Treatment of Anchorage of Main Bars with Terminal 180^o Hooks or 90^o Bends in Reinforced Concrete by Codes of Practice -A Critical Review (Part Two: Anchorages of Bars with Terminal 180^o Hooks or 90^o Bends)

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ABSTRACT--- ***This part presents a comparative study of the anchorages of bars with terminal 180^o hooks or 90^o bends anchorage in reinforced concrete according to the BS8110, BD44/95, EC2 and AC1-318. There appear to be no published substations of the BD's equation, or those in BS8100 and EC2, and the unpublished tests by the Cement and Concrete Association which appear to have been the basis for BS8110's expression were of "loops", i.e. 180° bends loaded at both ends.***

Due to the scarcity of results from tests of bent and hooked anchorages in beams or slabs no comparisons were made with the current codes, only a parametric study is carried out to demonstrate the differences in codes' treatments except ACI-318 The recommendations of ACI 318 do not provide a general method of calculating resistances of anchorages with hooks and bends.

There are considerable ambiguities in the available design recommendations particularly in regard to the circumstances in which the resistance to bearing stresses in the bends needs to be checked.

Keywords--- bearing stress, 180^o hooks or 90^o bends, tail length, concrete strength, concrete cover, transverse reinforcement, transverse pressure

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1. INTRODUCTION

If the end anchorage of a bar is assisted by a bend or hook , the action of the bend produces a concentrated compression on the concrete which produces transverse tension. Failure is often by splitting which is generally attributed solely to the bearing effect. A pull-out failure with the bar slipping around the bend is also possible.

In addition to the factors mentioned previously in part one in relation to bond others which should be considered in relation to bent anchorages are :

- the considerable movement of the bar corresponding to the compression within the bend , which may make it impossible for the resistance of the bend to be fully mobilized while the bond in the lead length is still intact.
- the uncertainty about the distributions of the bond and bearing stresses around a bend .
- the possibility of the splitting effects from bond and bearing being combined and so reducing the resistance to splitting.

2. CODE OF PRACTICE RECOMMENDATIONS

2.1 BS 8110 [1] and BD44/95 [3]

In the British code BS8110:2005, the design ultimate bond stress f_{bd} for bars with a minimum cover of at least one bar diameter(φ) and a minimum clear spacing also at least one bar diameter, is equal to $k\sqrt{f_{cu}}$, where k is a constant depending on the type of bar and whether the bar is in tension or compression and f_{cu} is the cube strength of the concrete. The design tensile force that can be developed in a bar is :

$$F_{sd} = k\sqrt{f_{cu}}.\pi.\varphi.l_{b,eff} \qquad \text{……………………..(1)}$$

For straight bars the effective anchorage length $l_{b,eff}$ is the distance from the bar end to the section at which F_{sd} is considered .

The design value of k for normal type 2 deformed bars in tension is 0.5 which corresponds to a characteristic value of 0.7. The code applies k =0.5 to bars in beams only if minimum links are provided . In the absence of minimum links the design value of k is 0.35. For bars in slabs k =0.5 whether or not there are links.This could well be interpreted as meaning that k=0.5 is all right for interior bars with or without minimum links, but requires links around corner bars.

For anchorages with end hooks or bends , BS8110 generally requires checks on both bond and bearing stresses.So far as bond is concerned , the design limit for the bar force at the start of the bend is

$$F_{Rd1} \le \pi.\varphi.l_{b,eff}.f_{bd} \qquad \text{……………………(2)}$$

where : f_{bd} is the same as for straight anchorages, $l_{b,eff}$ is in general the length of the bend plus that of the tail. However the following lengths may be used if greater

for 180° hooks $l_{b,eff} = 8r \le 24\varphi$

for 90° bends $l_{b,eff} = 4r \le 12\varphi$

Minimum bend radii are 2φ for $\varphi \le 16mm$ and 3.5φ for $20 \le \varphi \le 40\,mm$.The minimum tail length is 5φ in all cases.

Bearing stresses inside bends do not need to be checked if the tail length is 5φ or if any extension beyond this can be neglected in the bond stress check. In all other cases the bearing stress is calculated as $f_{bt} = F_{bt} / r.\varphi$ and its maximum design value is

$$\sigma_{bd} \le \frac{2f_{cu}}{1+2(\varphi/a_b)} \qquad \text{……………………(3)}$$

corresponding to a characteristic value

$$\sigma_{bk} \le \frac{3f_{cu}}{1+2(\varphi/a_b)} \qquad \text{……………………(4)}$$

Where a_b is the centre to centre spacing of the bent bars or the cover in the direction perpendicular to the bend plus the bar diameter.

Although the above definition of f_{bt} is that given under the heading ' Design bearing stress in bends' in the preceding clause on ' Minimum radius of bends' the bar force is that ' at the midpoint of the curve' and its design limit is that of equation (3) above.

BD 44/95[3] uses BS8110 bond stresses but its bearing strength equation is very different. It makes σ_{bd} proportional to $\sqrt{f_{cu}}$ not f_{cu}, which has some logic as the failure is tensile. Its treatment of cover/bar spacing is different and most importantly it takes account of the ratio between the beam's overall depth and the curved length over which bearing stresses act.

Its maximum design value for the bearing stress is:

$$\sigma_{bd} = \frac{5.63}{\sqrt{\gamma_{mc}}} \sqrt{\left(\frac{h}{l_c}\right).f_{cu}.\left(\frac{a_b}{\varphi}\right)^{1/3}} \qquad \text{……………………….. (5)}$$

where a_b is as in BS8110 and $(a_b/\varphi) \le 8$, l_c is the length of the bar measured inside the bend and bearing on the concrete i.e. $\pi r/2$ for 90^0 and πr for 180^0, h is the overall depth of the membe $h/l_c \le 3.0$ It is noteworthy that the partial safety factor applied here is $\sqrt{\gamma_{mc}}$ with $\gamma_{mc} = 1.5$. In BS 8110 the factor $\gamma_{mc}(=1.5)$ is used. It seems probable that BD44/95 is applying γ_{mc} to f_{cu}.

<u>2.2 Euro Code 2:2004</u> [2]

EC2 considers most of the parameters which have influences on bond resistance in reinforced concrete structures such as concrete strength, position and orientation during casting, anchorage type, concrete cover, bar spacing, transverse reinforcement and transverse pressure.

The Code defines a basic design ultimate bond stress for ribbed bars as:

$$f_{bd} = 2.25\eta_1\eta_2 f_{ctd} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where: f_{ctd} =design tensile strength of concrete, η_1 = is a coefficient related to the quality of the bond condition and the position of the bar during concreting, η_2 =is a coefficient which considers bar diameter, η_1 =1.0 where good conditions are obtained. e.g. for bottom bars and for top bars where there is no more than $250mm$ of fresh concrete below the bars or where the bars are more than 300mm from the top.

η_1 =0.7 for other cases e.g. bars more than 250mm from bottom (and less than 300mm from the top if $h > 600mm$) and for all bars in structural elements built with slip forms.

η_2 =1.0 for $\varphi \le 32mm$ and $\eta_2 = (132-\varphi)/100$ for $\varphi > 32mm$

The basic anchorage length is defined as : $l_{b,rqd} = \dfrac{\varphi}{4}\dfrac{f_{sd}}{f_{bd}}$ ……………………… (7)

Where: f_{sd} = design stress of a bar for the ULS at the position from where the anchorage is measured.

The design anchorage length l_{bd} can be calculated from:

$$l_{bd} = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5\, l_{b,rqd} \ge l_{b,\min} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

where : l_{bd} = design anchorage length, α_1 = the effect of the form of the bars (assuming adequate cover), α_2 = the effect of concrete cover. $c_d = \min(c_b, c_s, s/2)$, α_3 = the effect of confinement by transverse reinforcement, α_4 = the influence of one or more welded transverse bars along the design anchorage length l_{bd}, α_5 = the effect of pressure transverse to the plane of splitting along the design anchorage length, α_1 =0.7 for standard hooks and bends with side covers $\ge 3\varphi$ (applies only to bars in tension), $\alpha_2 = 1-0.15(c_d-3\varphi)/\varphi$ for other than straight bars(hooked and bent bars) - $\alpha_2 \ge 0.7$ and ≤ 1.0, α_3 =1- $K\lambda$ $-\alpha_3 \ge 0.7$ and ≤ 1.0 ,where : $\lambda = \left(\sum A_{st} - \sum A_{st,\min}\right)/A_s$

A_s = area of a single anchored bar with the maximum bar diameter , $\sum A_{st}$ = cross-sectional area of the transverse reinforcement along the design anchorage length. (note A_{st} =area of a transverse bar) $A_{st,\min}$ cross-sectional area of the minimum transverse reinforcement =0.25 A_s for beams and 0 for slabs, $K = 0.1$ for a bar in the bends of stirrups, $K = 0.05$ for a bar with transverse bars in its cover, $K = 0$ for a bar in the cover to transverse bars, α_4 is not relevant in the present context and is taken as 1.0 and $\alpha_5 = 1-0.04p$

In addition to the individual limits on $\alpha_2\alpha_3$ and α_5 the product of α_2 , α_3 and α_5 is limited to ≥ 0.7 and ≤ 1.0, p = transverse pressure $\left(N/mm^2\right)$

$l_{b,\min}$ = the minimum anchorage length if no other limitation is applied:

-for anchorage in tension : $l_{b,\min}$ > maximum of ($0.3\,l_{b,rqd}$;10φ ; 100mm)

-for anchorage in compression $l_{b,\min}$ > maximum of ($0.6\,l_{b,rqd}$;10φ ; 100mm)

From the above , ignoring $l_{b,\min}$

$$l_{bd} = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5\left(\frac{\varphi\,\sigma_{sd}}{9\eta_1\eta_2 f_{ctd}}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9)}$$

Where $f_{ctd} = f_{ctk,0.05}/15 = 0.14 f_{ck}^{2/3}$ for $f_{ck} \le 50N/mm^2$

In effect equation (9) corresponds to design and characteristic bond strengths

$$f_{bd} = \frac{2.25\eta_1\eta_2}{\alpha_1\alpha_2\alpha_3\alpha_4\alpha_5} f_{ctd} = \frac{0.315\eta_1\eta_2}{\alpha_1\alpha_2\alpha_3\alpha_4\alpha_5} f_{ck}^{2/3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(10)}$$

and $$f_{bk} = \frac{2.25\eta_1\eta_2}{\alpha_1\alpha_2\alpha_3\alpha_4\alpha_5} f_{ctk} = \frac{0.4725\eta_1\eta_2}{\alpha_1\alpha_2\alpha_3\alpha_4\alpha_5} f_{ck}^{2/3} \qquad \text{...........................(11)}$$

For $f_{ck} \succ 50\, N/mm^2$, $f_{ctk} = 1.48 \ln(1 + f_{cm}/10)$ where f_{cm} is the mean cylinder strength and can be taken as $f_{ck} + 8\, N/mm^2$, and $f_{ctd} = 0.99 \ln(1 + f_{cm}/10)$. However bond stresses greater than those for $f_{ck} = 60\, N/mm^2$ should not be used, " unless it can be verified that the average bond strength increases above this limit".

Minimum requirements for hooks and bends are internal diameters of bend of at least 4φ for $\varphi \le 16mm$ and 7φ for $\varphi > 16mm$ and tail lengths at least equal to 5φ. No check is required on bearing capacity if the bend diameter is as above, the anchorage does not require a length more than 5φ past the end of the bend, the bar is not positioned with the plane of bend close to a concrete surface, and there is a cross bar with a diameter $\ge \varphi$ inside the bend. Otherwise the requirement is $$F_{bt} \le \frac{f_{cd}\,(2r)}{\frac{1}{a_b} + \frac{1}{2\varphi}} \qquad \text{..........................(12)}$$

where F_{bt} is the tensile force in the bar at the ULS at the start of the bend, a_b is half of the centre-to-centre distance between bars perpendicular to the plane of the bend or the side cover plus $\varphi/2$

r is the internal radius of the bend f_{cd} should not be taken as greater than that for $f_{ck} = 55\, N/mm^2$

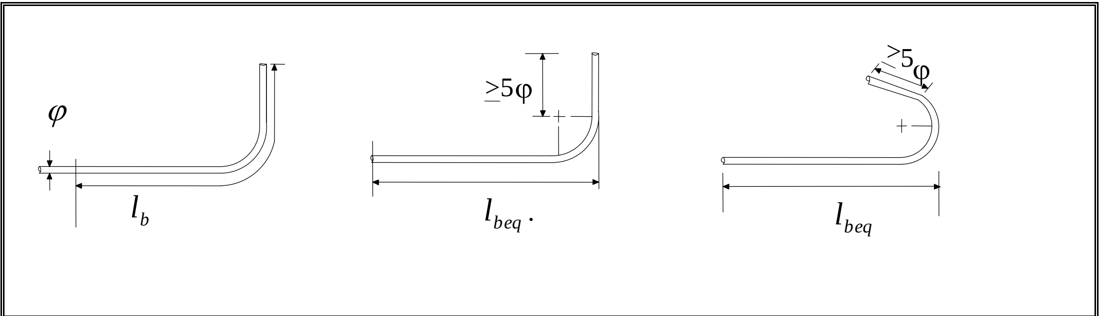


Fig.(1) Equivalent anchorage lengths for standard bends and hooks to EC2

The simplest treatment of a bend or hook using EC2 can be applied where c_s' (= lesser of c_s and $s/2$) is at least 3φ. The effect of the bend is then allowed for by the coefficient $\alpha_1 \ge 0.7$. α_2 can also be less than unity if $c_s' > 3\varphi$. No check on bearing is required and the calculated length l_{bd} can be used to define the length l_{beq} required (see Fig.1).

The above approach cannot be applied if $c_s' < 3\varphi$ and appears to be generally inappropriate for short anchorages, such as those at simple supports, as it makes the effect of the bend proportional to the length of the anchorage. The approach is therefore not considered further here.

A preferable approach consistent with EC2 is to base calculations on the actual bond length l_b, to take $\alpha_1 = 0.7$ if $c_s' \ge 3\varphi$ and $\alpha_2 < 1.0$ if $c_s' > 3\varphi$ and to check the bearing stress unless all the conditions for omitting it are met. This allows the bar force that can be developed at the start of the bend to be calculated. The bond resistance in the lead length over a support can be then be calculated with account taken of α_5.

2.3 ACI 318-2005[4]

ACI 318-05 treats the anchorage requirements For standard hooks and bends , the basic length l_{dh} (see Fig.2) required to anchor a lead end stress f_s is

$$l_{dh} = \frac{0.24 f_s}{\sqrt{f_c}}.\varphi \quad \begin{cases} \ge 8\varphi \\ \ge 150mm \end{cases} \text{whichever is greater.} \qquad \text{...............(13)}$$

This length may be modified by the following factors when $\varphi \le 36mm$

Conditions	Modifying factor
Side cover(normal to plane of hook or bend) $\ge 65mm$ and , for 90 bends , end cover $\ge 50mm$	0.7

For 90^0 bends with confining reinforcement as in Fig.2.7(a) or (b)	0.8
For 180^0 hooks with confining reinforcement as in Fig.2.7(b)	0.8

Note: The minimum US bar size is $9.5mm$, which defines the confining reinforcement.
Where applicable these factors may be combined.

Where a hook or bend is at the end of a member and both the side and top or bottom covers are less than 65mm, confining reinforcement as in Fig.(3-a or b) is required and no modification factor is applicable.This provision does not apply for hooked bars at discontinuous ends of slabs with confinement provided by the slab continuous on both sides normal to the plane of the hook.

No distinction is drawn between top and bottom cast bars. But factors, not given above, are included for epoxy-coated bars and for lightweight concrete.
The provisions cannot be applied to non-standard hooks or bends.

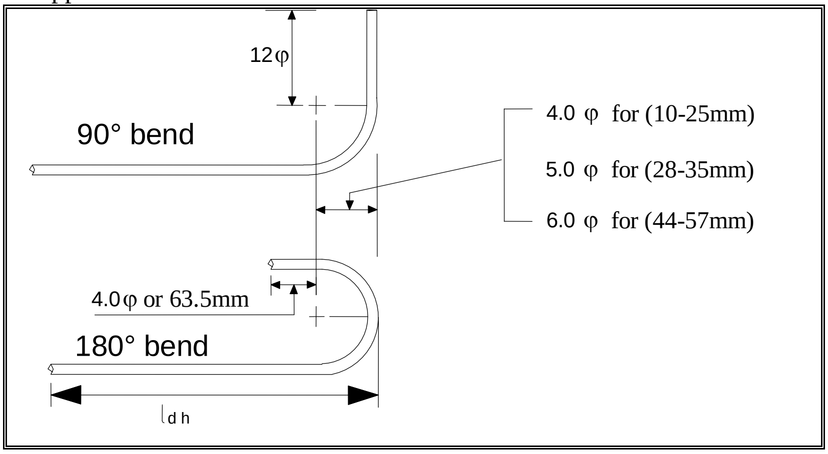
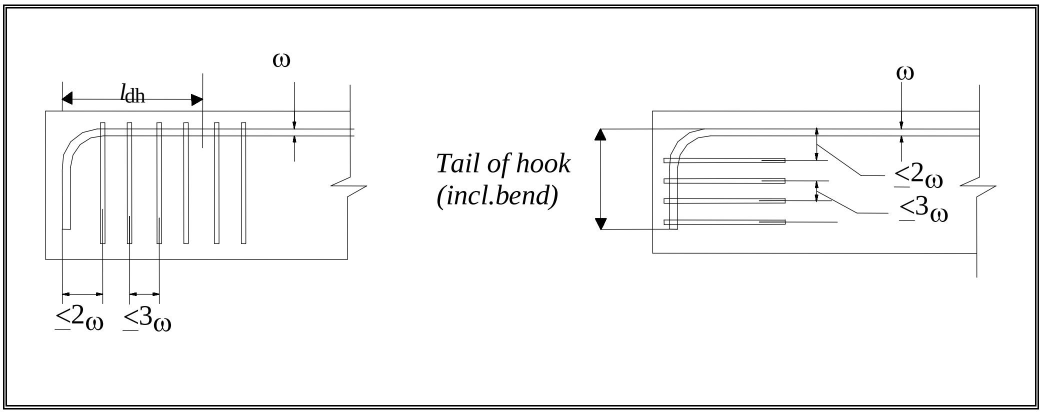


Fig.(2) Standard (minimum) hooks and bends to ACI-318



(a) Ties or stirrups placed perpendicular to the bar being developed, spaced along the development length l_{dh}

(b) Ties or stirrups placed parallel to the bar being developed

Fig.(3) Transverse reinforcement details in hooks and bends to ACI-318

3. DISSCUSSION AND PARAMETRIC STUDY

The methods considered further here are those of BS8110,EC2 and BD44/95 in which the bar force F_{sRd} that can be developed by the bend+tail part of an anchorage is in general the lesser of values corresponding to limits on bond and bearing stresses, i.e. F_{R2b} and $F_{R2\sigma}$.The following paragraphs give the relevant expressions in design terms for bottom bars in normal concrete with $f_{ck} \leq 50\,N/mm^2$.

BS 8100

$$F_{R2bd} = \pi\varphi l_{beff} f_{bd} \qquad \text{.........................(14)}$$

where for 90° bends with tail lengths = 5φ, $l_{beff} = 4r \le 12\varphi$ if this is greater than the actual length . For 180° bends with tail lengths = 5φ, $l_{beff} = 8r \le 24\varphi$ or the actual length.

$$f_{bd} = 0.5\sqrt{f_{cu}} \approx 0.56\sqrt{f_c}$$

$$F_{R2\sigma d} = \varphi r \sigma_{bd} \qquad \text{……………………..(15)}$$

where $$\sigma_{bd} \le \frac{2 f_{cu}}{1+2(\varphi/a_b)} \approx \frac{2.5 f_{ck}}{1+2(\varphi/a_b)} \qquad \text{……………………..(16)}$$

and $a_b = (c_s + \varphi)$ or $(s+\varphi)$

If the tail length is not greater than 5φ no check is required on the bearing pressure inside a bend and F_{sRd} is given by eqn (14) alone.

EC2

The following approach is not given in detail in EC2 but is consistent with the text.

$$F_{R2bd} = \pi \varphi l_b f_{bd}$$

with $$f_{bd} = \frac{2.25\eta_2}{\alpha_1\alpha_2} f_{ctd} \approx \frac{0.315}{\alpha_1\alpha_2}\eta_2 f_{ck}^{2/3} \qquad \text{………………………(17)}$$

where $\eta_2 = (132-\varphi)/100 \ge 1.0$, $\alpha_1 = 0.7$ if $c_s' > 3\varphi$, otherwise $\alpha_1 = 1.0$

$\alpha_2 = 1 - 0.15(c_s - 3\varphi)/\varphi \ge 0.7$ and ≤ 1.0

$$F_{R2\sigma d} = \varphi r \sigma_{bd}$$

where $$\sigma_{bd} = \frac{2.67 f_{ck}}{1+2(\varphi/a_b)} \qquad \text{……………………(18)}$$

and $a_b = (c_s + \varphi/2)$ or $(s+\varphi)/2$

No check is required on the bearing stress if

-the anchorage of the bar does not require a length $> 5\varphi$ beyond the end of the bend

-the bar is not close to an edge $(c_s \ge 3\varphi)$ and there is a cross- bar with a diameter $\ge \varphi$ within the bend.

-the mandrel diameter $(\varphi_m = 2r)$ is at least 4φ for $\varphi \le 16mm$ or 7φ for $\varphi > 16mm$.

BD 44/95

The expression for resistance as governed by bond is the same as that of BS 8110, as are the conditions under which bearing stresses need not be checked.

$$F_{R2\sigma d} = \varphi r \sigma_{bd}$$

with $$\sigma_{bd} = \frac{5.63}{\sqrt{\gamma_{mc}}}\sqrt{\left(\frac{h}{l_c}\right) . f_{cu}} . \left(\frac{a_b}{\varphi}\right)^{1/3} = 5.14\sqrt{\frac{h}{l_c} . f_{ck}} . \left(\frac{a_b}{\varphi}\right)^{1/3} \qquad \text{…………………(19)}$$

where $\gamma_{mc} = 1.5$, $h =$ overall depth of section, $l_c =$ length of inside of bend , with $(l_c / h) \le 3$ for calculation purposes, a_b is as defined in BS 8110 but $a_b / \varphi \le 8$

The expressions for σ_{bd} are discrete and separate from other considerations and can be compared rather simply. Those of BS 8110 and EC2 are basically similar, but differ in their definitions of a_b . Fig.(4) shows the relationships between σ_{bd} / f_{ck} and c_s / φ and s / φ. Although the bearing strengths for bars near side faces are similar, those for interior bars show a greater difference due to a_b being defined as $(s+\varphi)$ in BS 8110 but $(s+\varphi)/2$ in EC2.

Comparisons with BD 44/95 are not quite so simple, but in view of the similarity between BS 8110 and EC2 , at least for edge bars , it should be sufficient to compare BD 44/95's expression for σ_{bd} with that from BS 8110 . Fig.(5) shows σ_{bd} as a function of c_s / φ for three different concrete strengths. For each value of f_{ck} there are three lines for BD 44/95, corresponding to l_c / h=1,2 and 3, and two lines for BS 8110, one giving σ_{bd} and the other 1.225σ_{bd} , i.e. the value obtained if the safety factor is reduced to BD 44/95's $\sqrt{\lambda_{mc}}$.

With $f_{ck} = 20\,N/mm^2$, the BD 44/95 line for $h/l_c = 1$ is above the BS line but below 1.225 times the BS values, while the BD lines for h/l_c=2 and 3 are well above both BS lines. With $f_{ck} = 50\,N/mm^2$, the BD values of σ_{bd}/f_{ck} for $h/l_c = 1$ are only about 70% of BS 8110's, while the lines for h/l_c=2 and 3 are very close to those for BS 8110 and 1.225xBS 8110.

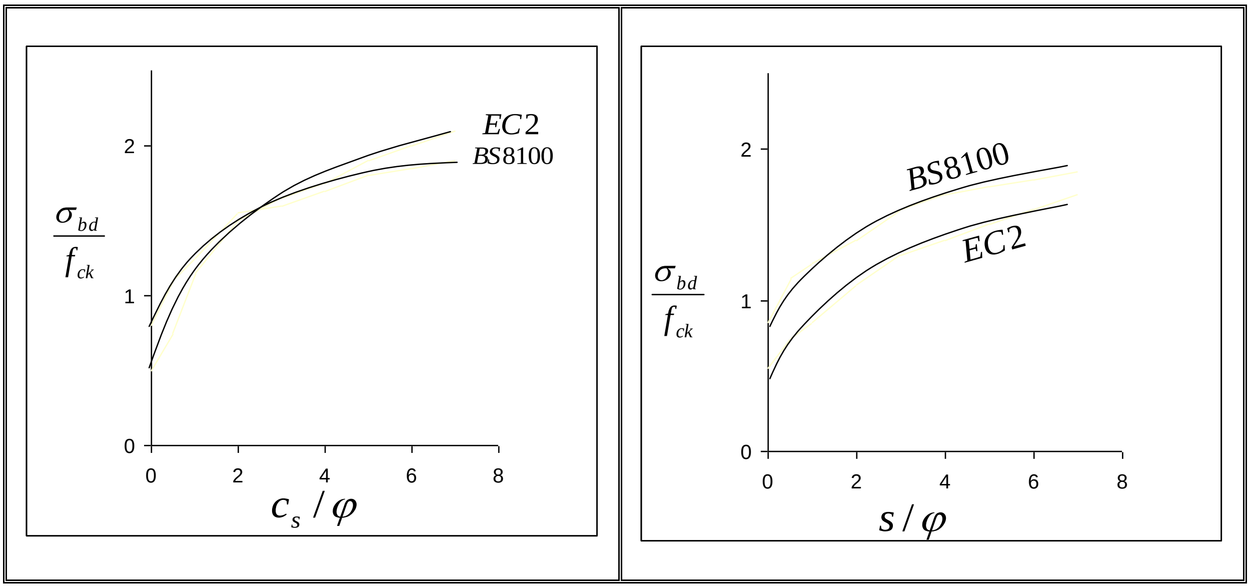
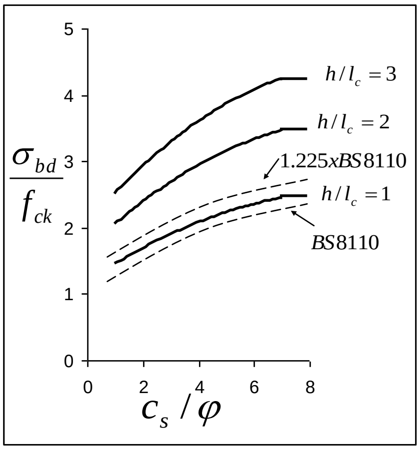


Fig.(4) Comparisons of bearing stress limits in BS8110 and EC2



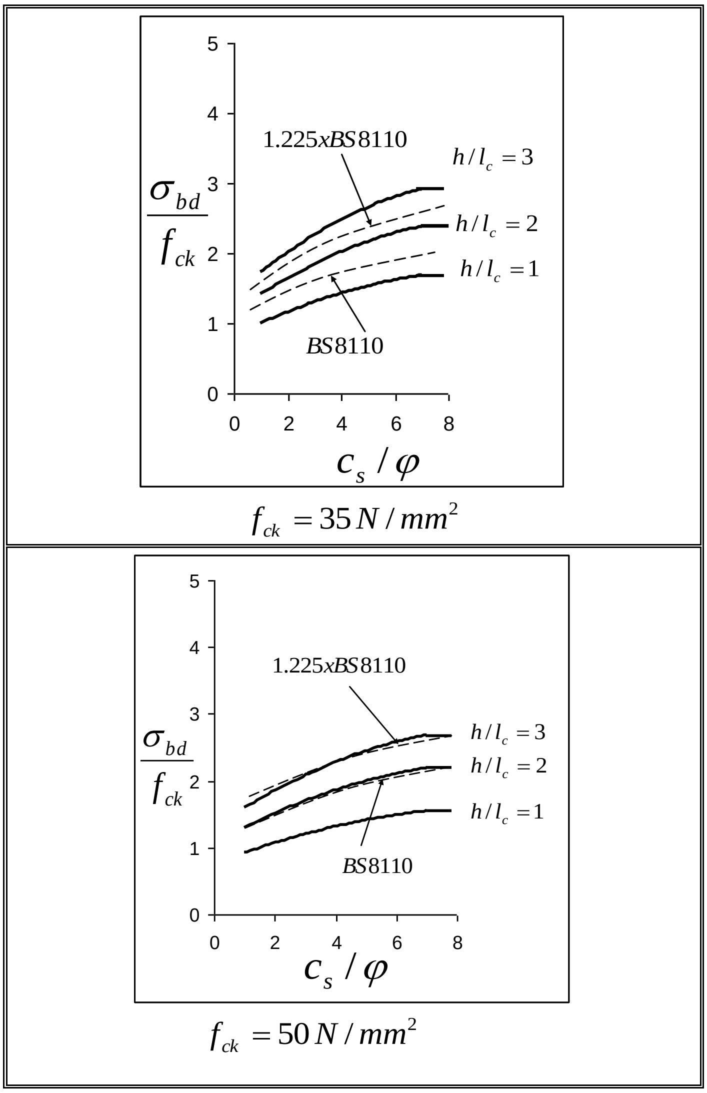


Fig.(5) Comparisons of σ_{bd} from BS8110 and BD 44/95

All three approaches generally require checks on bearing stresses but they allow the bearing limit to be discarded in particular cases. In BS8110 and BD 44 all that is required is that the tail length , or the part of it required for bond resistances, should be less than 4φ (or 5φ).

In EC2 there are the additional requirements that edge bars should have side covers greater than 3φ and that there should be cross-bars inside the bends.

If tail lengths are ≤ 4 or 5φ BS8110 and BD44/95 allow bond resistances to be calculated for lengths other than the actual anchored bar lengths. For 90° bends, $l_{b,eff}$ is the greater of $4r \leq 12\varphi$ and actual l_b and for 180° hooks, $l_{b,eff}$ is the greater of $8r \leq 24\varphi$ and actual l_b. These effective lengths are very similar to the actual lengths for 90° bends. However for 180° bends the differences can be significant, for example 36.5% when $\varphi_m/\varphi = 7$ and $l_t = 5\varphi$. Numerical comparisons have been made to illustrate the effects of using either l_b or l_{beff} in the bond strength equation and those of neglecting the check on bearing stress for different values of c_s/φ. Fig.(6) shows the design stress f_{sd} for the bar section at the loaded end of the bend plotted against φ_m/φ for three concrete strengths for:

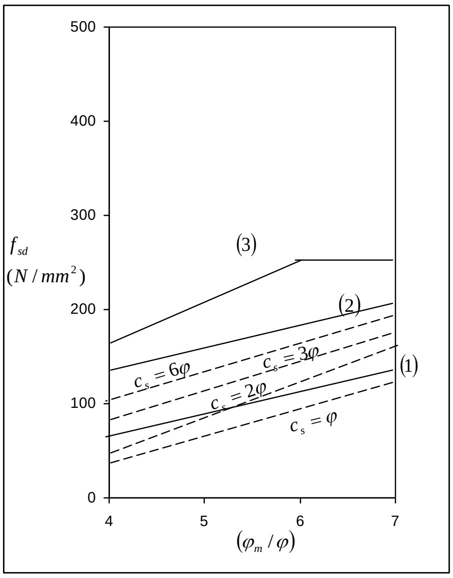
1) 90^0 bends with 5φ tails, with l_b used in eqn(1)

2) 180^0 bends with 5φ tails, with l_b used in eqn(1)

3) 180^0 bends with 5φ tails, with l_{beff} used in eqn(1)

The case of 90^0 bends with l_{beff} in eqn(1) has not been included as the results differ very little from those for case 1 above. If bearing is checked, at $f_{ck} = 20\,N/mm^2$ it governs for all 180^0 bends irrespective of whether l_b or l_{beff} is used in the bond calculation. It also governs for some 90^0 bends with small covers and/or small radii of bend. At $f_{ck} = 35\,N/mm^2$ a bearing limit would be critical for 90^0 bends if the side cover were equal to φ and $\varphi_m = 4\varphi$, but would govern for all 180^0 bends if l_{beff} were used in bond calculations and for a significant range of 180^0 bends in l_b were used. At $f_{ck} = 50\,N/mm^2$ bearing would be critical for some 180^0 bends if l_b were used and for practically all 180^0 bends if l_{beff} were used.

The combination of using l_{beff} in bond calculations and omitting a check on bearing stresses can double f_{sd} for 180^0 bends if c_s/φ is small and this must cause some concern about BS 8110. If a 180^0 bend with a 5φ tail is compared with a 90^0 bend with a 10 or 12φ tail, the bond lengths beyond the starts of the bends are similar but BS 8110 can allow f_{sd} to be twice as great for the 180^0 bend as for the 90^0 bend.



$f_{ck} = 20\,N/mm^2$

KEY

Broken lines - f_{sd} governed by bearing stresses

Full lines - f_{sd} governed by bond stresses

(1) 90° bends with 5φ tails ~ actual l_b

(2) 180° bends with 5φ tails ~ actual l_b

(3) 180° bends with 5φ tails ~ l_{beff}

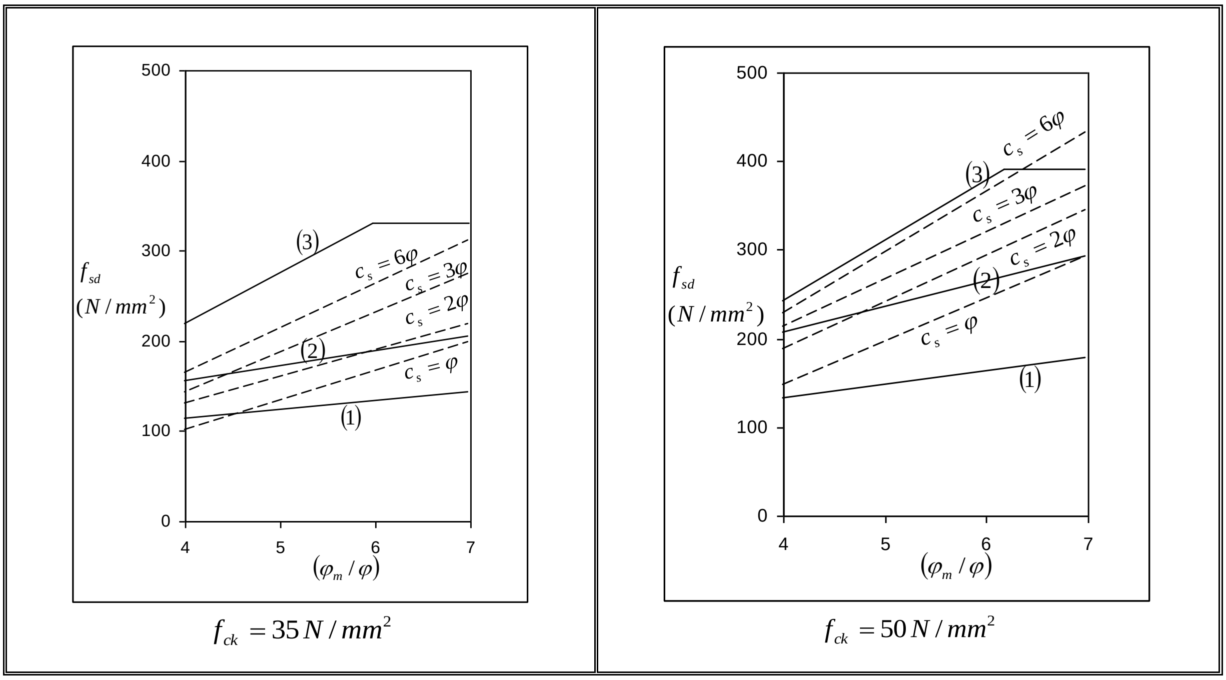


Fig.(6) Design bar stresses calculated by BS8110

According to EC2 it is not necessary to check the bearing stress in bends with 5φ tails when " the bar is not positioned at the edge (plane of bend close to concrete face) and there is a cross-bar with a diameter $\geq \varphi$ inside the bend" this means there are two cases to consider :

Case I - anchorages without cross-bars in the bends
Case II - anchorages with cross-bars in the bends

In both cases , if $c_s \leq 3\varphi$, bearing has to be checked , $\alpha_1 = 1.0$ and $\alpha_2 = 1.0$.

In case I, if $c_s \geq 3.0$, bearing has to be checked, $\alpha_1 = 0.7$ and $\alpha_2 = 1.0 - 0.15(c_s - 3\varphi)/\varphi, \geq 0.7$.

In case II, if $c_s \geq 3.0$ bearing need not be checked , if the tail length is not greater than 5φ, $\alpha_1 = 0.7$ and $\alpha_2 = 1.0 - 0.15(c_s - 3\varphi)/\varphi \geq 0.7$.

The need for a cross-bar to be present inside a bend , if the bearing check is to be omitted, raises questions about detailing requirements. EC2 gives no guidance on the positioning of the cross-bar along the length of the bend and does not stipulate any minimum for its extension beyond the plane of the bend. For edge bars, the latter issue could well be critical as any significant extension could compromise the requirement for cover. The lack of any guidance on the way in which the cross-bar is intended to act makes it very difficult for a designer to know how to obtain a satisfactory case II anchorage.

Fig.(7) shows comparisons between EC2 and BS8110 when $f_{ck} = 35N/mm^2$:

1- 90° bend + 5φ tail , case I.

2- 90° bend + 5φ tail , case II .

3- 180° bend + 5φ tail , case I ,

4-180° bend + 5φ tail , case II .

5- 90° bend + 10φ tails

The limiting bearing stresses of the two codes are similar and, with $f_{ck} = 35N/mm^2$, the BS8110 bond stress is almost the same as EC2's f_{bd}.The differences between the code's values for bar stresses at the loaded ends of bends arise primarily from :

-BS8110's use of l_{beff} which has a major effect for 180° hooks.

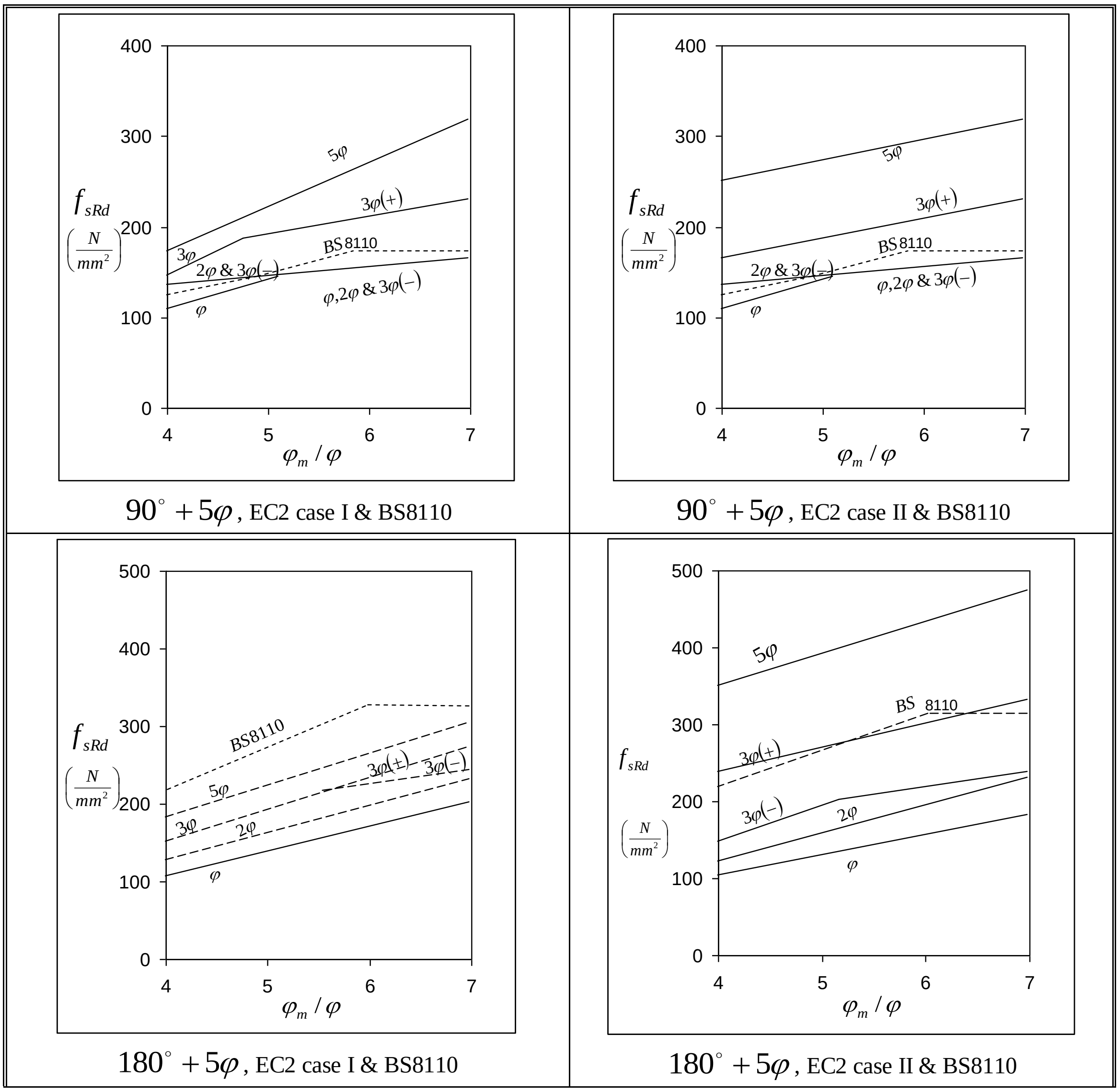
-EC2's bond stresses being dependent on c_s/φ .

-Omissions of checks on bearing stresses for all standard bends and hooks in BS8110 and the more limited omissions in EC2 , which are however coupled with increases of bond stresses from the coefficients α_1 and α_2.

The similarity of basic bond stresses makes f_{sRd} values from the two codes similar for $c_s \leq 3\varphi$, where $\alpha_1\alpha_2 = 1.0$, except in the case of 180° hooks where BS8110's l_{beff} influences the results.

For 180° hooks BS8110's use of l_{beff} increases the bond length by up to 50% and this brings the BS values of f_{sRd} above EC2's for case I at all values of c_s / φ. For case II, when c_s is just above 3φ , EC2 no longer requires a check on bearing and its bond stress is increased by 43% by α_1, with the result that its bar stresses are similar to BS8110's. At higher c_s / φ, EC2 bond stresses are increased further by α_2 (by a further 43% when $c_s = 5\varphi$) and its bar stresses are far above BS8110's.

For 90° bends with 5φ tails all the bar stresses are similar when $c_s < 3\varphi$, but,once α_1 applies, the EC2 stresses are higher and the difference again increases with increasing c_s up to 5φ. For 90° bends with 10φ tails the two codes give similar results when $c_s < 3\varphi$ but above this the EC2 values are again higher, although the difference from BS8110 is less than for 5φ tails as EC2 requires bearing checks in all cases. The differences between the bar stresses from the codes can be surprisngly high. BS8110 values can be up to 109% above EC2'S for 180° hooks with $c_s / \varphi = 1.0$, while EC2's case II values can be 67% above BS8110's for 180° hooks when $c_s = 5\varphi$. For 90° bends with 5φ of tails EC2 case II values can be 100% above BS8110's when $c_s = 5\varphi$.

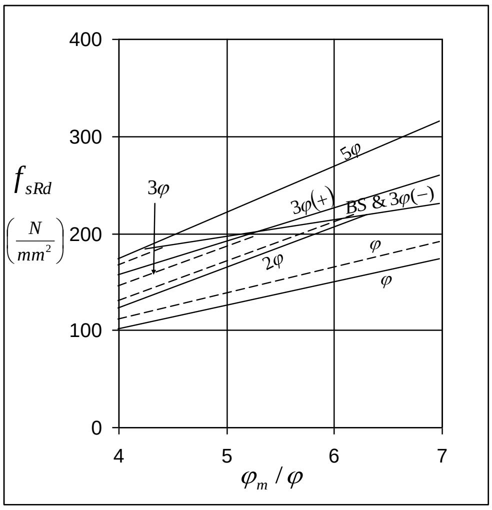


$90^\circ + 5\varphi$, EC2 case I & BS8110

$90^\circ + 5\varphi$, EC2 case II & BS8110

$180^\circ + 5\varphi$, EC2 case I & BS8110

$180^\circ + 5\varphi$, EC2 case II & BS8110



90° *Bends, with* 10φ *tails*

Note:

$f_{ck} = 35N/mm^2$

Case I-no cross bar in bend

Case II- cross bar in bend

Numbers beside lines are side covers

$3\varphi(-)$-cover just below 3φ so α_1 cannot be applied

$3\varphi(+)$-cover just above 3φ so α_1 can be applied and bearing not checked for standard hooks and bends

Fig.(7) Comparisons between EC2 and BS8110 for anchorages with 90° and 180° bends

4. CONCLUSION

The recommendations of ACI 318 do not provide a general method of calclating resistances of anchorages with hooks and bends.They treat only the standard bar dimensions of Fig.(2) and cannot be used for European standard bends with 5φ tail lengths. They do not treat the effects of varying radii of bend or of variations of cover other than its being less or more than $63.5mm$, irrespective of the bar size. The treatment of transverse reinforcement considers only the single spacing shown in Fig.(3). A potential problem with the EC2 is that where $c_s \geq 3\varphi$ and there is a cross-bar in the bend no check on bearing is required. The function envisaged for the cross-bar and the detailing expected for it are unclear and there seems to be no published justification for this rule.

The bearing stress limits in BS8110 and EC2 are relatively similar for bars at the sides of members. In both the limit stress is proportional to the compressive strength of the concrete and beyond that depends only on the side cover and the bar diameter. BD44/95(3) offers an alternative treatment of bearing with the limit stress for a side bar being a function of the ratio between the overall height of the member and the length of the stress on f_c replaced by one on $\sqrt{f_c}$. The treatment of geometric factors is closer to that commonly used for concentrated loads on concrete and also agrees with observations that the bearing resistances of bends in general decreases as the angle of the bend increases. The use of $\sqrt{f_c}$ is probably intended to reflect the tensile nature of bearing failures. In respect of bond the BD44/95 is the same as BS8110.

The use of the BD44/95(3) expression for bearing resistance has some merit compared with the expressions of EC2 and BS8110.It treats a less than proportionate relationship between bearing resistance and the cylinder strength of the concrete, which seems reasonable given the tensile nature of splitting failures. It involves both dimensions parallel and perpendicular to the plane of a bend in its treatment of the effect of the concentrated bearing force spreading into a larger body of concrete.

5. REFERENCES

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