Shape	Size (mm)	Correction factor
Cube	100 x100 x 100	0.97
Cube	(158 x 158 x 158) or (150 x 150 x 150)	1.00
Cube	200 x 200 x 200	1.05
Cube	300 x 300 x 300	1.12
Cylinder	100 x 200	1.20
Cylinder	150 x 300	1.25

ECP 203 requires that the target concrete compressive strength, f_m must exceed the *characteristic strength* f_{cu} by a safety margin *(M)*.

$$f_m = f_{cu} + M$$

Statistical data	Safety margin M		
	$f_{cu} < 20$ N/mm^2	20-40 N/mm^2	40-60 N/mm^2
40 test data or more	1.64 SD $\geq$ 4 N/mm^2	1.64 SD $\geq$ 6 N/mm^2	1.64 SD $\geq$ 7.5 N/mm^2
less than 40 test data	Not less than 0.6 f_{cu}	$\geq$ 12 N/mm^2	$\geq$ 15 N/mm^2

Shrinkage

$$B = \frac{2A_c}{P_c}$$

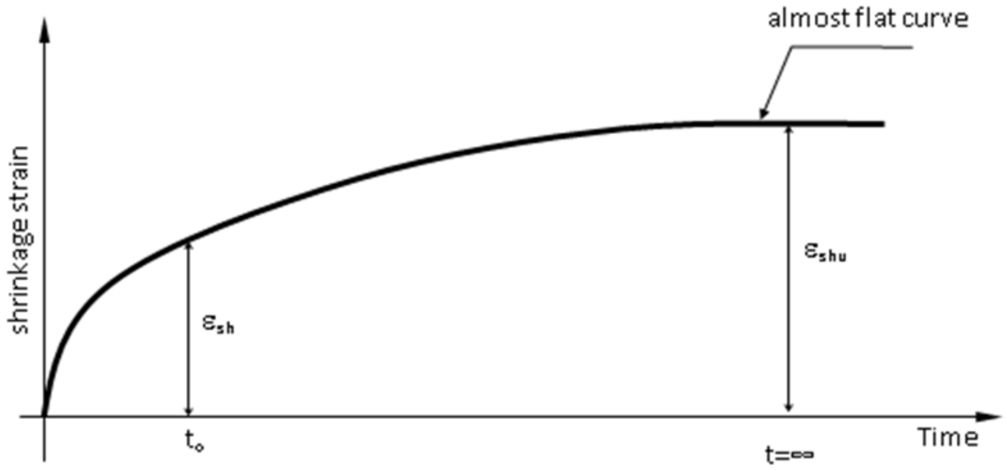


Fig. 1.11 Variation of shrinkage with time for a typical concrete mix

weather condition	Dry weather Relative humidity ≈55%			Humid weather Relative humidity ≈ 75%		
Time by days	Virtual thickness B			Virtual thickness B		
	$B \geq 600$	$600 < B > 200$	$B \leq 200$	$B \geq 600$	$600 < B > 200$	$B \leq 200$
3-7	0.31	0.38	0.43	0.21	0.23	0.26
7-60	0.30	0.31	0.32	0.21	0.22	0.23
>60	0.28	0.25	0.19	0.20	0.19	0.16

Reinforcement Bars

Creep

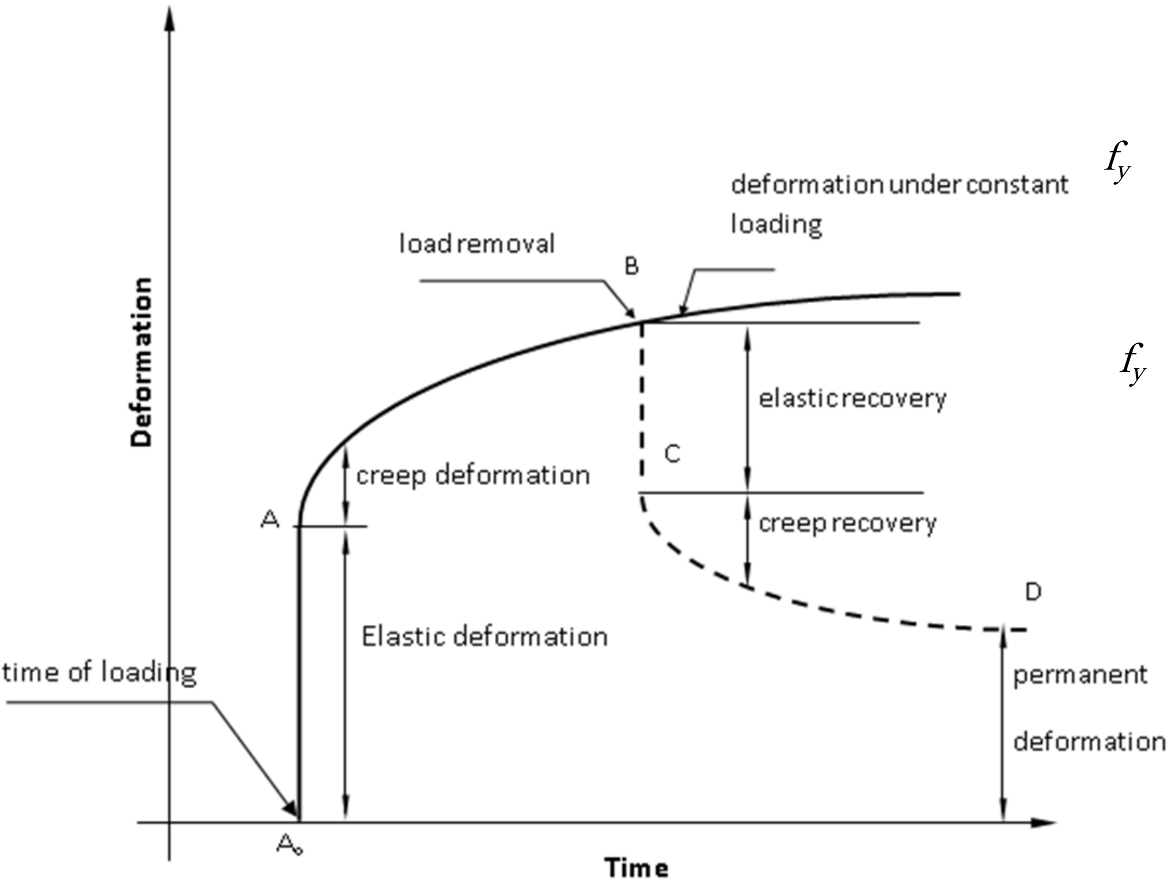
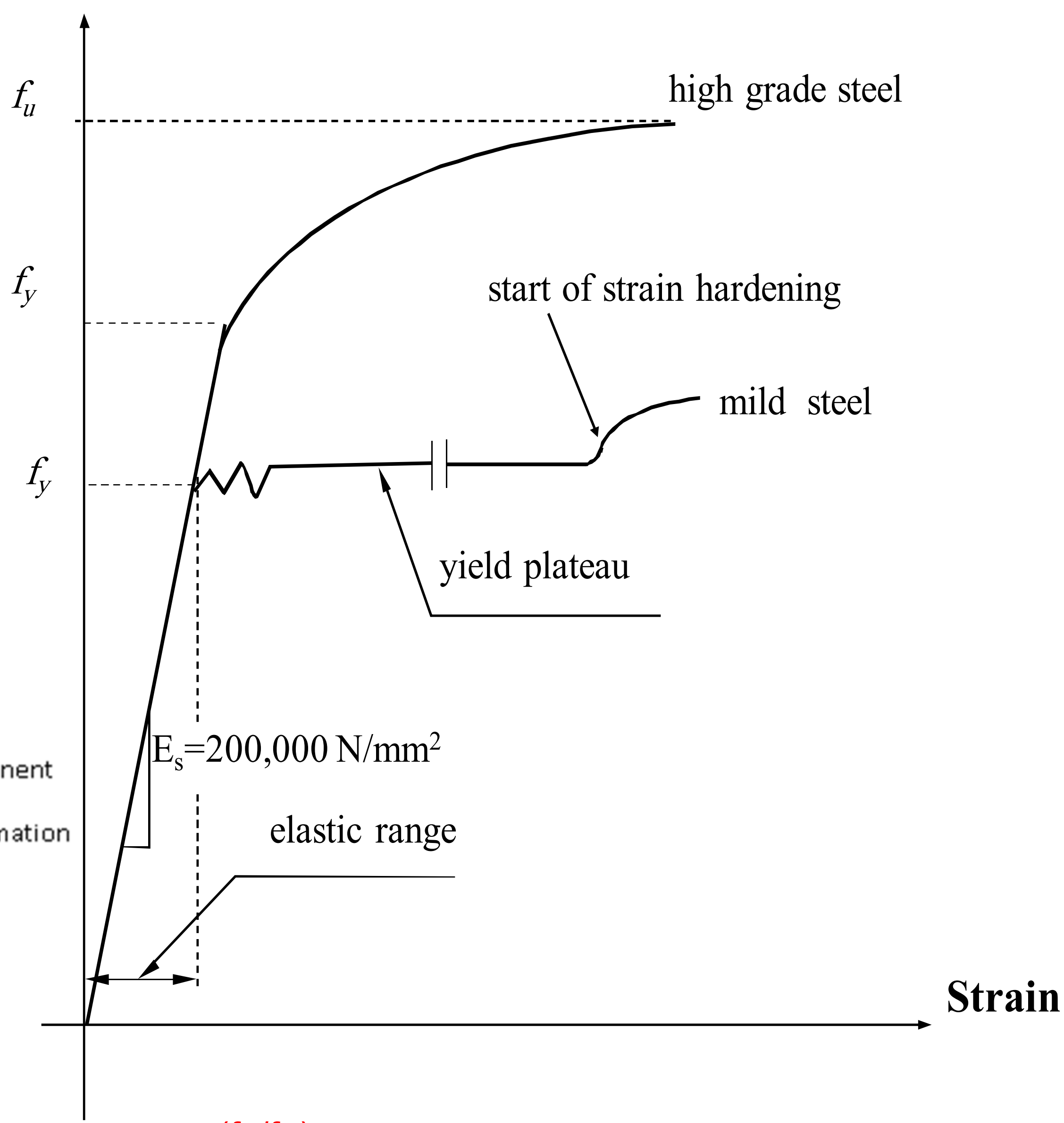


Fig. 1.12 Elastic and creep deformation of concrete



(fy/fu)

Mild Steel

(240/350) , (280/450)

High Grade Steel

(360/520) , (400/600)

Strength Reduction Factors

$$\gamma_c = 1.5 \times \left\{ \frac{7}{6} - \frac{(e/t)}{3} \right\} \geq 1.5$$

$$\gamma_s = 1.15 \times \left\{ \frac{7}{6} - \frac{(e/t)}{3} \right\} \geq 1.15$$

Stress-Strain Relationships for concrete

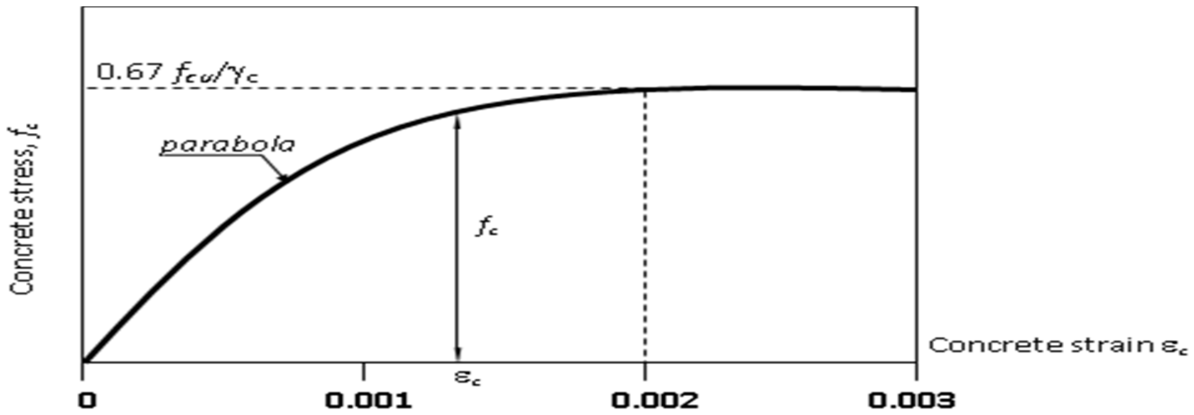


Fig 2.2 ECP 203 idealized stress-strain curve for concrete

Structure Type	Location/usage	Live load
Residential buildings	Rooms	2
	Balconies , stairs, kitchen	3
Office buildings	Offices	2.5
	Archives	5-10
	Balconies and stairs	4
Hospitals	Patient rooms	2.5
	Surgery/lab	4 or more
	Balconies and stairs	4

Minimum Area of Steel

$$A_{s\,min} = smaller\ of \begin{cases} \dfrac{0.225\sqrt{f_{cu}}}{f_y}\, b\ d \geq \dfrac{1.1}{f_y}\, b\ d \\ 1.3\, A_s \end{cases} \quad but\ not\ less\ than \begin{cases} \dfrac{0.25}{100}\, b\ \ d\,(mild\ steel) \\ \dfrac{0.15}{100}\, b\ d\,(high\ grade) \end{cases}$$

Table 3.1 Values of (d′) to ensure yielding of compression steel

$f_y (N/mm^2)$	240	280	360	400
d'/d at $c<c_{max}$ (code values)	≤ 0.20	≤ 0.20	≤ 0.15	≤ 0.10
d'/d at $c=c_{max}$ (max. values)	≤ 0.326	≤ 0.285	≤ 0.210	≤ 0.176

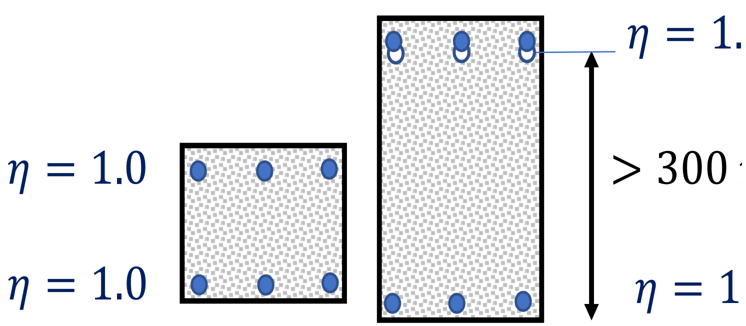
Development Length (L)

$$L_d = \frac{\alpha\ \beta\ \eta\ \left(\frac{fy}{\gamma_s}\right)}{4\ f_{bu}} \cdot \phi$$

$$f_{bu} = 0.3\sqrt{\frac{f_{cu}}{\gamma_c}}\ \text{N/mm}^2$$

جدول (٤-٨) قيم معامل التصحيح β

في الضغط	في الشد	حالة سيخ التسليح
٠,٧٠	١,٠٠	سيخ أملس
٠,٤٥	٠,٧٥	سيخ ذو نتوءات



جدول (٤-٧) قيم معامل التصحيح α

المعامل α في الضغط	المعامل α في الشد	شكل طرف السيخ	نوع التسليح
1	1	١ - مستقيم	أسياخ تسليح
1	0.75	٢ - جنش على شكل U	أسياخ تسليح
1	0.75	٣ - جنش على شكل L	أسياخ تسليح
1	0.75	٤ - جنش على شكل ∠	أسياخ تسليح
1	0.75	٥ - جنش على شكل	أسياخ تسليح
1	1	١ - أسياخ مستقيمة ولا يوجد أسياخ عرضية في طول L_d	الشبك الملحوم
0.70	0.70	٢ - أسياخ مستقيمة و يوجد سيخ عرضي في طول L_d	الشبك الملحوم
0.50	0.50	٣ - أسياخ مستقيمة و يوجد سيخان عرضيان في طول L_d	الشبك الملحوم

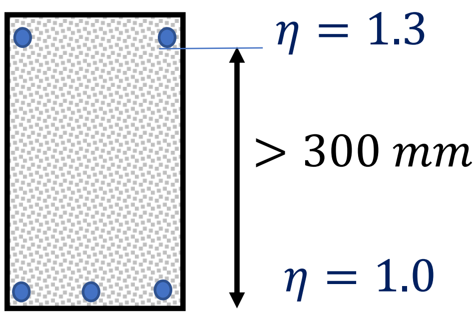
D = 4 ϕ for steel 240/350

D = 6 ϕ (or Φ) for 25 mm $\geq \phi$ (or Φ) > 6 mm } for high grade steel

D = 8 ϕ (or Φ) for ϕ (or Φ) > 25 mm

Development Length (L_d) 2018 – Simplified method:

$$L_d = \eta\ .\ \text{Factor (ECP Table 4-9)}\ .\ \phi$$



جدول (٤-٩) طول التماسك للأسياخ المنفردة يا مضاعف من قطر السيخ* (η= 1.0)

رتبة الخرسانة (ن/مم٢)	نوع التسليح			
	أسياخ من الصلب عالي المقاومة مستقيمة ذات نتوءات** f_y=400 (N/mm²) or 350 (N/mm²)		أسياخ من الصلب الطري ملساء بجنش*** f_y=240 (N/mm²)	
	في الشد	في الضغط	في الشد	في الضغط
20	60	40	38	35
25	55	40	36	35
30	50	40	35	35
35	45	40	35	35
40	42	40	35	35
أكبر من أو يساوي 45	40	40	35	35

* مع مراعاة ما جاء بالبند (٤-٢-٥-١-ج).

** في حالة أسياخ ذات نتوءات بجنش تضرب الأرقام أعلاه في 0.75.

*** غير مسموح باستخدام أسياخ ملساء بدون جنش.

Notes:

- ***The use of smooth bars without hooks is not allowed***
- ***For any case in tension or compression:***

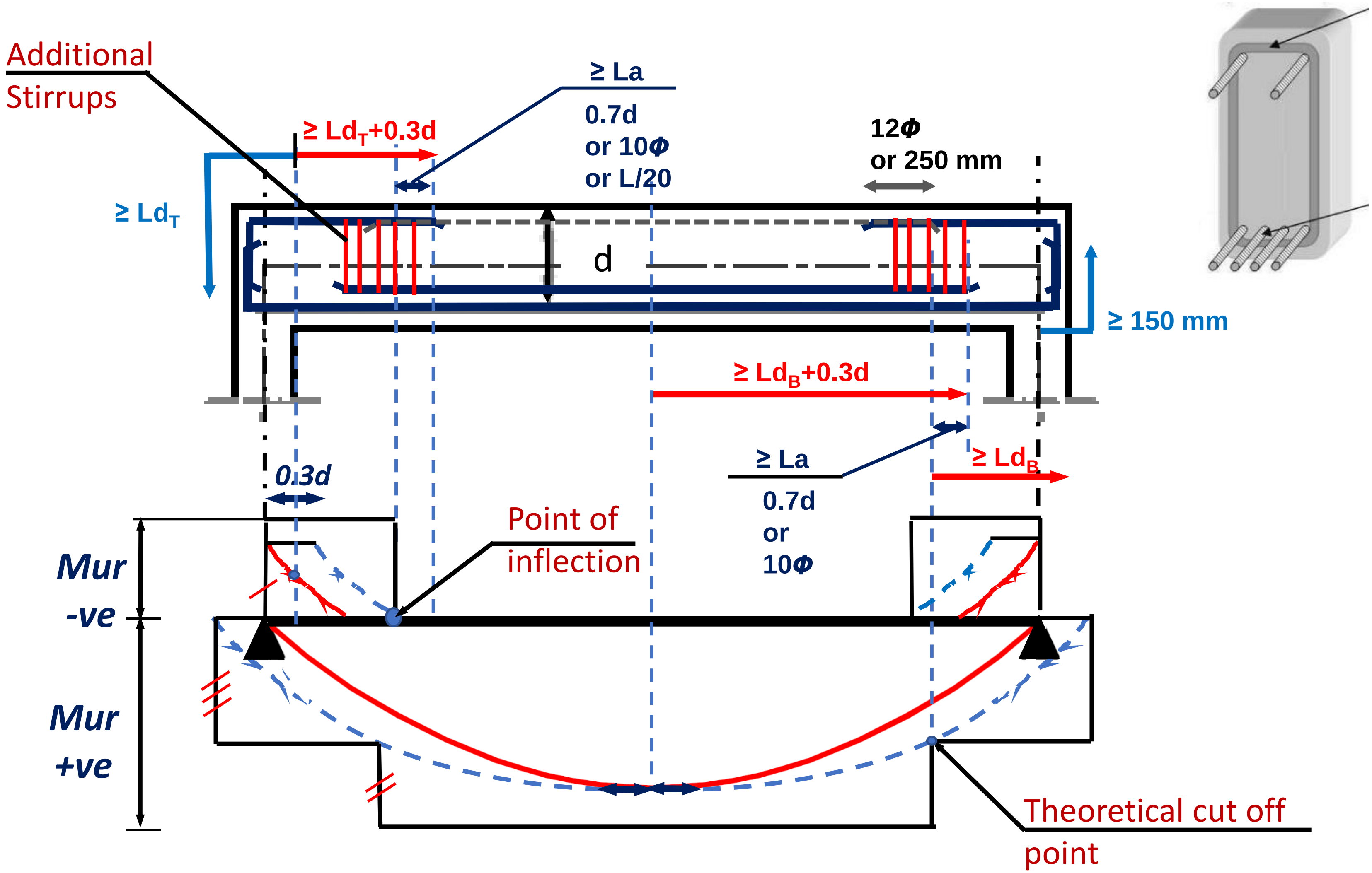
  - For smooth bars with hooks

    $$L_d \geq \text{bigger of } (35\emptyset\ or\ 400mm)$$

  - For deformed bars

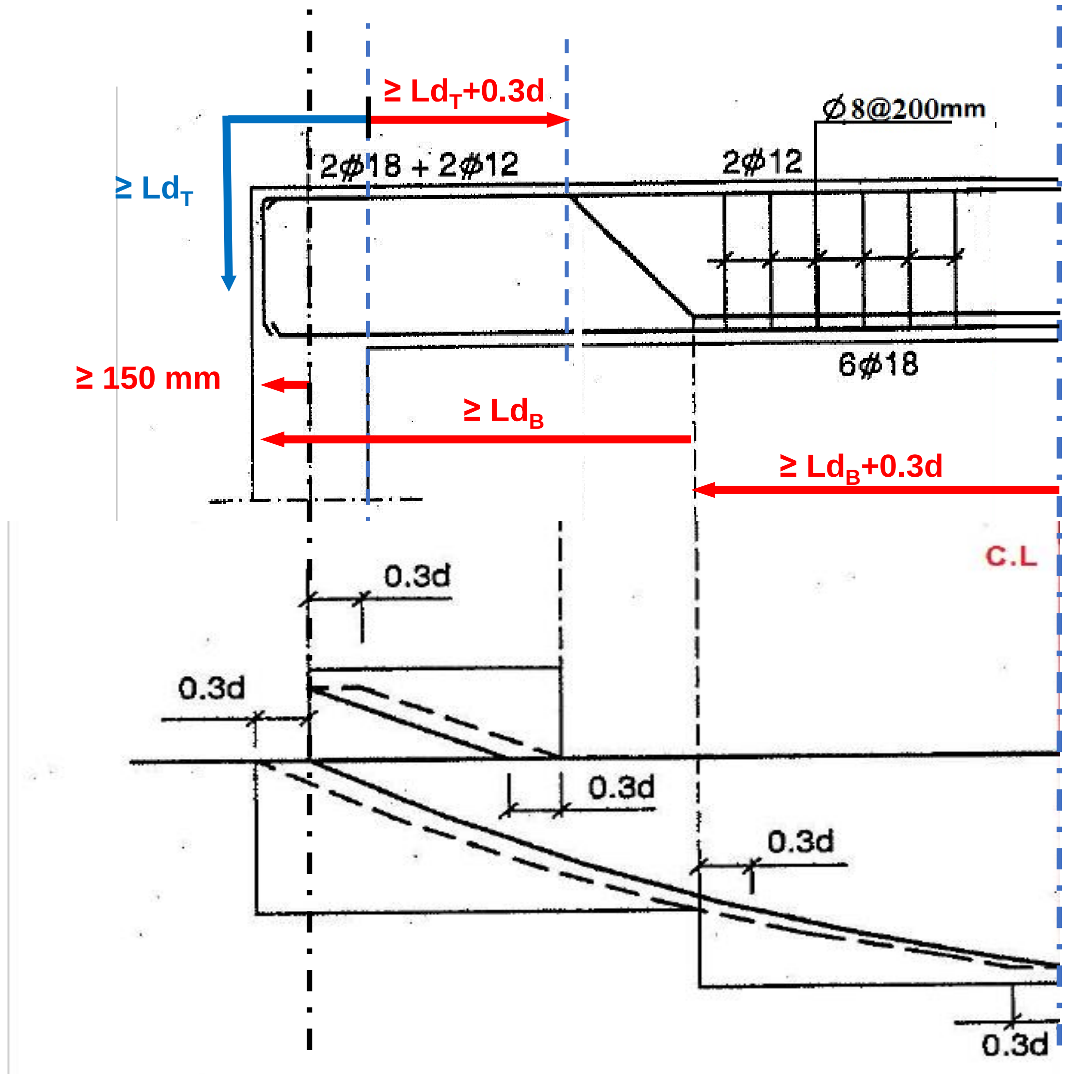
    $$L_d \geq \text{bigger of } (40\emptyset\ or\ 300mm)$$

Requirements for Steel Curtailment (ECP 203-2018)



Straight bars

Requirements for Steel Curtailment (ECP 203-2018)

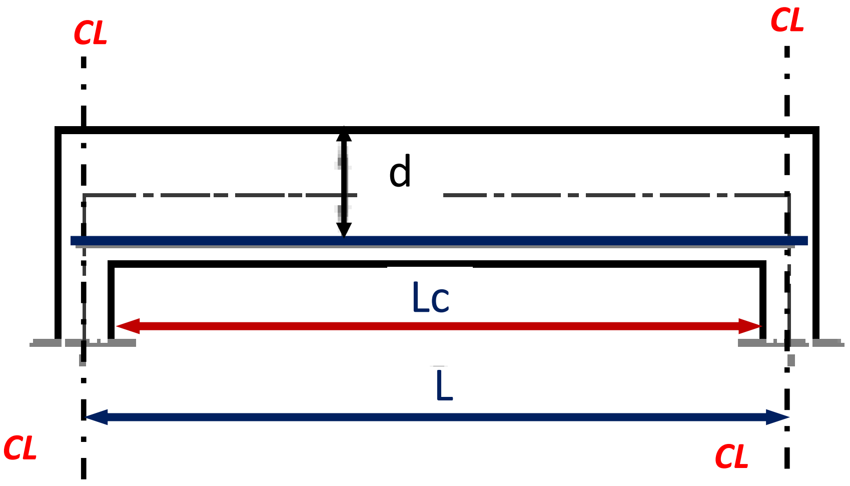


Bent bars

❖ Effective span (L_{eff})

Smallest of:

1. CL to CL of support (L)
2. 1.05 Lc
3. Lc + d



❖ Effective span (L_{2eff})

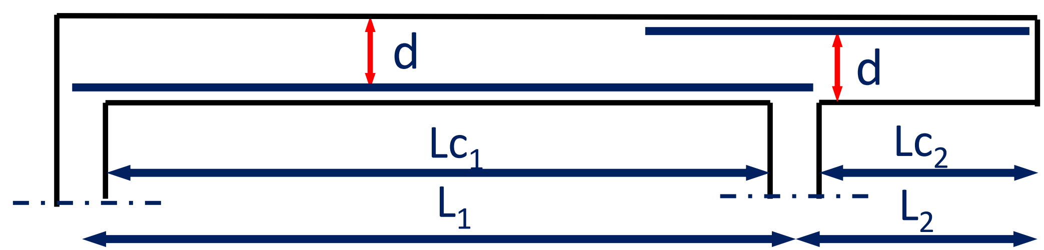
Smallest of:

1. Length of cantilever measured from CL (L_2)
2. L_{c2} + d

❖ Effective span (L_{1eff})

Smallest of:

1. CL to CL of support (L_1)
2. 1.05 L_{c1}



Effective Flange Width (B_{eff})

T section:

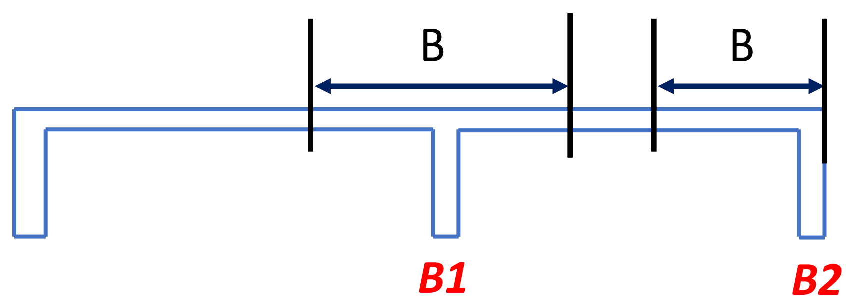
B = smallest of:

- **$16t_s + b$**
- **$L_2/5 + b$**
- **CL to CL**

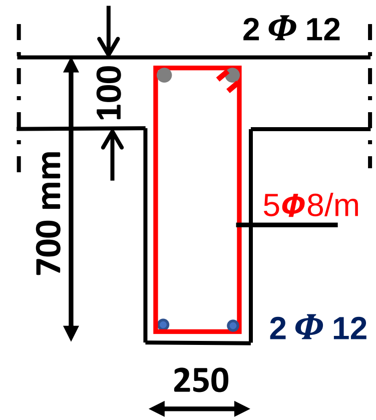
L section:

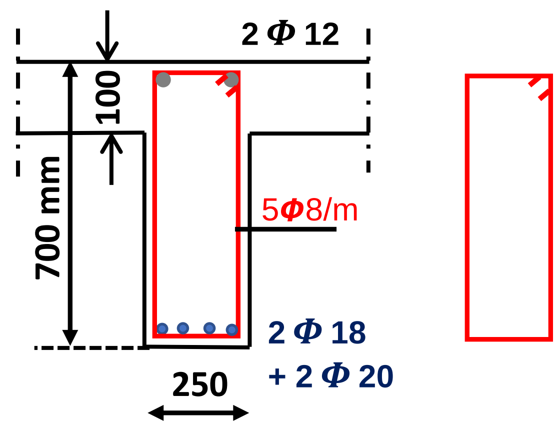
B = smallest of:

- **$6t_s + b$**
- **$L_2/10 + b$**
- **CL to Edge**



1. Minimum number of bars in the section is 2; one at each corner of the section whether in tension or compression.
2. Diameters used for main reinforcement 12, 14, 16, 18, 20, 22, 25.
3. Usually, High-Grade deformed Steel bars are used.
4. Two successive diameters could be used in the same section. For example, ***Φ*** 16 and ***Φ*** 18 or we can skip only one bars for example ***Φ*** 16 and ***Φ*** 20 but ***Φ*** 16 and ***Φ*** 22 can not be used.
5. If more than one diameter is used, the bigger diameter is placed at the corner.
6. Use Stirrup hangers (A's) not less than (0.1 As main) even if the section is designed for **α** = 0.0. The minimum to be used is 2 ***Φ*** 12.

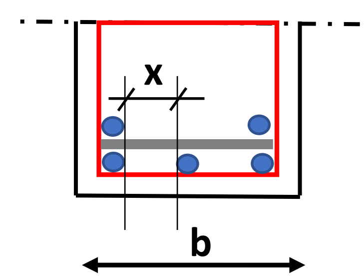




7. The spacing between bars should not be less than the larger of:

- Biggest used bar diameter
- 1.5 maximum aggregate size

The maximum number of bars in one row ≈ b/(50~60)



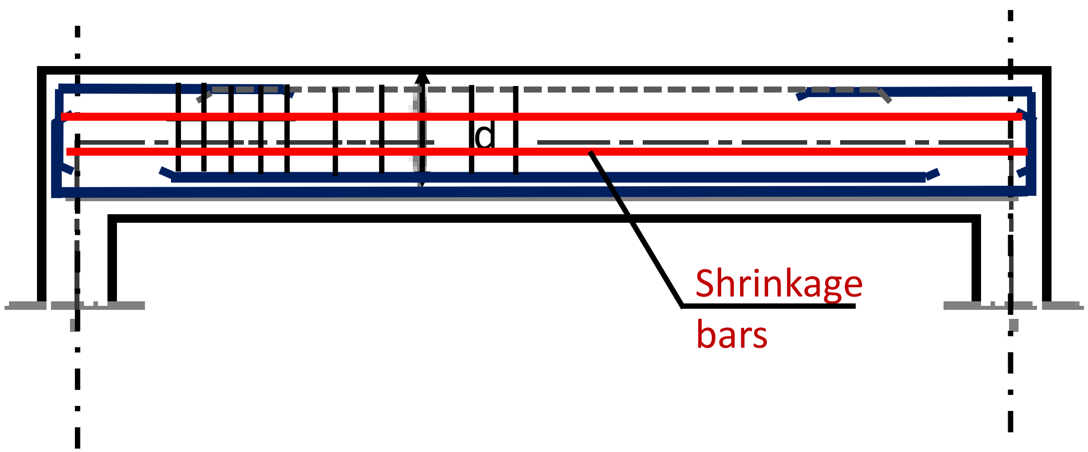
8. Reinforcement bars are preferred to be symmetrically arranged around the vertical axis of the section.

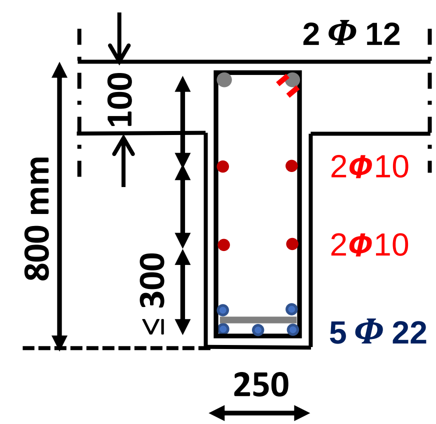
9. At least 1/3 of the total steel area at critical section should be extended to the support with a distance not less than 150 mm (measured from the center line of the support).

10. Shrinkage bars are added when the beam depth below slab > 600 mm
    The area of shrinkage bars Ash ≥ 0.08 As main
    Distance between shrinkage bars ≤ 300 mm

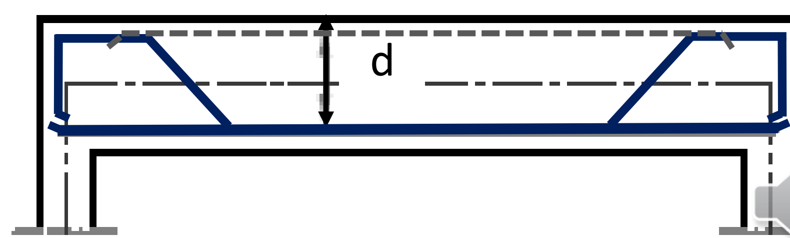
❖ Shrinkage bars

٥- تُزود الكمرات التي يزيد عمقها على ٦٠٠ مم، وذلك بخلاف سمك البلاطة، بأسياخ انكماش جانبية، لا تقل مساحتها عن ٨ % من مساحة تسليح الشد على ألا تزيد المسافة بينها على ٣٠٠مم.

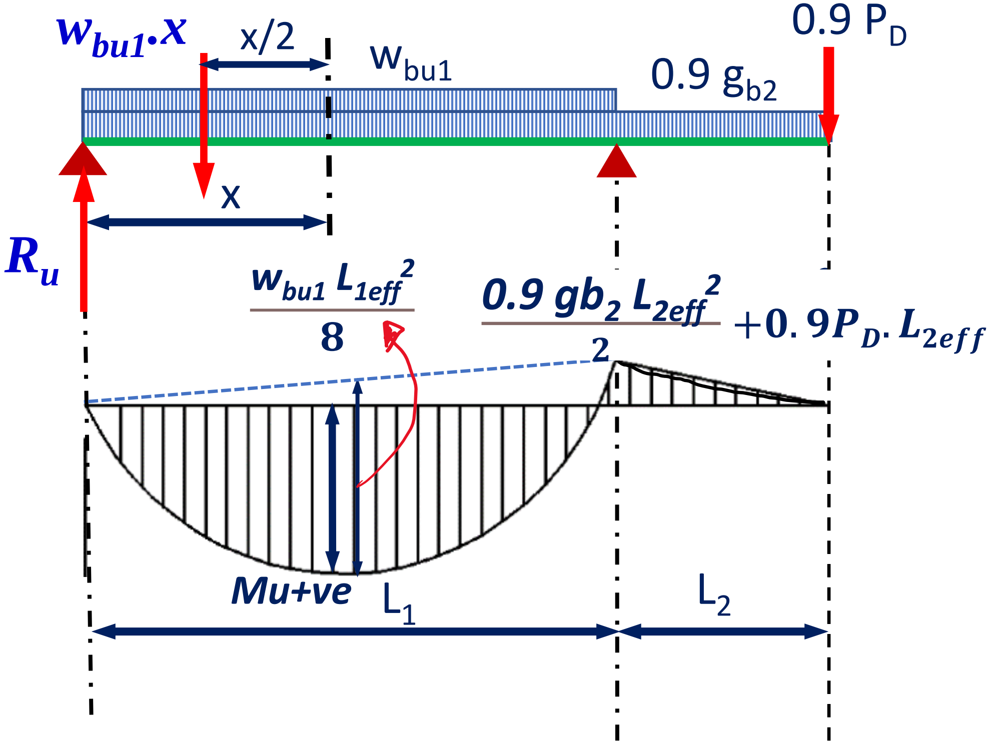




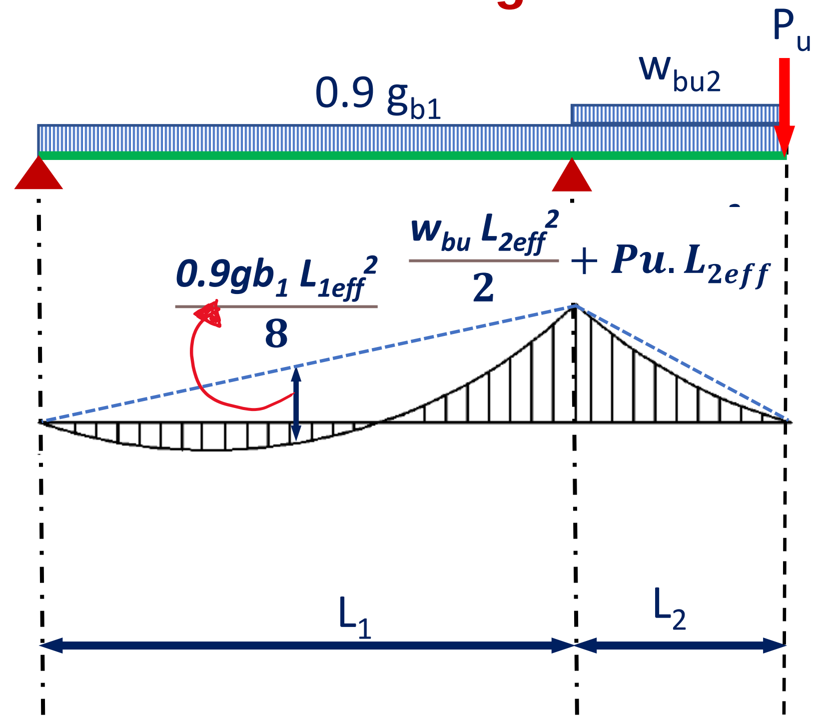
11. Number of bent bars in one group ≤ 4
12. Bent bar angle = 45º (sometimes 60º for beams with large depth/span ratio)



❖ Case 1: max positive BM



❖ Case 2: max negative BM



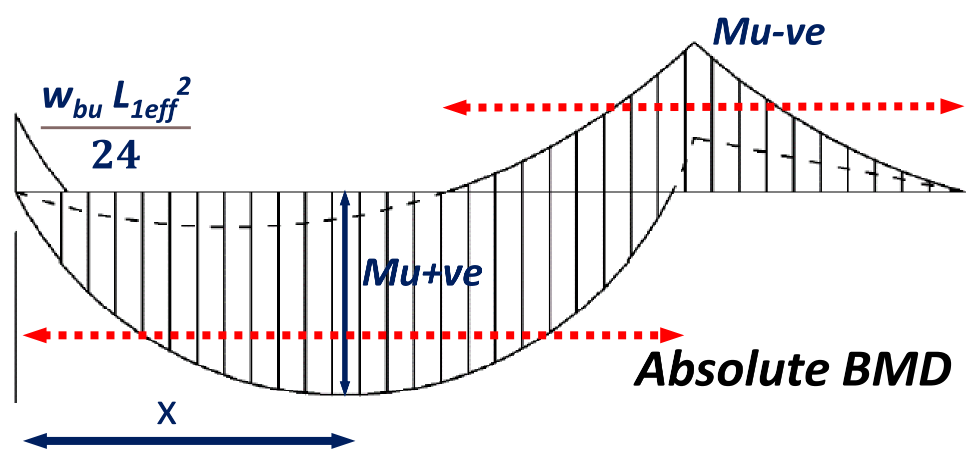
Calculate Ru

At point of zero shear:

$$\mathrm{Ru} - \mathrm{wbu1.x} = 0 \Rightarrow x = \frac{\mathrm{Ru}}{w_{bu1}}$$

Max Mu+ve:

$$\mathrm{Mu{+}ve} = \mathrm{Ru.x} - \frac{w_{bu1}\, x^2}{2}$$



جدول (٤-١٠) نسـبة البحر الخالص إلى العمق الكلى (L_n / t) ما لم يتم حسـاب الترخيم للكمرات ذات القطاعات المستطيلة والبلاطات ذات الاتجاه الواحد للبحور أقل من أو تساوى ٦ متر والكوابيل ذات الأطوال أقل من ٢ متر

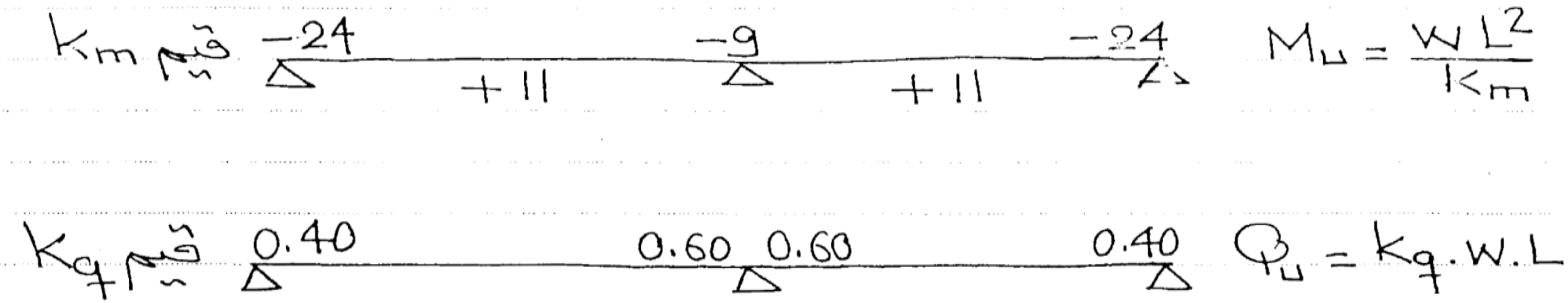
العنصر	بسيطة الارتكاز	مستمرة من ناحية واحدة	مستمرة من جانبين	الكابولي
البلاطات المصمتة	٢٥	٢٨	٣١	١٠
البلاطات ذات الأعصاب والكمرات المدفونة	٢٠	٢٣	٢٤	٨
الكمرات الجاسئة	١٢	١٤	١٦	٥

تطبق القيم السابقة في حالة استخدام حديد 420 MPa و في حالة استخدام حديد من نوع آخر فيتم ضرب العمق الناتج من القيم السابقة في المعامل: $\left(0.4 + \frac{f_y}{700}\right)$

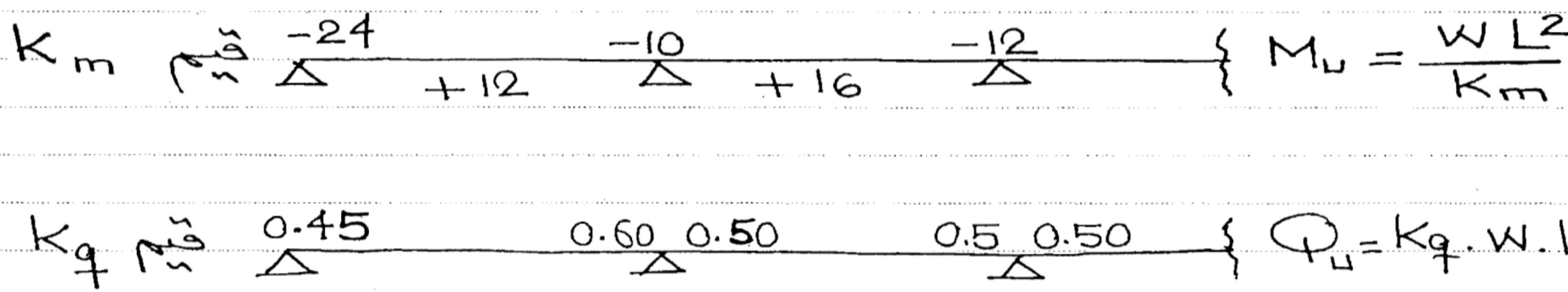
3.3. Continuous Beam – Equal Spans (B3):

Max. Difference in in Spans and Loads ≤ 20%

2-Spans:

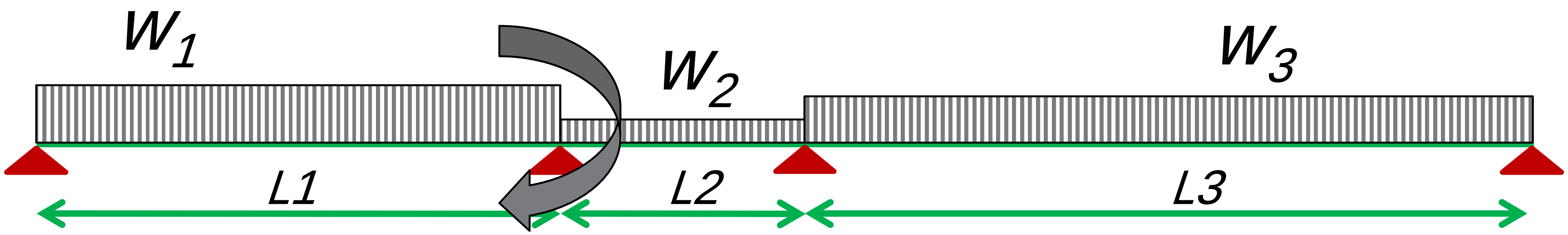


More than 2-Spans:



3.3. STRAINING ACTIONS

Unequal Spans



$$M_{-v} = \frac{w_1.(L'_1)^3 + w_2.(L'_2)^3}{8.5(L'_1 + L'_2)}$$

French equation

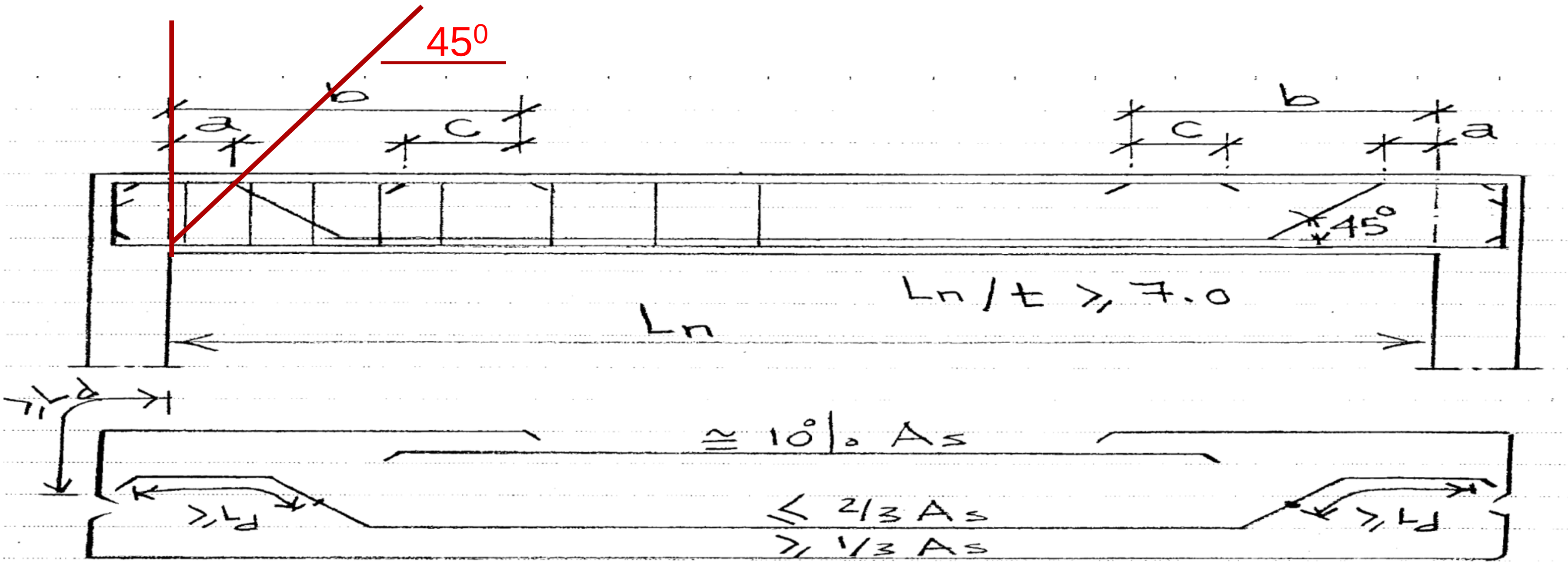
Where:

$L' = L$ for spans continuous from one side

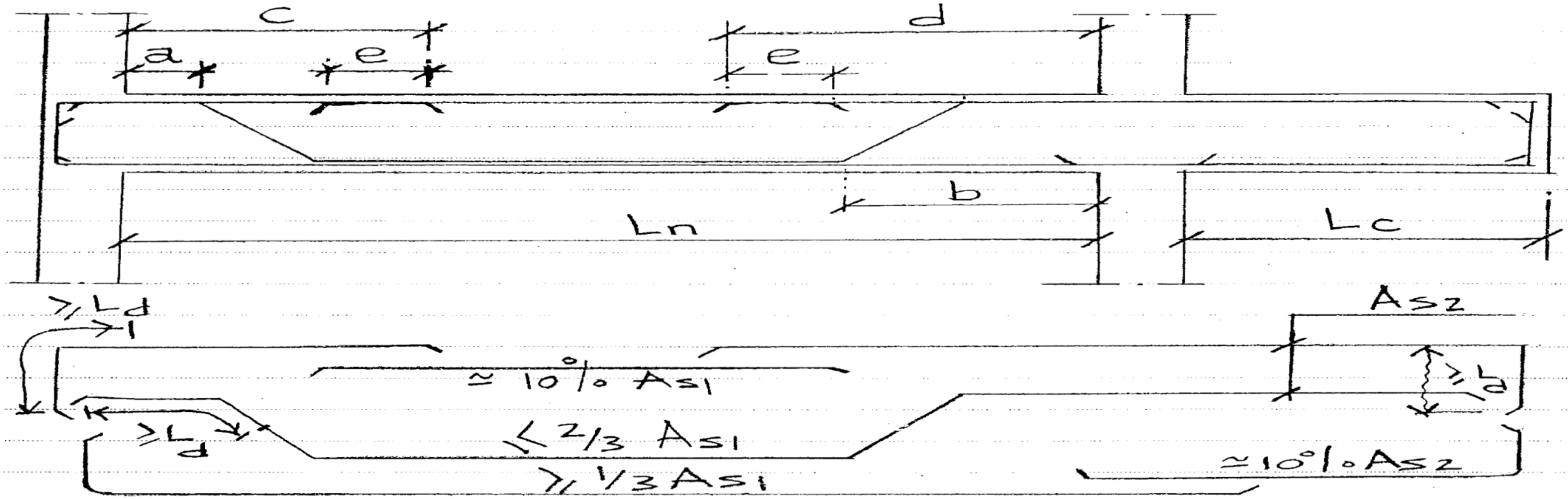
$L' = 0.8\ L$ for spans continuous from two sides

In the above figure $L_1' = L_1$

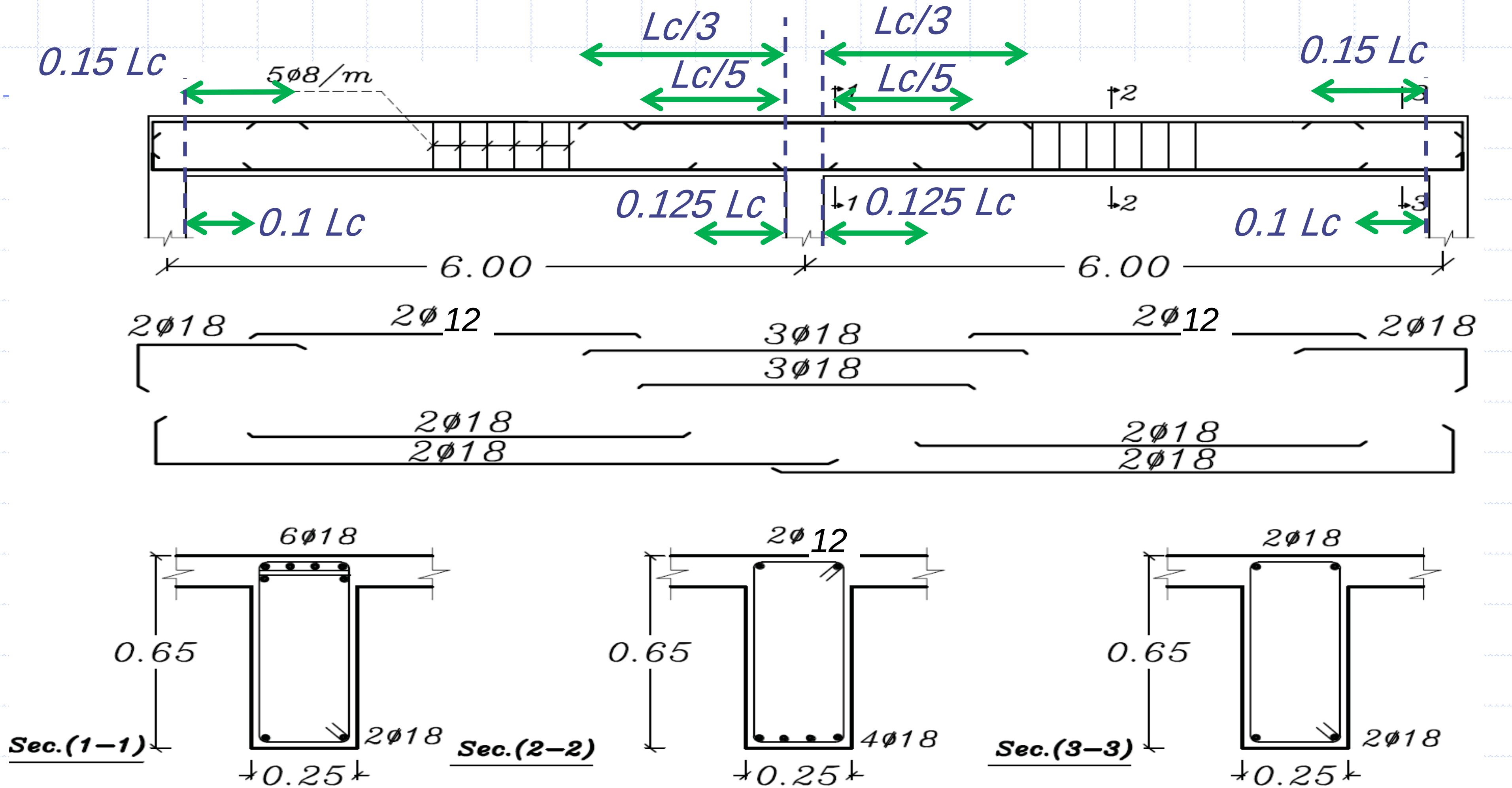
$L_2' = 0.8\ L_2$



Type	Length
a	Min. 10 cm
b	Min. 0.15 Ln
C	Bigger of (12Φ or 25 cm)

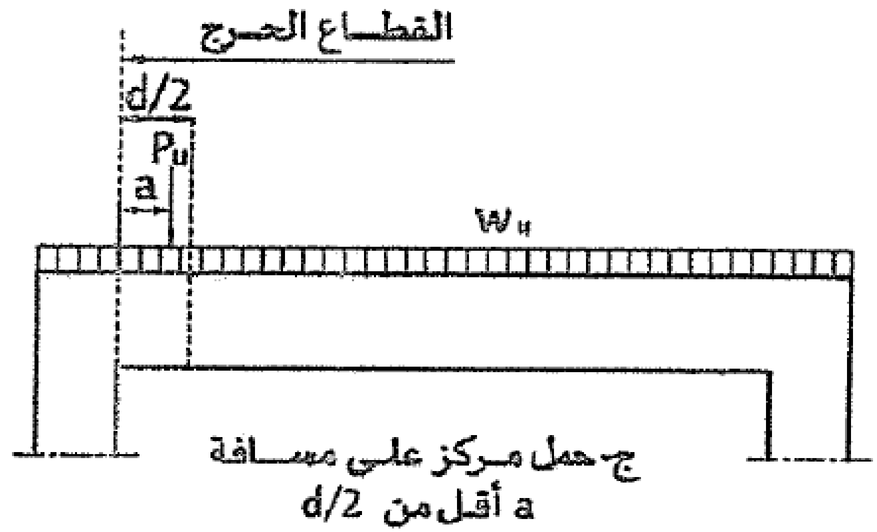


Type	Length
a	Min. 10 cm
b	Max. 0.20 Ln
c	Min. 0.15 Ln
d	Bigger of (1.50 Lc or 0.30 Ln)
e	Bigger of (12 ϕ or 25 cm)



0.15 Lc
5ø8/m
Lc/3
Lc/5
Lc/3
Lc/5
0.15 Lc
2
1
2
3
0.1 Lc
0.125 Lc
0.125 Lc
0.1 Lc
6.00
6.00
2ø18
2ø12
3ø18
3ø18
2ø12
2ø18
2ø18
2ø18
2ø18
2ø18
6ø18
2ø12
2ø18
0.65
0.65
0.65
2ø18
4ø18
2ø18
Sec.(1–1)
Sec.(2–2)
Sec.(3–3)
0.25
0.25
0.25

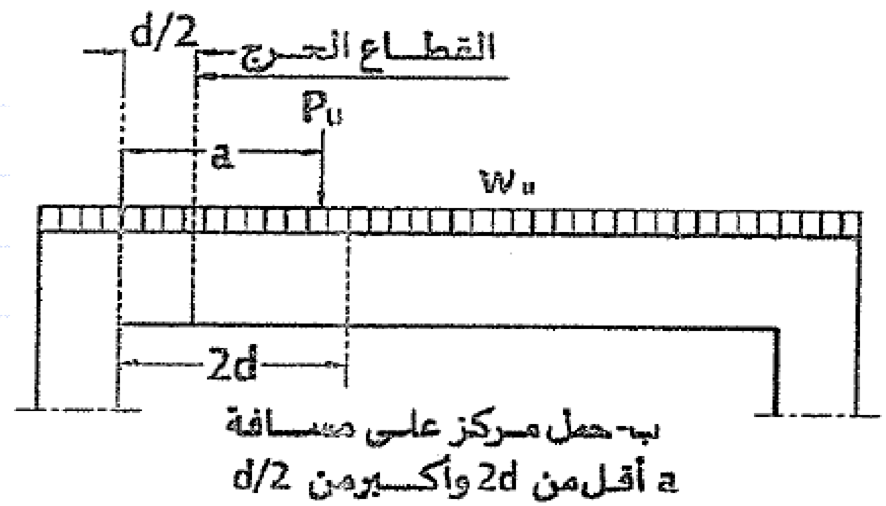
Where is the Critical Section?



If $a < d/2$

Critical section at C/2

$$Q_{cr} = \frac{WL}{2} - \frac{WC}{2} + \frac{PL_2}{L}\left(\frac{a}{2d}\right)$$



If $d/2 \leq a \leq 2d$

Critical section at (C/2 + d/2)

$$Q_{cr} = \frac{WL}{2} - w\left(\frac{C}{2} + \frac{d}{2}\right) + \frac{PL_2}{L}\left(\frac{a}{2d}\right)$$

If $a > 2d$

Critical section at (C/2 + d/2)

$$Q_{cr} = R - w\left(\frac{C}{2} + \frac{d}{2}\right)$$

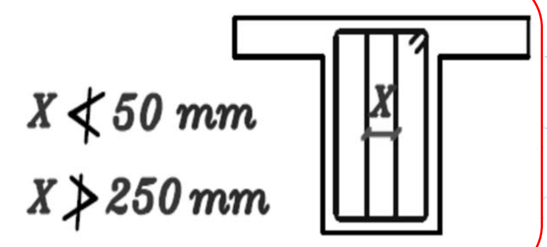
Concentrated Load

a- Using Stirrups

$$\boxed{q_s = q_U - q_{cu\,Cr.} = \frac{n * A_s * (f_y \backslash \gamma_s)}{b * S}}$$

عدد الفروع الرأسية للكانة

Note: If b ≥ 400 mm or b>t → n=4



f_y = stirrups yield stress 240, 350 , or 400 N/mm^2

S = spacing between stirrups mm (100 to 200 mm)

Minimum Stirrups

$$\mu_{min} = 0.4 / f_y \quad \text{or } 0.15\% \ (fy = 240) \text{ or } 0.1\% \ (fy = 350 \text{ or } 400$$

$$A_{st\,min} = \mu_{min}\ b\ S$$

b- Using Stirrups and Bent Bars

Concrete + Stirrups + Bent bars

$$\boxed{q_u = q_{cu\,Cr.} + q_{sus} + q_{sub}}$$

→ get q_{sub}

$$\boxed{\frac{A_{sb}}{b\,d} = \frac{q_{sub}}{(f_y \backslash \gamma_s)\,(\sin\alpha)}}$$

$$q_{sub} \leq 0.24\sqrt{\frac{f_{cu}}{\gamma_c}}\ \text{N/mm}^2$$

A_{sb} = Area of bent bars

Beams with Axial Tension or Compression

Tension Tu

$$q_{cu\,Uncr.} = \delta t * 0.16 \sqrt{\frac{f_{cu}}{\gamma_c}}$$

$$q_{cu\,Cr.} = \delta t * 0.12 \sqrt{\frac{f_{cu}}{\gamma_c}}$$

$$\delta t = 1 - 0.30 \left(\frac{T_U}{A_c}\right)$$

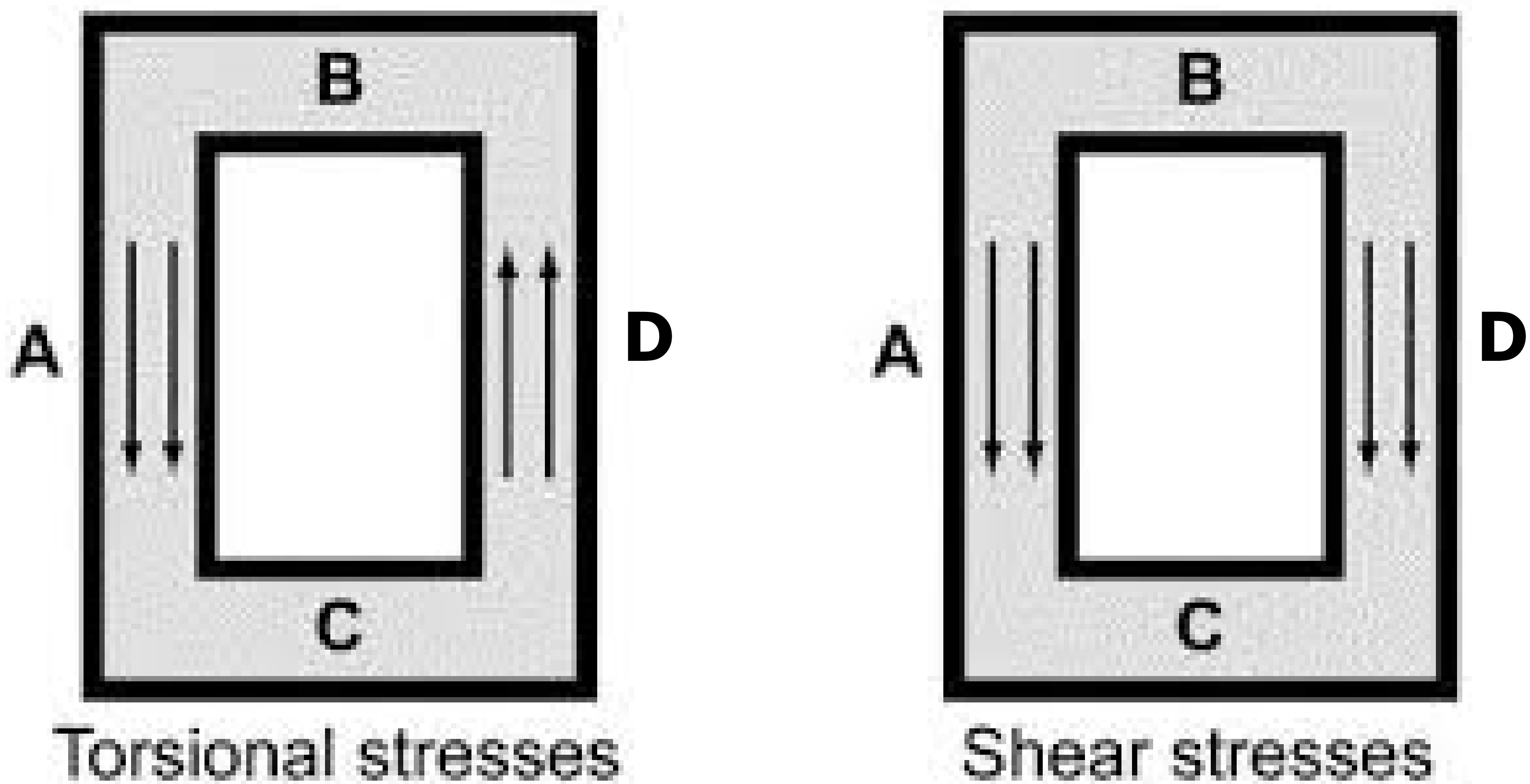
Compression Pu

$$q_{cu\,Uncr.} = \delta c * 0.16 \sqrt{\frac{f_{cu}}{\gamma_c}} \quad N\backslash mm^2$$

$$q_{cu\,Cr.} = \delta c * 0.12 \sqrt{\frac{f_{cu}}{\gamma_c}} \quad N\backslash mm^2$$

$$\delta c = 1 + 0.07 \left(\frac{P_U}{A_c}\right) \not> 1.5$$

Torsion

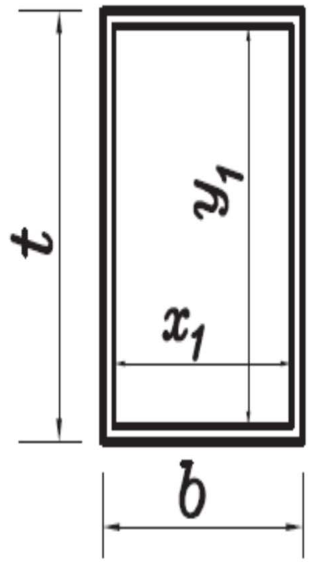


2. Shear Stress due to Torsion

$$\boxed{q_{tu} = \frac{M_{tu}}{2\,A_o\,t_e}}$$

$$t_e = A_{oh} / P_h$$

$$A_o = 0.85\,A_{oh}$$



$$x_1 = b - 50mm$$

$$y_1 = t - 50mm$$

$$\Longrightarrow \boxed{A_{oh} = x_1\,y_1}$$

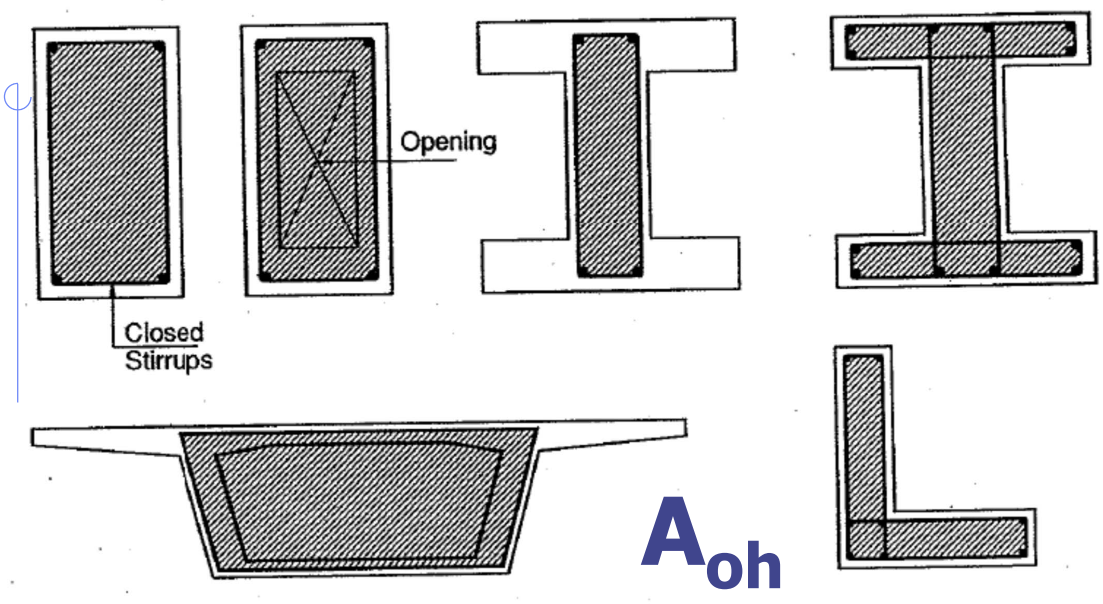
In hollow sections the actual thickness of the walls of the section should be used if it is less than t_e

3. Min. Torsional Stress

$$q_{tu\,min} = 0.06\sqrt{\frac{f_{cu}}{\gamma_c}} \quad \text{N/mm}^2$$

$q_{tu} \le q_{tu\,min} \rightarrow$ ***Torsion is neglected***

$q_{tu} > q_{tu\,min} \rightarrow$ ***Design for Torsion***



جدول (٤-٣) قيم إجهادات القص القصوى المسموح بها للقطاعات المعرضة لقوى قص غير مصحوبة أو مصحوبة بعزوم لي طبقا للمعادلة (٤-٢٧).

f_{cu} (N/mm^2)	20	25	30	35	40	50	60
q_{umax} (N/mm^2)	2.56	2.86	3.13	3.38	3.60	4.04	4.40

If $q_{tu} > q_{u\,max}$ ⟹ ***Increase concrete dimensions***

4. Check the concrete dimensions

$$q_{umax} = 0.7\sqrt{\frac{f_{cu}}{\gamma_c}} < 4.4 \quad \text{N/mm}^2$$

5. Design of Torsion Reinforcement

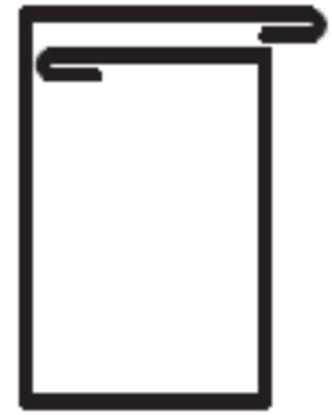
Closed Stirrups	Longitudinal Reinforcement
$$A_{str} = \frac{M_{tu}s}{2A_o\left(\frac{f_{yst}}{\gamma_s}\right)}$$	$$A_{sl} = \frac{A_{str}P_h}{s}\left(\frac{f_{yst}}{f_y}\right)$$
A_{str} = Area of stirrups M_{tu} = Torsional Moment S = spacing of stirrups A_o = 0.85 A_{oh} f_{yst} = Yield strength of stirrups	A_{sl} = Area of long. Rft. A_{str} = Area of stirrups P_h = Perimeter of outside stirrups f_y = Yield strength of long. Rft.

Minimum Stirrups

Check that: $n\,A_{str} \geq A_{st\,min}$

$$\mu_{min} = 0.4/f_y \quad \text{or } 0.15\%$$

$$A_{st\,min} = \mu_{min}\; b\, S$$



Max. S = smaller of 200 mm or $\frac{P_h}{8}$

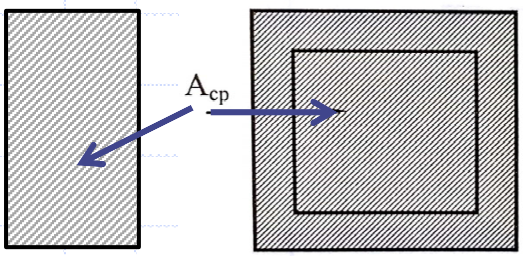
Minimum Longitudinal Bars:

$$A_{sl\,min} = \frac{0.4\sqrt{\frac{f_{cu}}{\gamma_c}}\,A_{cp}}{f_y/\gamma_s} - \left(\frac{A_{str}}{s}\right) P_h \left(\frac{f_{yst}}{f_y}\right)$$

Where $\frac{A_{str}}{s} \geq \frac{b}{6 f_{yst}}$

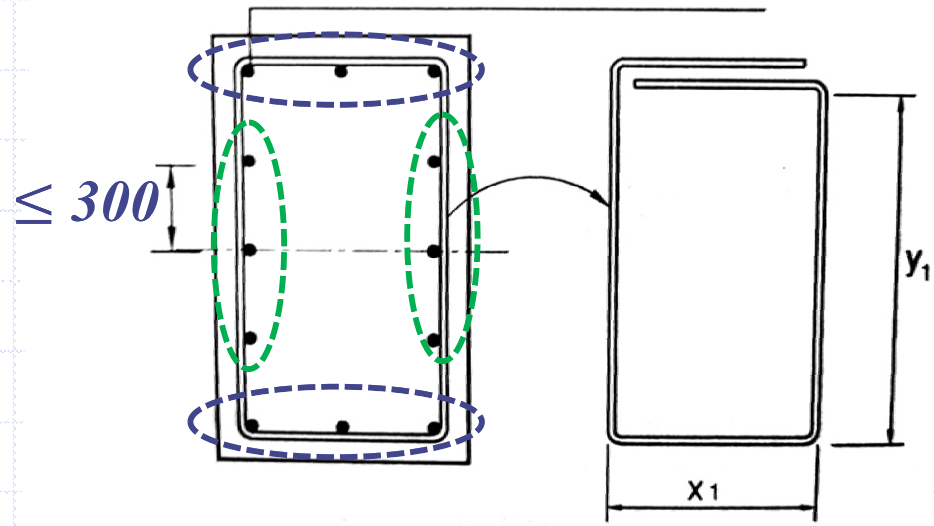
A_{cp} = Total area of the section including openings = b*t

المساحة الكلية للقطاع الخرسانى شاملة مساحة الفتحات

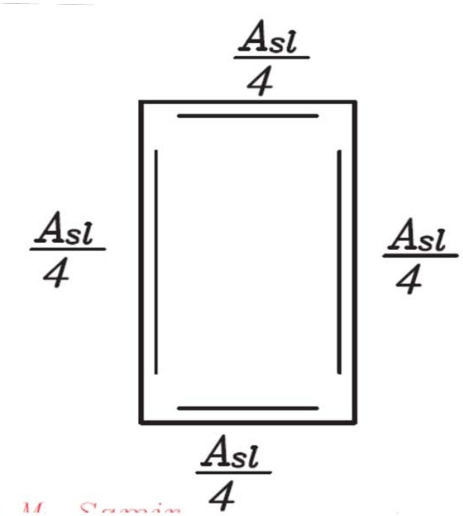


Notes: Longitudinal Bars

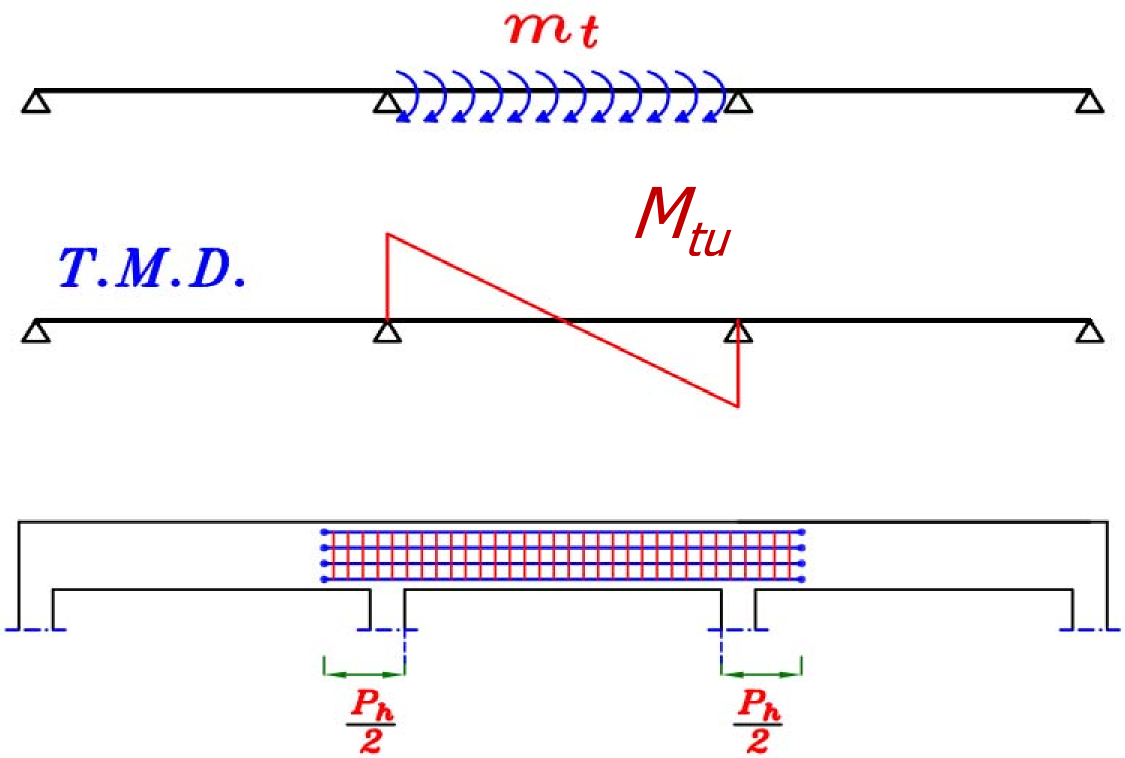
$$Min\ Bar\ dia = 12\ mm\ or\ S/15$$



- Distribute longitudinal bars uniformly along the perimeter of the section.
- The spacing between bars ≤ 300 mm
- Min. Bar Diameter = larger of 12 mm or S/15



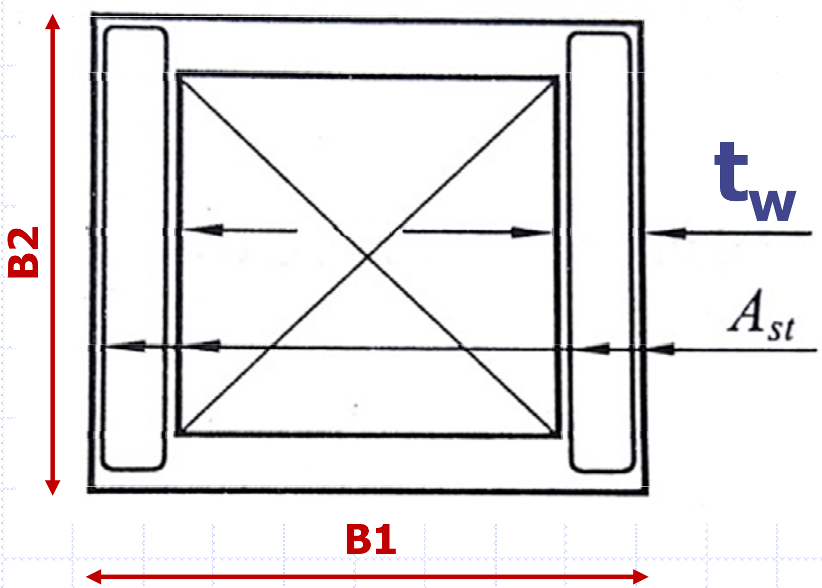
$$\boxed{A_{s_{total}} = A_{s_{(B.M.)}} + \frac{A_{sL}}{4}}$$



Closed Stirrups and longitudinal reinforcement must extend $P_h/2$ after the last section that requires torsional reinforcement

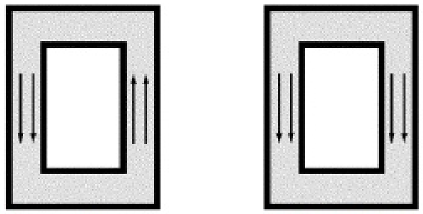
Notes: Hollow sections or box sections

- In hollow sections the actual thickness of the walls of the section should be used if it is less than t_e



- *t_e= smaller of A_{oh}/P_h or actual t_w*

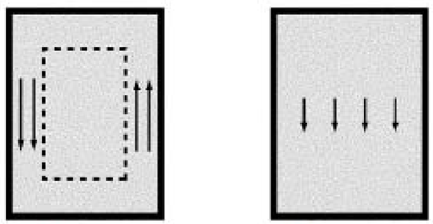
Combined Shear and Torsion



Torsional Stresses Shear Stresses

Hollow Section

$$q_u + q_{tu} \leq 0.7\sqrt{\frac{f_{cu}}{\gamma_c}} \leq 4.4 \text{ N/mm}^2$$



Torsional Stresses Shear Stresses

Solid Section

$$\sqrt{(q_u)^2 + (q_{tu})^2} \leq 0.7\sqrt{\frac{f_{cu}}{\gamma_c}} \leq 4.4 \text{ N/mm}^2$$

Shear \ *Torsion*	$q_{tu} \leq q_{tu_{min}}$	$q_{tu} > q_{tu_{min}}$
$q_u \leq q_{cu}$	*min Shear Rft*	*Design for Torsion only* **(case A)**
$q_u > q_{cu}$	*Design for Shear only* As before	*Design for Shear +Torsion* **(case B)**

Calculating closed Stirrups

Torsion

$$A_{str} = \frac{M_{tu} s}{2A_o \left(\frac{f_{yst}}{\gamma_s}\right)}$$

Get $A_{str} = ?\ S$ **(1)**

Shear

$$q_{su} = q_u - q_{cu\_cr} = \frac{A_{st} fy / \gamma_s}{b\ s} = \frac{n\ As\ fy / \gamma_s}{b\ s}$$

Assume n = 2 or 4 → Get $A_s = ?\ S$ **(2)**

Assume $S < S_{max}$ (= 100 mm)

Get $A_{s\ outer} = A_{str} + A_s$ ***and*** $A_{s\ inner} = A_s$