Design of Beams

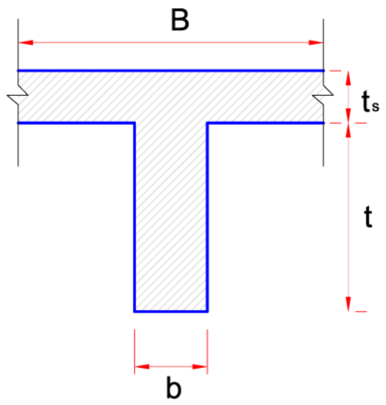
2 MODULE NO. 2: ULTIMATE FLEXURE STRENGTH (T&L-SECTION)

2.1 Inputs

2.1.1 Material Properties

- ✓ Concrete compressive strength (f_{cu})
- ✓ Reduction factor of concrete compressive strength (γ_c=1.50)
- ✓ Yield strength of longitudinal reinforcing steel bars (f_y)
- ✓ Reduction factor of reinforcing steel yield strength(γ_s=1.15)
- ✓ Modulus of elasticity of reinforcing steel bars (E_s = 200,000 N/mm^2)

2.1.2 Section Definition

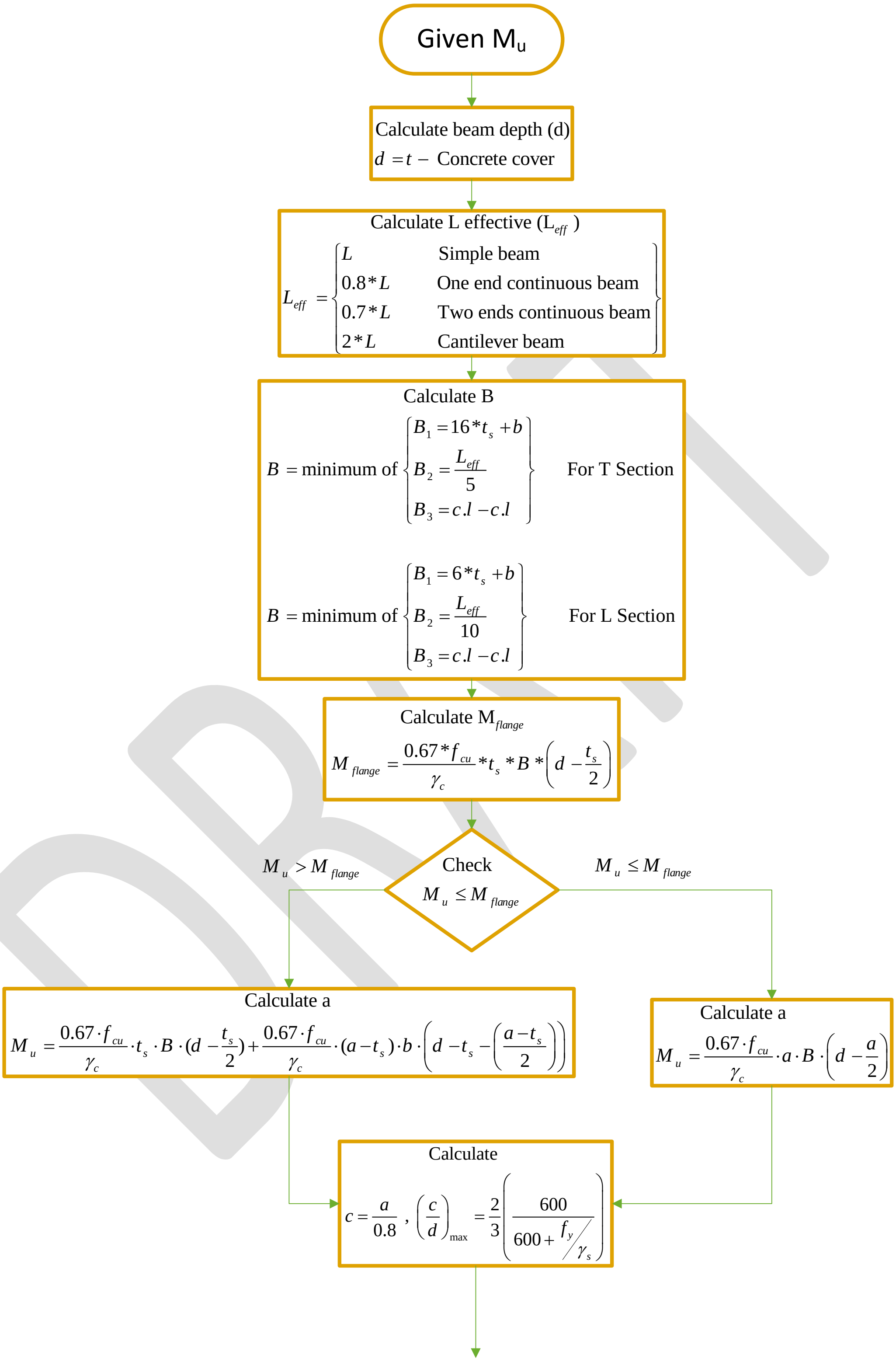


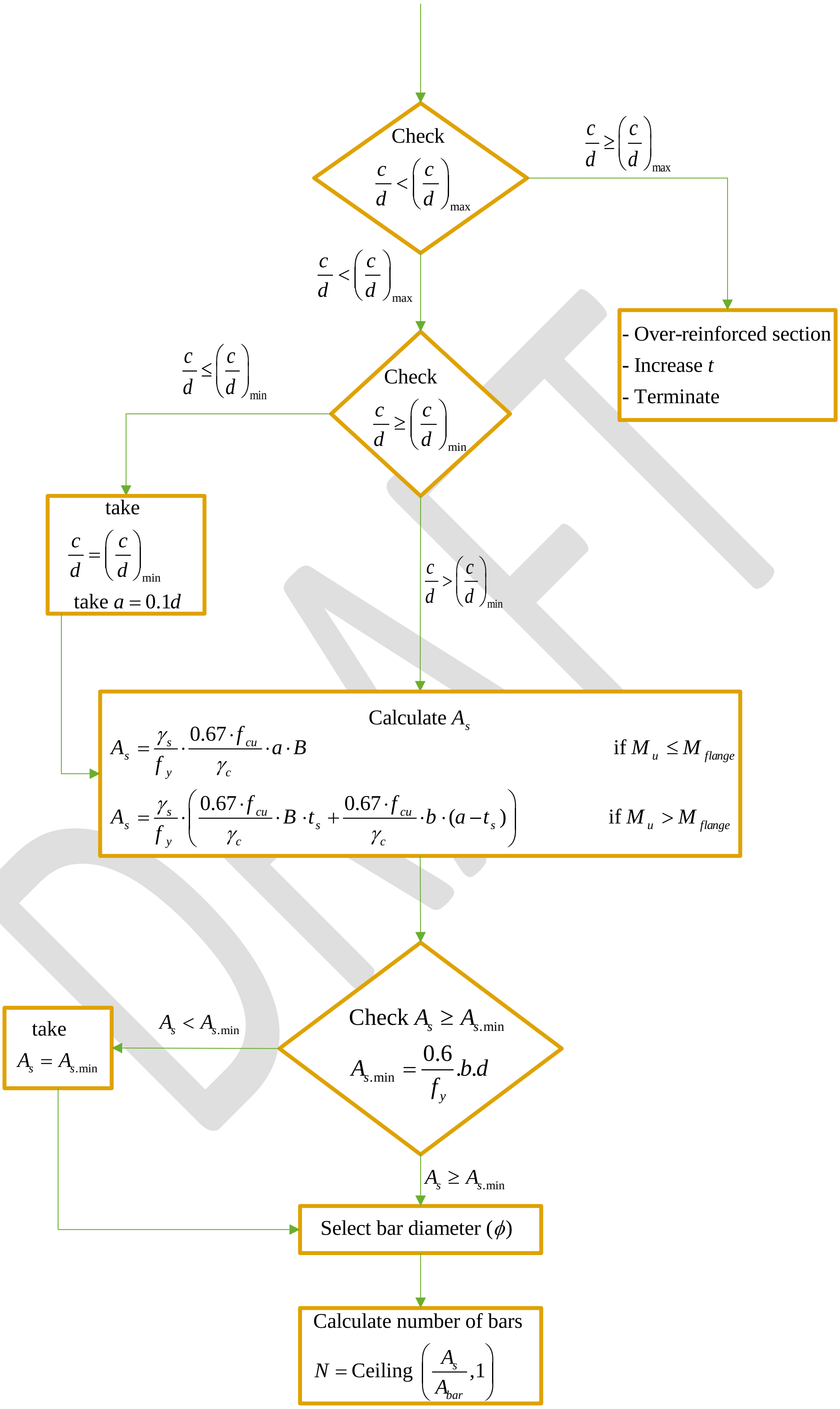
- ✓ Beam width (b)
- ✓ Total beam depth (t)
- ✓ Concrete cover
- ✓ Slab thickness (t_s)
- ✓ Beam span (L)
- ✓ Centerline to centerline span
- ✓ Beam condition
  - (Simple, one end continuous, two ends continuous)
- ✓ Section type (L, T)

2.1.3 Internal Forces

- ✓ Ultimate Factored Moment from analysis (M_u)

2.2 Calculation Procedure




Check
$\frac{c}{d} < \left(\frac{c}{d}\right)_{max}$
$\frac{c}{d} \geq \left(\frac{c}{d}\right)_{max}$
- Over-reinforced section
- Increase t
- Terminate
$\frac{c}{d} < \left(\frac{c}{d}\right)_{max}$
Check
$\frac{c}{d} \geq \left(\frac{c}{d}\right)_{min}$
$\frac{c}{d} \leq \left(\frac{c}{d}\right)_{min}$
take
$\frac{c}{d} = \left(\frac{c}{d}\right)_{min}$
take $a = 0.1d$
$\frac{c}{d} > \left(\frac{c}{d}\right)_{min}$
Calculate A_s
$A_s = \frac{\gamma_s}{f_y} \cdot \frac{0.67 \cdot f_{cu}}{\gamma_c} \cdot a \cdot B$
if $M_u \leq M_{flange}$
$A_s = \frac{\gamma_s}{f_y} \cdot \left(\frac{0.67 \cdot f_{cu}}{\gamma_c} \cdot B \cdot t_s + \frac{0.67 \cdot f_{cu}}{\gamma_c} \cdot b \cdot (a - t_s) \right)$
if $M_u > M_{flange}$
Check $A_s \geq A_{s.min}$
$A_{s.min} = \frac{0.6}{f_y} .b.d$
$A_s < A_{s.min}$
take
$A_s = A_{s.min}$
$A_s \geq A_{s.min}$
Select bar diameter (ϕ)
Calculate number of bars
$N = \text{Ceiling}\left(\frac{A_s}{A_{bar}}, 1\right)$

2.3 Design Outputs

- ✓ Beam total depth (t).
- ✓ Diameter of bars.
- ✓ Number of bars.

2.4 Example of Calculations using Mathcad

2.1 Input

2.1.1 Material Properties

$f_{cu} := 30 \dfrac{N}{mm^2}$	Concrete compressive strength
$f_y := 400 \dfrac{N}{mm^2}$	Yield strength of reinforcing steel bar
$E_s := 200000 \dfrac{N}{mm^2}$	Modulus of easticity of steel
$\gamma_c := 1.5$	Concrete strength reduction factor
$\gamma_s := 1.15$	Steel strength reduction factor

2.1.2 Section Definition

$b := 250\ mm$	Beam width
$t_s := 180\ mm$	Slab thickness
$t := 700\ mm$	Total beam depth
$conc.cover := 50\ mm$	Concrete Cover
$L := 5\ m$	Beam span
$cl.cl := 5.15\ m$	Center line to center line span
$sec.type :=$ "L"	sec.type values: "T" for T section "L" for L section
$beam.cond :=$ "one end connected"	beam.cond values "simple" "one end connected" "two ends connected"

2.1.3 Internal Forces

$M_u := 400\ kN \cdot m$	Ultimate factored moment from analysis

2.2 Calculation Procedure

$d := t - conc.cover = 650\ mm$ Calculate beam depth

$$L_{eff} := \text{if } beam.cond = \text{"simple"} \;\; \| \; L \;\; \text{also if } beam.cond = \text{"one end connected"} \;\; \| \; 0.8 \cdot L \;\; \text{also if } beam.cond = \text{"two ends connected"} \;\; \| \; 0.7 \cdot L \;\; \text{else} \;\; \| \; 2 \cdot L \quad = 4000\ mm$$

$$B_1 := \text{if}\left(sec.type = \text{"T"}, \left(16 \cdot t_s\right) + b, \text{if}\left(sec.type = \text{"L"}, \left(6 \cdot t_s\right) + b, b\right)\right) = 1330\ mm$$

$$B_2 := \text{if}\left(sec.type = \text{"T"}, \frac{L_{eff}}{5} + b, \text{if}\left(sec.type = \text{"L"}, \frac{L_{eff}}{10} + b, b\right)\right) = 650\ mm$$

$$B_3 := cl.cl = 5150\ mm$$

$$B := min\left(B_1, B_2, B_3\right) = 650\ mm$$

$$M_{flange} := \frac{0.67 \cdot f_{cu}}{\gamma_c} \cdot t_s \cdot B \cdot \left(d - \frac{t_s}{2}\right) = 878\ kN \cdot m$$

$$a := 1\ mm$$

$$a := \text{if } M_u \le M_{flange} \;\; \| \; \text{root}\left(M_u - 0.67 \frac{f_{cu}}{\gamma_c} \cdot a \cdot B \cdot \left(d - \frac{a}{2}\right), a\right) \;\; \text{else} \;\; \| \; \text{root}\left(M_u - 0.67 \frac{f_{cu}}{\gamma_c} \cdot a \cdot B \cdot \left(d - \frac{a}{2}\right) - 0.67 \cdot \frac{f_{cu}}{\gamma_c} \cdot \left(a - t_s\right) \cdot b \cdot \left(d - t_s - \left(\frac{a - t_s}{2}\right)\right), a\right)$$

$$a = 74.98\ mm$$

$$c := \frac{a}{0.8} = 93.7\ mm$$

$$\text{c/d} = \; f_{c1} := \text{if}\left(\frac{c}{d} \ge \frac{2}{3} \cdot \frac{0.003}{0.003 + \frac{f_y}{\gamma_s \cdot E_s}}, \text{"Over reinforced section, increase ts"}, \frac{c}{d}\right)$$

$$f_{c1} = 0.1$$

$$c := f_{c1} \cdot d = 93.7\ mm$$

$$c := \text{if}\left(c < 0.125 \cdot d, 0.125 \cdot d, c\right)$$

$$c = 93.7\ mm$$

$$a := 0.8 \cdot c = 75\ mm$$

$$A_s := \text{if } M_u \le M_{flange}\ \left\| 0.67 \cdot \frac{f_{cu}}{\gamma_c} \cdot \frac{\gamma_s}{f_y} \cdot a \cdot B \right.\ \text{else}\ \left\| \frac{\gamma_s}{f_y} \cdot \left(\frac{2}{3} \cdot \frac{f_{cu}}{\gamma_c} \cdot t_s \cdot B + \frac{2}{3} \cdot \frac{f_{cu}}{\gamma_c} \cdot (a - t_s) \cdot b \right) \right.$$

Calculate required area steel

$A_s = 1877.5\ mm^2$

$$A_{smin} := \frac{0.6 \frac{N}{mm^2} \cdot B \cdot d}{f_y} = 634\ mm^2$$

Calculate minimum required area steel

$A_s := \text{if}(A_s < A_{smin}, A_{smin}, A_s)$

$A_s = (2 \cdot 10^3)\ mm^2$

$\phi 6 := 28.3\ mm^2$

$\phi 8 := 50.3\ mm^2$

$\phi 10 := 78.5\ mm^2$

$\phi 12 := 113\ mm^2$

$\phi 16 := 201\ mm^2$

$\phi 18 := 254\ mm^2$

$\phi 20 := 314\ mm^2$

$\phi 22 := 380\ mm^2$

$\phi 25 := 491\ mm^2$

$\phi 28 := 616\ mm^2$

$\phi 32 := 804\ mm^2$

$$N := \frac{A_s}{\phi 18} = 7.4$$

$N := \text{Ceil}(N, 1) = 8$

2.3 Output

$t = 700\ mm$

$b = 250\ mm$

Use $N = 8 \quad \phi 18$