Design of Slabs

2 MODULE NO. 2: DEFLECTION LIMIT STATES

2.1 Inputs

2.1.1 Material Properties

- ✓ Concrete compressive strength (f_{cu})
- ✓ Yield strength of longitudinal reinforcing steel bars (f_{y})
- ✓ Modulus of elasticity of reinforcing steel bars (E_s = 200,000 N/mm^2)

2.1.2 Section Definition

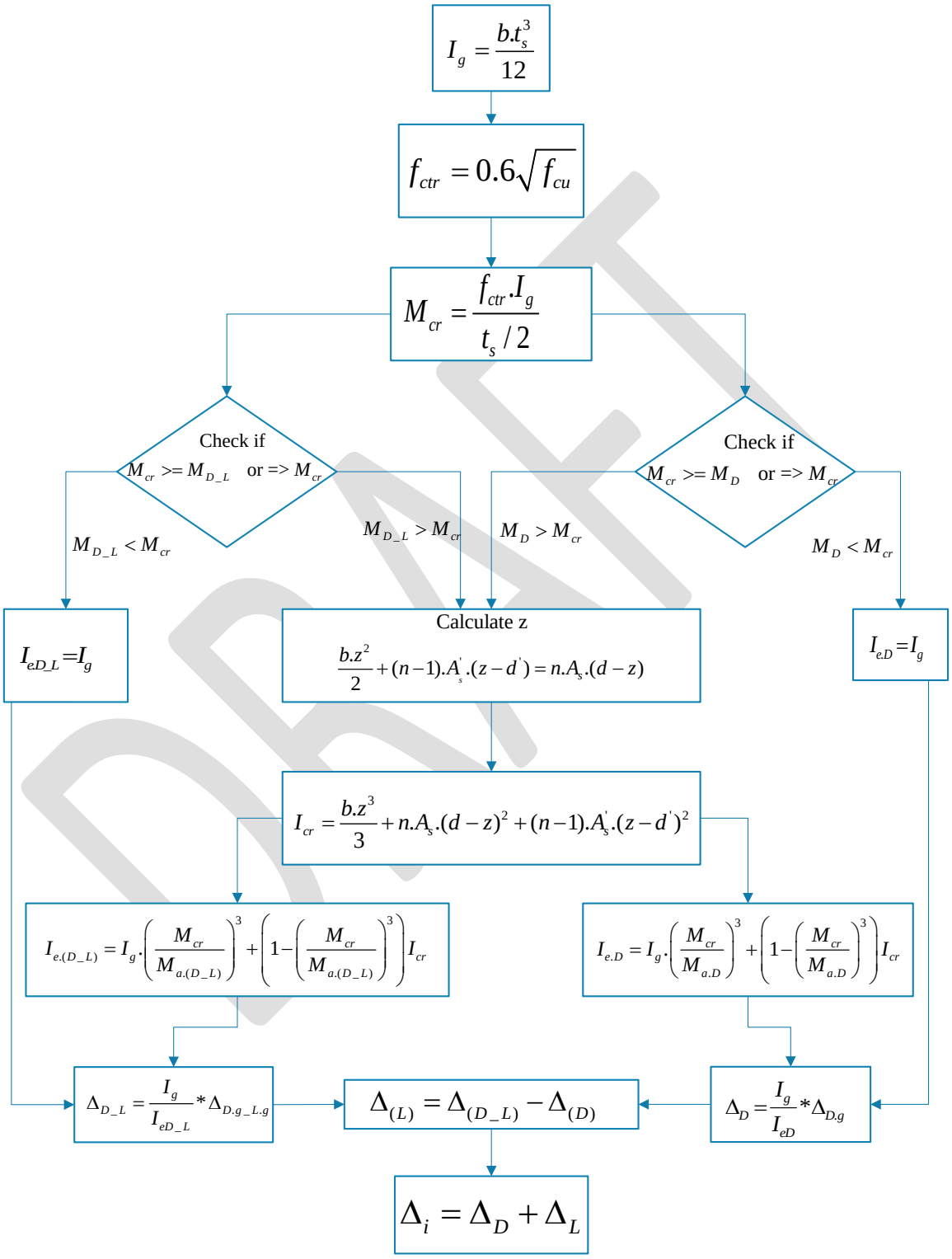
- ✓ Section width (b=1000 mm for 1-meter-wide strip)
- ✓ Slab thickness (t_s)
- ✓ Concrete cover to tension steel
- ✓ Area of reinforcing steel in tension (A_s)
- ✓ Area of reinforcing steel in compression (A_s')
- ✓ Concrete cover to compression steel (d')
- ✓ CL to CL span (L)
- ✓ Slab type (One way, two way or cantilever)
- ✓ Slab continuity (Continuous form one side, Continuous from both sides, Simple)
- ✓ Non-structural elements condition
  - Slab connected to non-structural element not affected by deflection
  - Slab connected to non-structural element affected by deflection

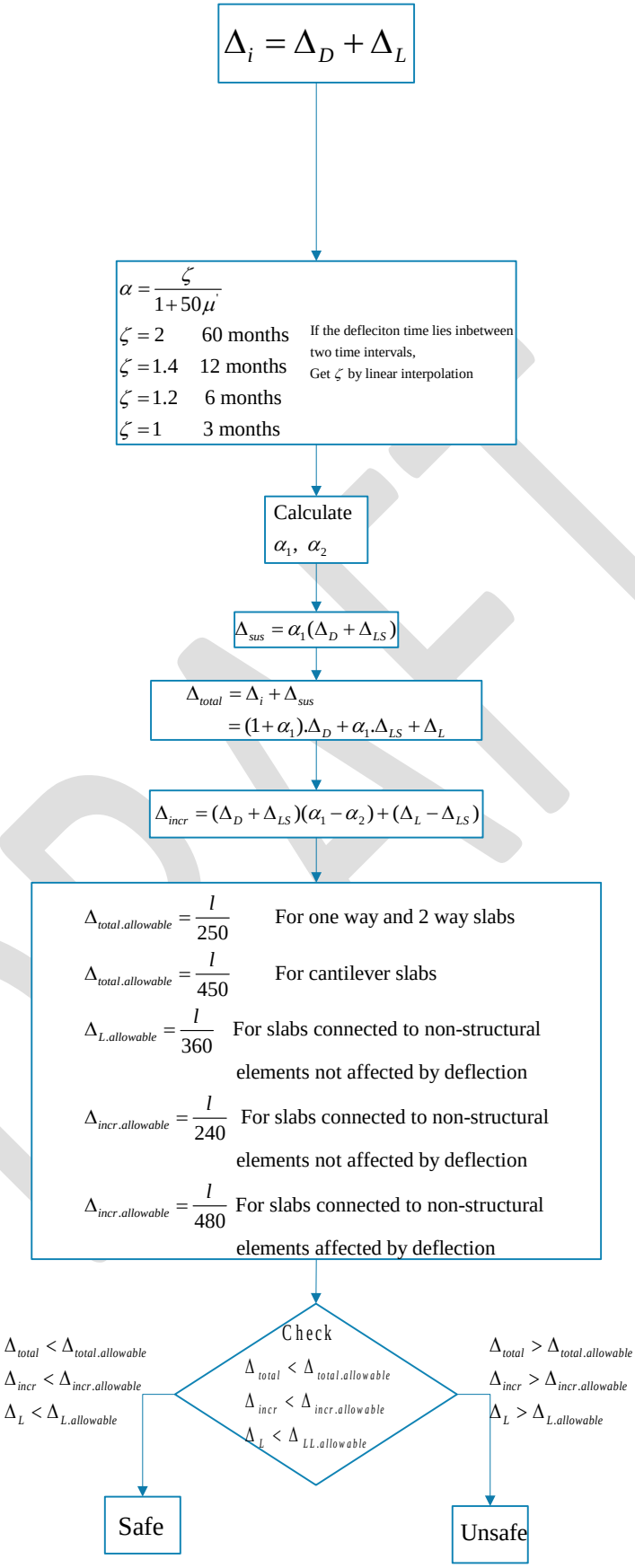
2.1.3 Internal Forces

- ✓ Un-factored service Moment from analysis for dead loads (M_D)
- ✓ Un-factored service Moment from analysis for dead and live loads (M_{D_L})
- ✓ Deflection due to dead load ($\Delta_{D.g}$) from gross moment of inertia analysis.
- ✓ Deflection due to dead and live loads ($\Delta_{D.g\_L.g}$) from gross moment of inertia analysis.
- ✓ Percentage of sustainable live load.
- ✓ Time for long-term deflection calculation (T_1) in months.

✓ Time of applying super-imposed dead loads (T_2) in months.

2.2 Calculation Procedure




$\Delta_i = \Delta_D + \Delta_L$
$\alpha = \frac{\zeta}{1+50\mu'}$
$\zeta = 2$ 60 months
$\zeta = 1.4$ 12 months
$\zeta = 1.2$ 6 months
$\zeta = 1$ 3 months
If the defleciton time lies inbetween two time intervals, Get ζ by linear interpolation
Calculate α_1, α_2
$\Delta_{sus} = \alpha_1(\Delta_D + \Delta_{LS})$
$\Delta_{total} = \Delta_i + \Delta_{sus}$
$= (1+\alpha_1).\Delta_D + \alpha_1.\Delta_{LS} + \Delta_L$
$\Delta_{incr} = (\Delta_D + \Delta_{LS})(\alpha_1 - \alpha_2) + (\Delta_L - \Delta_{LS})$
$\Delta_{total.allowable} = \frac{l}{250}$ For one way and 2 way slabs
$\Delta_{total.allowable} = \frac{l}{450}$ For cantilever slabs
$\Delta_{L.allowable} = \frac{l}{360}$ For slabs connected to non-structural elements not affected by deflection
$\Delta_{incr.allowable} = \frac{l}{240}$ For slabs connected to non-structural elements not affected by deflection
$\Delta_{incr.allowable} = \frac{l}{480}$ For slabs connected to non-structural elements affected by deflection
Check
$\Delta_{total} < \Delta_{total.allowable}$
$\Delta_{incr} < \Delta_{incr.allowable}$
$\Delta_L < \Delta_{LL.allowable}$
$\Delta_{total} < \Delta_{total.allowable}$
$\Delta_{incr} < \Delta_{incr.allowable}$
$\Delta_L < \Delta_{L.allowable}$
$\Delta_{total} > \Delta_{total.allowable}$
$\Delta_{incr} > \Delta_{incr.allowable}$
$\Delta_L > \Delta_{L.allowable}$
Safe
Unsafe

2.3 Design Outputs

- ✓ Check live load deflection.
- ✓ Check long-term deflection.
- ✓ Check additional deflection from applying super-imposed dead loads.

2.4 Example of Calculations using Mathcad

2- Module No. 2: Deflection Limit State

2.1 Input

2.1.1 Material Properties

$f_{cu} := 40 \frac{N}{mm^2}$	Concrete compressive strength
$f_y := 360 \frac{N}{mm^2}$	Yield strength of reinforcing steel bar
$E_s := 200000 \frac{N}{mm^2}$	Modulus of elasticity of steel

2.1.2 Section Definition

$b := 1000\ mm$	Section width
$t_s := 250\ mm$	Slab thickness
$conc.cover := 30\ mm$	Concrete Cover
$A_s := 393\ mm^2$	Area of reinforcing steel in tension
$A_s' := 393\ mm^2$	Area of reinforcing steel in compression
$d' := 30\ mm$	Cover of compression steel.
$L := 3.031\ m$	C.L to C.L span
$percent.sus.ll := 0.25$	Percentage of sustained live load
$slab.type := 1$	slab.type values 1= One way or two way 2= Cantilever
$slab.contin := 3$	slab continuty values 1 = Continuous from two sides 2 = Continuous from one side 3 = simple
$non.structural := 1$	Non-structural elements condition 1 = connected to non-structural elements not affected by deflection. 2 = connected to non-structural elements affected by deflection.

2.1.3 Internal Forces (From Analysis)

$M_D := 56.1\ kN \cdot m$	Unfactored service Moment from dead load
$M_{D.g\_L.g} := 80.2\ kN \cdot m$	Unfactored service Moment from dead and live loads
$\Delta_{D.g} := 3.38\ mm$	Deflection due to dead loads

$\Delta_{D.g\_L.g} := 4.49\ mm$ Deflection due to Dead and Live loads

$T_1 := 12$ Time of calculating long term deflection (months)

$T_2 := 60$ Time of applying super imposed dead loads (months)

2.2 Calculation Procedure

2.2.1 General Calculations

$$E_c := 4400\ \frac{1000\ kg^{0.5}}{m^{0.5}\cdot s}\cdot\sqrt{f_{cu}} = \left(2.783\cdot 10^4\right)\ \frac{N}{mm^2}$$

$$n := \frac{E_s}{E_c} = 7.187$$

$$d := t_s - conc.cover = 220\ mm$$

$$L_e := \text{if}\left(slab.contin = 1, 0.76\cdot L, \text{if}\left(slab.contin = 2, 0.87\cdot L, L\right)\right) = \left(3.031\cdot 10^3\right)\ mm$$

$$I_g := \frac{b\cdot t_s^{\,3}}{12} = \left(1.302\cdot 10^9\right)\ mm^4$$ Gross-moment of inertia

$$f_{ctr} := 0.6\ \frac{1000\ kg^{0.5}}{m^{0.5}\cdot s}\cdot\sqrt[2]{f_{cu}} = 3.795\ \frac{N}{mm^2}$$

$$M_{cr} := \frac{f_{ctr}\cdot I_g}{\frac{t_s}{2}} = 39.528\ kN\cdot m$$ Cracking Moment

$z := 1\ mm$ $\qquad z := \text{root}\left(\frac{b\cdot z^2}{2} - n\cdot A_s\cdot(d-z) + (n-1)\cdot A_s'\cdot(z-d'), z\right) = 32.378\ mm$

$$I_{cr} := b\cdot\frac{z^3}{3} + n\cdot A_s\cdot(d-z)^2 + (n-1)\cdot A_s'\cdot(z-d')^2 = \left(1.108\cdot 10^8\right)\ mm^4$$

2.2.2 Check Dead Load

$$Check1 := \text{if}\left(M_{cr} > M_D, \text{“Ie(Dead load) = Ig”}, \text{“Calculate Ie”}\right) = \text{“Calculate Ie”}$$

$$I_{e.D} := \left(\frac{M_{cr}}{M_D}\right)^3\cdot I_g + \left(1 - \left(\frac{M_{cr}}{M_D}\right)^3\right)\cdot I_{cr} = \left(5.275\cdot 10^8\right)\ mm^4$$

$$I_{e.D} := \text{if}\left(Check1 = \text{“Calculate Ie”}, I_{e.D}, I_g\right) = \left(5.275\cdot 10^8\right)\ mm^4$$

2.2.2 Check Total Load

$$Check2 := \text{if}\left(M_{cr} > M_{D.g\_L.g}, \text{“Ie(Dead+Liave) = Ig”}, \text{“Calculate Ie”}\right) = \text{“Calculate Ie”}$$

$$I_{eD\_L} := \left(\frac{M_{cr}}{M_{D.g\_L.g}}\right)^3\cdot I_g + \left(1 - \left(\frac{M_{cr}}{M_{D.g\_L.g}}\right)^3\right)\cdot I_{cr} = \left(2.534\cdot 10^8\right)\ mm^4$$

$$I_{e.D\_L} := \text{if}\left(Check2 = \text{“Calculate Ie”}, I_{eD\_L}, I_g\right) = \left(2.534\cdot 10^8\right)\ mm^4$$

2.2.3 Deflection Calculations

$\Delta_D := \frac{I_g}{I_{e.D}} \cdot \Delta_{D.g} = 8.343\ mm$ Dead load deflection

$\Delta_{D\_L} := \frac{I_g}{I_{e.D\_L}} \cdot \Delta_{D.g\_L.g} = 23.072\ mm$ Dead and Live load deflection

$\Delta_L := \Delta_{D\_L} - \Delta_D = 14.729\ mm$ Live load deflection

$\Delta_{LS} := percent.sus.ll \cdot \Delta_L = 3.682\ mm$ sustained live load deflection

$\Delta_i := \Delta_L + \Delta_D = 23.072\ mm$ Instantinuous deflection

$\zeta_1 := \text{if}\left(T_1 = 3, 1, \text{if}\left(T_1 = 6, 1.2, \text{if}\left(T_1 = 12, 1.4, \text{if}\left(T_1 \geq 60, 2, \text{“Use Linear Interpolation”}\right)\right)\right)\right)$

$\zeta_1 = 1.4 \qquad \alpha_1 := \frac{\zeta_1}{1 + 50 \cdot \frac{A_s'}{b \cdot d}} = 1.285$

$\zeta_2 := \text{if}\left(T_2 = 3, 1, \text{if}\left(T_2 = 6, 1.2, \text{if}\left(T_2 = 12, 1.4, \text{if}\left(T_2 \geq 60, 2, \text{“Use Linear Interpolation”}\right)\right)\right)\right)$

$\zeta_2 = 2 \qquad \alpha_2 := \frac{\zeta_2}{1 + 50 \cdot \frac{A_s'}{b \cdot d}} = 1.836$

$\Delta_{total} := \left(1 + \alpha_1\right) \cdot \Delta_D + \alpha_1 \cdot \Delta_{LS} + \Delta_L = 38.527\ mm$

$\Delta_{incr} := \left(\alpha_1 - \alpha_2\right) \cdot \left(\Delta_D + \Delta_{LS}\right) + \left(\Delta_L - \Delta_{LS}\right) = 4.423\ mm$

2.2.4 Allowable Deflection Calculations

$\mathbf{\Delta_{total.allow}} := \text{if}\left(slab.type = 1, \frac{L_e}{250}, \frac{L_e}{450}\right) = 12.124\ mm$

$\mathbf{\Delta_{L.allow}} := \frac{L_e}{360} = 8.419\ mm$

$\mathbf{\Delta_{incr.allow}} := \text{if}\left(non.structural = 1, \frac{L_e}{240}, \frac{L_e}{480}\right) = 12.629\ mm$

2.2.4 Deflection Checks

$\mathbf{Check3} := \text{if}\left(\Delta_{total} < \mathbf{\Delta_{total.allow}}, \text{“Total Deflection Safe”}, \text{“Total Deflection Unsafe”}\right)$

$\mathbf{Check4} := \text{if}\left(\Delta_L < \mathbf{\Delta_{L.allow}}, \text{“Live Load Deflection Safe”}, \text{“Live Load Deflection UnSafe”}\right)$

$\mathbf{Check5} := \text{if}\left(\Delta_{incr} < \mathbf{\Delta_{incr.allow}}, \text{“Additional Deflection Safe”}, \text{“Additional Deflection UnSafe”}\right)$

2.3 Output

Check3 = "Total Deflection Unsafe"

Check4 = "Live Load Deflection UnSafe"

Check5 = "Additional Deflection Safe"