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ProtaStructure Design Guide

RC Beam Deflection Checks to TS500

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Notations

f_{ck}	Characteristic Compressive Strength
f_{ctk}	Characteristic Tensile Strength
f_{ctd}	Design Tensile Strength
f_{yd}	Design yield strength of longitudinal reinforcement
f_{yk}	Characteristic yield strength of longitudinal reinforcement
d	Effective depth in case of flexural members
d'	Concrete cover measured from the centroid of compression reinforcement
h	Section Height
b	Flange Dimensions
b_w	Section Width
h_t	Flange Thickness
l_n	Clear Span
γ_{mc}	The material factor for concrete
γ_t	The factor for permanent load
E_s	Modüls of elasticity of reinforcement
E_c	Modüls of elasticity of concrete
A_{stop}	The cross-sectional area of the top reinforcement
$A_{sbottom}$	The cross-sectional area of the bottom reinforcement
y_{top}	Distance of section center of gravity to the top of the section
y_{bottom}	Distance of section center of gravity to the bottom of the section
I_c	Gross moment of inertia
I_{cr}	Cracked moment of inertia about the neutral axis
I_{ef}	Effective moment of inertia
M_{cr}	Cracking moment of the member under bending
M_{max}	Maximum bending moment of member
n	Number of tension bars
y	Distance between extreme tension fiber and neutral axis
δ_{ig}	Instantaneous deflection due to permanent loads
δ_i	Instantaneous deflection
δ_t	Total Deflection

λ	Permanent deflection multiplier
ρ'	The ratio of compression reinforcement in beams

Reinforced Concrete Beam Deflection Design

Concrete beam deflection design is considered for rectangular and flanged sections. In the example, a simplified pressure block is used, which is explained in the relevant sections. The calculations are done based on the **TS500** regulations.

Deflection is checked along the RC beam. Details of the calculations are described below.

Amount of Reinforcement Used in Calculations

Rectangular and Flanged Section Beam

$f_{ctk} = 0.35 \sqrt{f_{ck}}$	TS500, Subs. $3.3 - $ Equ. 3.1
$f_{ctd} = \dfrac{f_{ctk}}{\gamma_{mc}}$	TS500, Subs. $6.2.5 - $ Equ. 6.2
$f_{cd} = \dfrac{f_{ck}}{\gamma_{mc}}$	
$E_s = 2E^7 \dfrac{t}{m^2}$	
$E_c = 3250\sqrt{fck} + 14000\ Mpa$	Ts500, Subs. $3.3 - $ Equ. 3.2
$A_{s\,top}, A_{s\,bottom} = Total\ Reinforcement \times Reinforcement\ Area$	

The reinforcement ratio of cantilevers and simple beams is used in the calculations.

Simple beam;

- 25% of the upper right and left support reinforcement and 50% of the span bottom reinforcement shall be used as the total reinforcement area in the calculations.

0.25xAs		0.25xAs
Top	Top	Top
LEFT	SPAN	RIGHT
Bottom	Bottom	Bottom

Cantilever Beam;

- Since only the bottom reinforcement will work as the reinforcement area in the cantilever beams, only the bottom reinforcement is used as the pressure reinforcement area in the calculations.

Top	Top	Top
LEFT	SPAN	RIGHT
Bottom	Bottom	Bottom

As

For each region mentioned above, the maximum bending moment along the entire length of the region is determined for the load cases $'M_{max}'$, G and G+Q.

The moment of inertia, I_c , is calculated for a rectangular or flanged section. This moment of inertia is calculated according to the section center of gravity. The center of gravity of the section is denoted by y_{bottom} and y_{top} . The value is calculated as follows.

Rectangular Section Deflection Check
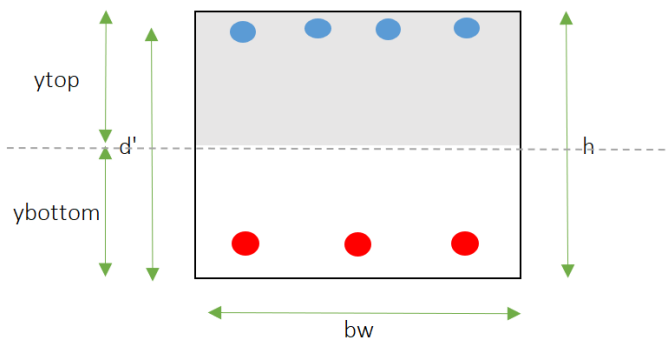
ProtaStructure applies the following steps for the bending design of rectangular sections:

Immediate Deflection

1. $$y_{top} = \frac{h}{2}$$

2. $$y_{bottom} = h - y_{top}$$

3. $$I_c = \frac{b_w h^3}{12}$$

4. $$I_{ef} = (\frac{M_{cr}}{M_{max}})^3 I_c + (1 - (\frac{M_{cr}}{M_{max}})^3) I_{cr}$$

5. $$I_{cr} = \frac{b_w c^3}{3} + (n-1) As_{bottom}(c - d')^2 + n As_{top}(d - c)^2$$

6. $\quad \text{M}_{cr} = 2,5 \, f_{ctd} \dfrac{I_c}{y}$

7. $\quad I_{cr-span} = \dfrac{b_w c^3}{3} + (n-1)As_{top}(c-d')^2 + nAs_{bottom}(d-c)^2$

8. $\quad I_{cr-support} = \dfrac{b_w c^3}{3} + (n-1)As_{bottom}(c-d')^2 + nAs_{top}(d-c)^2$

9. $\quad n = \dfrac{E_s}{E_c}$

10. $\quad a = 0.5 \, b_w \, (span) \quad a = 0.5 \, b_w \, (support)$

11. $\quad b_1 = nAs_{top} + n \, As_{bottom} - As_{top} \, (span)$

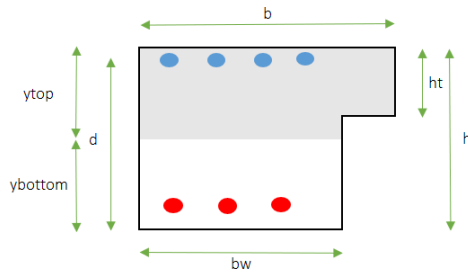12. $\quad b_1 = nAs_{bottom} + n \, As_{top} - As_{bottom} \, (support)$

13. $\quad c_1 = -nAs_{bottom}d - n \, As_{top}d' + As_{top}d' (span)$

14. $\quad c_1 = -nAs_{top}d - n \, As_{bottom}d' + As_{bottom}d' (support)$

15. $\quad \Delta = b_1{}^2 - 4ac_1 \quad when \, \Delta > 0 \; x_1 \; and \; x_2 \; calculated. \, Positive \; value \; is \; considered \; as \; 'c'.$

16. $\quad x_{1,2} = c = \dfrac{-b_1 \pm \sqrt{\Delta}}{2a}$

Flanged Section Beam Deflection Check

Immediate Deflection

1.	$$y_{top} = \frac{bh_t\frac{h_t}{2} + b_w(h - h_t)\left(h_t + \frac{h - h_t}{2}\right)}{bh_t + b_w(h - h_t)}$$
2.	$$y_{bottom} = h - y_{top}$$
3.	$$I_c = \frac{b_w h^3}{12} + (y_{bottom} - b_w)^2(b_w h) + \frac{(b - b_w)ht^3}{12} + \left(y_{top} - \frac{ht}{2}\right)^2 h_t(b - b_w)$$
4.	$$I_{ef} = (\frac{M_{cr}}{M_{max}})^3 I_c + (1 - (\frac{M_{cr}}{M_{max}})^3)I_{cr}$$
5.	$$M_{cr} = 2{,}5\, f_{ctd}\frac{I_c}{y}$$
6.	$$I_{cr-span} = \frac{bc^3}{3} + (n - 1)As_{top}(c - d')^2 + nAs_{bottom}(d - c)^2$$
7.	$$I_{cr-support} = \frac{b_w c^3}{3} + (n - 1)As_{bottom}(c - d')^2 + nAs_{top}(d - c)^2$$
8.	$$n = \frac{E_s}{E_c}$$
9.	$$a = 0.5\, b\ (span)\quad a = 0.5\, b_w\ (support)$$
10.	$$b = nAs_{top} + n\, As_{bottom} - As_{top}\ (span)$$
11.	$$b = nAs_{bottom} + n\, As_{top} - As_{bottom}\ (support)$$
12	$$c_1 = -nAs_{bottom}d - n\, As_{top}d' + As_{top}d'(span)$$
13.	$$c_1 = -nAs_{top}d - n\, As_{bottom}d' + As_{bottom}d'(support)$$
14.	$$\Delta = b^2 - 4ac_1\ when\ \Delta > 0\ x_1\ and\ x_2\ are\ calculated.\ Positive\ value\ is\ considered\ as\ 'c'.$$
15.	$$x_{1,2} = c = \frac{-b \pm \sqrt{\Delta}}{2a}$$

Case 1: $M_{max} \leq M_{cr}$

Moment of inertia, I_c, is used in the deflection calculation. It is assumed that no cracking occurs in the beam. M_{max} is the bending moment obtained from the beam's moment diagram.

Case 2: $M_{max} > M_{cr}$

Effective inertia moment, I_{ef}, is used in the beam deflection check. It is assumed that cracking has occurred in the beam. M_{max} is the bending moment obtained from the beam's moment diagram.

Case 3: Continuous Beam

$I_{efsupport} = \dfrac{I_{efleft} + I_{efright}}{2}$ and I_{efspan} are calculated. Then the value $I_{ef} = \dfrac{I_{efsupport} + I_{efspan}}{2}$ is used.

Case 4: Cantilever Beam

$I_{efsupport} = I_{ef}$ is considered.

Long-Term Deflection

Long-term deflection is calculated by considering the formula below.

$$\delta_t = \delta_i + \delta_{ig}\lambda$$

$$\lambda = \frac{\gamma_t}{1 + 50\rho'}$$

Permanent Load Duration Coefficient

The time coefficient, γ_t, is obtained from TS500 Table 13.

Loading Duration	Duration Coefficient γ_t
5 years or more	2.0
12 months	1.4
6 months	1.2
3 months	1.0

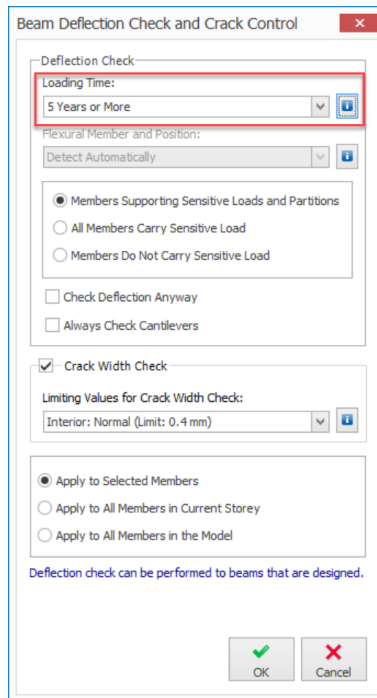*Table 1: Permanent Load Duration Coefficient Table (TS500 Table 13.2)*

Figure 1: ProtaStructure Beam Deflection Check UI – Loading Time Selection

Deflection Limits

Allowable deflection limits in bending elements are given in Table 13.3, depending on the free span.

ProtaStructure will issue a warning when the calculated deflections do not satisfy these limits.

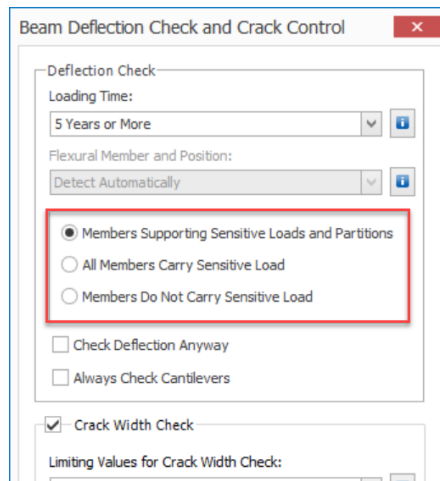| Flexural Member and Location	Cause of Deflection	Span/Deflection
Roof member with no partition walls	Instantaneous deflection due to live load	ln / 180
Floor member with no partition walls	Instantaneous deflection due to live load	ln / 360
Roof or floor member with partition walls(Carrying Members that may be affected by large deflections)	Sum of deflection due to permanent load and deflection due to remainder of live load	ln / 480
Roof or floor member with partition walls		ln / 240

Table 2: Deflection Limits Table

Figure 2: Program Beam Deflection Control Selection Table -Flexural Member and Position

The location of the beam element is determined according to the floor number that appears in the "**Building / Storey Operations/ Edit Storey / Effective Top Storey No**" field in ProtaStructure. The floor number in the "**Effective Top Storey No**" field is automatically accepted as the attic. Other stories will be considered regular stories. The algorithm for using this table by the program is as follows.

Members Supporting Sensitive Loads and Partitions:

If this option is checked, the member is considered in the 3rd category in Table 2, and the limit value is calculated by Ln/480. G+Q is taken into account in the total deflection calculation.

All Members Carry Sensitive Load:

If this option is checked, the member is considered in the 3rd category in Table 2, and the limit value is calculated by Ln/480. G+Q is taken into account in the total deflection calculation.

Members Do Not Carry Sensitive Load:

- Suppose there is a partition wall on the beam. In that case, the beam is considered in the 4th category in Table 2. The limit value is calculated by Ln/240, and G+Q is considered in the total deflection calculation.
- If no partition wall is on the beam and the beam is located on the effective top floor, it is considered in the 1st category in Table 2. The limiting deflection is calculated by Ln/180. Q is taken into account in the total deflection calculation.
- If no partition wall is on the beam and the beam is located on a regular storey, it is considered in the 2nd category in Table 2. The limiting deflection is calculated by Ln/360. Q is taken into account in the total deflection calculation.

Members that Don't Require Deflection Calculations

According to TS500 Article 13.2.1, it is not necessary to perform a detailed deflection check if the Height to Span ratio satisfies the limiting values in Table 13.1. The members in question should not also be carrying deflection-sensitive elements. If you still want to perform the deflection checks for these members, check the UI option '**Check Even if Deflection Calculation Does Not Require**'. Additionally,

when you check the option "**Always Check Cantilever Members**" for checking the deflection of cantilever members even if they don't require a check. The program automatically determines span types.

Member	Simple Support	Exterior Span	Interior Span	Cantilever
One-way Slab	1/20	1/25	1/30	1/10
Two-way Slab(Short Span)	1/25	1/30	1/35	-
Joist Slab	1/15	1/18	1/20	1/8
Beam	1/10	1/12	1/15	1/5

Table 3: Depth/Span ratios for flexural members for which deflection calculations are not necessary
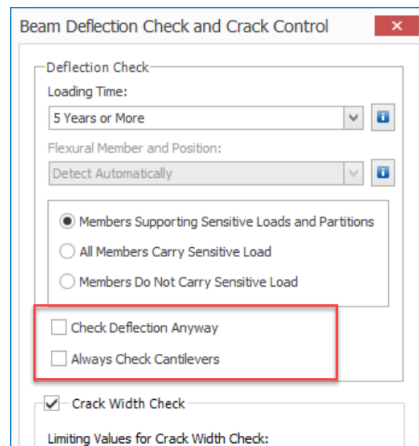

Figure 3: Program Beam Deflection Control Selection Table - Depth/Span ratios for flexural members for which deflection calculations are not necessary

Example

Example 1: Flanged Section

This example will examine the deflection calculation of the beam K103 with the following flanged section properties spanning 725 cm.
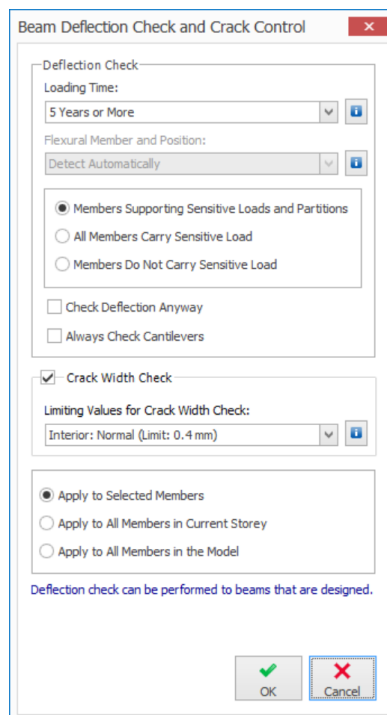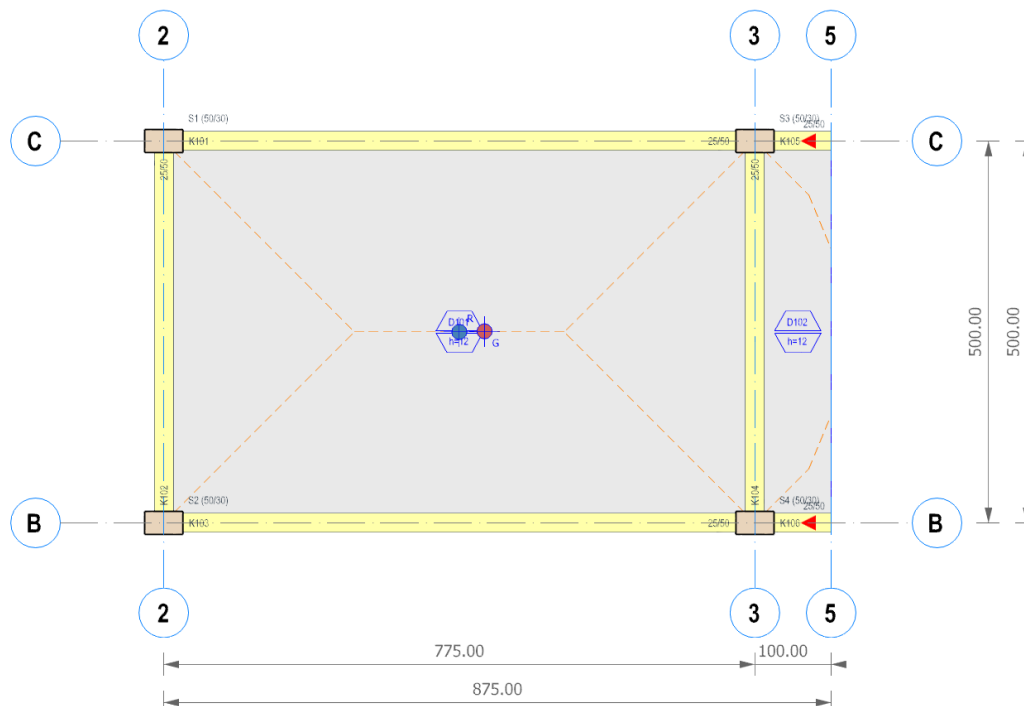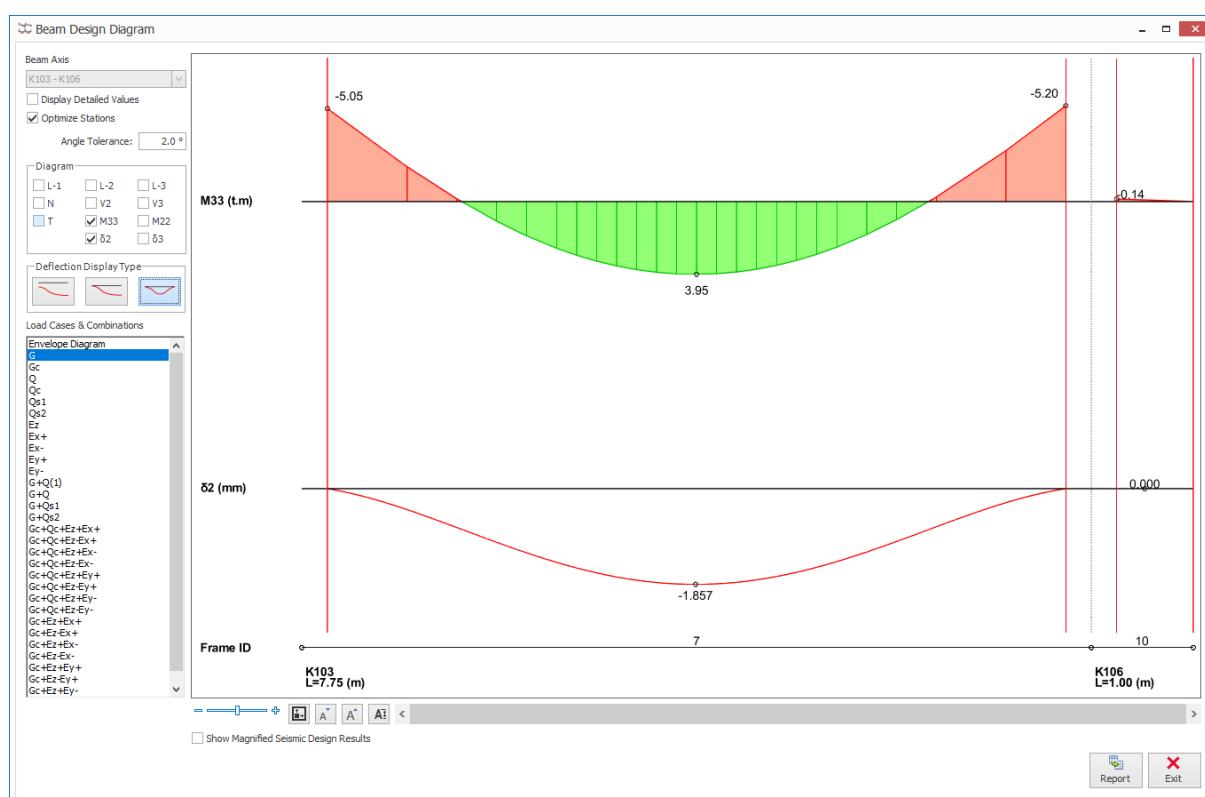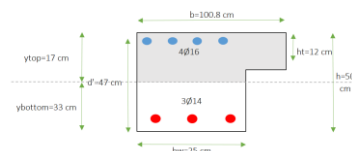

Figure 4: Building plan view

Figure 5: Beam Deflection Check and Crack Control Parameters

Parameters	Value (mm)	Parameters	Value (MPa)	
b_w	250	$f_c{}'$	25	
h	500	f_y	420	
d	470	f_{yt}	240	
d'	30	E_s	200000	

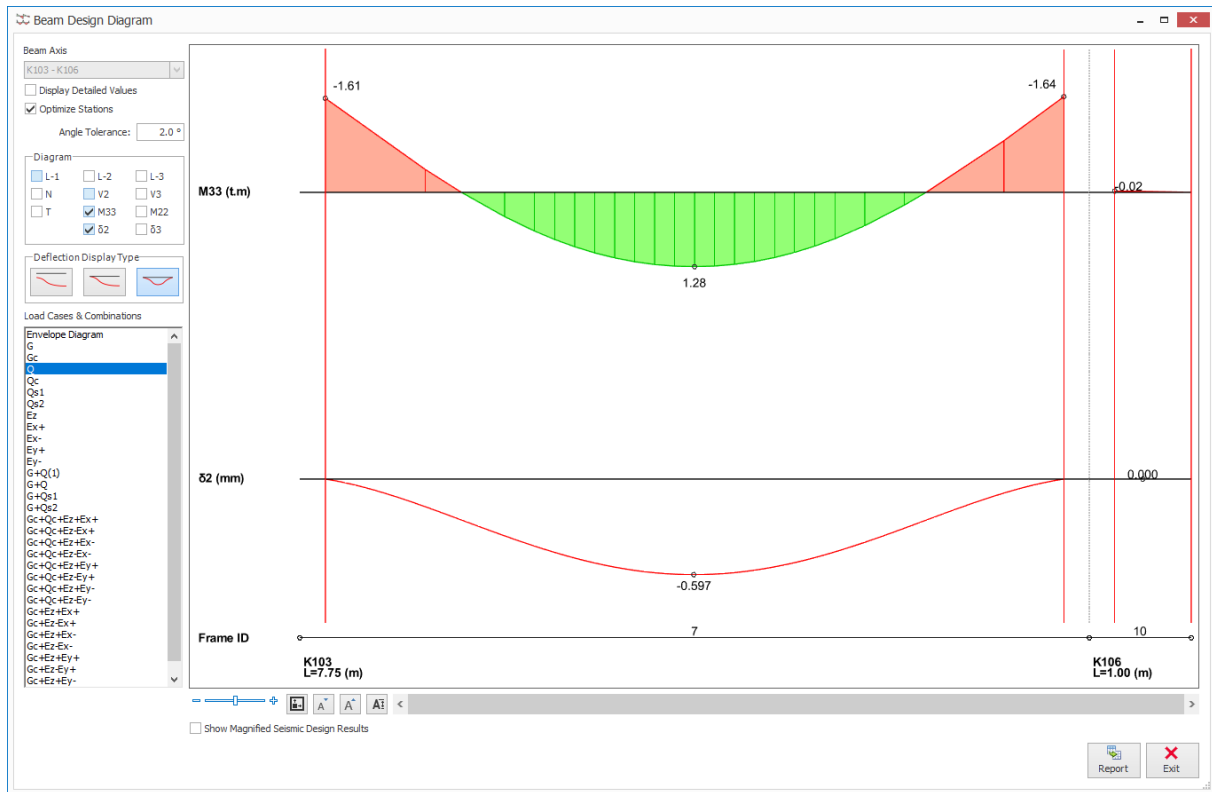*Figure 6: G Load Case M_{33} Moment Value and δ_2 Deflection Value*

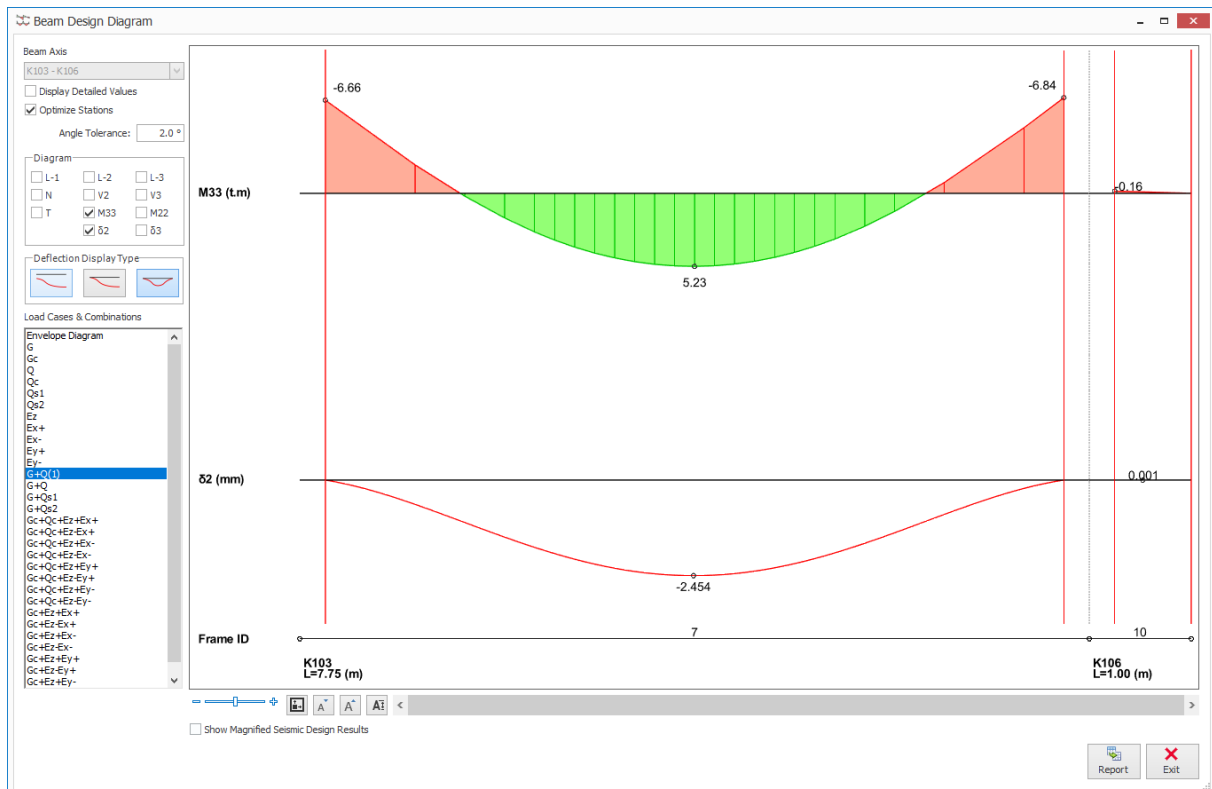Figure 7: Q Load Case M_{33} Moment Value and δ_2 Deflection Value

Figure 8: G+Q Load Combination M_{33} Moment Value and δ_2 Deflection Value

Deflection Calculation Requirement Check

1.	Span Type: Exterior Span
2.	$\dfrac{Clear\ Span}{Height} = \dfrac{725}{50} = 14.5$
3.	$14.5 > 12\ \ deflection\ calculation\ is\ required.$

Immediate Deflection Calculation

1.	$y_{top} = \dfrac{100.8 \times 12 \times \frac{12}{2} + 25 \times (50-12)\left(12 + \frac{50-12}{2}\right)}{100.2 \times 12 + 25 \times (50-12)} = 17\ cm$
2.	$y_{bottom} = 50 - 17 = 33\ cm$
3.	$I_c = \dfrac{25 \times 50^3}{12} + (33-25)^2 \times (25 \times 50) + \dfrac{(100.8-25) \times 12^3}{12} + \left(17 - \dfrac{12}{2}\right)^2 \times 12 \times (100.8 - 25) = 461393.5\ cm^4$ $= 0.004613\ m^4$
4.	$M_{cr-span} = 2{,}5\ \times 116.67 \times \dfrac{0.004613}{0.33} = 4.08\ tm$
5.	$M_{cr-support} = 2{,}5\ \times 116.67 \times \dfrac{0.004613}{0.17} = 7.91\ tm$
6.	$M_{max} \leq M_{cr}$ or $M_{max} > M_{cr}$ control is shown in Figure 7.
7.	$M_{max} \leq M_{cr}\ \ I_c$ should be used in calculations since it is on right and left support.
8.	$M_{max} > M_{cr}$ Since it is span, I_{ef} should be used in calculations.
9.	$n = \dfrac{20000000}{3025000} = 6.6$
10.	$As_{top} = 4 \times \dfrac{\pi \times 16^2}{4} = 804\ mm^2 = 8.04\ cm^2$
11.	$As_{bottom} = 3 \times \dfrac{\pi \times 14^2}{4} = 462\ mm^2 = 4.62\ cm^2$
12.	$a = 0.5\ \times 100.8 = 50.4\ cm\ (span\ )$
13.	$b_1 = 6.6 \times 8.04\ + 6.6 \times\ 4.62 - 8.04 = 75.516\ cm$
14.	$c_1 = -6.6 \times 4.62 \times 47 - 6.6 \times\ 8.04 \times 3 + 8.04 \times 3 = -1568.2\ cm$
15.	$\Delta = 75.516^2 - 4 \times 50.4 \times (-1568.2) = 321851$ $\Delta > 0\ \ when\ \Delta > 0\ \ x_1\ and\ x_2\ are\ calculated.\ Positive\ value\ is\ considered\ as\ 'c'.$

16.	$x_{1,2} = c = \dfrac{-75.516 \pm \sqrt{321851}}{2 \times 50.4} = 4.87$
17.	$I_{cr-span} = \dfrac{100.8 \times 4.87^3}{3} + (6.6 - 1) \times 8.04 \times (4.87 - 3)^2$ $+ 6.6 \times 4.62 \times (47 - 4.87)^2 = 58159 \ cm^4 = 0.000582 \ m^4$
18.	$I_{ef-span} = (\dfrac{4.08}{5.23})^3 \times 0.004613 + (1 - (\dfrac{4.08}{5.23})^3) \times 0.000582 = 0.002495 \ m^4$

Case	Left Support (t.m)	Right Support (t.m)	Span (t.m)
G (Mmax)	5.05	5.2	3.95
G+Q (Mmax)	6.66	6.84	5.23
Mcr	7.91	7.91	4.08

Figure 9: G and G+Q Load Case M_{max} and M_{cr} Values

Load Case	Left Support (t.m)	Craking Control	Right Support (t.m)	Craking Control	Span (t.m)	Craking Control
G (Mmax)	5.05<7.91	No	5.2<7.91	No	3.95<4.08	No
G+Q (Mmax)	6.66<7.91	No	6.84<7.91	No	5.23>4.08	Yes

Figure 10: G and G+Q Load Case Cracking Control

1.	Effective Inertia $G = 0.004613 \ m^4$
2.	Effective Inertia $G = 0.004613 \ m^4 \ G + Q = 0.25 \times 0.004613 \times 2 + 0.5 \times 0.002496$ $= 0.003554 \ m^4$
3.	Immediate Deflection $G = 1.857$ mm (Obtained from the diagram.)
4.	Immediate Deflection $G + Q = 2.454$ mm (Obtained from the diagram.)
5.	Immediate Deflection $Q = 0.597$ mm (Obtained from the diagram.)
6.	*Loading time accepted 5 years or more.*
7.	$\gamma_t = 2$
8.	$\rho'_{top} = \dfrac{8.04}{25 \times 47} = 0.006843$
9.	$\rho'_{bottom} = \dfrac{4.62}{25 \times 47} = 0.003932$
10.	$\rho'_{ort} = \dfrac{\rho'_{üst} + \rho'_{alt}}{2} = \dfrac{0.006843 + 0.003932}{2} = 0.005387$
11.	$\lambda = \dfrac{2}{1 + 50 \times 0.005387} = 1.5756$

12.	$\delta_t = 2.454 + 1.857 \times 1.5756 = 5.379 \text{ mm}$
13.	$Totol\ Deflection = 5.379 \leq \dfrac{7250}{480} = 15.104\ mm\ \checkmark$

Concrete Beam Deflection Check

K103 - Storey: 1

Flexural Member Type	: Beam		
Span Type	: Exterior Span		
Clear Span / Height	: 725.0 / 50.0 cm = 14.5 > 12 (TS-500 Table 13.1)		

Section Dimensions:	25.0 / 50.0 cm	d = 47.0 cm	d' = 3.0 cm
Flange Dimensions:	b = 100.8 cm	hf = 12.0 cm	
Uncracked Section:	Ic = 0.004613 m⁴	y(b) = 33.0 cm	y(t) = 17.0 cm
Concrete:	Fcd = 1666.67 t/m²	Fctd = 116.67 t/m²	Ec = 3025000.0 t/m²
Steel:	Fyd = 36521.74 t/m²	Es = 2.000E+07 t/m²	Es/Ec = 6.6

	Left Support	Right Support	Span
$A_s(t)/A_s(b)$	8.04 / 4.62 cm²	8.04 / 4.62 cm²	8.04 / 4.62 cm²
M(g) / M(g+q)	-5.05 / -6.66 t.m	-5.20 / -6.84 t.m	-3.95 / -5.23 t.m
M_{cr}	7.91 t.m	7.91 t.m	4.08 t.m
Cracking Status (G)	NO	NO	NO
Cracking Status (G+Q)	NO	NO	YES
Cracked Inertia (G)	-	-	-
Cracked Inertia (G+Q)	-	-	0.000582 m⁴
Effective Inertia (G)	0.004613 m⁴	0.004613 m⁴	0.004613 m⁴
Effective Inertia (G+Q)	0.004613 m⁴	0.004613 m⁴	0.002495 m⁴

Effective Inertia (G)	0.004613 m⁴
Effective Inertia (G+Q)	0.003554 m⁴
Immediate Def. (G)	1.857 mm
Immediate Def. (G+Q)	2.454 mm
Immediate Def. (Q)	0.597 mm
Loading Time	FIVE YEARS or MORE
Total Time Dep. Deflection	5.379 mm

Flexural Member and Position:	Storey/Roof Member Supporting Partition (Sensitive Load)
	Total Deflection = 5.379 mm ≤ 15.104 mm (7250/480) ... **Adequate** √

Figure 11: Concrete Beam Deflection Check

Example 2: Flanged Section

This example will examine the deflection calculation of the beam K104 with the following flanged section properties spanning 470 cm.
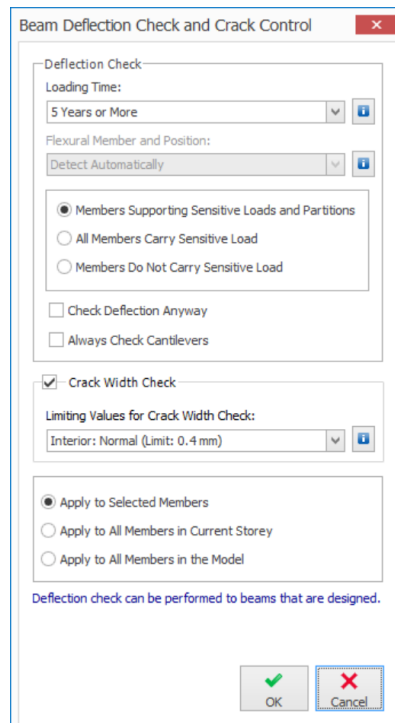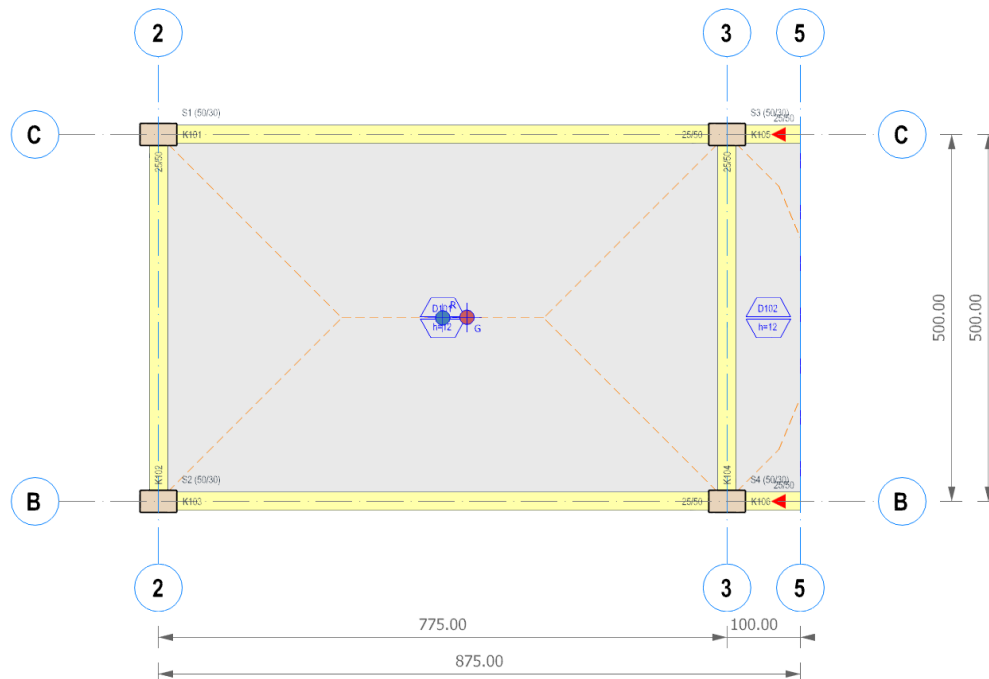

Figure 12: Building plan view

Figure 13: Beam Deflection Check and Crack Control Parameters

Deflection Calculation Requirement Check

1.	*Span Type: Simple Support*
2.	$\dfrac{Clear\ Span}{Height} = \dfrac{470}{50} = 9.4$
3.	$9.4 \leq 10\ TS500\ Table\ 13.1\ Deflection\ check\ is\ not\ required.$

Concrete Beam Deflection Check

K104 - Storey: 1
    Flexural Member Type   : Beam
    Span Type   : Simple Support
    Clear Span / Height   : 470.0 / 50.0 cm = 9.4 ≤ 10 (TS-500 Table 13.1)

DEFLECTION CHECK IS NOT REQUIRED.

Figure 14: Concrete Beam Deflection Check

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