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/mm² - in British design code BS5628 Part 2
EN 1990 Basis of Structural Design (Actions)

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

UK National Annex to EN1990 has adopted:

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

with 1.5Q_{k,1} as leading variable action
PARTIAL SAFETY FACTORS $\gamma$ – ULS
dead and imposed actions - dead & imposed other than wind

<table>
<thead>
<tr>
<th>Load type</th>
<th>$G_k$</th>
<th>$Q_k$</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC6</td>
<td>1.35</td>
<td>1.50</td>
<td>1.43 mean (-5% diff.)</td>
</tr>
<tr>
<td>UK N/A</td>
<td>1.0 fav.</td>
<td>leading variable action</td>
<td></td>
</tr>
<tr>
<td>BS5628</td>
<td>1.40</td>
<td>1.60</td>
<td>1.50 mean</td>
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</tbody>
</table>
## PARTIAL SAFETY FACTORS $\gamma$ – ULS
dead and imposed actions – wind actions on panels

<table>
<thead>
<tr>
<th>Load type</th>
<th>$G_k$</th>
<th>$Q_k$</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>EC6 UK N/A</td>
<td>1.35</td>
<td>1.50</td>
<td>1.50 (+25% diff.)</td>
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<tr>
<td></td>
<td></td>
<td>leading variable action</td>
<td></td>
</tr>
<tr>
<td>BS5628</td>
<td>1.40</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.40 stab.</td>
<td></td>
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</tbody>
</table>
## PARTIAL SAFETY FACTORS $\gamma$ – ULS
dead and imposed actions – earth walls

<table>
<thead>
<tr>
<th>Load type</th>
<th>$G_k$</th>
<th>$Q_k$</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>EC6</td>
<td>1.35</td>
<td>1.50</td>
<td>1.50 (+4% eff. diff.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.35</td>
<td>1.35 (-6% eff. diff.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>as permanent action</td>
<td></td>
</tr>
<tr>
<td>UK N/A</td>
<td>1.40</td>
<td>1.20 $E_u$</td>
<td>1.44 eff.</td>
</tr>
<tr>
<td>BS5628</td>
<td>1.40</td>
<td>1.20 $E_u$</td>
<td>1.44 eff.</td>
</tr>
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</table>
**PARTIAL SAFETY FACTORS $\gamma_m$ – ULS**

**Compression strength Cat I**

<table>
<thead>
<tr>
<th></th>
<th>EC6 UK N/A</th>
<th>EC6 DE N/A</th>
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<tbody>
<tr>
<td>Compression strength Cat I</td>
<td>2.0</td>
<td>1.76</td>
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</table>

**Compression strength Cat II**

<table>
<thead>
<tr>
<th></th>
<th>EC6 UK N/A</th>
<th>EC6 DE N/A</th>
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</thead>
<tbody>
<tr>
<td>Compression strength Cat II</td>
<td>2.3</td>
<td>---</td>
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</table>

**Shear strength**

<table>
<thead>
<tr>
<th></th>
<th>EC6 UK N/A</th>
<th>EC6 DE N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear strength</td>
<td>2.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Bond strength**

<table>
<thead>
<tr>
<th></th>
<th>EC6 UK N/A</th>
<th>EC6 DE N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond strength</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Steel strength**

<table>
<thead>
<tr>
<th></th>
<th>EC6 UK N/A</th>
<th>EC6 DE N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel strength</td>
<td>1.15</td>
<td>1.15</td>
</tr>
</tbody>
</table>
Partial Safety Factors $\gamma_m$ - ULS

BUT:

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

- $f_d = f_k / \gamma_m$

where $K$, $\alpha$, $\beta$ and $\gamma_m$ 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

<table>
<thead>
<tr>
<th>Comp. Strength</th>
<th>$f_b$</th>
<th>EC6 UK N/A $f_k$</th>
<th>BS5628 $f_k$</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>5.95</td>
<td>M12 3.7, M2 2.1</td>
<td>M12 3.6, M2 2.8</td>
<td>+3 &amp; -25</td>
</tr>
<tr>
<td>20</td>
<td>17.00</td>
<td>M12 7.7, M2 4.5</td>
<td>M12 7.4, M2 4.7</td>
<td>+4 &amp; -4</td>
</tr>
<tr>
<td>40</td>
<td>34.00</td>
<td>12.4, 7.3</td>
<td>11.5, 7.0</td>
<td>+8 &amp; +4</td>
</tr>
<tr>
<td>60</td>
<td>51.00</td>
<td>16.5, 9.7</td>
<td>15.0, 9.0</td>
<td>+10 &amp; +8</td>
</tr>
<tr>
<td>80</td>
<td>68.00</td>
<td>20.2, 11.8</td>
<td>18.2, 10.7</td>
<td>+11 &amp; +10</td>
</tr>
<tr>
<td>100</td>
<td>85.00</td>
<td>23.6, 13.8</td>
<td>21.0, 12.1</td>
<td>+12 &amp; +14</td>
</tr>
</tbody>
</table>
### COMPARISON OF $f_k$ VALUES
Group 1 clay brick masonry – standard format - 328mm wide wall

<table>
<thead>
<tr>
<th>Comp. Strength</th>
<th>$f_b$</th>
<th>EC6 UK N/A</th>
<th>BS5628</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$f_k$</td>
<td>$f_k$</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.95</td>
<td>M12</td>
<td>M12</td>
<td>-9 &amp; -29</td>
</tr>
<tr>
<td>20</td>
<td>17.00</td>
<td>2.9</td>
<td>3.2</td>
<td>-5 &amp; -12</td>
</tr>
<tr>
<td>40</td>
<td>34.00</td>
<td>10.0</td>
<td>10.0</td>
<td>0 &amp; -5</td>
</tr>
<tr>
<td>60</td>
<td>51.00</td>
<td>13.2</td>
<td>13.0</td>
<td>+2 &amp; -3</td>
</tr>
<tr>
<td>80</td>
<td>68.00</td>
<td>16.2</td>
<td>15.8</td>
<td>+3 &amp; +1</td>
</tr>
<tr>
<td>100</td>
<td>85.00</td>
<td>18.9</td>
<td>18.3</td>
<td>+3 &amp; +5</td>
</tr>
</tbody>
</table>
### COMPARISON OF $f_k$ VALUES

**Group 1** concrete block masonry – 215 by 100mm – 100mm wide wall

<table>
<thead>
<tr>
<th>Comp. Strength $f_b$</th>
<th>EC6 UK N/A $f_k$</th>
<th>BS5628 $f_k$</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M12$</td>
<td>$M2$</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>3.0</td>
<td>1.9</td>
<td>+7 &amp; -32</td>
</tr>
<tr>
<td>3.6</td>
<td>3.7</td>
<td>2.2</td>
<td>+6 &amp; -37</td>
</tr>
<tr>
<td></td>
<td>$M12$</td>
<td>$M2$</td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>4.9</td>
<td>2.9</td>
<td>-2 &amp; -34</td>
</tr>
<tr>
<td>7.3</td>
<td>6.2</td>
<td>3.6</td>
<td>-9 &amp; -36</td>
</tr>
<tr>
<td></td>
<td>$M12$</td>
<td>$M2$</td>
<td></td>
</tr>
<tr>
<td>10.4</td>
<td>8.0</td>
<td>4.7</td>
<td>-9 &amp; -33</td>
</tr>
<tr>
<td>22.5</td>
<td>13.7</td>
<td>8.0</td>
<td>-9 &amp; -24</td>
</tr>
</tbody>
</table>

Note: BS5628 f_k values are not available for this category.
REINFORCED MASONRY
EUROCODE 6 -- REINFORCED MASONRY --

Dissemination of information for training – Brussels, 2-3 April 2009
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 = 0.27f_d bd^2
- For cantilever walls compression capacity = 0.40f_d bd^2
  
  Or = 0.30f_d bd^2 for Groups 2, 3 & 4 and L. Agg. Units

for flanged section:

- M_{Rd} = f_d b_{ef} t_f (d - 0.5t_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

  $= f_{vd} bd + (0.9d A_{sw} f_{yd}/s)(1 + \cot\alpha)\sin\alpha$ 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 $\frac{(0.35N/mm^2 + 17.5\rho)}{\gamma_M}$ - 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

<table>
<thead>
<tr>
<th></th>
<th>Effective Span to Wall – out of plane bending</th>
<th>Depth Ratio Max. Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simply supported</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Continuous</td>
<td>45</td>
<td>26</td>
</tr>
<tr>
<td>Spanning two directions</td>
<td>45</td>
<td>-</td>
</tr>
<tr>
<td>Cantilever</td>
<td>18</td>
<td>7</td>
</tr>
</tbody>
</table>
EC6 Bending Elements

- Deep beam design and design equations included:
  - For beams compression capacity = 0.40f_d bd^2
    Or = 0.30f_d bd^2 for Groups 2, 3 & 4 and L. Agg. Units

  where z the lever arm is lesser of:

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

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

where: $\gamma_m$ is the steel partial safety factor in this case
**EC6 Racking Wall Elements**

- **Principles and Application Rules included:**

  - For walls shear capacity = $f_{vd} t_l$ for unreinforced section
  
  And = $f_{vd} t_l + 0.9A_{sw} f_{yd}$ for reinforced section

  where $(f_{vd} t_l + 0.9A_{sw} f_{yd})/ t_l$ is 2.0N/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 $\phi f_{yd}/4 f_{bod}$ (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

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

Minimum straight lap detailing:

= $l_b$ for tension/compression bars where < 30% - bars are lapped and $\geq 10$ bar $\phi$’s between bars

= 1.4 $l_b$ for tension bars where $\geq 30$% bars are - lapped or $< 10$ bar $\phi$’s between bars

= 2 $l_b$ for tension bars where $\geq 30$% bars are - lapped and $< 10$ bar $\phi$’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 $\gamma_f$ are only about $\pm 5\%$ different - except laterally loaded wind panels $+25\%$

- Partial material factors $\gamma_m$ 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 1: 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
- \( V_u = v d_0 b \) for basic shear capacity missing
- \( l_t = K_t \phi_t \sqrt{f_{cl}} \) 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 affect 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 $0.27f_d b d^2$
    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

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