EXAMPLE CSA A23.3-14 RC-BM-001

Flexural and Shear Beam Design

PROBLEM DESCRIPTION

The purpose of this example is to verify slab flexural design in SAFE. The load level is adjusted for the case corresponding to the following conditions:

- The stress-block extends below the flange but remains within the balanced condition permitted by CSA A23.3-14.
- The average shear stress in the beam is below the maximum shear stress allowed by CSA A23.3-14, requiring design shear reinforcement.

A simple-span, 6-m-long, 300-mm-wide, and 500-mm-deep T-beam with a flange 100 mm thick and 600 mm wide is modeled using SAFE. The beam is shown in Figure 1. The computational model uses a finite element mesh of frame elements, automatically generated by SAFE. The maximum element size has been specified to be 200 mm. The beam is supported by columns without rotational stiffnesses and with very large vertical stiffness (1×10^{20} kN/m).

The beam is loaded with symmetric third-point loading. One dead load case (DL30) and one live load case (LL100) with only symmetric third-point loads of magnitudes 30, and 100 kN, respectively, are defined in the model. One load combinations (COMB100) is defined using the CSA A23.3-14 load combination factors of 1.25 for dead loads and 1.5 for live loads. The model is analyzed for both of these load cases and the load combinations.

The beam moment and shear force are computed analytically. The total factored moment and shear force are compared with the SAFE results. These moment and shear force are identical. After completing the analysis, design is performed using the CSA A23.3-14 code in SAFE and also by hand computation. Table 1 shows the comparison of the design longitudinal reinforcements. Table 2 shows the comparison of the design shear reinforcements.

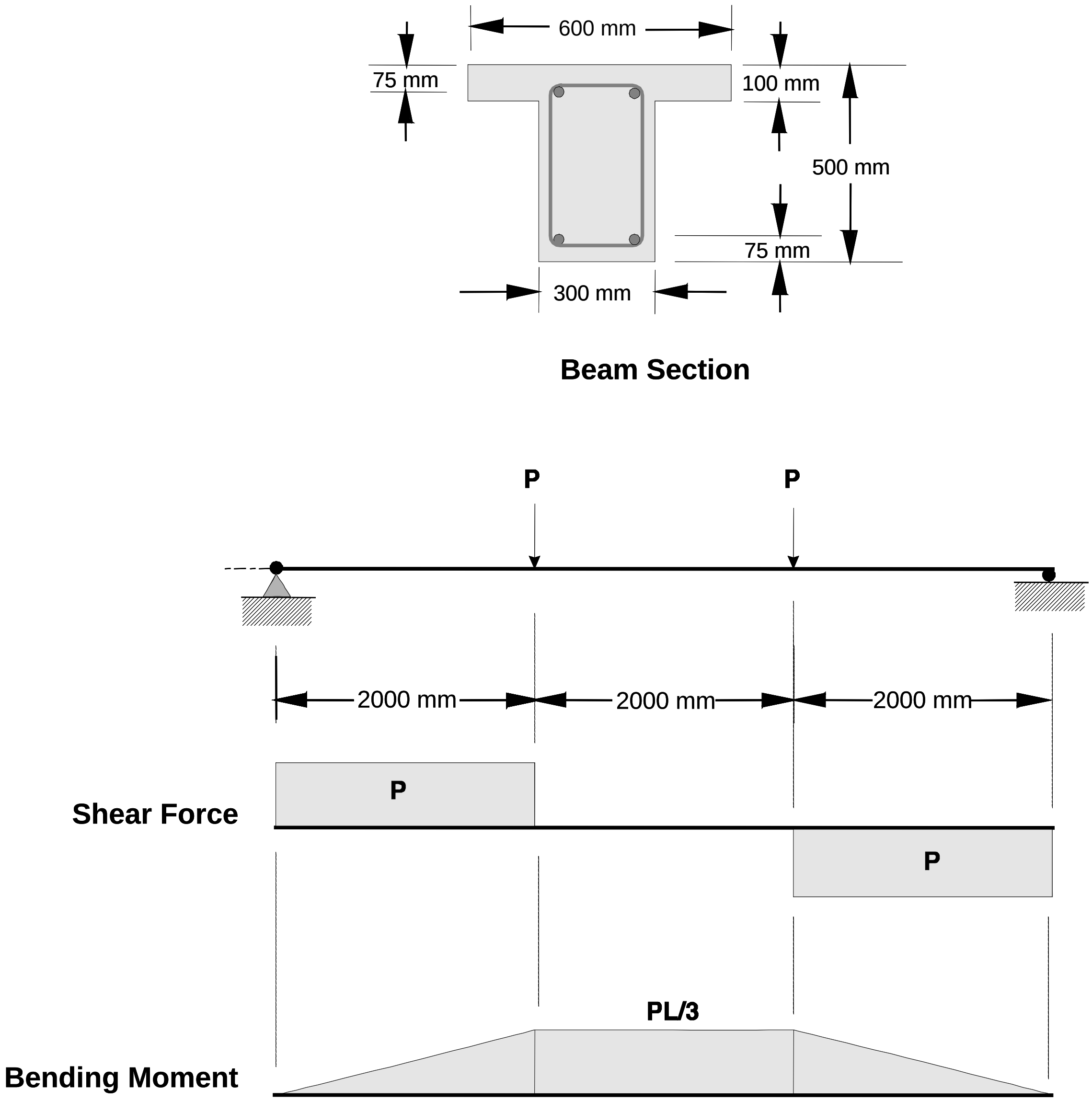

Figure 1 The Model Beam for Flexural and Shear Design

GEOMETRY, PROPERTIES AND LOADING

Clear span,	l	=	6000	mm
Overall depth,	h	=	500	mm
Flange thickness,	d_s	=	100	mm
Width of web,	b_w	=	300	mm
Width of flange,	b_f	=	600	mm
Depth of tensile reinf.,	d_c	=	75	mm
Effective depth,	d	=	425	mm
Depth of comp. reinf.,	d'	=	75	mm
Concrete strength,	f'_c	=	30	MPa
Yield strength of steel,	f_y	=	460	MPa
Concrete unit weight,	w_c	=	0	kN/m^3
Modulus of elasticity,	E_c	=	$25x10^5$	MPa
Modulus of elasticity,	E_s	=	$2x10^8$	MPa
Poisson's ratio,	v	=	0.2	
Dead load,	P_d	=	30	kN
Live load,	P_l	=	100	kN

TECHNICAL FEATURES OF SAFE TESTED

- Calculation of flexural and shear reinforcement
- Application of minimum flexural and shear reinforcement

RESULTS COMPARISON

Table 1 shows the comparison of the SAFE total factored moments in the design strip with the moments obtained by the analytical method. They match exactly for this problem. Table 1 also shows the design reinforcement comparison.

Table 1 Comparison of Moments and Flexural Reinforcements

Method	Moment (kN-m)	Reinforcement Area (sq-cm)
		A_s^+
SAFE	375	25.844
Calculated	375	25.844

$A^+_{s,min}$ = 535.82 sq-m

Table 2 Comparison of Shear Reinforcements

Shear Force (kN)	Reinforcement Area, $\frac{A_v}{s}$ (sq-cm/m)	
	SAFE	**Calculated**
187.5	12.573	12.573

COMPUTER FILE: CSA A23.3-14 RC-BM-001.FDB

CONCLUSION

The SAFE results show an exact comparison with the independent results.

HAND CALCULATION

Flexural Design

The following quantities are computed for all the load combinations:

ϕ_c = 0.65 for concrete

ϕ_s = 0.85 for reinforcement

$$A_{s,\min} = \frac{0.2\sqrt{f'_c}}{f_y}\, b_w\, h = 357.2 \text{ sq-mm}$$

$$\alpha_1 = 0.85 - 0.0015 f'_c \geq 0.67 = 0.805$$

$$\beta_1 = 0.97 - 0.0025 f'_c \geq 0.67 = 0.895$$

$$c_b = \frac{700}{700 + f_y}\, d = 256.46 \text{ mm}$$

$$a_b = \beta_1 c_b = 229.5366 \text{ mm}$$

$$A_s = \min[A_{s,\min}, (4/3)\, A_{s,\text{required}}] = \min[357.2, (4/3)2445] = 357.2 \text{ sq-mm}$$

COMB100

$$P = (1.25P_d + 1.5P_t) = 187.5\text{kN}$$

$$M^* = \frac{Pl}{3} = 375 \text{ kN-m}$$

$$M_f = 375 \text{ kN-m}$$

The depth of the compression block is given by:

$$C_f = \alpha_1 f'_c \left(b_f - b_w\right) \min\left(h_s, a_b\right) = 724.5 \text{ kN}$$

Therefore, $A_{s1} = \dfrac{C_f \phi_c}{f_y \phi_s}$ and the portion of M_f that is resisted by the flange is given by:

$$A_{s1} = \frac{C_f \phi_c}{f_y \phi_s} = 1204.411 \text{ sq-mm}$$

$$M_{ff} = C_f \left(d - \frac{\min(h_s, a_b)}{2} \right) \phi_c = 176.596 \text{ kN-m}$$

Therefore, the balance of the moment, M_f to be carried by the web is:

$$M_{fw} = M_f - M_{ff} = 198.403 \text{ kN-m}$$

The web is a rectangular section with dimensions b_w and d, for which the design depth of the compression block is recalculated as:

$$a_1 = d - \sqrt{d^2 - \frac{2M_{fw}}{\alpha_1 f'_c \phi_c b_w}} = 114.5745 \text{ mm}$$

If $a_1 \leq a_b$, the area of tension reinforcement is then given by:

$$A_{s2} = \frac{M_{fw}}{\phi_s f_y \left(d - \frac{a_1}{2} \right)} = 1379.94 \text{ sq-mm}$$

$A_s = A_{s1} + A_{s2} = 2584.351$ sq-mm

Shear Design

The basic shear strength for rectangular section is computed as,

$\phi_c =$ 0.65 for shear

$\lambda = \{1.00,$ for normal density concrete

d_v is the effective shear depth. It is taken as the greater of 0.9d or 0.72h = 382.5 mm (governing) or 360 mm.

$S_{ze} = 300$ if minimum transverse reinforcement

$$\varepsilon_x = \frac{M_f / d_v + V_f + 0.5 N_f}{2(E_s A_s)} \text{ and } \varepsilon_x \leq 0.003$$

$$\beta = \frac{0.40}{(1+1500\varepsilon_x)} \bullet \frac{1300}{(1000+S_{ze})} = 0.07272$$

$$V_c = \phi_c \lambda \beta \sqrt{f'_c} b_w d_v = 29.708 \text{ kN}$$

$$V_{r,\max} = 0.25\phi_c f'_c b_w d = 621.56 \text{ kN}$$

θ = 50

$$\frac{A_v}{s} = \frac{(V_f - V_c)\tan\theta}{\phi_s f_{yt} d_v} = 1.2573 \text{ mm}^2/\text{mm} = 12.573 \text{ cm}^2/\text{m}.$$