Detailing

Lecture 9
16th November 2017

Reinforced Concrete Detailing to Eurocode 2

EC2 Section 8 - Detailing of Reinforcement - General Rules
- Bar spacing, Minimum bend diameter
- Anchorage of reinforcement
- Lapping of bars
- Large bars, bundled bars

EC2 Section 9 - Detailing of Members and Particular rules
- Beams
- Solid slabs
- Flat slabs
- Columns
- Walls
- Deep beams
- Foundations
- Discontinuity regions
- Tying Systems
Section 8 - General Rules
Spacing of bars

EC2: Cl. 8.2  Concise: 11.2

- Clear horizontal and vertical distance ≥ φ, (d_g + 5mm) or 20mm
- For separate horizontal layers the bars in each layer should be located vertically above each other. There should be room to allow access for vibrators and good compaction of concrete.

Min. Mandrel Dia. for bent bars

EC2: Cl. 8.3  Concise: 11.3

Minimum mandrel size, \( \phi_m \)
- To avoid damage to bar is
  - Bar dia ≤ 16mm  Mandrel size  4 x bar diameter
  - Bar dia > 16mm  Mandrel size  7 x bar diameter
  - The bar should extend at least 5 diameters beyond a bend
Min. Mandrel Dia. for bent bars

EC2: Cl. 8.3
Concise: 11.3

Minimum mandrel size, \( \phi_m \)

- To avoid failure of the concrete inside the bend of the bar:

\[ \phi_{m,\text{min}} \geq \frac{F_{bt} ((1/a_b) + 1/(2 \phi))}{f_{cd}} \]

- \( F_{bt} \) ultimate force in a bar at the start of a bend
- \( a_b \) for a given bar is half the centre-to-centre distance between bars.
  For a bar adjacent to the face of the member, \( a_b \) should be taken as the cover plus \( \phi / 2 \)

Mandrel size need not be checked to avoid concrete failure if:
- anchorage does not require more than 5\( \phi \) past end of bend
- bar is not the closest to edge face and there is a cross bar \( \geq \phi \) inside bend
- mandrel size is at least equal to the recommended minimum value

Anchorage of reinforcement

EC2: Cl. 8.4
The design value of the ultimate bond stress,
\[ f_{bd} = 2.25 \eta_1 \eta_2 f_{ctd} \]

where
\[ f_{ctd} \text{ should be limited to } C60/75 \]
\[ \eta_1 = 1 \text{ for ‘good’ and 0.7 for ‘poor’ bond conditions} \]
\[ \eta_2 = 1 \text{ for } \phi \leq 32, \text{ otherwise } (132 - \phi)/100 \]

**Ultimate bond stress**
EC2: Cl. 8.4.2

Good and ‘bad’ bond conditions

- a) \( 45° \leq \alpha \leq 90° \)
- b) \( h \leq 250 \text{ mm} \)
- c) \( h > 250 \text{ mm} \)
- d) \( h > 600 \text{ mm} \)

unhatched zone - ‘good’ bond conditions
hatched zone - ‘poor’ bond conditions

Top is ‘poor’ Bond condition
Basic required anchorage length

EC2: Cl. 8.4.3
Concise: 11.4.3

\[ l_{b,rqd} = \left( \frac{\varphi}{4} \right) \left( \frac{\sigma_{sd}}{f_{bd}} \right) \]

where

\[ \sigma_{sd} = \text{the design stress of the bar at the position from where the anchorage is measured.} \]

For bent bars \( l_{b,rqd} \) should be measured along the centreline of the bar.

Design Anchorage Length, \( l_{bd} \)

EC2: Cl. 8.4.4
Concise: 11.4.2

\[ l_{bd} = a_1 a_2 a_3 a_4 a_5 l_{b,rqd} \geq l_{b,min} \]

However: \( (a_2 a_3 a_5) \geq 0.7 \)

\[ l_{b,min} > \max(0.3l_{b,rqd} ; 10\varphi, 100\text{mm}) \]

Alpha values are in EC2: Table 8.2

To calculate \( a_2 \) and \( a_3 \) Table 8.2 requires values for:

- \( C_d \): Value depends on cover and bar spacing, see Figure 8.3
- \( K \): Factor depends on position of confinement reinforcement, see Figure 8.4
- \( \lambda \): \( = (\Sigma A_{st} - \Sigma A_{st,min}) / A_s \) Where \( A_{st} \) is area of transverse reinf.
### Table 8.2 - \( C_d \) & \( K \) factors

**Concise:** Figure 11.3  
**EC2:** Figure 8.3

<table>
<thead>
<tr>
<th>Type of Bar</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a) Straight bars</strong></td>
<td>( C_d = \min (a/2, c_1, c) )</td>
</tr>
<tr>
<td><strong>b) Bent or hooked bars</strong></td>
<td>( C_d = \min (a/2, c_1) )</td>
</tr>
<tr>
<td><strong>c) Looped bars</strong></td>
<td>( C_d = c )</td>
</tr>
</tbody>
</table>

**Beam corner bar?**

**EC2:** Figure 8.4  

\[ K = 0.1 \]

### Table 8.2 - Other than straight shapes

**Concise:** Figure 11.1  
**EC2:** Figure 8.1

<table>
<thead>
<tr>
<th>Shape</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>b) Equivalent anchorage length for standard bend</strong> ( 90^\circ \leq \alpha &lt; 150^\circ ) where ( l_{h,eq} = \alpha \cdot l_{h,eq} )</td>
<td></td>
</tr>
<tr>
<td><strong>c) Equivalent anchorage length for standard hook</strong> where ( l_{h,eq} = \alpha \cdot l_{h,eq} )</td>
<td></td>
</tr>
<tr>
<td><strong>d) Equivalent anchorage length for standard loop</strong> where ( l_{h,eq} = \alpha \cdot l_{h,eq} )</td>
<td></td>
</tr>
</tbody>
</table>
**Alpha values**

**EC2: Table 8.2**

<table>
<thead>
<tr>
<th>Influencing factor</th>
<th>Type of anchorage</th>
<th>Reinforcement bar</th>
<th>In tension</th>
<th>In compression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Straight</td>
<td>$\alpha_1 = 1.0$</td>
<td>$\alpha_1 = 1.0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other than straight (see Figure 8.1 (b), (c) and (d))</td>
<td>$\alpha_1 = 0.7$ if $C_2 &gt; 3C_1$</td>
<td>$\alpha_1 = 1.0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(see Figure 8.3 for values of $C_1$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Straight</td>
<td>$\alpha_2 = 1 - 0.15 (C_2 - C_1) \leq 1.0$</td>
<td>$\alpha_2 = 1.0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other than straight (see Figure 8.1 (b), (c) and (d))</td>
<td>$\alpha_2 = 1 - 0.15 (C_2 - 3C_1) \leq 0.7$</td>
<td>$\alpha_2 = 1.0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(see Figure 8.3 for values of $C_1$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Confinement by transverse reinforcement not welded to main reinforcement</td>
<td>$\alpha_3 = 1 - K_2 \leq 1.0$</td>
<td>$\alpha_3 = 1.0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All types</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Confinement by welded transverse reinforcement*</td>
<td>$\alpha_4 = 0.7$</td>
<td>$\alpha_4 = 0.7$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All types, position and size as specified in Figure 8.1 (e)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Confinement by transverse pressure</td>
<td>$\alpha_5 = 1 - 0.04\theta \leq 1.0$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Anchorage of links**

**EC2: Cl. 8.5**

**Concise: Fig 11.2**

- Bend angle $> 150^\circ$
- Bend angle $\leq 150^\circ$
Laps
EC2: Cl. 8.7

Design Lap Length, $l_0$ (8.7.3)
EC2: Cl. 8.7.3, Table 8.3

\[ l_0 = \alpha_1 \alpha_2 \alpha_3 \alpha_5 \alpha_6 l_{b,rqd} \geq l_{0,\text{min}} \]

$\alpha_1, \alpha_2, \alpha_3, \alpha_5$ are as defined for anchorage length

$\alpha_6 = (\rho_1/25)^{0.5}$ but between 1.0 and 1.5
where $\rho_1$ is the % of reinforcement lapped within 0.65$l_0$ from the centre of the lap

<table>
<thead>
<tr>
<th>Percentage of lapped bars relative to the total cross-section area</th>
<th>&lt; 25%</th>
<th>33%</th>
<th>50%</th>
<th>&gt;50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_6$</td>
<td>1.0</td>
<td>1.15</td>
<td>1.4</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Note: Intermediate values may be determined by interpolation.

\[ l_{0,\text{min}} \geq \max\{0.3 \alpha_6 l_{b,rqd}; 15\phi; 200\} \]
Arrangement of Laps
EC2: Cl. 8.7.3, Fig 8.8

Example: Bars II and III are outside the section being considered: $\% = 50$ and $\alpha = 1.4$

Figure 8.8: Percentage of lapped bars in one lapped section

Worked example

Anchorage and lap lengths
Anchorage Worked Example

Calculate the tension anchorage for an H16 bar in the bottom of a slab:

a) Straight bars
b) Other shape bars (Fig 8.1 b, c and d)

Concrete strength class is C25/30
Nominal cover is 25mm

Assume maximum design stress in the bar

**Bond stress, \( f_{bd} \)**

\[
f_{bd} = 2.25 \eta_1 \eta_2 f_{ctd}
\]

\( \eta_1 = 1.0 \) 'Good' bond conditions
\( \eta_2 = 1.0 \) bar size ≤ 32

\[
f_{ctd} = \alpha_{ct} \frac{f_{ck,0.05}}{\gamma_c}
\]

\( \alpha_{ct} = 1.0 \)

\( \gamma_c = 1.5 \)

\[
f_{ctk,0.05} = 0.7 \times 0.3 f_{ck}^{2/3}
\]

\( = 0.21 \times 25^{2/3} \)

\( = 1.795 \text{ MPa} \)

\[
f_{ctd} = \alpha_{ct} \frac{f_{ctk,0.05}}{\gamma_c} = 1.795/1.5 = 1.197
\]

\[
f_{bd} = 2.25 \times 1.197 = 2.693 \text{ MPa}
\]
Basic anchorage length, $l_{b,\text{req}}$

$$l_{b,\text{req}} = \left(\frac{\varnothing}{4}\right) \left( \frac{\sigma_{sd}}{f_{bd}} \right)$$  
EC2 Equ 8.3

Max stress in the bar, $\sigma_{sd} = \frac{f_{yk}}{\gamma_s} = \frac{500}{1.15} = 435\text{MPa}$.

$$l_{b,\text{req}} = \left(\frac{\varnothing}{4}\right) \left( \frac{435}{2.693} \right)$$
$$= 40.36 \varnothing$$
For concrete class C25/30

Design anchorage length, $l_{bd}$

$$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \left( l_{b,\text{req}} \right) \geq l_{b,\text{min}}$$

$$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \left( 40.36\varnothing \right)$$  For concrete class C25/30
## Alpha values

**EC2: Table 8.2**

<table>
<thead>
<tr>
<th>Influencting factor</th>
<th>Type of anchorage</th>
<th>Reinforcement bar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>In tension</td>
</tr>
<tr>
<td><strong>Shape of bars</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>$\alpha = 1,0$</td>
<td>$\alpha = 1,0$</td>
</tr>
<tr>
<td>Other than straight (see Figure 8.1)</td>
<td>$\alpha = 0,15 (C_d - d/\phi) \geq 0,7$</td>
<td>$\alpha = 1,0$</td>
</tr>
<tr>
<td>Concrete cover</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>$\alpha = 1 - 0,15 (C_d - d/\phi) \geq 1,0$</td>
<td>$\alpha = 1,0$</td>
</tr>
<tr>
<td>Other than straight (see Figure 8.1)</td>
<td>$\alpha = 0,15 (C_d - 3d/\phi) \geq 0,7$</td>
<td>$\alpha = 1,0$</td>
</tr>
<tr>
<td>Confinement by transverse reinforcement not welded to main reinforcement</td>
<td>$\alpha = 1 - K\alpha \geq 0,7$</td>
<td>$\alpha = 1,0$</td>
</tr>
<tr>
<td>Confinement by welded transverse reinforcement*</td>
<td>$\alpha = 0,7$</td>
<td>$\alpha = 0,7$</td>
</tr>
<tr>
<td>Confinement by transverse pressure</td>
<td>$\alpha = 1 - 0,04p \geq 0,7$</td>
<td>$\alpha = 1,0$</td>
</tr>
</tbody>
</table>

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## Table 8.2 - C_d & K factors

**EC2: Figure 8.3**

- **a) Straight bars**
  - $C_d = \min (a/2, c_1, c)$
- **b) Bent or hooked bars**
  - $C_d = \min (a/2, c_1)$
- **c) Looped bars**
  - $C_d = c$

**Concise: Figure 11.3**

- **K = 0,1**
  - EC2: Figure 8.4
- **K = 0,05**
  - EC2: Figure 8.4
- **K = 0**
Design anchorage length, $l_{bd}$

\[ l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \, l_{b,req} \geq l_{b,min} \]

\[ l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \, (40.36\varnothing) \quad \text{For concrete class C25/30} \]

a) Tension anchorage - *straight bar*

- $\alpha_1 = 1.0$
- $\alpha_3 = 1.0$ conservative value with $K = 0$
- $\alpha_4 = 1.0$ N/A
- $\alpha_5 = 1.0$ conservative value
- $\alpha_2 = 1.0 - 0.15 \,(C_d - \varnothing)/\varnothing$
- $\alpha_2 = 1.0 - 0.15 \,(25 - 16)/16 = 0.916$

\[ l_{bd} = 0.916 \times 40.36\varnothing = 36.97\varnothing = 592mm \]

b) Tension anchorage - *Other shape bars*

- $\alpha_1 = 1.0$ $C_d = 25 \text{ is } \leq 3 \, \varnothing = 3 \times 16 = 48$
- $\alpha_3 = 1.0$ conservative value with $K = 0$
- $\alpha_4 = 1.0$ N/A
- $\alpha_5 = 1.0$ conservative value
- $\alpha_2 = 1.0 - 0.15 \,(C_d - 3\varnothing)/\varnothing \leq 1.0$
- $\alpha_2 = 1.0 - 0.15 \,(25 - 48)/16 = 1.25 \leq 1.0$

\[ l_{bd} = 1.0 \times 40.36\varnothing = 40.36\varnothing = 646mm \]
Worked example - summary

H16 Bars - Concrete class C25/30 - 25 Nominal cover

Tension anchorage - straight bar \( l_{bd} = 36.97\Phi = 592\text{mm} \)

Tension anchorage - Other shape bars \( l_{bd} = 40.36\Phi = 646\text{mm} \)

\( l_{bd} \) is measured along the centreline of the bar

Compression anchorage \( (\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 1.0) \)

\( l_{bd} = 40.36\Phi = 646\text{mm} \)

Anchorage for ‘Poor’ bond conditions, \( l_{bd} = ‘Good value’ /0.7 \)

Lap length, \( l_0 = \) anchorage length \( \times \alpha_6 \)

Anchorage & lap lengths

How to design concrete structures using Eurocode 2

Table 2

<table>
<thead>
<tr>
<th>Bond condition, (see Figure 1)</th>
<th>Bond class</th>
<th>( f_y ) (N/mm²)</th>
<th>( f_{ck} ) (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight bars only</td>
<td>Good</td>
<td>610</td>
<td>345</td>
</tr>
<tr>
<td>Other bars</td>
<td>Poor</td>
<td>230</td>
<td>100</td>
</tr>
<tr>
<td>50% lapped in one location</td>
<td>Good</td>
<td>440</td>
<td>250</td>
</tr>
<tr>
<td>100% lapped in one location</td>
<td>Poor</td>
<td>630</td>
<td>350</td>
</tr>
</tbody>
</table>

Notes
1. Nominal cover at all sides ≥ 25 mm. \( \alpha_1 = 1 \). At laps, clear distance between bars ≥ 50mm.
2. \( \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 1.0 \). For the beneficial effect of shape of bar, cover and confinement see Eurocode 2, Table 8.2.
3. Design stress has been taken at 415 MPa. Where the design stress in the bar at the position where the anchorage is measured, \( \sigma_y \), is less than 415 MPa the figures in this table can be factored by \( \frac{\sigma_y}{415} \). The minimum lap length is given in 8.7.3 of Eurocode 2.
4. The anchorage and lap lengths have been rounded up to the nearest 10 mm.
5. When 2/3 of bars are lap in one location, decrease the lap lengths for 1/3 lapped in one location by a factor of 0.82.
6. The figures in this table have been prepared for concrete class C25/30. Refer to Table 3.1 for other classes or use the following factors for other concrete classes.

<table>
<thead>
<tr>
<th>Concrete class</th>
<th>C20/25</th>
<th>C25/30</th>
<th>C30/35</th>
<th>C40/50</th>
<th>C50/60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>1.16</td>
<td>0.93</td>
<td>0.86</td>
<td>0.80</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Column lap length for 100% laps & grade C40/50 = 0.73 \times 61\Phi = 44.5 \Phi
## Anchorage /lap lengths for slabs

### Manual for the design of concrete structures to Eurocode 2

### Table 5.25: Typical values of anchorage and lap lengths for slabs

<table>
<thead>
<tr>
<th>Bond conditions</th>
<th>Length in bar diameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f_{ck}/f_{cu}$</td>
</tr>
<tr>
<td></td>
<td>25/30</td>
</tr>
<tr>
<td>'good'</td>
<td>40</td>
</tr>
<tr>
<td>'poor'</td>
<td>58</td>
</tr>
</tbody>
</table>

### Notes:
- The following is assumed:
  - Bar size is not greater than 32mm. If >32 then the anchorage and lap lengths should be increased by a factor (132 - bar size)/100
  - Normal cover exists
  - No confinement by transverse pressure
  - No confinement by transverse reinforcement

Lap lengths provided (for nominal bars, etc.) should not be less than 15 times the bar size or 200mm, whichever is greater.

### Arrangement of Laps

**EC2: Cl. 8.7.2**  
**Concise: Cl 11.6**

Laps between bars should normally be staggered and not located in regions of high stress.

**Arrangement of laps should comply with Figure 8.7:**

Distance ‘a’ is used in cl 8.7.4.1 (3), Transverse reinf.

All bars in compression and secondary (distribution) reinforcement may be lapped in one section.
Strut-and-tie models

STM models help us understand:

- The anchorage of bars

Transverse Reinforcement at Laps

Bars in tension

EC2: Cl. 8.7.4, Fig. 8.9

- Transverse reinforcement is required in the lap zone to resist transverse tension forces.
- Any transverse reinforcement provided for other reasons will be sufficient if the lapped bar $\varnothing < 20\text{mm}$ or laps $< 25\%$
- If the lapped bar $\varnothing \geq 20\text{mm}$ the transverse reinforcement should have a total area, $\Sigma A_{st} \geq 1.0 A_s$ of one spliced bar. It should be placed perpendicular to the direction of the lapped reinforcement. Also it should be positioned at the outer sections of the lap as shown.

There is transverse tension

Figure 8.9 (a) - bars in tension
Transverse Reinforcement at Laps

Bars in tension

EC2: Cl. 8.7.4, Fig 8.9

- Also, if the lapped bar $\varnothing \geq 20\text{mm}$ and more than 50% of the reinforcement is lapped at one point and the distance between adjacent laps at a section, $a \leq 10\varnothing$, then transverse bars should be formed by links or U bars anchored into the body of the section.

![Adjacent laps](image)

Transverse Reinforcement at Laps

Bars in compression

EC2: Cl. 8.7.4, Fig 8.9

In addition to the rules for bars in tension one bar of the transverse reinforcement should be placed outside each end of the lap length.

![Bars in compression](image)
Detailing of members and particular rules

EC2 Section 9

Beams
EC2: Cl. 9.2

- \( A_{s,\text{min}} = 0.26 \left( \frac{f_{\text{ctm}}}{f_{\text{yk}}} \right) b_{t} d \) but \( \geq 0.0013 b_{t} d \)

<table>
<thead>
<tr>
<th>Strength class</th>
<th>C12/15</th>
<th>C16/20</th>
<th>C20/25</th>
<th>C25/30</th>
<th>C30/37</th>
<th>C35/45</th>
<th>C40/50</th>
<th>C45/55</th>
<th>C50/60</th>
<th>C28/35</th>
<th>C32/40</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_{s,\text{min}} ) as a % of ( b_{t} d )</td>
<td>0.130</td>
<td>0.130</td>
<td>0.130</td>
<td>0.135</td>
<td>0.151</td>
<td>0.166</td>
<td>0.182</td>
<td>0.198</td>
<td>0.213</td>
<td>0.146</td>
<td>0.156</td>
</tr>
</tbody>
</table>

- \( A_{s,\text{max}} = 0.04 A_{c} \)
- Section at supports should be designed for a hogging moment \( \geq 0.25 \) max. span moment
- Any design compression reinforcement (\( \phi \)) should be held by transverse reinforcement with spacing \( \leq 15 \phi \)
Beams

EC2: Cl. 9.2

- Tension reinforcement in a flanged beam at supports should be spread over the effective width (see 5.3.2.1)

![Diagram of tension reinforcement in flanged cross-section.](image)

Figure 9.1: Placing of tension reinforcement in flanged cross-section.

Curtailment

EC2: Cl. 9.2.1.3

(1) Sufficient reinforcement should be provided at all sections to resist the envelope of the acting tensile force, including the effect of inclined cracks in webs and flanges.

(2) For members with shear reinforcement the additional tensile force, $\Delta F_{td}$, should be calculated according to 6.2.3 (7). For members without shear reinforcement $\Delta F_{td}$ may be estimated by shifting the moment curve a distance $a_l = d$ according to 6.2.2 (5). This "shift rule" may also be used as an alternative for members with shear reinforcement, where:

$$a_l = \frac{z \left( \cot \theta - \cot a \right)}{2} = 0.5 z \cot \theta \text{ for vertical shear links}$$

$z =$ lever arm, \hspace{1em} $\theta =$ angle of compression strut

$$a_l = 1.125 \, d \text{ when } \cot \theta = 2.5 \text{ and } 0.45 \, d \text{ when } \cot \theta = 1$$
‘Shift Rule’ for Shear

Curtailment of longitudinal tension reinforcement

\[ \frac{M}{z} - \frac{V \cot \theta}{2} = \frac{V}{\sin \theta} \cdot \cos \theta = V \cot \theta \]

\[ \frac{M}{z} + \frac{V \cot \theta}{2} = \frac{(M + Vz \cot \theta/2)}{z} \]

\[ \therefore \Delta M = Vz \cot \theta/2 \]

\[ \frac{dM}{dx} = V \]

\[ \therefore \Delta M = V \Delta x \therefore \Delta x = z \cot \theta/2 = a_i \]

For members without shear reinforcement this is satisfied with \( a_i = d \)

For members with shear reinforcement: \( a_i = 0.5 z \cot \theta \)

But it is always conservative to use \( a_i = 1.125d \) (for \( \theta = 45^\circ \), \( a_i = 0.45d \))
Anchorage of Bottom Reinforcement at End Supports

EC2: Cl. 9.2.1.4

- $A_s$ bottom steel at support $\geq 0.25 A_s$ provided in the span
- $l_{bd}$ is required from the line of contact of the support.
- Transverse pressure may only be taken into account with a ‘direct’ support. $a_s$ anchorage coefficient

Simplified Detailing Rules for Beams

Concise: Cl 12.2.4

How to ... EC2
Detailing section
Supporting Reinforcement at ‘Indirect’ Supports

EC2: Cl. 9.2.5

- Supporting beam with height $h_1$
- Supported beam with height $h_2$ ($h_1 \geq h_2$)

Plan view

- The supporting reinforcement is in addition to that required for other reasons
- The supporting links may be placed in a zone beyond the intersection of beams

Solid slabs

EC2: Cl. 9.3

- Curtailment - as beams except for the “Shift” rule $a_l = d$ may be used
- Flexural Reinforcement - min and max areas as beam
- Secondary transverse steel not less than 20% main reinforcement
- Reinforcement at Free Edges
### Detailing Comparisons

#### Beams

<table>
<thead>
<tr>
<th>Clause / Values</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Bars in Tension</strong></td>
<td></td>
</tr>
<tr>
<td>$A_{s,min}$</td>
<td>9.2.1.1 (1): $0.26\frac{f_{ctm}}{f_{yk}}bd \geq 0.0013\ bd$</td>
</tr>
<tr>
<td>$A_{s,max}$</td>
<td>9.2.1.1 (3): $0.04\ bd$</td>
</tr>
<tr>
<td><strong>Main Bars in Compression</strong></td>
<td></td>
</tr>
<tr>
<td>$A_{c,min}$</td>
<td>--</td>
</tr>
<tr>
<td>$A_{c,max}$</td>
<td>9.2.1.1 (3): $0.04\ bd$</td>
</tr>
<tr>
<td><strong>Spacing of Main Bars</strong></td>
<td></td>
</tr>
<tr>
<td>$s_{min}$</td>
<td>8.2 (2): $d_g + 5\ \text{mm or } \phi$ or $20\ \text{mm}$</td>
</tr>
<tr>
<td>$s_{max}$</td>
<td>Table 7.3N</td>
</tr>
<tr>
<td><strong>Links</strong></td>
<td></td>
</tr>
<tr>
<td>$A_{sw,min}$</td>
<td>9.2.2 (5): $(0.08 \sqrt{f_{ck}} b_s)/f_{yk}$</td>
</tr>
<tr>
<td>$s_{l,max}$</td>
<td>9.2.2 (6): $0.75\ d$</td>
</tr>
<tr>
<td><strong>Secondary Transverse Bars</strong></td>
<td></td>
</tr>
<tr>
<td>$A_{s,min}$</td>
<td>9.3.1.1 (2): $0.2A_{s}$ for single way slabs</td>
</tr>
<tr>
<td>$A_{s,max}$</td>
<td>9.2.1.1 (3): $0.04\ bd$</td>
</tr>
</tbody>
</table>

#### Slabs

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<tr>
<th>Clause / Values</th>
<th>BS 8110 Values</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td><strong>Spacing of Bars</strong></td>
<td></td>
</tr>
<tr>
<td>$s_{min}$</td>
<td>8.2 (2): $d_g + 5\ \text{mm or } \phi$ or $20\ \text{mm}$</td>
</tr>
<tr>
<td>$s_{max}$</td>
<td>secondary: $3.5h \leq 450\ \text{mm}$</td>
</tr>
</tbody>
</table>

**Places of maximum moment:**
- main: $2h \leq 250\ \text{mm}$
- secondary: $3h \leq 400\ \text{mm}$
### Detailing Comparisons

<table>
<thead>
<tr>
<th>Punching Shear</th>
<th>EC2 Clause / Values</th>
<th>BS 8110 Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Links</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_{sw,min}$</td>
<td>9.4.3 (2): Link leg = 0.053s, $s_t \sqrt{(f_{ck})/f_{yk}}$</td>
<td>Total = 0.4ud/0.87fyv</td>
</tr>
<tr>
<td>$S_r$</td>
<td>9.4.3 (1): 0.75d</td>
<td>0.75d</td>
</tr>
<tr>
<td>$S_t$</td>
<td>9.4.3 (1):</td>
<td>1.5d</td>
</tr>
<tr>
<td></td>
<td>within 1st control perim.: 1.5d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>outside 1st control perim.: 2d</td>
<td></td>
</tr>
</tbody>
</table>

| Columns        |                     |                 |

<table>
<thead>
<tr>
<th>Main Bars in Compression</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{s,min}$</td>
<td>9.5.2 (2): $0.10N_{ed}/f_{yk} \leq 0.002bh$</td>
<td>0.004 bh</td>
</tr>
<tr>
<td>$A_{s,max}$</td>
<td>9.5.2 (3): 0.04 bh</td>
<td>0.06 bh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Links</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Min size</td>
<td>9.5.3 (1): 0.25φ or 6 mm</td>
<td>0.25φ or 6 mm</td>
</tr>
<tr>
<td>$S_{cl,tmax}$</td>
<td>9.5.3 (3): min(12φmin; 0.6b; 240 mm)</td>
<td>12φ</td>
</tr>
<tr>
<td></td>
<td>9.5.3 (6): 150 mm from main bar</td>
<td>150 mm from main bar</td>
</tr>
</tbody>
</table>

### Identification of bars on site

Current BS 4449

<table>
<thead>
<tr>
<th>Class A</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class C</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

www.ukcares.co.uk
www.uk-bar.org
Identification on site
Current BS 4449

UK CARES (Certification - Product & Companies)
1. Reinforcing bar and coil
2. Reinforcing fabric
3. Steel wire for direct use of for further processing
4. Cut and bent reinforcement
5. Welding and prefabrication of reinforcing steel

Identification System

CARES Identification System

Country or Regional Grouping is as follows:

- Germany: 1 rib
- Belgium, Netherlands, Luxembourg: 2 ribs
- France: 3 ribs
- Italy: 4 ribs
- United Kingdom, Eire: 5 ribs
- Scandinavia: 6 ribs
- Spain, Portugal: 7 ribs
- Greece, Turkey: 8 ribs
- Outside Europe: 9 ribs

Detailing Issues

<table>
<thead>
<tr>
<th>EC2 Clause</th>
<th>Issue</th>
<th>Possible resolve in 2018?</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.4.4.1</td>
<td>Lap lengths</td>
<td></td>
</tr>
</tbody>
</table>

- Table 8.3
  - \( \alpha_6 \) varies depending on amount staggered
  - \( \alpha_6 \) should always = 1.5.
  - Staggering doesn’t help at ULS

- 8.7.2(3) & Fig 8.7
  - 0.3 l_0 gap between ends of lapped bars is onerous.
  - For ULS, there is no advantage in staggering bars (fib bulletin Mar 2014). For SLS staggering at say 0.5 l_0 might be helpful.
## Detailing Issues

<table>
<thead>
<tr>
<th>EC2 Clause</th>
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<th>Possible resolve in 2018?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 8.2</td>
<td>$\alpha_2$ for compression bars</td>
<td>Should be the same as for tension. Initial test suggests $\alpha_2 = 0.7$</td>
</tr>
<tr>
<td>Table 8.2</td>
<td>$\alpha_2$ for bent bars</td>
<td>Currently, anchorage worse than for straight bars</td>
</tr>
<tr>
<td>8.7.4.1(4) &amp; Fig 8.9</td>
<td>Requirements for transverse bars are impractical</td>
<td>Requirement only makes 10-15% difference in strength of lap (Corrigendum 1 no longer requires transverse bars to be between lapped bar and surface.)</td>
</tr>
<tr>
<td>Fig 9.3</td>
<td>$l_{bd}$ anchorage into support</td>
<td>May be OTT as compression forces increase bond strength. Issue about anchorage beyond CL of support</td>
</tr>
<tr>
<td>6.4</td>
<td>Numbers of perimeters of punching shear links</td>
<td>Work of CEN TC 250.SC2/WG1/TG4</td>
</tr>
</tbody>
</table>

### Tying systems

![Diagram of Tying systems](image-url)
Tying systems

- **Peripheral ties** (9.10.2.2) & NA:
  \[ F_{\text{tie,per}} = (20 + 4n_0) \leq 60\text{kN} \]
  where \( n_0 \) is the number of storeys

- **Internal ties (including transverse ties)** (9.10.2.3) & NA:
  \[ F_{\text{tie,int}} = \left( \frac{(g_k + q_k)}{7.5} \right) \left( \frac{l}{5} \right) F_t \geq F_t\text{ kN/m} \]
  where \((g_k + q_k)\) is the sum of the average permanent and variable floor loads (kN/m²), \( l \) is the greater of the distances (m) between the centres of the columns, frames or walls supporting any two adjacent floor spans in the direction of the tie under consideration and \( F_t = (20 + 4n_0) \leq 60\text{kN}. \)
  Maximum spacing of internal ties = 1.5 \( l \)

- **Horizontal ties to columns or walls** (9.10.2.4) & NA:
  \[ F_{\text{tie,fac}} = F_{\text{tie,col}} \geq (2 F_t \leq \left( \frac{l_s}{2.5} \right) F_t) \] \( \geq 3\% \) of \( N_{\text{Ed}} \)
  \( N_{\text{Ed}} \) = the total design ultimate vertical load carried by the column or wall at that level. Tying of external walls is only required if the peripheral tie is not located within the wall. \( F_{\text{tie,fac}} \) in kN per metre run of wall, \( F_{\text{tie,col}} \) in kN per column and \( l_s \) is the floor to ceiling height in m.

**Tying Systems**

**Internal Ties:** EC2 specifies a 20kN/m requirement which is significantly less than BS8110.

**UK NA requirements similar to BS 8110**
Vertical ties (9.10.2.5):
In panel buildings of 5 storeys or more, ties should be provided in columns and/or walls to limit damage of collapse of a floor.

Normally continuous vertical ties should be provided from the lowest to the highest level.

Where a column or wall is supported at the bottom by a beam or slab accidental loss of this element should be considered.

Continuity and anchorage ties (9.10.3):
Ties in two horizontal directions shall be effectively continuous and anchored at the perimeter of the structure.

Ties may be provided wholly in the in situ concrete topping or at connections of precast members.

Exercise
Lecture 9
Lap length for column longitudinal bars
Column lap length exercise

Design information

- C40/50 concrete
- 400 mm square column
- 45mm nominal cover to main bars
- Longitudinal bars are in compression
- Maximum ultimate stress in the bars is 390 MPa

Exercise:
Calculate the minimum lap length using EC2 equation 8.10:

\[ l_0 = \alpha_1 \alpha_2 \alpha_3 \alpha_5 \alpha_6 \frac{l_{b,req}}{f_{n,cd}} \geq l_{0,min} \]

Column lap length exercise

Procedure

- Determine the ultimate bond stress, \( f_{bd} \)  
  EC2 Equ. 8.2
- Determine the basic anchorage length, \( l_{b,req} \)  
  EC2 Equ. 8.3
- Determine the design anchorage length, \( l_{bd} \)  
  EC2 Equ. 8.4
- Determine the lap length, \( l_0 = \text{anchorage length} \times \alpha_6 \)
End of Lecture 9

Email: pgregory@concrecentre.com