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DESIGN GUIDE FOR
USE OF HEADED BARS TO EUROCODE 2

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Design Guide for

Use of Headed Bars to Eurocode 2

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Design Guide for Use of Headed Bars to Eurocode 2

by Chiew Sing Ping

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PREFACE

This design guide on headed bars is consistent with the design recommendations given in BS EN1992-1-1: 2023 [1]. At the time of writing, this 2nd Generation EN1992-1-1: 2023 [1] has not been adopted for use in Singapore yet, and it will take several years for the current 1st Generation SS EN1992-1-1: 2008 [2] to be replaced with the new 2nd Generation EN1992-1-1. The current 1st Generation SS EN1992-1-1: 2008 [2] does not provide any design guidance on how to use headed bars, hence there is an urgent need to develop this guide to bridge the gap as our industry is keen to adopt headed bars in construction to improve concrete quality and productivity.

The main objective of this guide is to set out clear design rules on how to use anchor heads on main longitudinal reinforcement bars in tension. Its focus is on the contribution provided by the head to anchor the bar so that the anchorage length can be reduced, and its design model and rules are in line with BS EN1992-1-1: 2023 [1]. In this way, this guide will be aligned to the 2nd Generation EN 1992-1-1 when it is fully implemented in Singapore in the future. In addition, this guide also provides typical applications where headed bars can be used efficiently and additional rules for good practice.

As a guide, it only provides guidance and recommendations, and it should not be construed as mandatory requirements by the Building and Construction Authority. The Qualified Persons should ensure that the ensuing design and execution of his/her projects are in accordance with the Authority's requirements. Additional references could be made to the appropriate sections in BS EN1992-1-1: 2023 [1] if necessary.

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1.0 INTRODUCTION

1.1 Background

Headed Bars (also known as headed reinforcement anchors) can contribute to the tension anchorage of reinforcement bars in concrete, under certain qualifying design situations they can even provide the full tension anchorage. They provide anchorage via direct bearing of the head on to the concrete as shown in Figure 1.1. They depart from the traditional reinforcement anchorage which relies mainly on bond along the length of the bar. In this manner, the headed bars can provide straight anchorage with a reduced anchorage length.

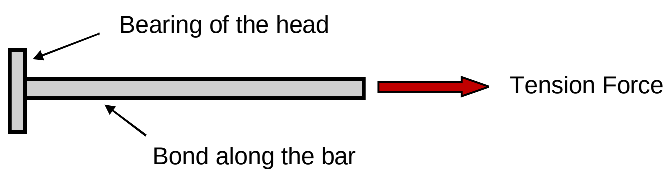


Figure 1.1 Force Transfer in a Headed Bar

For load transfer, the heads can be very effective; they are particularly advantageous in design situations when it is not practical to rely on the bar bond alone to provide the anchorage length. By reducing the bar anchorage lengths, the heads can:

a) reduce bar congestion at the joints.
b) improve concrete compaction and quality.
c) lead to simpler and quicker installation.
d) improve productivity.
e) reduce overall bar tonnage; and
f) potentially lead to net cost savings.

There are different ways of connecting the heads to the bars, generally they can be classified into either welding, hot forging, threading, swaging or bolting type. They are supplied by specialist trade manufacturers and are product specific using their own proprietary systems to connect the heads to the bars, details of which can be obtained directly from the manufacturers themselves.

1.2 Scope

The main objective of this design guide is to set out the design rules on the use of headed bars, it focuses on the contribution of the head to the total anchorage of the bar through bearing on the concrete. Essentially, the design rules to calculate this contribution of the head are in accordance with those given in Section 11.4.7 of the 2nd Generation BS EN1992-1-1: 2023 [1].

This guide is split into three main sections and an annex following this introduction, i.e.

a) Section 2 covers design rules. Some information of the design model is first given, followed by the specific design rules, and worked examples for design engineers.
b) Section 3 covers applications. Some typical applications where headed bars can be used most advantageously are given, together with some additional rules for good practice and comparisons with other design codes.
c) Section 4 covers product certification. Requirements for product conformance and approval for use in Singapore are given.
d) Annex A covers the design considerations to provide the readers a better insight and understanding of the design rules set out in Section 2.

2.0 DESIGN RULES

2.1 Design Model

The design model considers the combined anchorage contributions from bearing resistance provided by the head and bond along the bar length as illustrated in Figure 2.1. The bearing resistance of the head follows the design rules given in the BS EN1992-1-1: 2023 [1]. The design anchorage length of the rebar l_{bd} is calculated from the remaining balance stress $\sigma_{sd\ bond} = \sigma_{sd} - \sigma'_{sd}$ using the design rules given in the existing SS EN1992-1-1: 2008 [2]. In addition, the design anchorage length is increased by a factor of 1.1 to account for the interaction between the stresses developed behind the head and slip along the bar, as recommended in BS EN1992-1-1: 2023 [1]. Further explanation on this design consideration is given in Annex A.

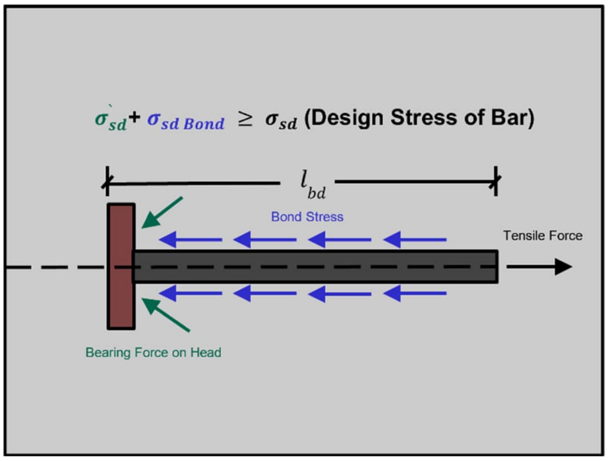


Figure 2.1 Force Transfer Mechanism

The governing principles in BS EN1992-1-1: 2023 [1] assume the head is sufficiently embedded inside the concrete, and there are adequate distances to any free surfaces to ensure concrete side blowout failure shown in Figure 2.2 will not occur and this is covered under Equation 2.1 of this guide.

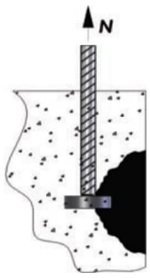


Figure 2.2 Concrete Side-Blowout Failure (reproduced from Figure 7e of *The Structural Engineer*, September 2013) [6]

2.2 Design Assumptions

This guide is intended for use as a non-contradictory complementary supplement to the existing SS EN1992-1-1: 2008 [2] and relevant National Annex within the jurisdiction of their design projects. In line with this, the following design assumptions are made, i.e.

a) The head is strong and stiff enough to withstand the governing design force at ULS. The design of the head, connection between the head and bar as well as its material requirements are outside the scope of this guide; they should be covered under their product's ETAs or equivalents.

b) The performance of anchor heads under fire conditions is not considered explicitly, and they are treated in the same manner as bars as far as fire protection is concerned.

c) This guide assumes perfect compaction of the concrete behind the anchor head without any reduction factor, and unlike bonded bars, there is no consideration for good or poor compaction.

d) The guide considers the heads to be concentrically connected to the bars and they are either circular, square, or rectangular in shape only; other shapes are outside the scope of this guide.

e) The head bearing area should be flat and perpendicular to the longitudinal axis of the rebar. A single product bearing area should be considered for calculation purposes.

2.3 Specific Design Rules

2.3.1 Head Resistance

The maximum tensile stress in the reinforcing steel developed by the head should be calculated as:

$$\sigma'_{sd} = k_{h,A} \cdot f_{cd} + \mathrm{v}_{\mathrm{part}} \cdot \frac{\sqrt{f_{ck}}}{\gamma_c} \cdot \frac{a_d}{\phi} \cdot \left(\frac{\phi_{\mathrm{h}}}{\phi}\right)^{\frac{5}{6}} \cdot \left(\frac{d_{dg}}{\phi}\right)^{\frac{1}{3}} \leq \mathrm{v}_{\mathrm{part}} \cdot k_{h,A} \cdot f_{cd} \quad \text{(Eqn. 2.1)}$$

where

$k_{h,A}$ is the ratio between the net area of the head and the cross-sectional area of the reinforcement:

$$k_{h,A} = \frac{A_h - A_s}{A_s} = \left(\frac{\phi_{\mathrm{h}}}{\phi}\right)^2 - 1 \quad \text{(Eqn. 2.2)}$$

A_h is the total area of the head

ϕ_{h} is the diameter of a circular head

ϕ is the diameter of the bar

$\mathrm{v}_{\mathrm{part}}$ = 11.0 for uncracked concrete in the region of the head

= 8.0 for concrete cracked in the region of the head

a_d is the nominal value of the distance between the bar and a free surface which may be assumed as:

Table 2.1 – Definitions of Nominal Distance a_d and Limits of Applicability

Case	Limits of Applicability	Definition of nominal distance a_d
Single Bar near to an Edge		$a_d = a_{\mathrm{y}}$
Corner Bar	$a_{\mathrm{x}} \geq 2a_{\mathrm{y}} + 1.2\phi_{\mathrm{h}}$	$a_d = a_{\mathrm{y}}$
	$a_{\mathrm{x}} < 2a_{\mathrm{y}} + 1.2\phi_{\mathrm{h}}$	$a_d = 0.5a_y + 0.25a_x - 0.3\phi_{\mathrm{h}}$
Group of Bars	$s_x \geq 4a_{\mathrm{y}}$	$a_d = a_{\mathrm{y}}$
	$\phi_{\mathrm{h}} \leq s_x < 4a_{\mathrm{y}}$	$a_d = a_y \dfrac{s_x - \phi_{\mathrm{h}}}{4a_y - \phi_{\mathrm{h}}} + 0.23(a_y - \dfrac{\phi_{\mathrm{h}}}{2}) \dfrac{4a_y - s_x}{4a_y - \phi_{\mathrm{h}}} (1 - \dfrac{1}{(\phi_{\mathrm{h}}/\phi)^2})$

Note: *In case a_x becomes smaller than a_y, the dimensions a_x and a_y should be inverted in the calculation.*

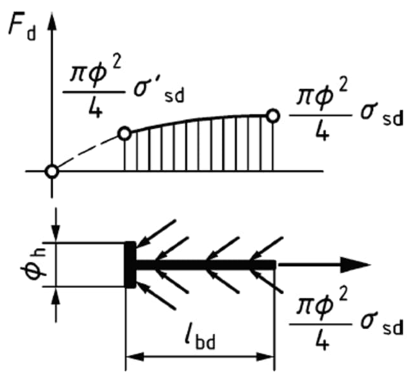
where

a_y is the distance between the bar axis and the nearest edge as defined in Figure 2.3b.

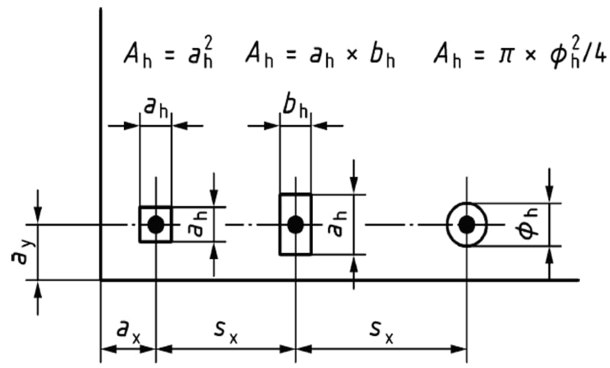
a_x is the minimum distance between the bar axis and a corner as defined in Figure 2.3b.

For rectangular heads elongated in the direction of the considered edge, a_x should be considered according to Figure 2.3 (c). In case a_x becomes smaller than a_y, the dimensions a_x and a_y should be inverted in the verification; s_x is the bar spacing of a group of bars along the considered edge as defined in Figure 2.3.

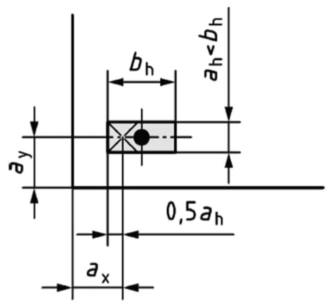
a_h and b_h are the widths of square and rectangular heads which shall not be taken larger than 4 times the thickness of the head plate.



a) definition of design anchorage length for headed bars in tension



b) definition of head dimensions (a_h, b_h, ϕ_h, A_h), distance to the considered edge (a_y), distance to the corner (a_x) and bar spacing (s_x) for square, rectangular and circular heads



c) definition of distance a_x for rectangular heads near to corners

Figure 2.3 Definition of Design Anchorage Length, Head Size and Bar Distance for Headed Bars (reproduced from Figure 11.9 of BS EN1992-1-1: 2023 [1])

2.3.2 Further Explanations on Corner, Single and Group of Bars

2.3.2.1 Single Bar near to an Edge and Group of Bars

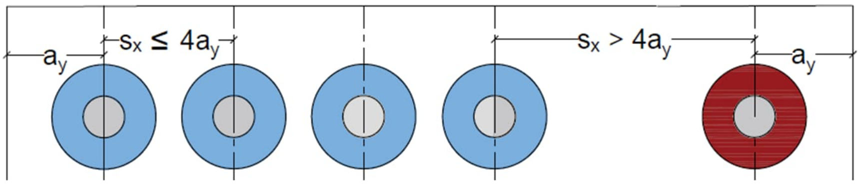


Figure 2.4 Definition of Single Bar to an Edge and Group of Bars

For a single bar near to an edge to be applicable (in red colour), it must be closed to a free surface and sufficiently distant away from a corner or another bar where the spacing s_x to the next bar is more than four times the distance a_y (the distance from the bar axis to the nearest edge). In this instance, the nominal distance $a_d = a_y$.

Conversely, for a group of bars (those in blue colour) with bar spacing s_x to the next bar is less than four times a_y, the nominal distance a_d can be determined from Table 2.1 which has been derived assuming a linear transition between the two limits: $a_d = a_y$ for the upper limit with $s_x = 4a_y$ (no interaction between bars) and the lower limit for $s_x = \phi_h$.

2.3.2.2 Corner Bar

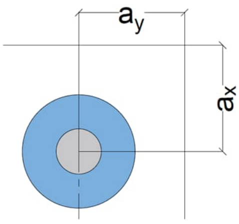


Figure 2.5 Definition of Corner Bar

In the case involving a corner bar, the bar must be located near to two edges. The nominal distance a_d is derived to account for reduced confinement near to a corner and the potential failure due to spalled concrete which further diminishes the confining zone.

For elongated heads (rectangular) near a corner, the failure can occur under the head portion, the distance a_x must be calculated using Figure 2.3c. It should be noted for circular and square heads, the formula in Table 2.1 uses the smallest distance to an edge a_y ($a_x \geq a_y$, otherwise, a_x shall be replaced by a_y and vice versa). For elongated heads, both combinations must be verified and for headed bars near multiple edges, each edge should be verified separately. Some examples where corner bars are applicable include anchoring roof beams to column joints and anchoring beams to beams.

2.3.3 Bond Resistance

When the design tensile stress of the bar is larger than the anchorage capacity of the head, the shortfall needs to be resisted by the bar in terms of bond resistance. Further study was carried out to confirm that the approach of adopting the 1st generation EC2 to calculate the anchorage is conservative. Additionally, the factor of 1.1 adopted by the 2nd generation EC2 is also adopted. Therefore, the design anchorage length in the reinforcing bar l_{bd} to develop the remaining tensile stress $\sigma_{sd} - \sigma'_{sd}$ may be calculated as:

$$l_{bd} = 1.1 \cdot (l_{bd}(\sigma_{sd}) - l_{bd}(\sigma'_{sd})) \qquad \text{(Eqn. 2.3)}$$

From SS EN1992-1-1: 2008 [2] (see equation 8.3 & 8.4),

$$l_{b,rqd} = \frac{\phi}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} \qquad \text{(Eqn. 2.4)}$$

$$l_{bd} = \alpha_1\, \alpha_2\, \alpha_3\, \alpha_4\, \alpha_5\, l_{b,rqd} \qquad \text{(Eqn. 2.5)}$$

where $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 1$

$$\therefore l_{bd} = l_{b,rqd}$$

From BS EN1992-1-1: 2023 [1] (see equation 11.11),

$$l_{bd} = 1.1(l_{b,rqd})$$

$$\therefore l_{bd} = 1.1\left(\frac{\phi}{4} \cdot \frac{\sigma_{sd} - \sigma'_{sd}}{f_{bd}}\right) \qquad \text{(Eqn. 2.6)}$$

As specified in SS EN 1992-1-1:2008 [2] under Section 8.6, the minimum anchorage length is $l_{bd,min} \geq 10\phi$ should be satisfied.

2.3.4 Limits of Applicability for Full Head Resistance

Theoretically, a reinforcing steel bar $\sigma_{sd} = 435\ MPa$ can develop full resistance without any need for additional anchorage length if its head $\phi_{\mathrm{h}} \geq 3\phi$ with $f_{\mathrm{ck}} \geq 25$ MPa, $\phi \leq 25\ mm;$ $d_{dg} \geq 32\ mm$ and:

- $a_{\mathrm{y}} \geq 3\phi$ for headed bars in uncracked concrete or $a_{\mathrm{y}} \geq 4\phi$ for headed bars in cracked concrete;
- $a_{\mathrm{x}} \geq 2a_{\mathrm{y}} + 1.2\phi_{\mathrm{h}}$;
- $s_{\mathrm{x}} \geq 4a_{\mathrm{y}}$

where

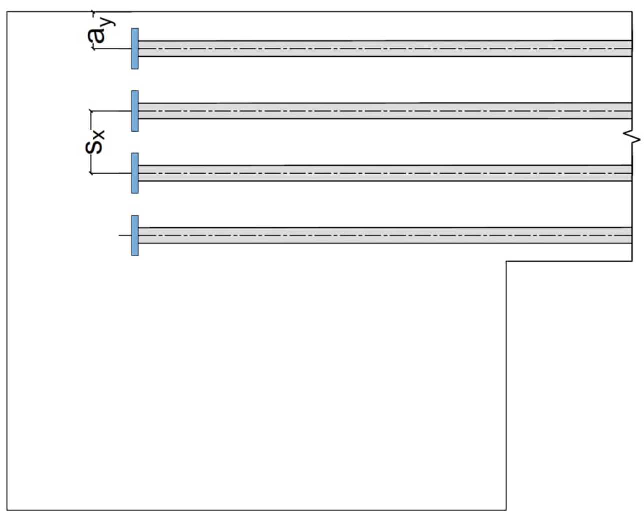
ϕ_{h} is the diameter of a circular head $\leq 4t_h$ (where t_h is the head thickness) or the diameter of a circle with the same area as that of the actual head

$$\phi_{\mathrm{h}} = 2\sqrt{\frac{A_{\mathrm{h}}}{\pi}} \qquad \text{(Eqn. 2.7)}$$

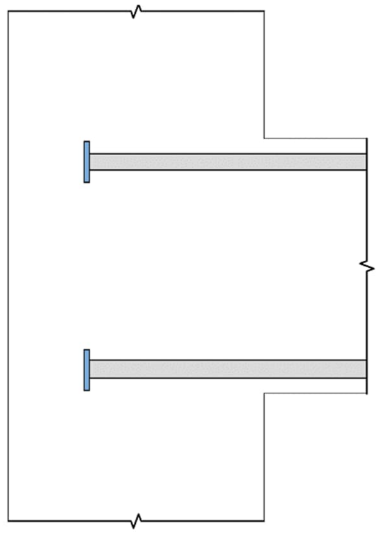
where A_{h} is the total area of the head defined in Figure 2.4b.

2.4 Worked Examples

2.4.1 Example 1 (Beam - Column Joint)



Plan View



Elevation View

Assumed Design Parameters:

Column: 800 x 800 mm	f_{bd} = 2.31 $(poor\ bond)$
Beam: 400 x 500 mm	v_{part} = 11 $(assumed\ uncracked)$
Bar $\phi = 25$ mm	Cover = Bar ϕ+ 10mm = 35mm
Circular Head Diameter ϕ_h = 65 mm	Bar Spacing $s_x = \frac{400-(2*35)-25}{3} \approx 101$ mm
Head Thickness t = 9 mm	γ_c = 1.5
Concrete Grade: C35/45	d_{dg} = 20 + 16 = 36 mm
f_{ck} = 35 MPa	
f_{cd} = 23.3 MPa	Design Stress, $\sigma_{sd} = \frac{500}{1.15} = 434.8$

**Note:* *The values for cover and bar spacing are intentionally chosen to demonstrate the application of design equations in a more constrained joint situation.*

For Group of Bars:

The bar closest to the edge is selected as the most conservative case for calculating the anchorage length because it has the shortest distance to the concrete's free surface.

Bar Spacing s_x = 101 mm

$$a_y = Cover + \frac{1}{2}\ bar$$

$$a_y = 35 + 12.5 = 47.5 \text{ mm}$$

$$s_x = 101 \text{ mm}, \ 4a_\mathrm{y} = 190 \text{ mm}$$

where $s_x < 4a_\mathrm{y}$,

$$\therefore a_d = a_y \frac{s_x - \phi_\mathrm{h}}{4a_y - \phi_\mathrm{h}} + 0.23(a_y - \frac{\phi_\mathrm{h}}{2}) \frac{4a_y - s_x}{4a_y - \phi_\mathrm{h}} (1 - \frac{1}{(\phi_\mathrm{h}/\phi)^2})$$

$$a_d = 15.8$$

$$k_{h,A} = \left(\frac{\phi_\mathrm{h}}{\phi}\right)^2 - 1 \quad \text{(Eqn. 2.2)}$$

$$= \left(\frac{65}{25}\right)^2 - 1 = 5.8$$

$$\grave{\sigma}_{sd} = k_{h,A} \cdot f_{cd} + \mathrm{v}_\mathrm{part} \cdot \frac{\sqrt{f_{ck}}}{\gamma_c} \cdot \frac{a_d}{\phi} \cdot \left(\frac{\phi_\mathrm{h}}{\phi}\right)^{\frac{5}{6}} \cdot \left(\frac{d_{dg}}{\phi}\right)^{\frac{1}{3}} \leq \mathrm{v}_\mathrm{part} \cdot k_{h,A} \cdot f_{cd} \quad \text{(Eqn. 2.1)}$$

$$\grave{\sigma}_{sd} = 202.7\ MPa < 1345.6$$

$$\sigma_{sd} - \grave{\sigma}_{sd} = 434.8 - 202.7 = 232.1\ MPa$$

$$\mathrm{f_{bd}} = 2.25 \cdot 0.7 \cdot 1 \cdot \frac{2.2}{1.5} = 2.31$$

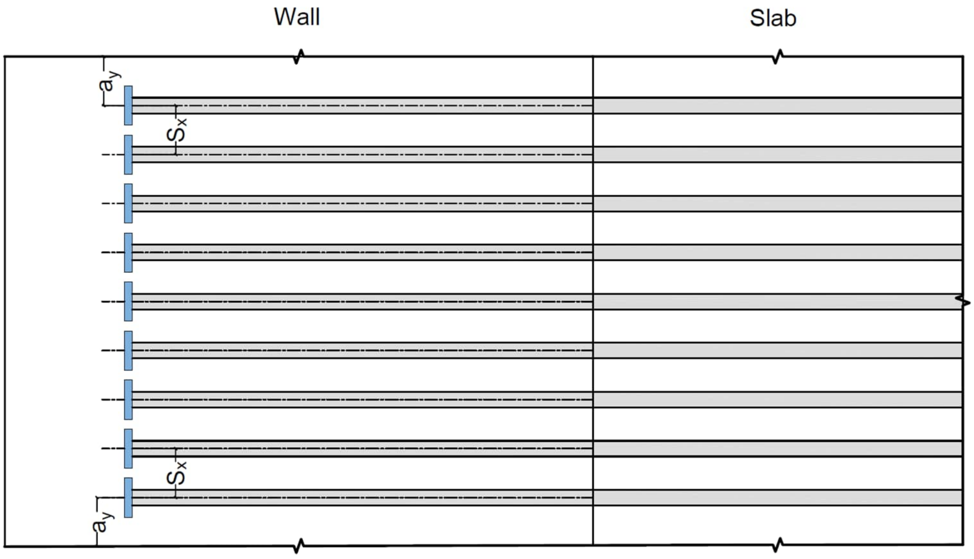
$$l_{bd} = 1.1\left(\frac{\phi}{4} \cdot \frac{\sigma_{sd} - \grave{\sigma}_{sd}}{\mathrm{f_{bd}}}\right) \quad \text{(Eqn. 2.6)}$$

$$= 1.1\left(\frac{25}{4} \cdot \frac{232.1}{2.31}\right)$$

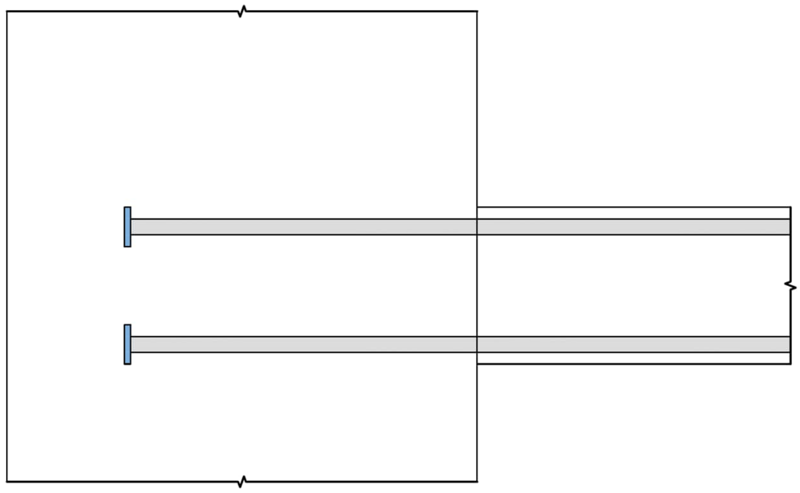
l_{bd} = 690.6 mm > 250 mm (min 10ϕ)

(The calculated $\boldsymbol{l_{bd}}$ of **690.6 mm** meets the recommended development length of not less than 3/4 the width of the column or walls for good practice.)

2.4.2 Example 2 (Slab to D-Wall Junction)



Plan View



Elevation View

Assumed Design Parameters:

Slab: 400 mm thickness	f_{bd} = 2.31 ($poor\ bond$)
Wall: 1200 mm thickness	v_{part} = 11
Rebar $\phi = 32$ mm	$s_x = 100\ mm$
Circular Head Diameter ϕ_h = 80 mm	γ_c = 1.5
Head Thickness t = 9 mm	d_{dg} = 20 + 16 = 36 mm
Concrete Grade: C35/40	Design Stress, $\sigma_{sd} = \frac{500}{1.15}$ = 434.8
f_{ck} = 35 MPa	Cover = Bar ϕ+ 10mm = 42 mm
f_{cd} = 23.3 MPa	

**Note: The values for cover and bar spacing are intentionally chosen to demonstrate the application of design equations in a more constrained joint situation.*

For Group of Bars:

The bar closest to the edge is selected as the most conservative case for calculating the anchorage length because it has the shortest distance to the concrete's free surface.

Bar Spacing s_x = 100 mm

$$a_y = Cover + \frac{1}{2}\ bar$$

$$a_y = 42 + 16 = 58 \text{ mm}$$

Conservatively, a_y is taken from the nearest bar to the edge, where $s_x < 4a_y$

s_x = 100 mm, $4a_y$ = 232 mm

where $s_x < 4a_y$,

$$\therefore a_d = a_d = a_y \frac{s_x - \phi_h}{4a_y - \phi_h} + 0.23\left(a_y - \frac{\phi_h}{2}\right)\frac{4a_y - s_x}{4a_y - \phi_h}\left(1 - \frac{1}{(\phi_h/\phi)^2}\right)$$

$$a_d = 10.7$$

$$k_{h,A} = \left(\frac{\phi_h}{\phi}\right)^2 - 1$$

$$= \left(\frac{80}{32}\right)^2 - 1 = 5.3$$

$$\sigma_{sd}^{`} = k_{h,A} \cdot f_{cd} + v_{part} \cdot \frac{\sqrt{f_{ck}}}{\gamma_c} \cdot \frac{a_d}{\phi} \cdot \left(\frac{\phi_h}{\phi}\right)^{\frac{5}{6}} \cdot \left(\frac{d_{dg}}{\phi}\right)^{\frac{1}{3}} \leq v_{part} \cdot k_{h,A} \cdot f_{cd}$$

$$\sigma_{sd}^{`} = 154.6 < 1345.6$$

$$\sigma_{sd\ bond} = \sigma_{sd} - \sigma_{sd}^{`}$$

$$\sigma_{sd\ bond} = 434.8 - 154.6$$

$$\sigma_{sd\ bond} = 280.2\ MPa$$

$$f_{bd} = 2.25 \cdot 0.7 \cdot 1 \cdot \frac{2.2}{1.5} = 2.31$$

$$l_{bd} = 1.1\left(\frac{\phi}{4} \cdot \frac{\sigma_{sd\ bond}}{f_{bd}}\right) = 1.1\left(\frac{32}{4} \cdot \frac{280.2}{2.31}\right)$$

$$\boldsymbol{l_{bd} = 1067.6 \text{ mm} > 320 \text{ mm (min } 10\phi)}$$

(The calculated $\boldsymbol{l_{bd}}$ of **1067.6 mm** meets the recommended development length of not less than 3/4 the width of the column or walls for good practice.)

3.0 APPLICATIONS

This section provides some typical design situations where headed bars can be applied most efficiently including some additional rules for good practice. In addition, the use of headed bars is also permitted in other design codes, and it is useful to see where this design guide stands in comparison with the other design codes.

3.1 Typical Applications

Headed bars are most effective in joint regions with high congestion and interlinking bent bars. Their use will lead to lesser rebar congestion and better concrete consolidation in these regions.

Some typical applications where the use of the traditional 90^{o} bent hook can be replaced with a straight headed bar are illustrated below, i.e.

a) Beam to Column Joint (see Figures 3.1 & 3.2)
b) Beam to Beam Joint (see Figures 3.3 & 3.4)
c) Slab to D-Wall Junction (see Figures 3.5 to 3.6)

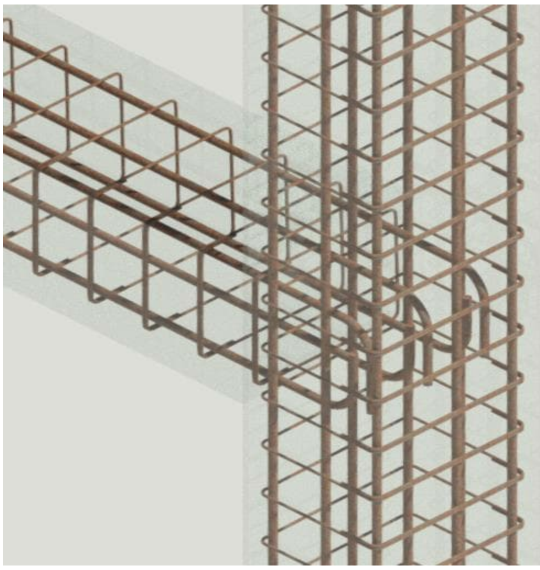


Figure 3.1 Beam to Column Joint using traditional 90^{0} Bent Hook

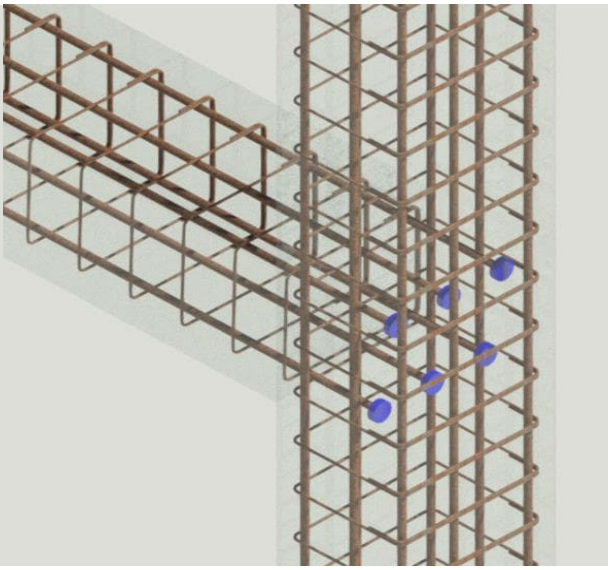


Figure 3.2 Beam to Column Joint using Headed Bar

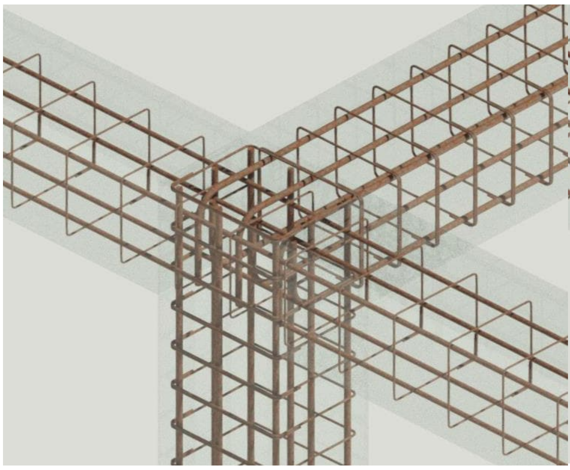


Figure 3.3 Beam to Beam Joint using traditional 90^0 Bent Hook

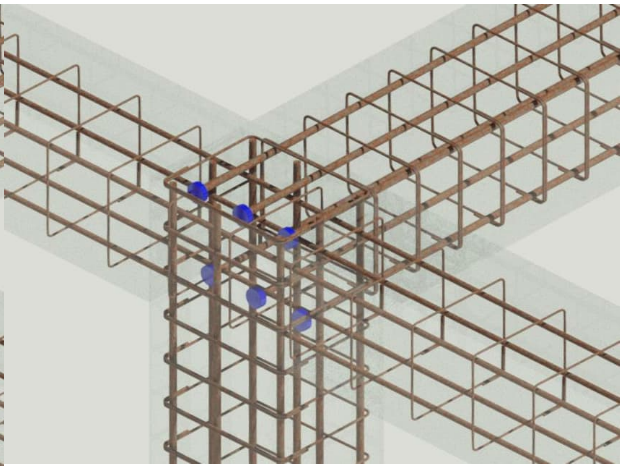


Figure 3.4 Beam to Beam Joint using Headed Bar

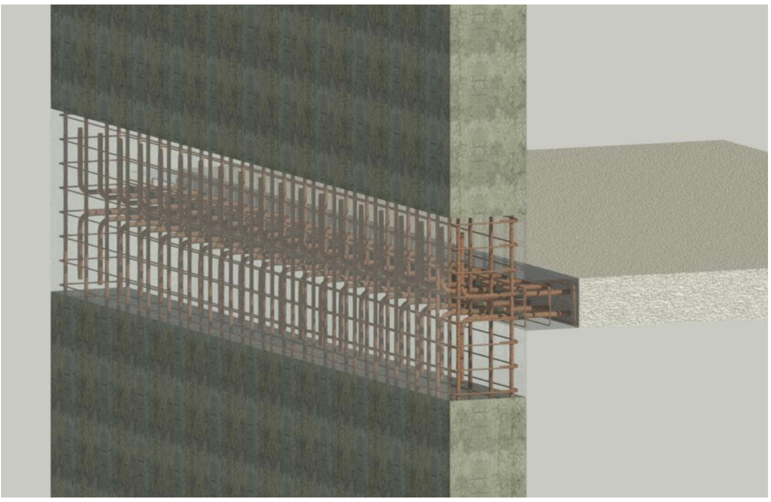


Figure 3.5 Slab to D-Wall Junction using traditional 90^0 Bent Hook

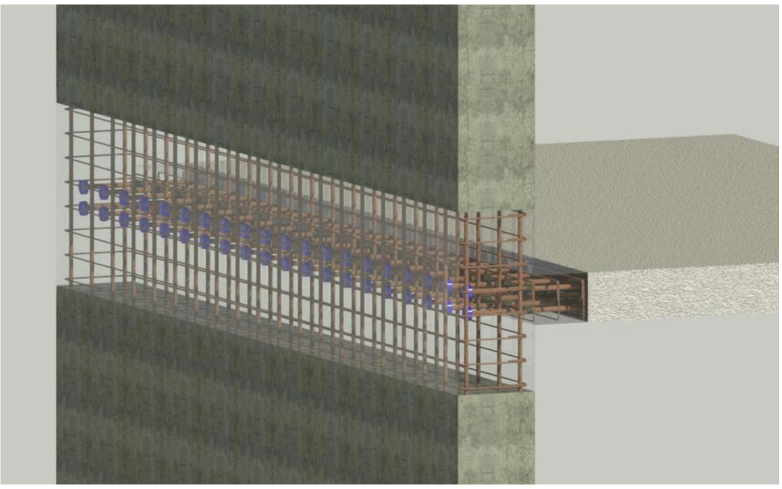


Figure 3.6 Slab to D-Wall Junction using Headed Bar

3.2 Additional Rules for Good Practice

a) When anchoring longitudinal reinforcement bars of structural members such as beams and slabs, the heads should be well embedded within the steel cages of the columns and walls where possible.

b) As a recommendation for good practice, the development length of headed bars should extend to the far side of the columns and walls and should not be less than 3/4 of the width of the columns and walls. However, the resulting development length should not be unusually long such that the development length exceeds the equivalent anchorage length, required for bond, as defined in Eurocode 2 (SS EN1992-1-1:2008, Clause 8.4.1(2)).

c) Transverse reinforcement should be considered in situation where the minimum anchorage length in the direction of the tension force of the headed bars from the concrete free surface cannot be met.

d) It may be necessary to restrain diagonal cracking through the joint and breakout of bars through the top surface with proper detailing in special situations involving beam-column joints at the roof level with insufficient restraints from the transverse beams.

e) The maximum bar diameter shall not exceed 40 mm, and the head-to-bar bearing area ratio A_{head}/A_{bar} should not be less than 4 where A_{head} refers to the net bearing area.

f) The minimum clear spacing between heads should be sufficient to allow the concrete to be placed, depending on its workability. The larger of 12 mm or the head thickness is recommended [6] .

g) Where heads are staggered, the clear distance between the bearing surface of one head and the reverse face of the staggered head must be sufficient to achieve a dense concrete matrix. The larger of the head thickness, 20mm or the aggregate size plus 5mm in accordance with SS EN1992-1-1[2] Clause 8.2(2) is recommended.

h) For effective head contribution, it is recommended to adopt 2 d_{bar} for minimum cover to the bar and 4 d_{bar} for minimum centre to centre spacing between bars.

i) The minimum clear spacing between parallel bars away from heads and cover should still be in accordance with SS EN1992-1-1[2]Clause 8.2(1) and Clause 4.4.1 respectively.

j) The use of headed bars does not alter the rules given in SS EN1992-1-1[2] Section 9 regarding minimum and maximum areas or spacings.

k) Headed bars should not be used for lapping, conventional laps or mechanical couplers should be used instead. They should also not be arranged to form lapping (parallel alignment) and overlapping (orthogonal intersection) of the headed bars within the joints (See Fig K.1 & K.2). This restriction is only intended to prevent the formation of a lap within the joint; it does not prohibit the use of headed bars in moment-resisting joints.
Note: In the design and detailing of any moment-resisting joint, consideration should be given to effective moment transfer and to prevent diagonal cracking in the joint, provisions such as the use of transverse reinforcement may be used where required.

Lapping of headed bars occurs in continuous joints subject to hogging moments over supports (Fig. K.1).	**Overlapping** refers to orthogonal headed bar intersections commonly found in joints associated with portal frames, cantilevered elements, or continuous external hull corners. (Fig. K.2).

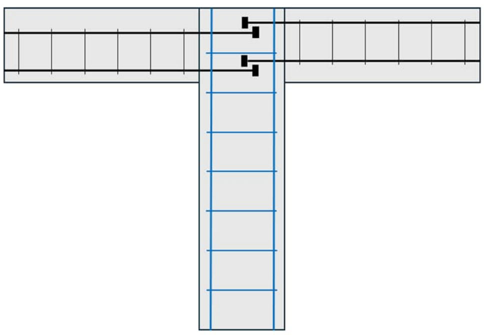
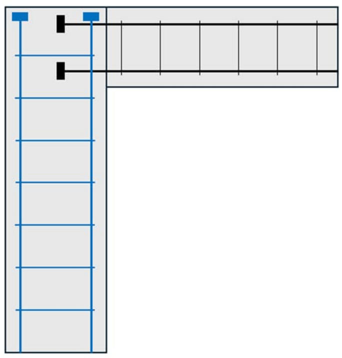

	

Figure K.1: Lapping of headed bars over support	**Figure K.2**: Orthogonal arrangement of headed bars at Corner

l) The headed bars are not meant to transfer compression forces, it can only be used on compression bars provided the load transfer mechanisms do not lead to a situation where the concrete beyond the heads is overstressed as a result.

m) The design rules specified in this guide should be read in conjunction with design and application rules written in the product-specific technical approvals issued by independent assessment bodies, if any.

3.3 Comparison with ACI 318 and AS 3600

Unlike others, these two international design codes, i.e. ACI 318-19 [4] and AS 3600 [5] have clear design rules which take into consideration the contribution from the headed bars; hence they are selected for comparison against this design guide.

3.3.1 American Concrete Institute ACI 318-19

The American Concrete Institute ACI 318-19 specifies certain rules to comply with under their Clause 25.4.4.1, for the use of a head to develop tension in a deformed bar. The rules to comply with are:

a) $A_{h,net}/A_{bar} \geq 4$
b) Minimum cover to the bar $\geq 2\ d_{bar}$
c) Centre-to-Centre spacing between bars$\geq 3\ d_{bar}$
d) $d_{bar} \leq 35mm$

* Note: $A_{h,net}$ refers to net bearing area of the head

Under their clause 25.4.4.2., the calculation for the anchorage length for headed bars in tension shall be the longest of (a) through (c):

a) $(\frac{f_y \psi_e \psi_p \psi_o \psi_c}{75\sqrt{f_c'}}) d_b{}^{1.5}$; where $\psi_e, \psi_p, \psi_o, and\ \psi_c$ are modification factors for concrete strength and location etc.
b) $8d_b$
c) 150mm

This minimal of 8 d_{bar} is lesser than the 10 d_{bar} specified in this design guide.

3.3.2 Australian Standard AS 3600

The Australian Standard AS 3600 also specify certain rules to comply with under their Clause 13.1.4 to take advantage of the contribution of the anchor head, these rules are:

a) $\frac{A_{h,net}}{A_{bar}} \geq 4$
b) Bar diameter, $d_{bar} \leq 40mm$
c) Minimum cover to the bar $\geq 2\ d_{bar}$
d) Clear spacing between bars $\geq 4\ d_{bar}$

*Note: $A_{h,net}$ refers to net bearing area of the head

Under their clause 13.1.2., the calculation for the anchorage length of a deformed bar in tension is calculated from:

$L_{sy,lb} = \frac{0.5 k_1 k_3 f_{sy} d_b}{k_2 \sqrt{f_c'}}$, where the k factors are modification factors for concrete strength and bar placement etc.

If the ratio of the net area of the anchor head to the area of the bar is more than 4, it is possible for the anchorage length for the headed bar to be reduced to half of the anchorage length required for the traditional 90^0 hook anchorage, under their Clause 13.1.4. The anchorage length can be further reduced to 6 times the bar diameter if this area ratio is equal to 10. However, all these may not be very practical because it will lead to clashing due to the large head sizes although their anchorage lengths can be reduced quite significantly.

Both documents have placed importance on the minimum size of the head, as well as minimum cover to the side bar and minimum spacing of the intermediate bars. For the head to develop full anchorage on its own, it is obvious large bar spacings and minimum concrete grade are required. However, it is not practical to rely on the head alone because there is still a need to provide minimum anchorage to prevent shear cone pull-out failure. A more practical design is to rely on both head bearing and bar bond, and design calculations to consider all the key parameters to determine the anchorage length required.

Table 3.1 compares the anchorage lengths calculated using ACI 318-19, AS 3600 and this design guide. The values calculated from this guide are slightly conservative but reasonable when compared to the other two design codes.

Table 3.1 – Comparison of Anchorage Lengths (mm)

$f_{yk} = 500MPa \, , and \; f_{ck} = 35MPa$

Bar ϕ	Design Guide	ACI 318-19	AS 3600: 2018 (4*)
16	411	172	322
20	534	241	417
25	689	337	545
32	912	487	747
40	1170	-	1015

Note: 4* means that the net bearing area of head is equal to 4 times of bar area. The parameters used to calculate the anchorage length includes minimum cover to bar ≥ 2 d_{bar}, clear spacing between bars ≥ 4 d_{bar} , f_{bd} = 2.4 (assume poor bond), and d_{dg} = 36mm. ACI 318-19 is only applicable for bar diameters not exceeding 35 mm.

4.0 PRODUCT CERTIFICATION

4.1 Product Conformance Requirements

There are many proprietary headed bar systems that are commercially available in the market. Obviously, they are construction products which need to be manufactured under stringent factory control processes and certified by independent assessment bodies to ensure the headed bar products meet certain performance requirements, for example, the strength of the steel material for the head and its connection to the bar and whether they are adequate and safe to be used in construction.

At the time of writing, a harmonized European Product Standard does not exist for headed bars, hence it is not possible for any independent notified body to carry out product conformity assessment and issue a CE mark to any headed bar product. As a result, manufacturers could only opt to apply for a European Technical Approval (ETA) issued by national technical assessment bodies under the European Organization for Technical Assessment (EOTA) using the European Assessment Document (EAD) No. 160012-00-0301 [7] for which the base reference standard is ISO15698 [8].

4.2 Approval for Use in Singapore

Only headed bar products with the following technical approvals which have been evaluated independently can be used with this design guide in Singapore, i.e.

a) ETAs issued by EOTA's technical assessment bodies based on EAD No. 160012-00-0301 [7] and ISO 15698 [8].

b) Technical Approvals based on EAD No. 160012-00-0301 [7] and ISO 15698 [8] issued by SAC-accredited assessment bodies or assessment bodies accredited by other national accreditation councils having mutual recognition arrangement (MRA) with SAC.

c) ETA-equivalent Technical Approvals accepted by BCA include those issued by assessment bodies accredited by national accreditation body or authority such as the United Kingdom Accreditation Service (UKAS) or Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT). ETA-equivalent Technical Approvals besides the above mentioned are subject to independent evaluation and approval by BCA.

5.0 CONCLUSION

This design guide on headed bars is intended for use as a non-conflicting complementary supplement to the existing SS EN1992-1-1: 2008 [2] and it deals primarily with the anchorage of headed bars in accordance with the provisions of BS EN1992-1-1:2023 [1]. The guide bridges a current design gap, and it will allow our industry to adopt headed bars to facilitate construction where applicable. It will also pave the way for our design engineers to transit to the new 2nd generation EN 1992-1-1: 2023 easily in the future.

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ANNEX A

Design Considerations

The design model involves understanding of the mechanical behaviour of concrete under triaxial compression under the head and ensuring the concrete strength and confining pressure are sufficient to prevent failure. For the full derivation of the design model, readers can refer to background document by Muttoni & Caldentey [3] and BS EN1992-1-1: 2023 [1]. The key considerations and assumptions of the design model are summarized below, i.e.

a) The steel stress which can be activated in the anchored reinforcement bar without accounting for a bond component corresponds to the triaxial concrete compressive strength $f_{c,3}$ which can be activated under the head multiplied by the ratio between the net area of the head and the cross-sectional area of the reinforcement bar A_s:

$$k_{h,A} = \frac{A_h - A_s}{A_s} = \left(\frac{\phi_h}{\phi}\right)^2 - 1 \quad \text{(Eqn. A.1)}$$

where

A_h is the total area of the head

ϕ_h is the diameter of a circular head

ϕ is the diameter of the bar

b) The concrete compressive stress under the head can exceed the uniaxial compressive concrete strength f_c (which should be reduced by the strength reduction factor η_{cc}, see clause 5.1.6(1) of BS EN 1992-1-1:2023 [1]), due to the confinement effect of the surrounding concrete. It can be calculated as [Eqn. A.2]:

$$f_{c,3} = \eta_{cc} \cdot f_c + 4 \cdot \sigma_{c,1} \quad \text{(Eqn. A.2)}$$

c) The confinement concrete compressive stress $\sigma_{c,1}$ in the confined area $A_{c,c}$ parallel to the free surface is in equilibrium with a confining tensile stress $f_{ct,eff}$ acting on the confining area $A_{c,t}$ and can be calculated as [Eqn. A.3]:

$$\sigma_{c,1} = f_{ct,eff} \frac{A_{ct}}{A_{cc}} \qquad \text{(Eqn. A.3)}$$

d) The confined area $A_{c,c}$ under the head (indicated as the blue area in Figure A.1 is assumed to be proportional to the net head area $A_h - A_s$;

e) The confining area A_{ct} where the effective tensile strength $f_{ct,eff}$ can act (see red area in Figure A.1) is assumed to be proportional to the distance a_d between the bar axis and the free surface times the nominal head diameter ϕ_{h};

f) Similarly to [Eqn. A.3], the effective concrete tensile strength $f_{ct,eff}$ is assumed to be proportional to the square root of the compressive concrete strength and is reduced with a size effect factor which depends on the aggregate size parameter d_{dg} (defined in 8.2.1(4)) of BS EN 1992-1-1:2023 [1] and the nominal size $\sqrt{\phi_{\mathrm{h}} \cdot \phi}$ with an exponent of 1/3:

$$f_{ct,eff} = k_1\sqrt{f_c}\left(\frac{d_{dg}}{\sqrt{\phi_{\mathrm{h}} \cdot \phi}}\right)^{1/3} \quad \text{(Eqn. A.4)}$$

where k_1 is a calibration factor.

Considering that the force in the bar is equal to the force that can be transmitted to concrete through the head area before failure ($\sigma_s \frac{\pi}{4}\phi^2 = \sigma_{c,1}(A_h - A_s)$), the stress which can be activated in the reinforcement becomes thus:

$$\begin{aligned} \sigma_s' &= k_{h,A} \cdot \eta_{cc} \cdot f_c + 4 \cdot k_1\sqrt{f_c}\left(\frac{d_{dg}}{\sqrt{\phi_{\mathrm{h}} \cdot \phi}}\right)^{1/3} k_2 \frac{a_d \cdot \phi_{\mathrm{h}}}{A_h - A_s} \cdot \frac{A_h - A_s}{\frac{\pi}{4}\phi^2} \\ &= k_{h,A} \cdot \eta_{cc} \cdot f_c + k_3\sqrt{f_c}\,\frac{a_d}{\phi}\left(\frac{\phi_{\mathrm{h}}}{\phi}\right)^{5/6}\left(\frac{d_{dg}}{\phi}\right)^{1/3} \qquad \text{(Eqn. A.5)} \end{aligned}$$

where k_1 is a calibration factor replacing $16 \cdot k_1 \cdot k_2/\pi$

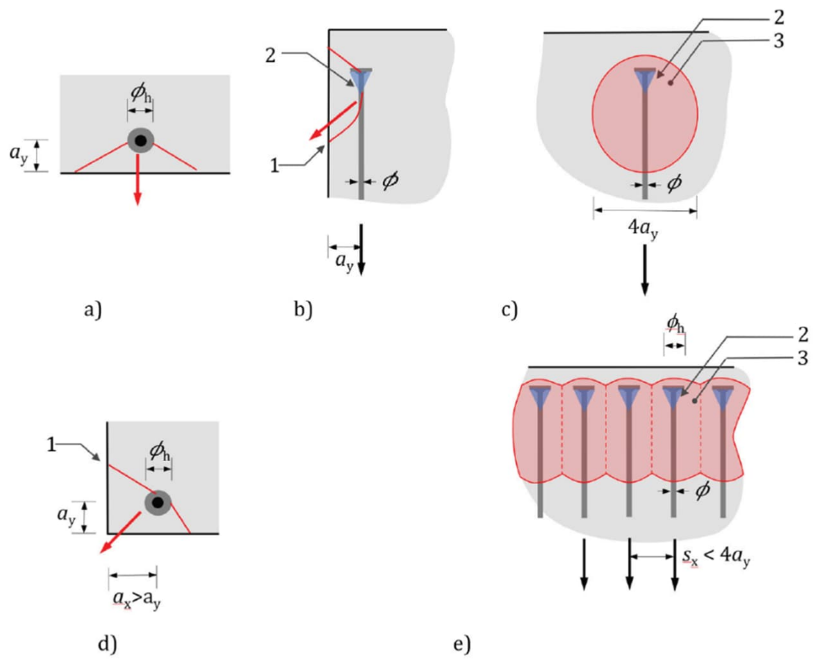
g) It must be noted that [Eqn. A.5] covers the failure mode related to spalling of the concrete cover (also called “blow-out” failure). For large covers, very high stresses can be reached, and local failure can occur due to compression of the matrix in the concrete and collapse of pores [see C.11.4.7.7 of Muttoni & Caldentey [3]]. For this reason, the concrete stress $f_{c,3}$ must be limited to the maximum value:

$$f_{c,3} \leq v_{part} \cdot \eta_{cc} \cdot f_c \qquad \text{(Eqn. A.6)}$$

Based on the tests presented in [C11.4.7.7 of Muttoni & Caldentey [3]], a v_{part} of about 15 can be assumed for uncracked concrete in the region of the head. Nevertheless, for the sake of simplicity (and even though the calibration factors k_1 of Formula [Eqn. A.5] and v_{part} of [Eqn. A.6] refer to different failure modes and different calibrations), the same value of v_{part}= 11.0 is assumed. In a similar manner as according to EN1992-4: 2018, coefficient v_{part} shall be reduced for concrete cracked in the region of the head (v_{part}= 8.0 can be assumed for this case).

h) With reference to Muttoni & Caldentey (C11.4.7.8) [3], the same partial safety factor as for concrete in compression (γ_c= 1.50) can be used. The design formula in BS EN1992-1-1: 2023 [1] (based on Formulae (C11.4.7.4) and (C11.4.7.5)) becomes thus:

$$\sigma'_{sd} = k_{h,A} \cdot f_{cd} + v_{part} \cdot \frac{\sqrt{f_{ck}}}{\gamma_c} \cdot \frac{a_d}{\phi} \cdot \left(\frac{\phi_h}{\phi}\right)^{\frac{5}{6}} \cdot \left(\frac{d_{dg}}{\phi}\right)^{\frac{1}{3}} \leq k_{h,A} \cdot v_{part} \cdot f_{cd} \quad \text{(Eqn. A.7)}$$



1 potential crack associated to spalling (blow-out) or splitting;
2 confined area (with transversal compression);
3 confining area (with transversal tensile stress)
Red vectors: assumed movement of the concrete cover at failure

Figure A.1

Failure mechanisms, confined areas and confining areas for: (a-c) single bar; (d)corner bar and (e) group of bars (reproduced from Figure C11.4.7.3 of Muttoni & Caldentey [3])

i) In case of headed bars consisting of ribbed or indented reinforcement, a combination of the force carried by the head and the bond strength developed along the anchorage length may be accounted for according to Figure A.1. In this case, the required anchorage length l_{bd} to carry the remaining stress $\sigma_{sd} - \grave{\sigma}_{sd}$ defined in Figure 2.3 may be calculated according to (Eqn. A.8):

$$l_{bd} = 1.1 \cdot (l_{bd}(\sigma_{sd}) - l_{bd}(\sigma'_{sd})) \quad \text{(Eqn. A.8)}$$

where the coefficient 1.1 accounts for:

- the detrimental interaction between the tensile splitting stresses generated by bond and by the head, and
- the fact that the maximum bond strength can develop for a bar slip which is smaller than the head penetration required to activate the head resistance.