How to calculate anchorage and lap lengths to Eurocode 2

Introduction

This article provides guidance on how to calculate anchorage and lap lengths to Eurocode 2. EC2 provides information about reinforcement detailing in Sections 8 and 9 of Part 1-1 (BS EN 1992-1-1). Section 8 provides information on the general aspects of detailing and this is where the rules for anchorage and lap lengths are given. Section 9 sets out the rules for detailing different types of elements, such as beams, slabs and columns.

The calculation for anchorage and lap lengths is described in EC2 and is fairly extensive. There are shortcuts to the process, the first being to use one of the tables produced by others. These are based on the bar being fully stressed and the cover being 25mm or ‘normal’. These assumptions are conservative, particularly the assumption that the bar is fully stressed, as bars are normally anchored or lapped away from the points of high stress. Engineering judgement should be used when applying any of the tables to ensure that the assumptions are reasonable and not overly conservative.

This article discusses how to calculate an anchorage and lap length for steel ribbed reinforcement subjected to predominantly static loading using the information in Section 8. Coated steel bars (e.g. coated with paint, epoxy or zinc) are not considered. The rules are applicable to normal buildings and bridges.

An anchorage length is the length of bar required to transfer the force in the bar into the concrete. A lap length is the length required to transfer the force in one bar to another bar. Anchorage and lap lengths are both calculated slightly differently depending on whether the bar is in compression or tension.

For bars in tension, the anchorage length is measured along the centreline of the bar. Figure 1 shows a tension anchorage for a bar in a pad base. The anchorage length for bars in tension can include bends and hooks (Figure 2), but bends and hooks do not contribute to compression anchorages. For a foundation, such as a pile cap or pad base, this can affect the depth of concrete that has to be provided.

Most tables that have been produced in the UK for anchorage and lap lengths have been based on the assumption that the bar is fully stressed at the start of the anchorage or at the lap length. This is rarely the case, as good detailing principles put laps at locations of low stress and the area of steel provided tends to be greater than the area of steel required.

In EC2, anchorage and lap lengths are proportional to the stress in the bar at the start of the anchorage or lap. Therefore, if the bar is stressed to only half its ultimate capacity, the lap or anchorage length will be half what it would have needed to be if the bar were fully stressed.

Ultimate bond stress

Both anchorage and lap lengths are determined by the ultimate bond stress $f_{bd}$ which depends on the concrete strength and whether the anchorage or lap length is in a ‘good’ or ‘poor’ bond condition.

$$f_{bd} = 2.25 \eta_1 \eta_2 f_{cd}$$ (Expression 8.2 from BS EN 1992-1-1)

where:

- $f_{cd}$ is the design tensile strength of concrete, $f_{cd} = \alpha_{ct} f_{ck,0.05} / \gamma_C$
- $f_{ck,0.05}$ is the characteristic tensile strength of concrete, $f_{ck,0.05} = 0.7 \times f_{ck}$
- $f_{ck}$ is the mean tensile strength of concrete, $f_{ck} = 0.3 \times f_{ck}$
- $\gamma_C$ is the partial safety factor for concrete ($\gamma_C = 1.5$ in UK National Annex)
- $\alpha_{ct}$ is a coefficient taking account of long-term effects on the tensile strength and of unfavourable effects resulting from the way the load is applied ($\alpha_{ct} = 1.0$ in UK National Annex)

Figure 1 Tension Anchorage
Table 1 gives the design tensile strengths for structural concretes up to C50/60.

- \( \eta_1 \) is the coefficient relating to the bond condition and \( \eta_1 = 1 \) when the bond condition is 'good' and \( \eta_1 = 0.7 \) when the bond condition is 'poor'.

It has been found by experiment that the top section of a concrete pour provides less bond capacity than the rest of the concrete and therefore the coefficient reduces in the top of a section. Figure 8.2 in BS EN 1992-1-1 gives the locations where the bond condition can be considered 'poor' (Figure 3). Any reinforcement that is vertical or in the bottom of a section can be considered to be in 'good' bond condition. Any horizontal reinforcement in a slab 275mm thick or thinner can be considered to be in 'good' bond condition. Any horizontal reinforcement in the top of a thicker slab or beam should be considered as being in 'poor' bond condition.

Confinement of concrete results in the characteristic compression strength being greater than \( f_{ck} \) and is known as \( f_{ck,c} \). If the concrete surrounding a steel reinforcing bar is confined, the characteristic strength of the concrete is increased and so will be the bond stress between the bar and the concrete. Increasing the bond stress will reduce the anchorage length. Concrete can be confined by external pressure, internal stresses or reinforcement.

**Anchorage lengths**

Figure 4 gives the basic design procedure for calculating the anchorage length for a bar. There are various shortcuts, such as making all \( \alpha \) coefficients = 1, that can be made to this procedure in order to ease the design process, although they will give a more conservative answer.

Both anchorage and lap lengths are determined from the ultimate bond strength \( f_{bd} \). The basic required anchorage length \( l_{b,rqd} \) can be calculated from:

\[
l_{b,rqd} = (\frac{\sigma_{sd}}{f_{bd}}) \phi
\]

where \( \sigma_{sd} \) is the design stress in the bar at the position from where the anchorage is measured. If the design stress \( \sigma_{sd} \) is taken as the maximum allowable design stress:

\[
\sigma_{sd} = f_{yd} = f_{yk}/\gamma_s = \frac{500}{1.15} = 435 \text{MPa}
\]

This number is used for most of the published anchorage and lap length tables, but the design stress in the bar is seldom the maximum allowable design stress, as bars are normally anchored and lapped away from positions of maximum stress and the \( A_{prov} \) is normally greater than \( A_{req} \).

The design anchorage length \( l_{b,d} \) is taken from the basic required anchorage length \( l_{b,rqd} \) multiplied by up to five coefficients, \( \alpha_i \) to \( \alpha_5 \):

\[
l_{b,d} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 \cdot l_{b,rqd} \geq l_{b,min}
\]

where the coefficients \( \alpha_1 \) to \( \alpha_5 \) are influenced by:

- \( \alpha_1 \) – shape of the bar
- \( \alpha_2 \) – size of the bar
- \( \alpha_3 \) – bond condition
- \( \alpha_4 \) – confinement
- \( \alpha_5 \) – method of support

\( \phi = 1.0 \) for bar diameters \( \phi \leq 32 \text{mm} \)

\( \eta_2 = (132 – \phi)/100 \) for \( \phi > 32 \text{mm} \) (\( \eta_2 = 0.92 \) for 40mm bars)

\( \phi \) is the diameter of the bar.
α₂ – concrete cover
α₃ – confinement by transverse reinforcement
α₅ – confinement by transverse pressure

The minimum anchorage length \( l_{\text{bd},\text{min}} \) is:

\[
\max \{0.3 \ell_{\text{bd},\text{req}}; 10\ell; 100\text{mm}\} \quad \text{for a tension anchorage}
\]

\[
\max \{0.6 \ell_{\text{bd},\text{req}}; 10\ell; 100\text{mm}\} \quad \text{for a compression anchorage}
\]

The maximum value of all the five alpha coefficients is 1.0. The minimum is never less than 0.7. The value to use is given in Table 8.2 of BS EN 1992-1-1. In this table there are different values for \( \alpha_1 \) and \( \alpha_2 \) for straight bars and bars called other than straight. The other shapes are bars with a bend of 90° or more in the anchorage length. Any benefit in the \( \alpha \) coefficients from the bent bars is often negated by the effects of cover. Note that the product of \( \alpha_2 \), \( \alpha_3 \), and \( \alpha_5 \) has to be ≥ 0.7.

To calculate the values of \( \alpha \) and \( \beta \), the value of \( c_\ell \) is needed. \( c_\ell \) is obtained from Figure 8.3 in BS EN 1992-1-1 and shown here in Figure 5. \( c_\ell \) is often the nominal cover to the bars. In any published anchorage tables, a conservative value for the nominal bar cover has to be assumed and 25mm is used in the Concrete Centre tables. If the cover is larger than 25mm, the anchorage length may be less than the value quoted in most published tables. For hooked or bent bars in wide elements, such as slabs or walls, \( c_\ell \) is governed by the spacing between the bars.

In Table 8.2 of BS EN 1992-1-1 anchorage length alpha coefficients are given for bars in tension and compression. The alpha values for a compression anchorage are all 1.0, the maximum value, except for \( \alpha_4 \) which is 0.7, the same as a tension anchorage. Hence, the anchorage length for a compression anchorage can always conservatively be used as the anchorage length for a bar in tension.

**Figure 4** Flow chart for anchorage lengths
Alpha values for tension anchorage

Alpha values for tension anchorage are provided in Table 8.2 of BS EN 1992-1-1.

α₁ – shape of the bar
Straight bar, α₁ = 1.0
There is no benefit for straight bars; α₁ is the maximum value of 1.0.

Bars other than straight, α₁ = 0.7 if cₜ > 3ø; otherwise α₁ = 1.0

If we assume that the value of cₜ is 25mm, then the only benefit for bars other than straight is for bars that are 8mm in diameter or less. For bars larger than 8mm, α₁ = 1.0. However, for hooked or bobbed bars in wide elements, where cₜ is based on the spacing of the bars, α₁ will be 0.7 if the spacing of the bars is equal to or greater than 7ø.

α₂ – concrete cover
Straight bar, α₂ = 1 – 0.15(Ø – ø)/ø
0.7 ≤ α₂ ≤ 1.0

There is no benefit in the value of α₂ for straight bars unless (Ø – ø) is positive, which it will be for small diameter bars. If cₜ is 25mm, then there will be some benefit for bars less than 25mm in diameter, i.e. for 20mm diameter bars and smaller, α₂ will be less than 1.0. Bars other than straight, α₂ = 1 – 0.15(Ø – 3ø)/ø ≥ 0.7 ≤ 1.0

Table 1: Design tensile strength, fₜₙₜ

<table>
<thead>
<tr>
<th>C20/25</th>
<th>C25/30</th>
<th>C28/35</th>
<th>C30/37</th>
<th>C32/40</th>
<th>C35/45</th>
<th>C40/50</th>
<th>C50/60</th>
</tr>
</thead>
<tbody>
<tr>
<td>fₜₙₕ</td>
<td>2.21</td>
<td>2.56</td>
<td>2.77</td>
<td>3.00</td>
<td>3.02</td>
<td>3.21</td>
<td>3.51</td>
</tr>
<tr>
<td>fₜₙₕ,ₚ</td>
<td>1.55</td>
<td>1.80</td>
<td>1.94</td>
<td>2.03</td>
<td>2.12</td>
<td>2.25</td>
<td>2.46</td>
</tr>
<tr>
<td>fₜₙₜ</td>
<td>1.03</td>
<td>1.20</td>
<td>1.29</td>
<td>1.35</td>
<td>1.41</td>
<td>1.50</td>
<td>1.64</td>
</tr>
</tbody>
</table>
Table 2: Anchorage and lap lengths for locations of maximum stress

<table>
<thead>
<tr>
<th>Bond Condition</th>
<th>Reinforcement in tension, bar diameter, ( \Phi ) (mm)</th>
<th>Reinforcement in compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight bars only</td>
<td>Good: 230 320 410 600 780 1010 1300 1760 40( \Phi )</td>
<td>Poor: 330 450 580 850 1120 1450 1850 2510 58( \Phi )</td>
</tr>
<tr>
<td>Other bars only</td>
<td>Good: 320 410 490 650 810 1010 1300 1760 40( \Phi )</td>
<td>Poor: 460 580 700 930 1160 1450 1850 2510 58( \Phi )</td>
</tr>
<tr>
<td>Lap length, ( l_{la} )</td>
<td>50% lapped in one location ( (\alpha = 1.4) )</td>
<td>Good: 320 440 570 830 1090 1420 1810 2460 57( \Phi )</td>
</tr>
<tr>
<td>100% lapped in one location ( (\alpha = 1.5) )</td>
<td>Good: 340 470 610 890 1170 1520 1940 2640 61( \Phi )</td>
<td>Poor: 490 680 870 1270 1670 2170 2770 3770 87( \Phi )</td>
</tr>
</tbody>
</table>

Notes:
1) Nominal cover to all sides and distance between bars ≥2mm (i.e. \( \alpha_1 < 1 \)). At laps, clear distance between bars ≤50mm.
2) \( \alpha_1 = \alpha_3 = \alpha_4 = \alpha_5 = 1.0 \). For the beneficial effects of shape of bar, cover and confinement see Eurocode 2, Table 8.2.
3) Design stress has been taken as 435MPa. Where the design stress in the bar at the position from where the anchorage is measured, \( \sigma_{sd} \), is less than 435MPa the figures in this table can be factored by \( \sigma_{sd}/435 \). The minimum lap length is given in cl. 8.7.3 of Eurocode 2.
4) The anchorage and lap lengths have been rounded up to the nearest 10mm.
5) Where 33\% of bars are lapped in one location, decrease the lap lengths for ‘50\% lapped in one location’ by a factor of 0.82.
6) The figures in this table have been prepared for concrete class C25/30.

<table>
<thead>
<tr>
<th>Concrete class</th>
<th>C20/25</th>
<th>C28/35</th>
<th>C30/37</th>
<th>C32/40</th>
<th>C35/45</th>
<th>C40/50</th>
<th>C45/55</th>
<th>C50/60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>1.16</td>
<td>0.93</td>
<td>0.89</td>
<td>0.85</td>
<td>0.80</td>
<td>0.73</td>
<td>0.68</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Figure 5: Values of \( C_D \) (\( C_a \) and \( C_D \) are taken to be \( C_{nom} \))

Figure 6: Values of \( K \)
There is no benefit in the value of $\alpha_2$ for bars other than straight unless $(c_d - 3\theta)$ is positive. If we assume that the value of $c_d$ is 25mm, then the only benefit for bars other than straight is for bars that are 8mm in diameter or less. For bars larger than 8mm $\alpha_2 = 1.0$. Again, for hooked or bobbed bars in wide elements, where $c_d$ is based on the spacing of the bars, $\alpha_2$ will be less than 1.0 if the spacing of the bars is equal to or greater than 7\theta.

$\alpha_3$ – confinement by transverse reinforcement

All bar types, $\alpha_3 = 1 - K \lambda \geq 0.7 \leq 1.0$

where:

- $K$ depends on the position of the confining reinforcement. The value of $K$ is given in Figure 8.4 of BS EN 1991-1-1 and shown here in Figure 6. A corner bar in a beam has the highest value for $K$ of 0.1. Bars which are in the outermost layer in a slab are not confined and the $K$ value is zero
- $\lambda$ is the amount of transverse reinforcement providing confinement to a single anchored bar of area $A_s = (\Sigma A_{st} - \Sigma A_{st,min}) / A_s$
- $\Sigma A_{st}$ is the cross-sectional area of the transverse reinforcement with diameter $\delta t$ along the design anchorage length $l_{bd}$
- $\Sigma A_{st,min}$ is the cross-sectional area of the minimum transverse reinforcement = $0.25 A_s$ for beams and zero for slabs

For example, if anchoring an H25 bar in a beam with H10 links at 300mm centres:

$A_s = 491 \text{mm}^2$ for a 25mm diameter bar

$\Sigma A_{st,min} = 0.25 \times 491 = 123 \text{mm}^2$

$\Sigma A_{st} = 4 \times 78.5 = 314 \text{mm}^2$, assuming links will provide at least four 10mm diameter transverse bars in the anchorage length

$\lambda = (\Sigma A_{st} - \Sigma A_{st,min}) / A_s = (314 - 123) / 491 = 0.38$

$\alpha_3 = 1 - K \lambda = 1 - 0.1 \times 0.38 = 0.96$

$\alpha_4$ – confinement by welded transverse reinforcement

$\alpha_4 = 0.7$ if the welded transverse reinforcement satisfies the requirements given in Figure 8.1e of BS EN 1992-1-1. Otherwise $\alpha_4 = 1.0$.

$\alpha_5$ – confinement by transverse pressure

All bar types, $\alpha_5 = 1 - 0.04p \geq 0.7 \leq 1.0$ where $p$ is the transverse pressure (MPa) at the ultimate limit state along the design anchorage length, $l_{bd}$.

One place where the benefit of $\alpha_5$ can be used is when calculating the design anchorage length $l_{bd}$ of bottom bars at end supports. This benefit is given in BS EN 1992-1-1 cl. 9.2.1.4(3) and Figure 9.3, and is shown here in Figure 7. It applies to beams and slabs.

Lap lengths

A lap length is the length two bars need to overlap each other to transfer a force $F$ from one bar to the other. If the bars are of different diameter, the lap length is based on the smaller bar. The bars are typically placed next to each other with no gap between them. There can be a gap, but if the gap is greater than 50mm or four times the bar diameter, the gap distance is added to the lap length.

Lapping bars, transferring a force from one bar to another via concrete, results in transverse tension and this is illustrated in Figure 8 which is a plan view of a slab. Cl.8.7.4.1 of BS EN 1992-1-1 gives guidance on the amount and position of the transverse reinforcement that should be provided. Following these rules can cause practical detailing issues if you have to lap bars where the stress in the bar is at its maximum. If possible, lapping bars where they are fully stressed should be avoided and, in
The diagram outlines a flowchart for determining bond stress in concrete structures. It involves several steps:

1. **Start**
   - Determine $f_{ctd}$ from Table 1

2. **Is the bar in 'good' position?**
   - If yes, $\eta_1 = 1.0$
   - If no, $\eta_1 = 0.7$

3. **Is smaller bar diameter $\phi \leq 32\text{mm}$?**
   - If yes, $\eta_2 = 1.0$
   - If no, $\eta_2 = (132-\phi)/100$

4. **Determine ultimate bond stress $f_u = 2.25 \eta_1 \eta_2 f_{ctd}$**

5. **Determine $\alpha_3 = 1$ – $K\lambda$**
   - If $0.7 \leq \alpha_3 \leq 1.0$

6. **Determine $l_0 = \alpha_1 \alpha_2 \alpha_3 \alpha_4 l_{lamb}$**
   - Check $l_0 > \max\{0.3\alpha_6 l_{lamb}; 15\phi; 200\text{mm}\}$

7. **Take $\alpha_2 \alpha_3 \alpha_5 = 0.7$**

8. **Determine $\alpha_5 = 1 - 0.04p$**
   - If $0.7 \leq \alpha_5 \leq 1.0$

9. **Is the bar confined by transverse pressure?**
   - If yes, $\alpha_6 = 1 - 0.04p$
   - If no, $\alpha_6 = 1 - K\lambda$

10. **Determine $\alpha_6$**
    - If $0.7 \leq \alpha_6 \leq 1.0$

11. **Is the bar in compression?**
    - If yes, $\alpha_1 = 1.0$
    - If no, $\alpha_1 = 0.7$ if $c_0 > 3\phi$
    - If yes, $\alpha_1 = 1.0$ if $c_0 \leq 3\phi$

12. **Determine $\alpha_1 = 1 - 0.15(c_0/\phi)/\phi$ if $0.7 \leq \alpha_1 \leq 1.0$**

13. **Does the bar have another bar between the surface of the concrete and itself?**
    - If yes, $\alpha_2 = 0.7$ if $c_0 > 3\phi$
    - If no, $\alpha_2 = 1.0$ if $c_0 \leq 3\phi$

The process concludes with the determination of bond stress, anchorage lengths, and other design parameters.

Figure 9: Flow chart for lap lengths
“The largest possible savings in lap and anchorage length can be obtained by considering the stress in the bar where it is lapped or anchored.”

Typical building structures, there is usually no need to lap bars where they are fully stressed, e.g. lapsing bars in the bottom of a beam or slab near mid-span. Examples where bars are fully stressed and laps are needed are in raft foundations and in long-span bridges.

The wording of this clause regarding guidance on the provision of transverse reinforcement is that it should be followed rather than it must be followed. This may allow the designer some scope to use engineering judgement when detailing the transverse reinforcement, e.g. increasing the lap length may reduce the amount of transverse reinforcement.

All the bars in a section can be lapped at one location if the bars are in one layer. If more than one layer is required, then the laps should be staggered.

A design procedure to determine a lap length is given in Figure 9 and, as can be seen in the flow chart, the initial steps are the same as for the calculation of an anchorage length.

Design lap length, \( l_0 = \alpha_1 \alpha_2 \alpha_3 \alpha_5 \alpha_6 \)

\( l_{b,rqd} \geq l_{0,min} \) (Eq. 8.10 in BS EN 1992-1-1)

The coefficients \( \alpha_1, \alpha_2, \) and \( \alpha_5 \) are calculated in the same way as for anchorage lengths and, again, all the coefficients can be taken as \( = 1.0 \) as a simplification.

\( \alpha_3 \) is calculated slightly differently. When calculating \( \alpha_3 \) for a lap length \( \Sigma A_{st,min} = A_s(\sigma_{sd}/f_yd) \), with \( A_s = \) area of one lapped bar.

The design lap length can therefore be determined by multiplying the design anchorage length by one more alpha coefficient \( \alpha_6 \), provided \( \alpha_3 \) has been calculated for a lap rather than an anchorage.

Design lap length, \( l_0 = \alpha_6 l_{b,rqd} \geq l_{0,min} \)

Minimum anchorage length, \( l_{0,min} = \max \{0.3 \alpha_6 l_{b,rqd}; 15o; 200mm\} \)

\( \alpha_6 \) – coefficient based on the percentage of lapped bars in one lapped section, \( \rho \)

\( \alpha_6 = (\rho/25)^{0.5} \geq 1.0 \leq 1.5 \)

where:

\( \rho \) is the percentage of reinforcement lapped within 0.65\( l_0 \) from the centre of the lap length considered

In most cases either the laps will all occur at the same location, which is 100% lapped and where \( \alpha_6 = 1.5 \), or the laps will be staggered, which is 50% lapped and where \( \alpha_6 = 1.4 \).

For vertically cast columns, good bond conditions exist at laps.

**Recommendations**

The largest possible savings in lap and anchorage length can be obtained by considering the stress in the bar where it is lapped or anchored.

For most locations, the old rule of thumb of lap lengths being equal to 40\( o \) should be sufficient. For this to be the case, the engineer should use their judgement and should satisfy themselves that the lap and anchorage locations are away from locations of high stress for the bars being lapped or anchored. Where it is not possible to lap or anchor away from those areas of high stress, the lengths will need to be up to the values given in Table 2.

This article presents the rules currently set out in EC2. However, there has been significant recent research which may find its way into the next revision of the Eurocode. For example, research into the effect of staggering on the strength of the lap (\( \alpha_6 \)) was discussed by John Cairns in Structural Concrete (the fib journal) in 2014. In the review of the Eurocodes, the detailing rules have been the subject of 208 comments (18% of the total for EC2) and it is acknowledged that the rules need to be simplified in the next revision.

**References:**


2) Bond A. J., Brooker O., Harris A. J. et al. (2011) How to Design Concrete Structures using Eurocode 2, Camberley, UK: MPA The Concrete Centre


