cover reinforced or prestressed design



EN 1996 DESIGN OF MASONRY STRUCTURES

- REINFORCED AND PRESTRESSED MASONRY -

2 and 3 April 2009 - Brussels

Presented by Peter Watt

Charlwood Partnership Ltd