EXAMPLE EUROCODE 2-04 RC-PN-001

Slab Punching Shear Design

PROBLEM DESCRIPTION

The purpose of this example is to verify slab punching shear design in SAFE

The numerical example is a flat slab that has three 8-m spans in each direction, as shown in Figure 1.

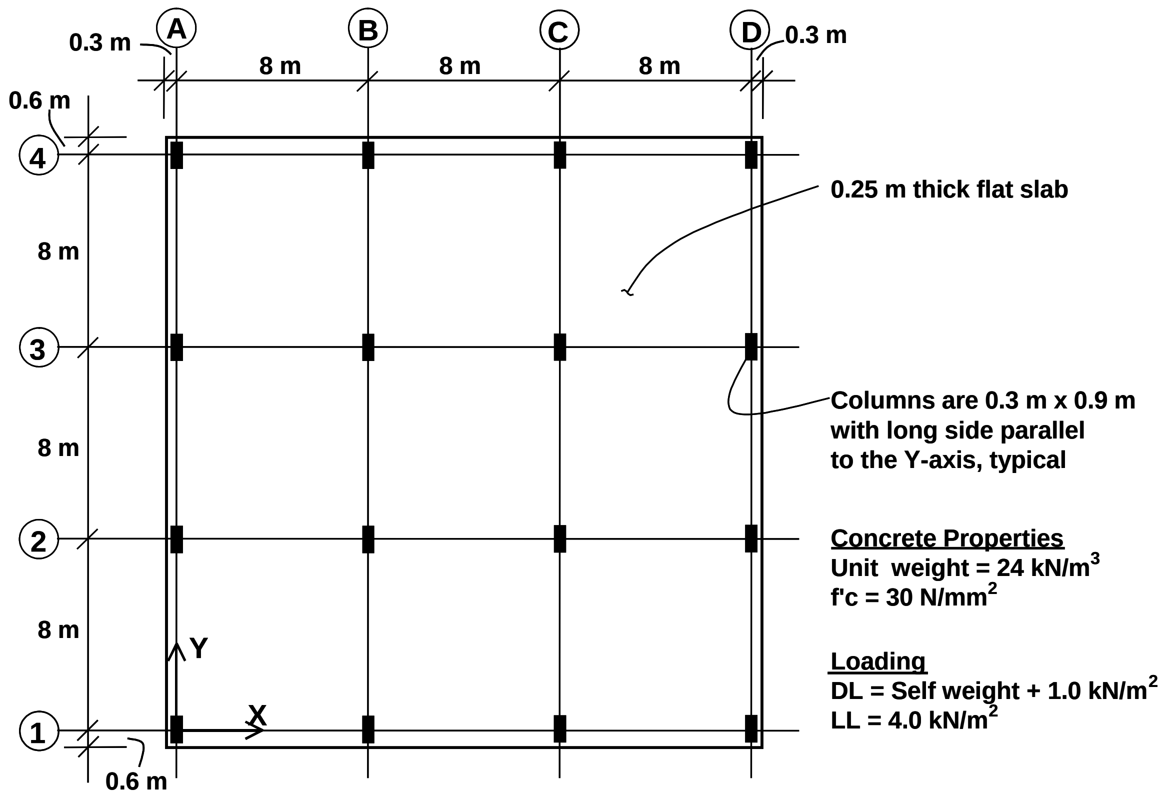

Figure 1: Flat Slab for Numerical Example

The slab overhangs beyond the face of the column by 0.15 m along each side of the structure. The columns are typically 0.3 m x 0.9 m with the long side parallel to the Y-axis. Thick plate properties are used for the slab.

The concrete has a unit weight of 24 kN/m^3 and a *f'c* of 30 N/mm^2. The dead load consists of the self weight of the structure plus an additional 1 kN/m^2. The live load is 4 kN/m^2.

TECHNICAL FEATURES OF SAFE TESTED

- Calculation of punching shear capacity, shear stress and D/C ratio.

RESULTS COMPARISON

Table 1 shows the comparison of the punching shear capacity, shear stress ratio and D/C ratio obtained from SAFE with the punching shear capacity, shear stress ratio and D/C ratio obtained by the analytical method. They match exactly for this problem.

Table 1 Comparison of Design Results for Punching Shear at Grid B-2

National Annex	Method	Shear Stress (N/mm^2)	Shear Capacity (N/mm^2)	D/C ratio
CEN Default, Norway, Slovenia and Sweden	SAFE	1.100	0.578	1.90
	Calculated	1.099	0.578	1.90
Finland, Singapore and UK	SAFE	1.100	0.5796	1.90
	Calculated	1.099	0.5796	1.90
Denmark	SAFE	1.100	0.606	1.82
	Calculated	1.099	0.606	1.81

COMPUTER FILE: EUROCODE 2-04 RC-PN-001.FDB

CONCLUSION

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

HAND CALCULATION

Hand Calculation for Interior Column using SAFE Method

$d = [(250 - 26) + (250 - 38)]/2 = 218$ mm

Refer to Figure 2.

$u_1 = u = 2 \bullet 300 + 2 \bullet 900 + 2 \bullet \pi \bullet 436 = 5139.468$ mm

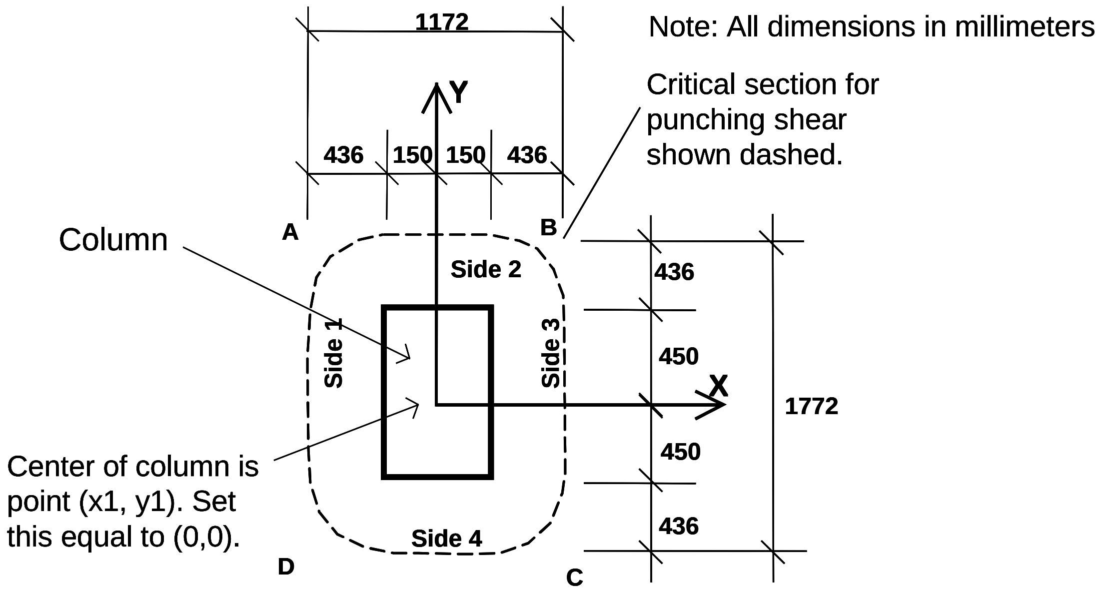

Figure 2: Interior Column, Grid B-2 in SAFE Model

From the SAFE output at Grid B-2:

$V_{Ed} = 1112.197$ kN

$k_2 M_{Ed2} = 41.593$ kN-m

$k_3 M_{Ed3} = 20.576$ kN-m

Maximum design shear stress in computed in along major and minor axis of column:

$$v_{Ed} = \frac{V_{Ed}}{ud}\left[1 + \frac{k_2 M_{Ed,2} u_1}{V_{Ed} W_{1,2}} + \frac{k_3 M_{Ed,3} u_1}{V_{Ed} W_{1,3}}\right] \qquad \text{(EC2 6.4.4(2))}$$

$$W_1 = \frac{c_1^2}{2} + c_1 c_2 + 4 c_2 d + 16 d^2 + 2\pi d c_1$$

$$W_{1,2} = \frac{900^2}{2} + 300 \bullet 900 + 4 \bullet 300 \bullet 218 + 16 \bullet 218^2 + 2\pi \bullet 218 \bullet 900$$

$$W_{1,2} = 2{,}929{,}744.957 \text{ mm}^2$$

$$W_{1,3} = 3\frac{900^2}{2} + 900 \bullet 300 + 4 \bullet 900 \bullet 218 + 16 \bullet 218^2 + 2\pi \bullet 218 \bullet 300$$

$$W_{1,2} = 2{,}271{,}104.319 \text{ mm}^2$$

$$v_{Ed} = \frac{V_{Ed}}{u_1 d}\left[1 + \frac{k_2 M_{Ed,2} u_1}{V_{Ed} W_{1,2}} + \frac{k_3 M_{Ed,3} u_1}{V_{Ed} W_{1,3}}\right]$$

$$v_{Ed} = \frac{1112.197 \bullet 10^3}{5139.468 \bullet 218}\left[1 + \frac{41.593 \bullet 10^6 \bullet 5139.468}{1112.197 \bullet 10^3 \bullet 2929744.957} + \frac{20.576 \bullet 10^6 \bullet 5139.468}{1112.197 \bullet 10^3 \bullet 2271104.319}\right]$$

$$v_{Ed} = 1.099 \text{ N/mm}^2$$

Thus v_{max} = **1.099 N/mm²**

For CEN Default, Finland, Norway, Singapore, Slovenia, Sweden and UK:

$$C_{Rd,c} = 0.18/\gamma_c = 0.18/1.5 = 0.12 \qquad \text{(EC2 6.4.4)}$$

For Denmark:

$$C_{Rd,c} = 0.18/\gamma_c = 0.18/1.45 = 0.124 \qquad \text{(EC2 6.4.4)}$$

The shear stress carried by the concrete, $V_{Rd,c}$, is calculated as:

$$V_{Rd,c} = \left[C_{Rd,c} k \left(100 \rho_1 f_{ck}\right)^{1/3} + k_1 \sigma_{cp}\right] \qquad \text{(EC2 6.4.4)}$$

with a minimum of:

$$v_{Rd,c} = \left(v_{\min} + k_1 \sigma_{cp}\right) \qquad \text{(EC2 6.4.4)}$$

$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0 = 1.9578$ (EC2 6.4.4(1))

k_1 = 0.15. (EC2 6.2.2(1))

$\rho_1 = \frac{A_{s1}}{b_w d} \leq 0.02$

Area of reinforcement at the face of column for design strip are as follows:

For CEN Default, Norway, Slovenia and Sweden:

A_s in Strip Layer A = 9204.985 mm^2

A_s in Strip Layer B = 8078.337 mm^2

Average A_s = $(9204.985 + 8078.337)/2$ = 8641.661 mm^2

ρ_1 = $8641.661/(8000 \bullet 218)$ = 0.004955 ≤ 0.02

For Finland, Singapore and UK:

A_s in Strip Layer A = 9319.248 mm^2

A_s in Strip Layer B = 8174.104 mm^2

Average A_s = $(9319.248 + 8174.104)/2$ = 8746.676 mm^2

ρ_1 = $8746.676/(8000 \bullet 218)$ = 0.005015 ≤ 0.02

For Denmark:

A_s in Strip Layer A = 9606.651 mm^2

A_s in Strip Layer B = 8434.444 mm^2

Average A_s = $(9606.651 + 8434.444)/2$ = 9020.548 mm^2

ρ_1 = $9020.548/(8000 \bullet 218)$ = 0.005172 ≤ 0.02

For CEN Default, Denmark, Norway, Singapore, Slovenia, Sweden and UK:

$$v_{\min} = 0.035k^{3/2} f_{ck}^{\ 1/2} = 0.035(1.9578)^{3/2}(30)^{1/2} = 0.525 \text{ N/mm}^2$$

For Finland:

$$v_{\min} = 0.035k^{2/3} f_{ck}^{\ 1/2} = 0.035(1.9578)^{2/3}(30)^{1/2} = 0.3000 \text{ N/mm}^2$$

For CEN Default, Norway, Slovenia and Sweden:

$$v_{Rd,c} = \left[0.12 \bullet 1.9578(100 \bullet 0.004955 \bullet 30)^{1/3} + 0\right] = 0.5777 \text{ N/mm}^2$$

For Finland, Singapore, and UK:

$$v_{Rd,c} = \left[0.12 \bullet 1.9578(100 \bullet 0.005015 \bullet 30)^{1/3} + 0\right] = 0.5796 \text{ N/mm}^2$$

For Denmark:

$$v_{Rd,c} = \left[0.124 \bullet 1.9578(100 \bullet 0.005015 \bullet 30)^{1/3} + 0\right] = 0.606 \text{ N/mm}^2$$

For CEN Default, Norway, Slovenia and Sweden:

$$\text{Shear Ratio} = \frac{v_{\max}}{v_{Rd,c}} = \frac{1.092}{0.5777} = 1.90$$

For Finland, Singapore and UK:

$$\text{Shear Ratio} = \frac{v_{\max}}{v_{Rd,c}} = \frac{1.092}{0.5796} = 1.90$$

For Denmark:

$$\text{Shear Ratio} = \frac{v_{\max}}{v_{Rd,c}} = \frac{1.092}{0.606} = 1.81$$