coefficients k_A and k_B denote the rigidity of restraint at the column ends :

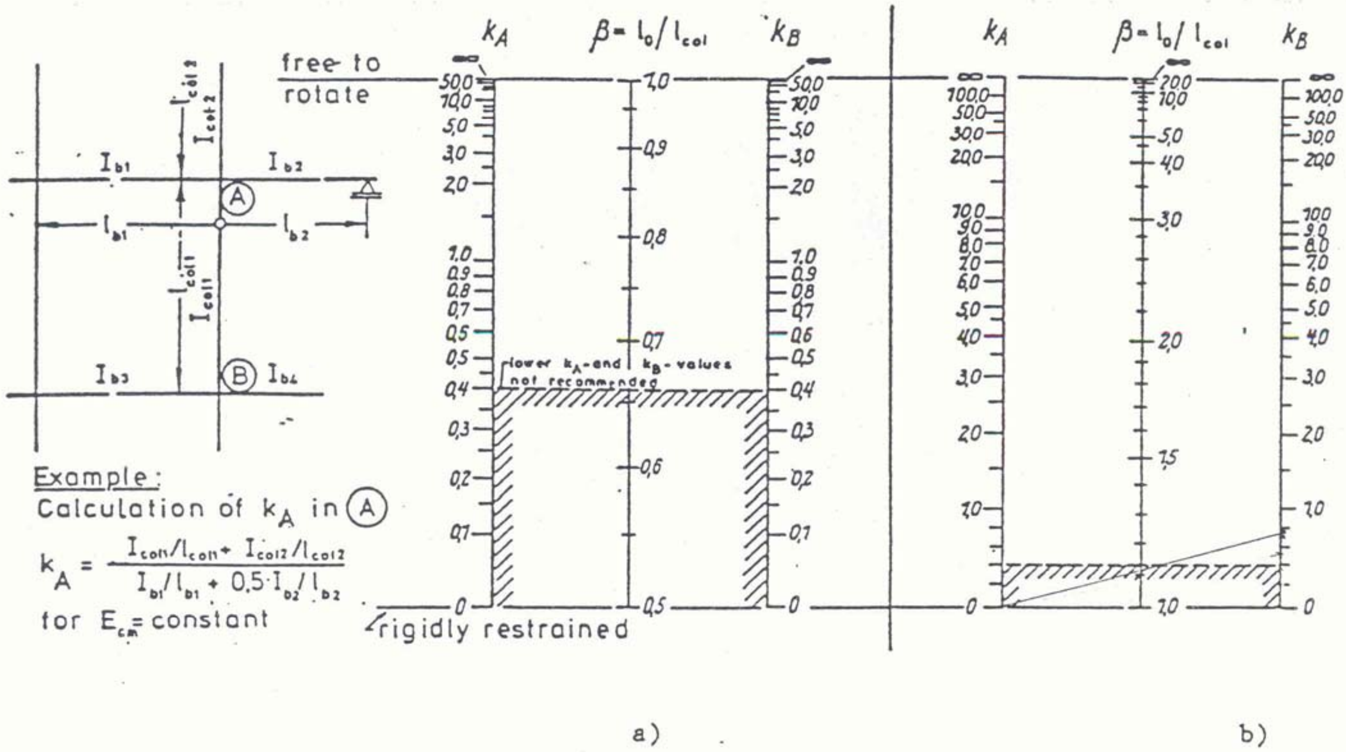


Figure 4.27 : Nomograms for the calculation of the effective length
[(a) Non-sway frame (b) Sway-frame]

$$k_A \text{ (or } k_B) = \frac{\Sigma E_{cm} \cdot I_{col}/l_{col}}{\Sigma E_{cm} \cdot \alpha \cdot I_b/l_{eff}} \quad (4.60)$$

where

E_{cm} modulus of elasticity of the concrete (see 3.1.2.5.2)

I_{col}, I_b moment of inertia (gross section) of the column or beam respectively

l_{col} height of the column measured between centres of restraint

l_{eff} effective span of the beam

α factor taking into account the conditions of restraint of the beam at the opposite end :

$\alpha = 1.0$ opposite end elastically or rigidly restrained
$\alpha = 0.5$ opposite end free to rotate
$\alpha = 0$ for a cantilever beam.

(2) The maximum aggregate size, d_g, should be chosen to permit adequate compaction of the concrete round the bars.

(3) The clear distance (horizontal and vertical) between individual parallel bars or horizontal layers of parallel bars should be not less than the |maximum bar diameter or 20 mm|. In addition where $d_g > 32$ mm, these distances should be not less than $d_g + 5$ mm.

(4) Where bars are positioned in separate horizontal layers, the bars in each layer should be located vertically above each other and the space between the resulting columns of bars should permit the passage of an internal vibrator.

(5) Lapped bars may touch one another within the lap length.

5.2.1.2 Permissible curvatures

P(1) The minimum diameter to which a bar is bent shall be such as to avoid crushing or splitting of the concrete inside the bend of the bar, and to avoid bending cracks in the bar.

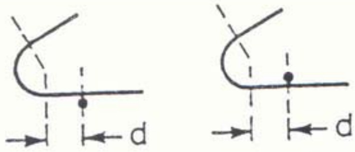
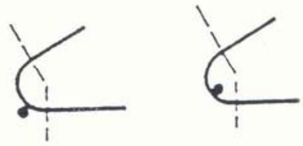
(2) For bars or wires, the minimum diameter of the mandrel used should be not less than the values given in Table 5.1

Table 5.1 : Minimum diameters of mandrels

<table>
<tr><td></td><td colspan="2">Hooks, bends, loops (see Figure 5.2)</td><td colspan="3">Bent-up bars or other curved bars</td></tr>
<tr><td></td><td colspan="2">Bar diameter</td><td colspan="3">Value of minimum concrete cover, perpendicular to plane of curvature</td></tr>
<tr><td></td><td>$\varnothing < 20$ mm</td><td>$\varnothing \geqq 20$ mm</td><td>> 100 mm and $> 7 \varnothing$</td><td>> 50 mm and $> 3 \varnothing$</td><td>$\leqq 50$ mm and $\leqq 3 \varnothing$</td></tr>
<tr><td>Plain bars S 220</td><td>|2.5 ø|</td><td>|5 ø|</td><td>|10 ø|</td><td>|10 ø|</td><td>|15 ø|</td></tr>
<tr><td>High bond bars S400, S500</td><td>|4 ø|</td><td>|7 ø|</td><td>|10 ø|</td><td>|15 ø|</td><td>|20 ø|</td></tr>
</table>

(3) For welded reinforcement and mesh bent after welding, the minimum diameters of mandrels are given in Table 5.2.

Table 5.2 - Minimum diameters of mandrels for welded bent reinforcement

Minimum diameter of the mandrel	
Welds outside bends	Welds inside bends
	
$d < 4 \phi$: 20ϕ $d \geqq 4 \phi$: Table 5.1 applies	20ϕ

5.2.2 BOND

5.2.2.1 Bond Conditions

P(1) The quality of the bond depends on the surface pattern of the bar, on the dimension of the member and on the position and inclination of the reinforcement during concreting.

(2) For normal weight concrete, the bond conditions are considered to be good for:

a) all bars, with an inclination of |45° to 90°| to the horizontal, during concreting (Figure 5.1.a);

b) all bars which have an inclination of |0° to 45°| to the horizontal during concreting and are :

- either placed in members whose depth in the direction of concreting does not exceed |250 mm| (Figure 5.1.b),
- or embedded in members with a depth greater than |250 mm| and when concreting is completed, are :
  . either in the lower half of the member (Figure 5.1c)
  . or at least |300 mm| from its top surface (Figure 5.1d)

(3) All other conditions are considered poor.

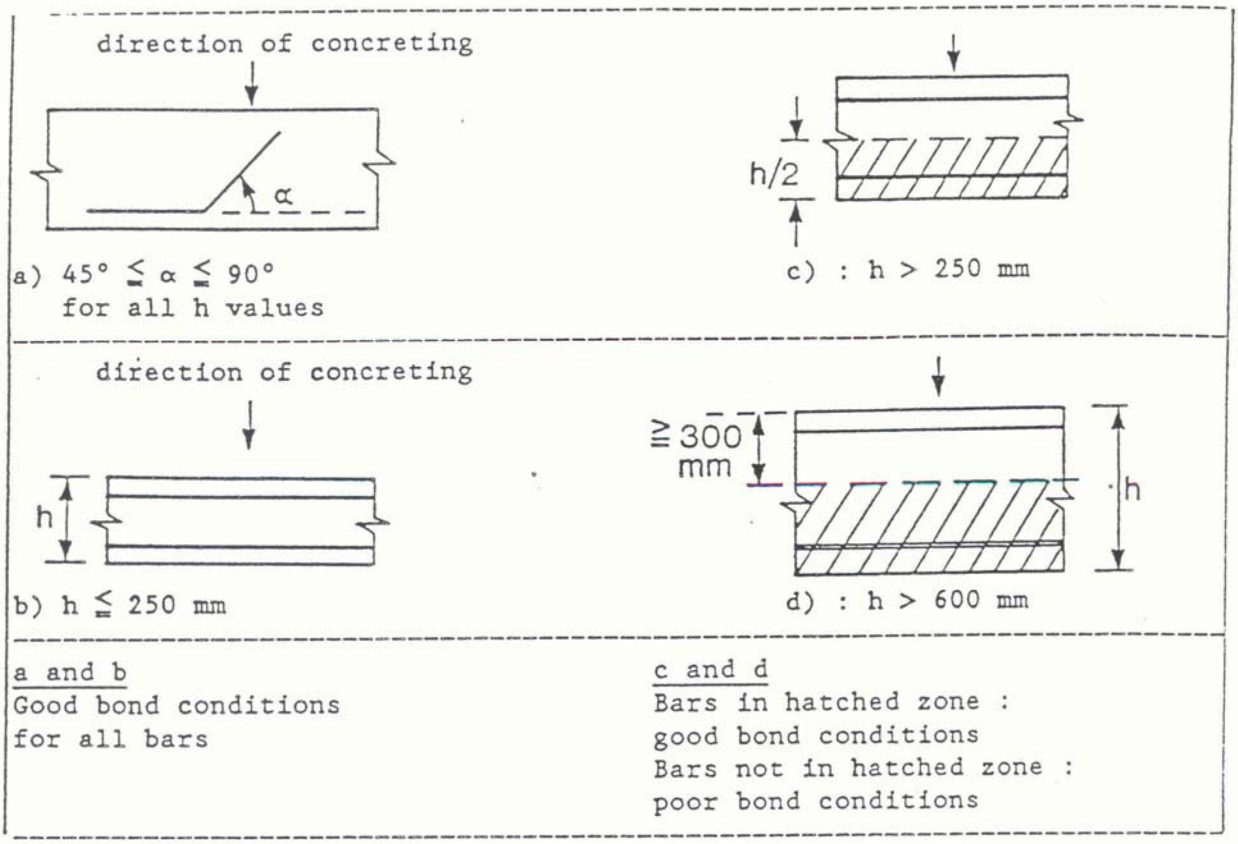


Figure 5.1 : Definition of bond conditions

5.2.2.2 Ultimate bond stress

P(1) The ultimate bond stress shall be such that no significant relative displacement between the steel and concrete occurs under service loads, and that there is an adequate safety margin against bond failure.

(2) In conditions of good bond, the design values for the ultimate bond stress f_{bd} are given in Table 5.3. In all other cases, the values in Table 5.3 should be multiplied by a coefficient 0.7.

Table 5.3 : Design values f_{bd} (N/mm²) for good bond conditions (these values incorporate a γ_c value equal to 1.5).

f_{ck}	12	16	20	25	30	35	40	45	50
Plain bars	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
High bond bars where $\phi \leq$ |32| mm or welded mesh fabrics made of ribbed wires	1.6	2.0	2.3	2.7	3.0	3.4	3.7	4.0	4.3

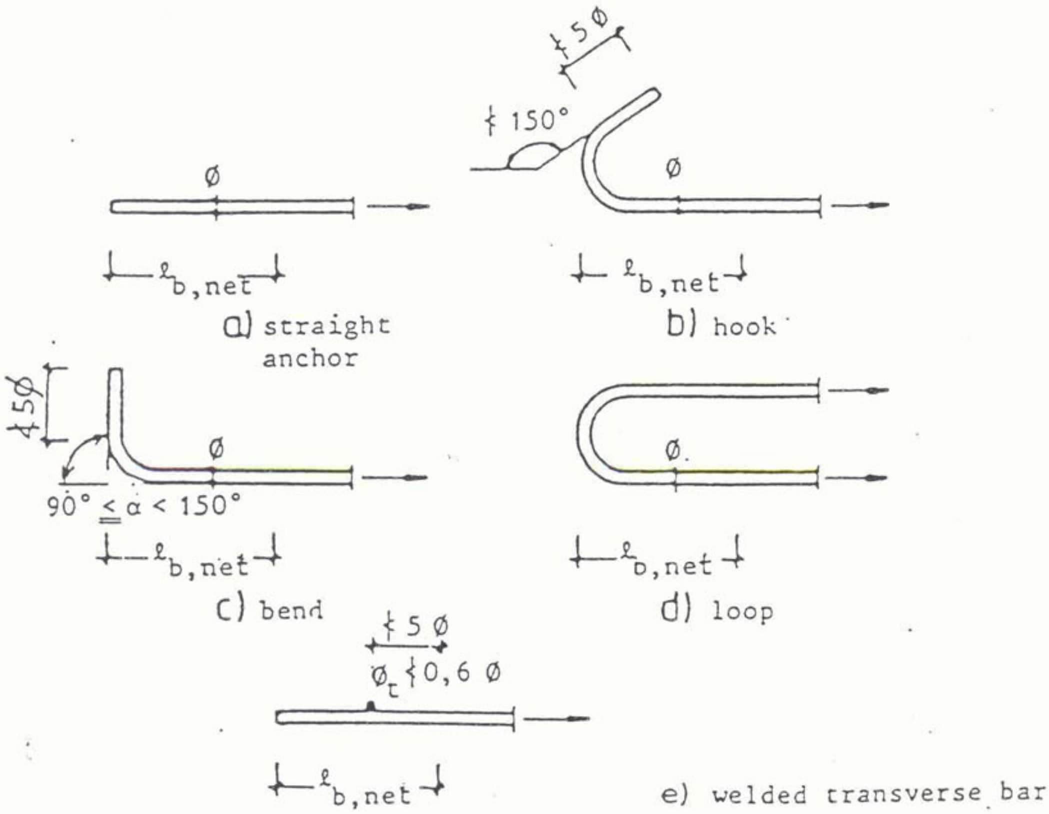


Figure 5.2 : Required anchorage length

(4) Spalling or splitting of the concrete may be prevented by complying with Table 5.1 and avoiding concentrations of anchorages.

5.2.3.3 Transverse reinforcement parallel to the concrete surface

(1) In beams transverse reinforcement should be provided :

- for anchorages in tension, if there is no transverse compression due to the support reaction (as is the case for indirect supports, for example),

- for all anchorages in compression.

(2) The minimum total area of the transverse reinforcement (legs parallel to the layer of the longitudinal reinforcement) is |25| percent of the area of one anchored bar (Figure 5.3).

$\Sigma A_{st} = n.A_{st}$ where :

n = number of bars along anchorage length

A_{st} = area of one bar of the transverse reinforcement

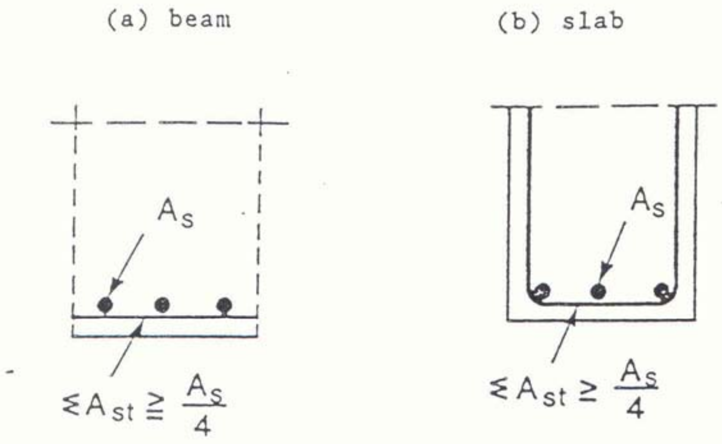


Figure 5.3 : Transverse reinforcement in the region of anchored bars

(3) The transverse reinforcement should be evenly distributed along the anchorage length. At least one bar should be placed in the region of the hook, bend or loop of curved bar anchorages.

(4) For bars in compression, the transverse reinforcement should surround the bars, being concentrated at the end of the anchorage, and extend beyond it to a distance of at least 4 times the diameter of the anchored bar (see Figure 5.5b).

5.2.3.4 Required anchorage length

5.2.3.4.1 Bars and wires

(1) The required anchorage length $l_{b,net}$ may be calculated from :

$$l_{b,net} = \alpha_a \, l_b \, \frac{A_{s,req}}{A_{s,prov}} \nless l_{b,min} \qquad (5.4)$$

where (see Figure 5.2) :

l_b is given by Equation (5.3), see 5.2.2.3 (2)

$A_{s,req}$ and $A_{s,prov}$ respectively denote the area of reinforcement required by design - and actually provided

$l_{b,min}$ denotes the minimum anchorage length :

- for anchorages in tension $\quad l_{b,min} = 0.3\, l_b \; (\nless 10\,\phi$ or $\nless 100$ mm$) \qquad (5.5)$
- for anchorages in compression $\quad l_{b,min} = 0.6\, l_b \; (\nless 10\,\phi$ or $\nless 100$ mm$) \qquad (5.6)$

α_a is a coefficient which takes the following values :

α_a = 1 for straight bars

α_a = 0.7 for curved bars in tension (see Figure 5.2) if the concrete cover perpendicular to the plane of curvature is at least |3ø| in the region of the hook, bend or loop.

5.2.3.4.2 Welded meshes made of high bond wires

(1) Equation (5.4) may be applied

(2) If welded transverse bars are present in the anchorage, a coefficient |0.7| should be applied to the values given by Equation (5.4).

5.2.3.4.3 Welded meshes made of smooth wires

(1) These may be used, subject to relevant Standards.

5.2.3.5 Anchorage by mechanical devices

P(1) The suitability of mechanical anchorage devices should be demonstrated by an Agrément certificate.

(2) For the transmission of the concentrated anchorage forces to the concrete, see 5.4.8.1

5.2.4 SPLICES

P(1) The detailing of splices between bars shall be such that :

- the transmission of the forces from one bar to the next is assured ;
- spalling of the concrete in the neighbourhood of the joints does not occur ;
- the width of cracks at the end of the splice does not significantly exceed the values given in Section 4.4.2.1.

5.2.4.1 Lap splices for bars or wires

5.2.4.1.1 Arrangement of lapped joints

(1) As far as possible :

- laps between bars should be staggered and should not be located in areas of high stress, (see also Section 2.5.3, Analysis).

- laps at any one section should be arranged symmetrically and parallel to the outer face of the member,

(2) Clauses 5.2.3.2 (1) to (4) are also applicable to lap splices.

(3) The clear space betwen the two lapped bars in a joint should comply with the values indicated in Figure 5.4.

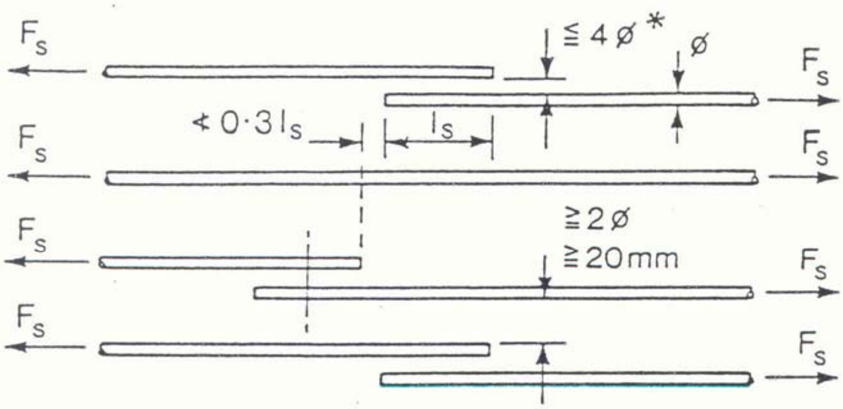


Figure 5.4 : Adjacent laps

* otherwise the lap length shall be increased by the amount by which the clear space exceeds |4 ø|.

5.2.4.1.2 Transverse reinforcement

(1) If the diameter ø of the lapped bars is less than |16 mm|, or if the percentage of lapped bars in any one section is less than 20 % , then the minimum transverse reinforcement provided for other reasons (e.g. shear reinforcement, distribution bars) is considered as sufficient.

(2) If $\phi \geqq$ |16 mm|, then the transverse reinforcement should:

- have a total area (sum of all legs parallel to the layer of the spliced reinforcement, see Figure 5.5,) of not less than the area A_s of one spliced bar ($\Sigma A_{st} \geqq 1.0\ A_s$)

- be formed as links if a $\leqq$ |10 ø| (see Figure 5.6) and be straight in other cases

- the transverse reinforcement should be placed between the longitudinal reinforcement and the concrete surface.

(3) For the distribution of the transverse reinforcement, 5.2.3.3 (3) and (4) apply.

5.2.4.1.3 Lap length

(1) The necessary lap length is :

$$l_s = l_{b,net} \cdot \alpha_1 \nless l_{s,min} \quad (5.7)$$

with :

$l_{b,net}$ according to Equation (5.4)

$$l_{s,min} \nless 0.3 \,.\, \alpha_a . \alpha_1 . l_b \nless 15\ \phi \nless 200 \text{ mm} \quad (5.8)$$

Values of α_a are given in 5.2.3.4.1.

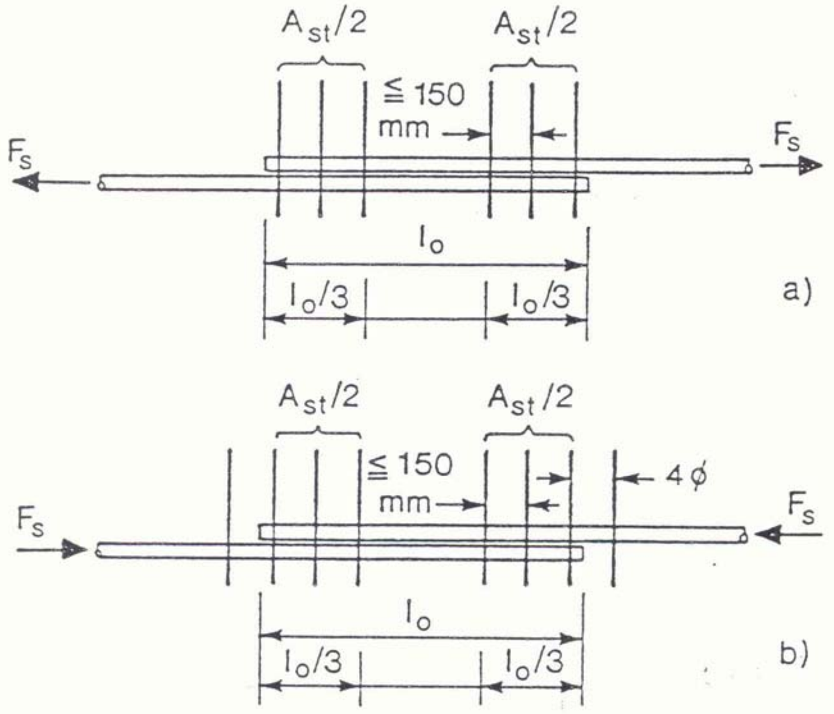


Figure 5.5 : Transverse reinforcement for lapped splices

The coefficient α_1 takes the following values :

$\alpha_1 = 1$ for lap lengths of bars in compression and of lap lengths in tension where less than 30 % of the bars in the section are lapped and, according to Figure 5.6, where $a \nless |10\,\phi|$ and $b \nless |5\,\phi|$.

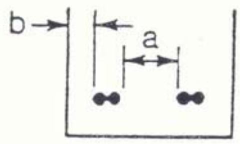


Figure 5.6 : Evaluation of α_1 [see 5.2.4.1.3 (1)]

$\alpha_1 = 1.4$ for tension lap lengths where

either (i) 30 % or more of the bars at a section are lapped

or (ii) according to Figure 5.6, if $a < |10\,\phi|$ or $b < |5\,\phi|$,

but not both.

$\alpha_1 = 2$ for tension lap lengths if both (i) and (ii) above apply simultaneously.

5.4 STRUCTURAL MEMBERS

In order to satisfy the requirements of Chapter 4, the following rules related to detailing arrangements should be satisfied :

5.4.1 COLUMNS

This clause deals with columns for which the larger dimension b is not greater than 4 times the smaller dimension h .

5.4.1.1 Minimum dimensions

(1) The minimum permissible transverse dimension of a column cross-section is :

- |200 mm| for columns of solid section, cast in situ (vertically)

- |140 mm| for precast columns cast horizontally.

5.4.1.2 Longitudinal and transverse reinforcement

5.4.1.2.1 Longitudinal reinforcement

(1) Bars should have a diameter of not less than 12 mm.

(2) The minimum amount of total longitudinal reinforcement $A_{s,min}$ should be derived from the following condition :

$$A_{s,min} = \frac{0.15\ N_{Sd}}{f_{yd}} \nless |0.003|\ A_c \qquad (5.13)$$

where:

f_{yd} is the design yield strength of the reinforcement

N_{Sd} is the design axial compression force

A_c is the cross-section of the concrete

(3) Even at laps, the area of reinforcement should not exceed the upper limit $|0.08\ A_c|$.

(4) The longitudinal bars should be distributed around the periphery of the section. For columns having a polygonal cross-section, at least one bar shall be placed at each corner. For columns of circular cross-section the minimum number of bars is |6|.

5.4.1.2.2 Transverse reinforcement

(1) The diameter of the transverse reinforcement (links, loops or helical spiral reinforcement) should not be less than |6 mm| or |one quarter| of the maximum diameter of the longitudinal bars, whichever is the greater ; the diameter of the wires of welded mesh fabric for transverse reinforcement should not be less than |5 mm|.

(2) The transverse reinforcement should be adequately anchored.

(3) The spacing of the transverse reinforcement along the column should not exceed the lesser of the following three distances :

- 12 times the minimum diameter of the longitudinal bars ;
- the least dimension of the column ;
- 300 mm

(4) The spacing should be reduced by a factor |0.6| :

(i) in sections located above and below a beam or slab over a height equal to the larger dimension of the column cross-section ;

(ii) near lapped joints, if the maximum diameter of the longitudinal bars is greater than |14 mm|.

(5) Where the direction of the longitudinal bars changes, (e.g. at changes in column size), the spacing of transverse reinforcement should be calculated, while taking account of the lateral forces involved.

(6) Every longitudinal bar (or group of longitudinal bars) placed in a corner should be held by transverse reinforcement.

(7) A maximum of |5| bars in or close to each corner can be secured against buckling by any one set of transverse reinforcement.

5.4.2 BEAMS

5.4.2.1 Longitudinal reinforcement

5.4.2.1.1 Minimum and maximum reinforcement percentage

(1) The effective cross-sectional area of the longitudinal tensile reinforcement should be not less than that required to control cracking (see 4.4.2), nor less than :

$$|0.6|\ b_t d/f_{yk} \not< |0.0015|\ b_t d \quad (f_{yk} \text{ in N/mm}^2) \qquad (5.14)$$

where b_t denotes the mean width of the tension zone ; for a T-beam with the flanges in compression, only the width of the web is taken into account in calculating the value of b_t. Sections containing less reinforcement than that given by Equation (5.14) should be considered as unreinforced.

(2) The cross-sectional areas of the tension reinforcement and of the compression reinforcement should not be greater than $|0.04A_c|$, other than at laps.

5.4.2.1.2 Other detailing arrangements

(1) In monolithic construction, even when simple supports have been assumed in design, the section should be designed for bending moment arising from partial fixity of at least |25%| of the maximum bending moment in the span.

(2) At intermediate supports of continuous beams, the total amount of tensile reinforcement A_s of a flanged cross-section may be divided approximately equally between the internal and external parts of the flange. (See Figure 5.10).

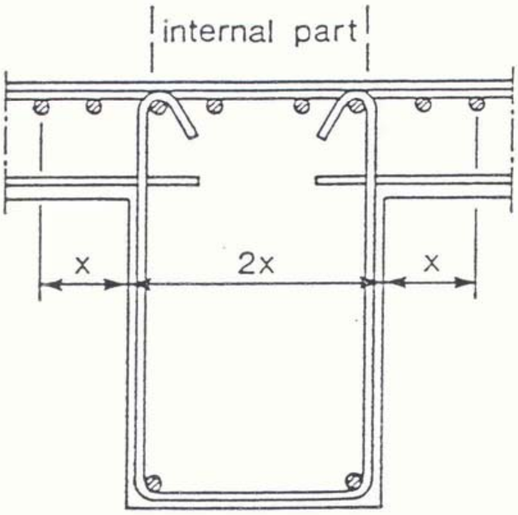


Figure 5.10 : Internal and external parts of a T-beam

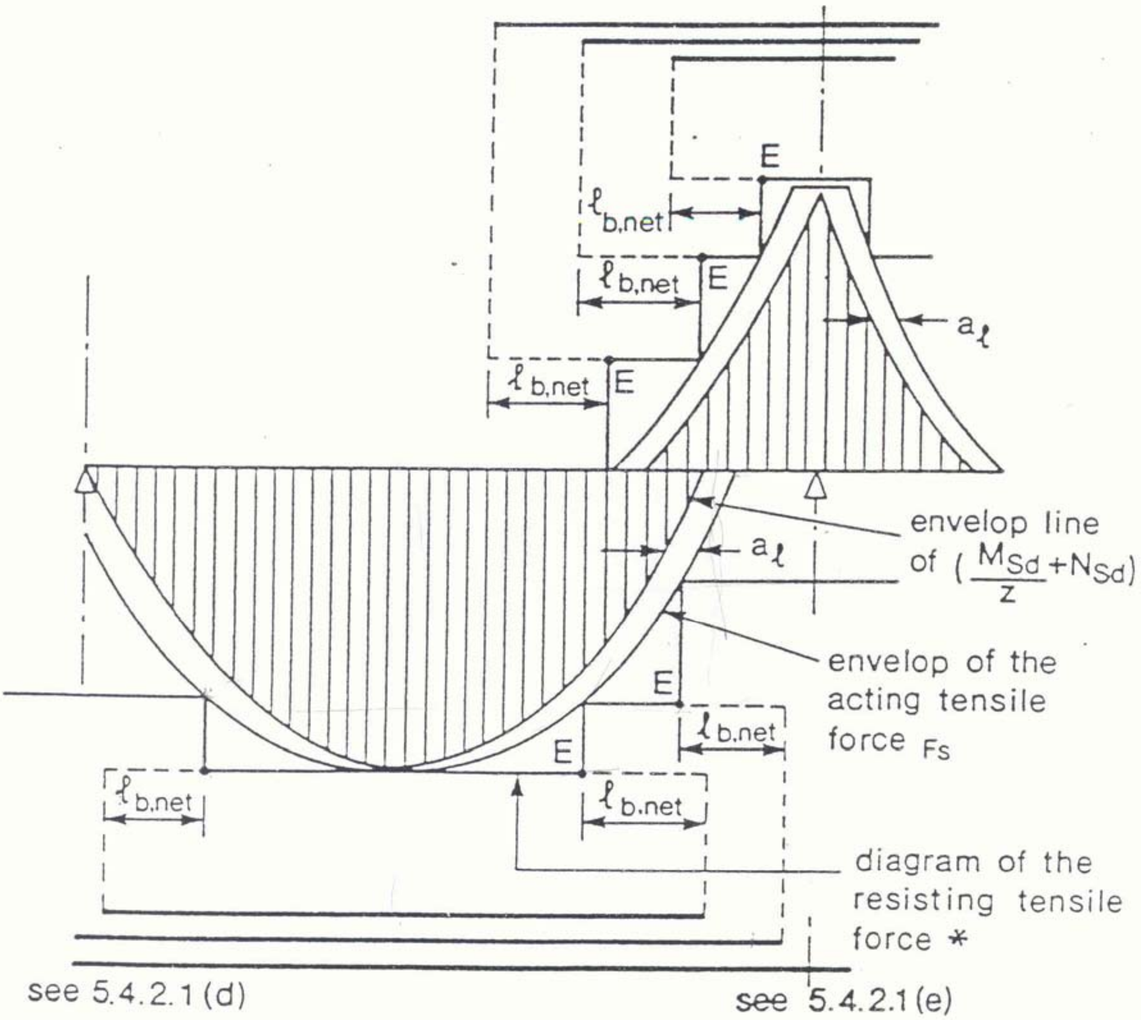
5.4.2.1.3 Length of the longitudinal tension reinforcement

(1) The envelop line of the tensile force in the longitudinal reinforcement is obtained by a horizontal displacement a_l of the envelop line of F_s, F_s being the tensile force in the longitudinal reinforcement obtained by a cross-section analysis according to 4.3. (See Figure 5.11). If the shear reinforcement is calculated according to the standard method, (see Section 4.3.2.4.3), $a_l = z\ (1 - \cot\alpha)/2 \nless 0$, α being the angle of the shear reinforcement with the longitudinal axis. If the shear reinforcement is calculated according to the variable strut inclination method, see Section 4.3.2.4.4, $a_l = z\ (\cot\theta - \cot\alpha)/2 \nless 0$, θ being the angle of the concrete struts with the longitudinal axis. Normally z can be taken as 0.9 d.

For reinforcement in the flange, placed outside the web (see 5.4.2.1.2 (2)), a_l should be increased by the distance of the bar from the web. (distance x in Figure 5.10).

(2) Cut-off bars should be anchored with $l_{b,net} \nless d$ from the point where they are no longer needed. ($l_{b,net}$: see Equation (5.4) in 5.2.3.4.1. d = effective depth of the member).

The diagram of the resisting tensile forces should lie outside the envelop line of the acting tensile force, displaced as described in (1) above (see Figure 5.11).



* It is also permitted to use a diagram in which the resisting tensile force is progressively decreasing on the length $l_{b,net}$.

Figure 5.11 : Envelop line for the design of flexural members. Anchorage lengths

(3) The anchorage lengths of bent-up bars which contribute to the resistance to shear should be not less than 1.3 $l_{b,net}$ in the tension zone and 0.7 $l_{b,net}$ in the compression zone.

5.4.2.1.4 Anchorage of bottom reinforcement at an end support

(1) Over supports with little or no end fixity it is necessary to retain not less than |one-quarter| of the steel section present in the span ;

(2) The anchorage of the reinforcement should be capable of resisting a tensile force of :

$$F_s = V_{Sd} \cdot a_l/d + N_{Sd} \quad (5.15)$$

where N_{Sd} denotes the design axial tensile force.

(3) The anchorage length is measured from the line of contact between the beam and its support ; it should be taken as:

- for a direct support : |2/3| $l_{b,net}$ (see Figure 5.12a) ;
- for an indirect support : $l_{b,net}$ (see Figure 5.12b).

with $l_{b,net}$ according to Equation (5.4).

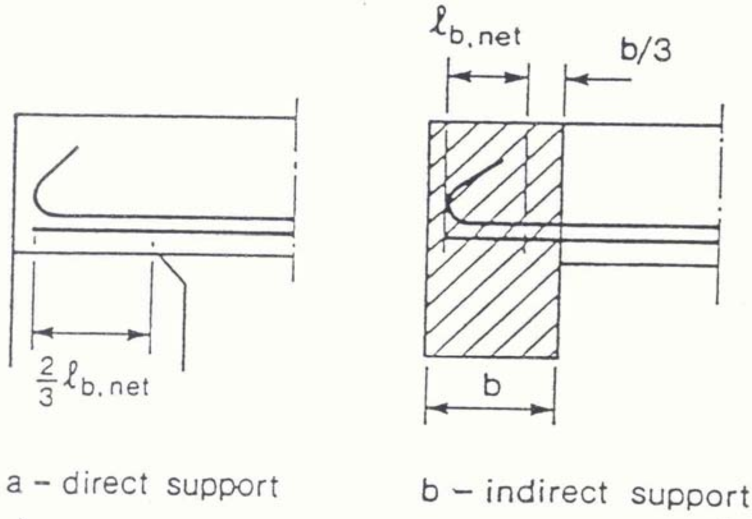


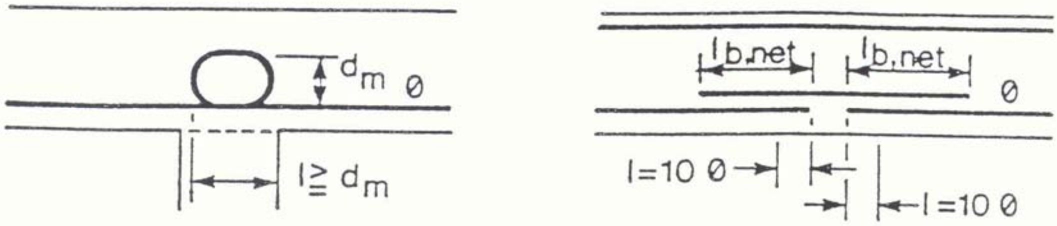
Figure 5.12 - Anchorages of bottom reinforcement at end supports

5.4.2.1.5 Anchorage of bottom reinforcement at intermediate supports

(1) Amount of reinforcement : 5.4.2.1.4 (1) applies.

(2) Such anchorage should have a length of not less than 10 ø (for straight bars) or not less than the diameter of the mandrel (for hooks and bends) (see Figure 5.13a).

(3) In addition, it is recommended that the reinforcement used should be continuous and able to resist accidental positive moments (settlement of the support, explosion, etc., see Figure 5.13b).



(a) (d_m = diameter of mandrel) (b)

Figure 5.13 - Anchorage at intermediate supports

5.4.2.2 Shear reinforcement

(1) The shear reinforcement should form an angle of 90° to 45° with the mid-plane of the structural element.

(2) The shear reinforcement may consist of a combination of :

- links enclosing the longitudinal tensile reinforcement and the compression zone ;
- bent-up bars;
- shear assemblies in the form of cages, ladders, etc. of high bond bars which are cast in without enclosing the longitudinal reinforcement (see Figure 5.14), but should be properly anchored in the compression and tension zones.

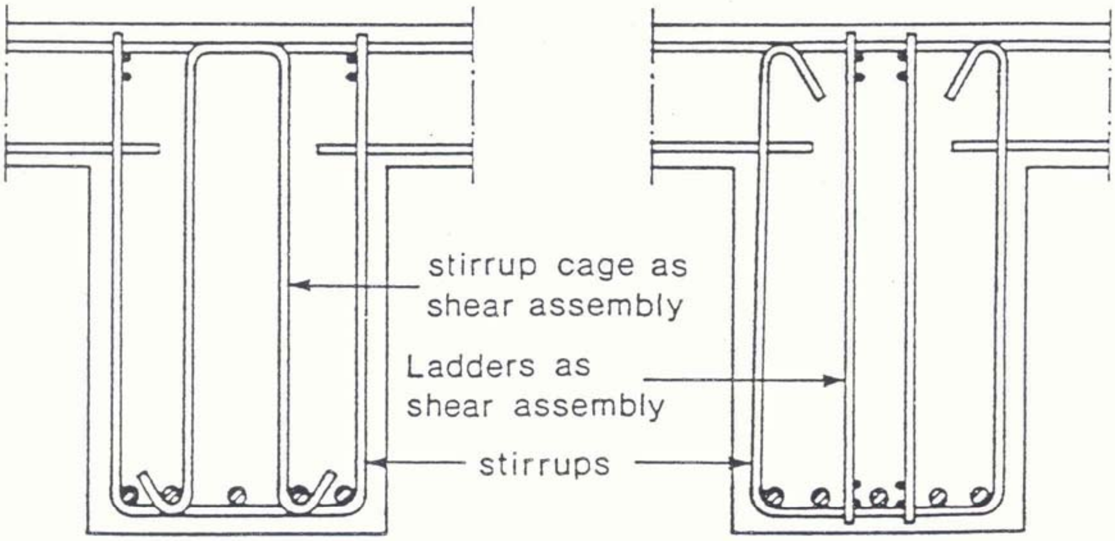


Figure 5.14 : Examples for combinations of links and shear reinforcement

(3) Links should be effectively anchored. A lap joint on the leg near the surface of a web is allowed only for high bond bars.