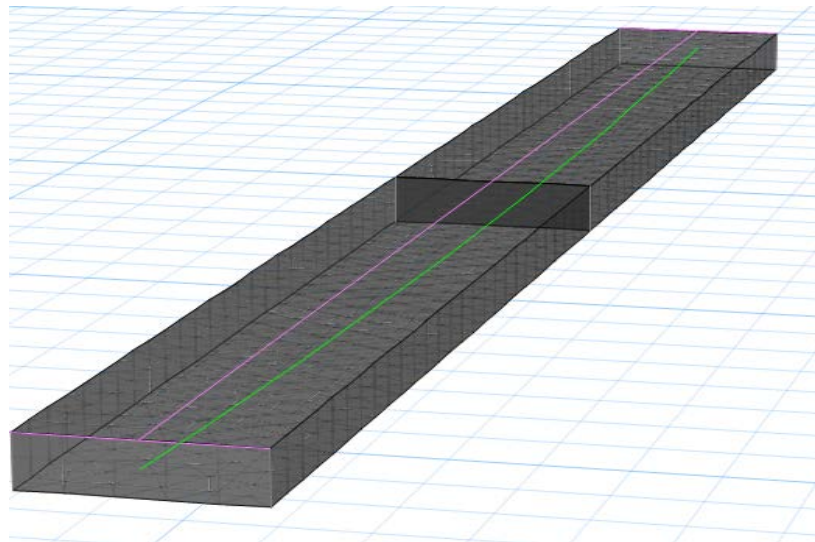
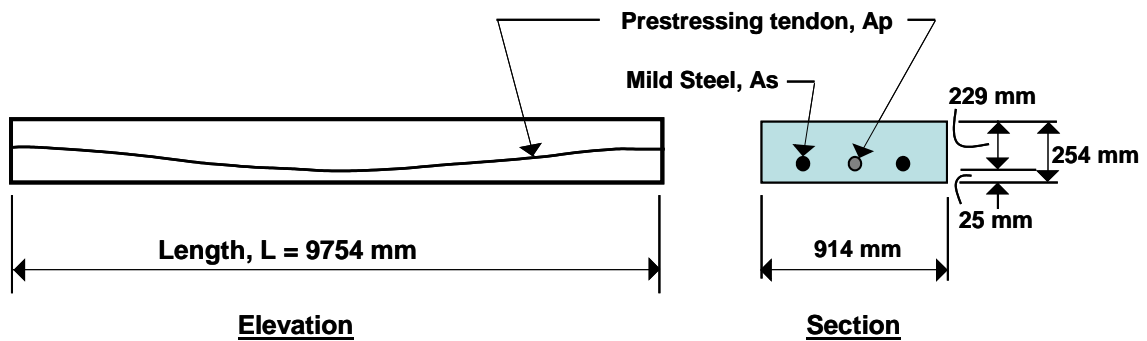


**EXAMPLE Eurocode 2-04 PT-SL-001**  
**Post-Tensioned Slab Design**

**PROBLEM DESCRIPTION**

The purpose of this example is to verify the slab stresses and the required area of mild steel strength reinforcing for a post-tensioned slab.

A one-way, simply supported slab is modeled in SAFE. The modeled slab is 254 mm thick by 914 mm wide and spans 9754 mm as shown in shown in Figure 1.



*Figure 1 One-Way Slab*

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A 254-mm-wide design strip is centered along the length of the slab and has been defined as an A-Strip. B-strips have been placed at each end of the span, perpendicular to Strip-A (the B-Strips are necessary to define the tendon profile). A tendon with two strands, each having an area of 99 mm<sup>2</sup>, was added to the A-Strip. The self weight and live loads have been added to the slab. The loads and post-tensioning forces are as follows:

Loads: Dead = self weight, Live = 4.788 kN/m<sup>2</sup>

The total factored strip moments, required area of mild steel reinforcement, and slab stresses are reported at the mid-span of the slab. Independent hand calculations were compared with the SAFE results and summarized for verification and validation of the SAFE results.

## GEOMETRY, PROPERTIES AND LOADING

Thickness	$T, h =$	254	mm
Effective depth	$d =$	229	mm
Clear span	$L =$	9754	mm
Concrete strength	$f'_c =$	30	MPa
Yield strength of steel	$f_y =$	400	MPa
Prestressing, ultimate	$f_{pu} =$	1862	MPa
Prestressing, effective	$f_e =$	1210	MPa
Area of Prestress (single strand)	$A_p =$	198	mm <sup>2</sup>
Concrete unit weight	$w_c =$	23.56	KN/m <sup>3</sup>
Modulus of elasticity	$E_c =$	25000	N/mm <sup>2</sup>
Modulus of elasticity	$E_s =$	200,000	N/mm <sup>2</sup>
Poisson's ratio	$\nu =$	0	
Dead load	$w_d =$	self	KN/m <sup>2</sup>
Live load	$w_l =$	4.788	KN/m <sup>2</sup>

## TECHNICAL FEATURES OF SAFE TESTED

- Calculation of the required flexural reinforcement
- Check of slab stresses due to the application of dead, live, and post-tensioning loads.

## RESULTS COMPARISON

Table 1 shows the comparison of the SAFE total factored moments, required mild steel reinforcing, and slab stresses with independent hand calculations.

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**Table 1 Comparison of Results**

FEATURE TESTED	INDEPENDENT RESULTS	SAFE RESULTS	DIFFERENCE
Factored moment, Mu (Ultimate) (kN-m)	166.41	166.41	0.00%
Transfer Conc. Stress, top (D+PT <sub>I</sub> ), MPa	-5.057	-5.057	0.00%
Transfer Conc. Stress, bot (D+PT <sub>I</sub> ), MPa	2.839	2.839	0.00%
Normal Conc. Stress, top (D+L+PT <sub>F</sub> ), MPa	-10.460	-10.465	0.05%
Normal Conc. Stress, bot (D+L+PT <sub>F</sub> ), MPa	8.402	8.407	0.06%
Long-Term Conc. Stress, top (D+0.5L+PT <sub>F(L)</sub> ), MPa	-7.817	-7.817	0.00%
Long-Term Conc. Stress, bot (D+0.5L+PT <sub>F(L)</sub> ), MPa	5.759	5.759	0.00%

**Table 2 Comparison of Design Moments and Reinforcements**

National Annex	Method	Design Moment (kN-m)	Reinforcement Area (sq-cm)
			A <sub>s</sub> <sup>+</sup>
CEN Default, Norway, Slovenia and Sweden	SAFE	166.41	15.39
	Calculated	166.41	15.36
Finland, Singapore and UK	SAFE	166.41	15.89
	Calculated	166.41	15.87
Denmark	SAFE	166.41	15.96
	Calculated	166.41	15.94

**COMPUTER FILE:** EUROCODE 2-04 PT-SL-001.FDB

**CONCLUSION**

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

# Software Verification

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## HAND CALCULATIONS:

Design Parameters:

Mild Steel Reinforcing

$$f'c = 30\text{MPa}$$

$$f_y = 400\text{MPa}$$

Post-Tensioning

$$f_{pu} = 1862\text{ MPa}$$

$$f_{py} = 1675\text{ MPa}$$

$$\text{Stressing Loss} = 186\text{ MPa}$$

$$\text{Long-Term Loss} = 94\text{ MPa}$$

$$f_i = 1490\text{ MPa}$$

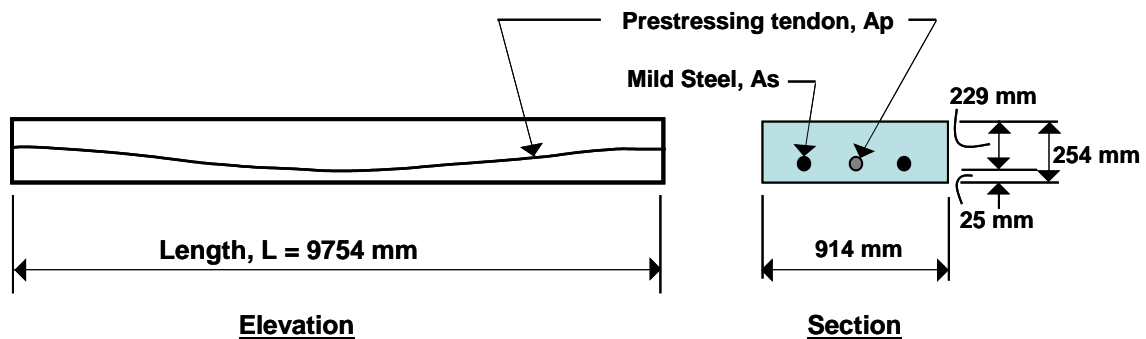
$$f_e = 1210\text{ MPa}$$

$$\gamma_{m, steel} = 1.15$$

$$\gamma_{m, concrete} = 1.50$$

$$\eta = 1.0 \text{ for } f_{ck} \leq 50\text{ MPa}$$

$$\lambda = 0.8 \text{ for } f_{ck} \leq 50\text{ MPa}$$



Loads:

$$\text{Dead, self-wt} = 0.254\text{ m} \times 23.56\text{ kN/m}^3 = 5.984\text{ kN/m}^2\text{ (D)} \times 1.35 = 8.078\text{ kN/m}^2\text{ (D}_u\text{)}$$

$$\text{Live,} = 4.788\text{ kN/m}^2\text{ (L)} \times 1.50 = 7.182\text{ kN/m}^2\text{ (L}_u\text{)}$$

$$\text{Total} = \frac{10.772\text{ kN/m}^2\text{ (D+L)}}{1.35} = 15.260\text{ kN/m}^2\text{ (D+L)}_{ult}$$

$$\omega = 10.772\text{ kN/m}^2 \times 0.914\text{ m} = 9.846\text{ kN/m}, \quad \omega_u = 15.260\text{ kN/m}^2 \times 0.914\text{ m} = 13.948\text{ kN/m}$$

$$\text{Ultimate Moment, } M_U = \frac{w l_1^2}{8} = \frac{13.948 \times (9.754)^2}{8} = 165.9\text{ kN-m}$$

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$$\begin{aligned}
 \text{Ultimate Stress in strand, } f_{PS} &= f_{SE} + 7000d \left( 1 - 1.36 \frac{f_{PU} A_P}{f_{CK} bd} \right) / l \\
 &= 1210 + 7000(229) \left( 1 - 1.36 \frac{1862(198)}{30(914)(229)} \right) / (9754) \\
 &= 1361 \text{ MPa}
 \end{aligned}$$

$$\text{Ultimate force in PT, } F_{ult,PT} = A_P (f_{PS}) = 2(99)(1361)/1000 = 269.5 \text{ kN}$$

**CEN Default, Norway, Slovenia and Sweden:**

 Design moment  $M = 166.4122 \text{ kN-m}$ 

$$\begin{aligned}
 \text{Compression block depth ratio: } m &= \frac{M}{bd^2 \eta f_{cd}} \\
 &= \frac{166.4122}{(0.914)(0.229)^2 (1)(30000/1.50)} = 0.1736
 \end{aligned}$$

Required area of mild steel reinforcing,

$$\omega = 1 - \sqrt{1 - 2m} = 1 - \sqrt{1 - 2(0.1736)} = 0.1920$$

$$A_{EquivTotal} = \omega \left( \frac{\eta f_{cd} bd}{f_{yd}} \right) = 0.1920 \left( \frac{1(30/1.5)(914)(229)}{400/1.15} \right) = 2311 \text{ mm}^2$$

$$A_{EquivTotal} = A_P \left( \frac{1361}{400/1.15} \right) + A_S = 2311 \text{ mm}^2$$

$$A_S = 2311 - 198 \left( \frac{1361}{400/1.15} \right) = 1536 \text{ mm}^2$$

**Finland, Singapore and UK:**

 Design moment  $M = 166.4122 \text{ kN-m}$ 

$$\begin{aligned}
 \text{Compression block depth ratio: } m &= \frac{M}{bd^2 \eta f_{cd}} \\
 &= \frac{166.4122}{(0.914)(0.229)^2 (0.85)(30000/1.50)} = 0.2042
 \end{aligned}$$

Required area of mild steel reinforcing,

$$\omega = 1 - \sqrt{1 - 2m} = 1 - \sqrt{1 - 2(0.2042)} = 0.23088$$

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$$A_{EquivTotal} = \omega \left( \frac{\eta f_{cd} b d}{f_{yd}} \right) = 0.23088 \left( \frac{0.85(30/1.5)(914)(229)}{400/1.15} \right) = 2362 \text{ mm}^2$$

$$A_{EquivTotal} = A_p \left( \frac{1361}{400/1.15} \right) + A_s = 2362 \text{ mm}^2$$

$$A_s = 2362 - 198 \left( \frac{1361}{400/1.15} \right) = 1587 \text{ mm}^2$$

## Denmark:

Design moment  $M = 166.4122 \text{ kN-m}$

$$\begin{aligned} \text{Compression block depth ratio: } m &= \frac{M}{b d^2 \eta f_{cd}} \\ &= \frac{166.4122}{(0.914)(0.229)^2 (1.0)(30000/1.45)} = 0.1678 \end{aligned}$$

Required area of mild steel reinforcing,

$$\omega = 1 - \sqrt{1 - 2m} = 1 - \sqrt{1 - 2(0.1678)} = 0.1849$$

$$A_{EquivTotal} = \omega \left( \frac{\eta f_{cd} b d}{f_{yd}} \right) = 0.1849 \left( \frac{1.0(30/1.45)(914)(229)}{400/1.20} \right) = 2402 \text{ mm}^2$$

$$A_{EquivTotal} = A_p \left( \frac{1361}{400/1.2} \right) + A_s = 2402 \text{ mm}^2$$

$$A_s = 2402 - 198 \left( \frac{1361}{400/1.2} \right) = 1594 \text{ mm}^2$$

## Check of Concrete Stresses at Midspan:

**Initial Condition (Transfer),** load combination (D+PT<sub>i</sub>) = 1.0D+0.0L+1.0PT<sub>i</sub>

Tendon stress at transfer = jacking stress – stressing losses = 1490 – 186 = 1304 MPa

The force in the tendon at transfer = 1304(197.4)/1000 = 257.4 kN

Moment due to dead load,  $M_D = 5.984(0.914)(9.754)^2/8 = 65.04 \text{ kN-m}$

Moment due to PT,  $M_{PT} = F_{PTI}(\text{sag}) = 257.4(102 \text{ mm})/1000 = 26.25 \text{ kN-m}$

$$\text{Stress in concrete, } f = \frac{F_{PTI}}{A} \pm \frac{M_D - M_{PT}}{S} = \frac{-257.4}{0.254(0.914)} \pm \frac{65.04 - 26.23}{0.00983}$$

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where  $S = 0.00983\text{m}^3$

$$f = -1.109 \pm 3.948 \text{ MPa}$$

$$f = -5.058(\text{Comp}) \text{ max}, 2.839(\text{Tension}) \text{ max}$$

**Normal Condition**, load combinations:  $(D+L+PT_F) = 1.0D+1.0L+1.0PT_F$

Tendon stress at normal = jacking – stressing – long-term =  $1490 - 186 - 94 = 1210 \text{ MPa}$

The force in tendon at normal =  $1210(197.4)/1000 = 238.9 \text{ kN}$

Moment due to dead load  $M_D = 5.984(0.914)(9.754)^2/8 = 65.04 \text{ kN-m}$

Moment due to live load  $M_L = 4.788(0.914)(9.754)^2/8 = 52.04 \text{ kN-m}$

Moment due to PT,  $M_{PT} = F_{PTI}(\text{sag}) = 238.9(102 \text{ mm})/1000 = 24.37 \text{ kN-m}$

Stress in concrete for  $(D+L+PT_F)$ ,

$$f = \frac{F_{PTI}}{A} \pm \frac{M_{D+L} - M_{PT}}{S} = \frac{-238.8}{0.254(0.914)} \pm \frac{117.08 - 24.37}{0.00983}$$

$$f = -1.029 \pm 9.431$$

$$f = -10.460(\text{Comp}) \text{ max}, 8.402(\text{Tension}) \text{ max}$$

**Long-Term Condition**, load combinations:  $(D+0.5L+PT_{F(L)}) = 1.0D+0.5L+1.0PT_F$

Tendon stress at normal = jacking – stressing – long-term =  $1490 - 186 - 94 = 1210 \text{ MPa}$

The force in tendon at normal, =  $1210(197.4)/1000 = 238.9 \text{ kN}$

Moment due to dead load,  $M_D = 5.984(0.914)(9.754)^2/8 = 65.04 \text{ kN-m}$

Moment due to live load,  $M_L = 4.788(0.914)(9.754)^2/8 = 52.04 \text{ kN-m}$

Moment due to PT,  $M_{PT} = F_{PTI}(\text{sag}) = 238.9(102 \text{ mm})/1000 = 24.37 \text{ kN-m}$

Stress in concrete for  $(D+0.5L+PT_{F(L)})$ ,

$$f = \frac{F_{PTI}}{A} \pm \frac{M_{D+0.5L} - M_{PT}}{S} = \frac{-238.9}{0.254(0.914)} \pm \frac{91.06 - 24.33}{0.00983}$$

$$f = -1.029 \pm 6.788$$

$$f = -7.817(\text{Comp}) \text{ max}, 5.759(\text{Tension}) \text{ max}$$