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ProtaStructure Design Guide

Design of Formworks and Formwork Scaffolds

Version 1.0 27 September 2022

Please contact us for your training and technical support queries

asiasupport@protasoftware.com

globalsupport@protasoftware.com

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Notations

A_l	Section Area of Sheathing mm2
A_{bk}	Section Area of Joist, mm2
A_{ik}	Section Area of Stringer, mm2
b_l	Width of Sheathing, mm
E_l	Elastic Modulus of Sheathing, MPa
f_{ebk}	Bending Strength of Joist, MPa
f_{el}	Bending Strength of Sheathing, MPa
f_{kbk}	Shear Strength of Joist, MPa
f_{kl}	Shear Strength of Sheathing, MPa
I_{bk}	Moment of Inertia of Joist, mm4
I_l	Moment of Inertia of Sheathing, mm4
S_{bk}	Section Modulus of Joist, mm3
S_l	Section Modulus of Sheathing, mm^3
R	Concrete Placement Speed, m/hr
T	Concrete's Temperature, °C
ρ	Dead and Live Load Pressure on Formwork, MPa
ρ_{max}	Maximum Hydrostatic Concrete Pressure, MPa
ρ_d	Total Pressure on Shores, MPa
EIx	Rigidity
$G_{concrete}$	Concrete Dead Load, kN/m2
$G_{formwork}$	Formwork Dead Load, kN/m2
γ_c	Unit Weight of Concrete
N_d	Shore Axial Compression Load Capacity or Connection Member Tension Load Capacity, kN
L_{bk}	Spacing of Joists, cm
L_{ik}	Spacing of Stringers, cm

L_d	Spacing of Shores, cm
q	Wind Pressure, kN/m2

Introduction

ProtaStructure provides calculations and calculation reports of wooden and metal formwork and formwork scaffolds as per, the code "Bina İnşaatlarında Kullanılacak Ahşap ve Metal Esaslı Kalıpların ve Taşıyıcı Kalıp İskelelerinin Tasarım, Hesap ve Yapım Esasları" established by the Ministry of Environment and Urbanization in the Official Gazette dated 06 November 2020 and numbered 31296. In this document, the formwork and formwork scaffold calculations are explained in case studies.

Slab Formwork Design

Slab Properties

Plan view of slab D101, which will be used in the case study, can be seen below.

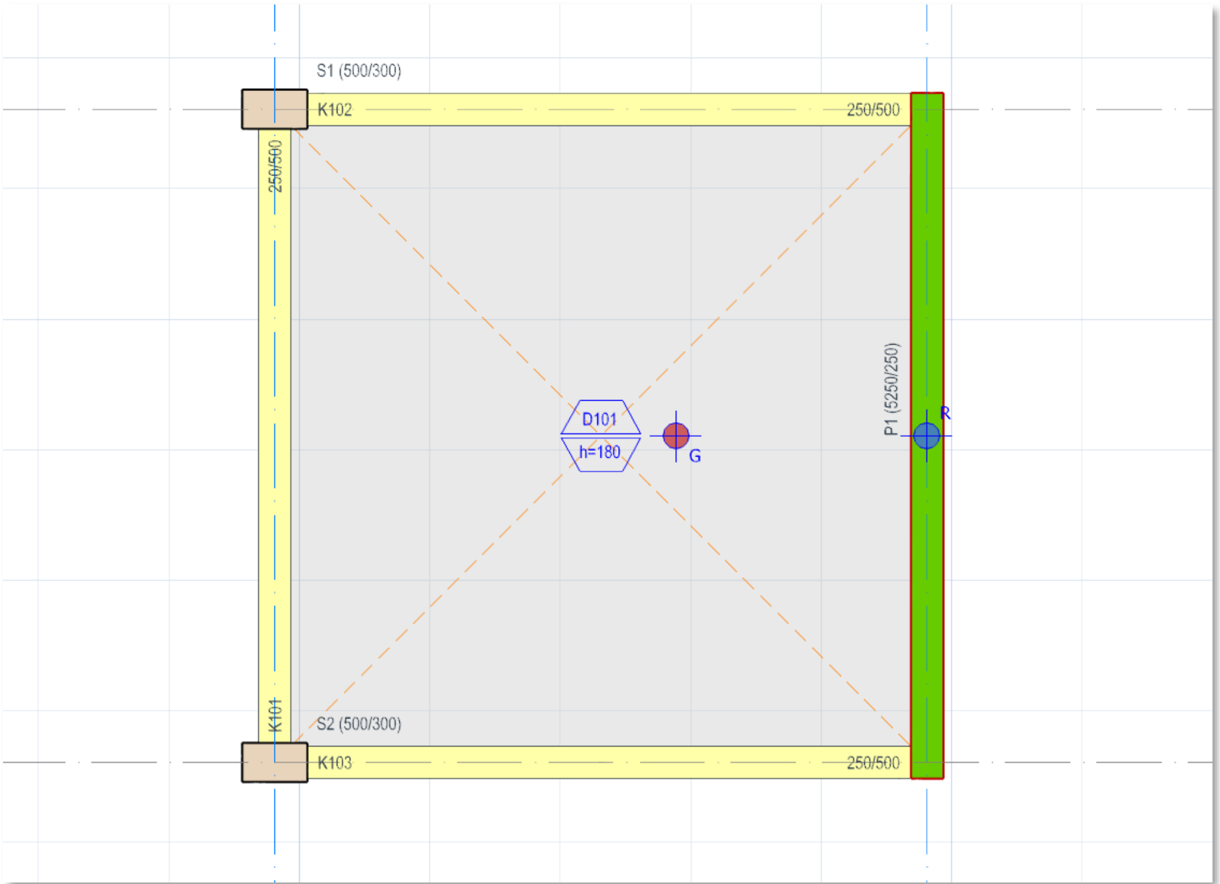

Figure 1: Slab Plan View

Sheathing Properties

Sheating properties are taken from the TS_EN_12369 code. Sheating properties can be accessed from Building Analysis/Edit Materials section of ProtaStructure 2022. Also, member material properties can be edited manually. F20-E50/E40(T) is selected for this case.

Sınıf[a]	Karakteristik mukavemet değerleri (N/mm²veya MPa)		
	Yüzey lif yönü[a]		
	0 ve 90	0	90
	Eğilme	Çekme ve basınç	
	$f_{m,05}$	$f_{t\text{-}c,05}$	
F 3	3	1,2	1,5
F 5	5	2	2,5
F 10	10	4	5
F 15	15	6	7,5
F 20	20	8	10
F 25	25	10	12,5
F 30	30	12	15
F 40	40	16	20
F 50	50	20	25
F 60	60	24	30
F 70	70	28	35
F 80	80	32	40

a Sınıf, liflere paralel (0) ve liflere dik(90) her iki yön için tarif edilir. Mukavemet için F sınıfları, EN 636'da tanımlanmıştır.

Figure 2: Characteristic Strength Values

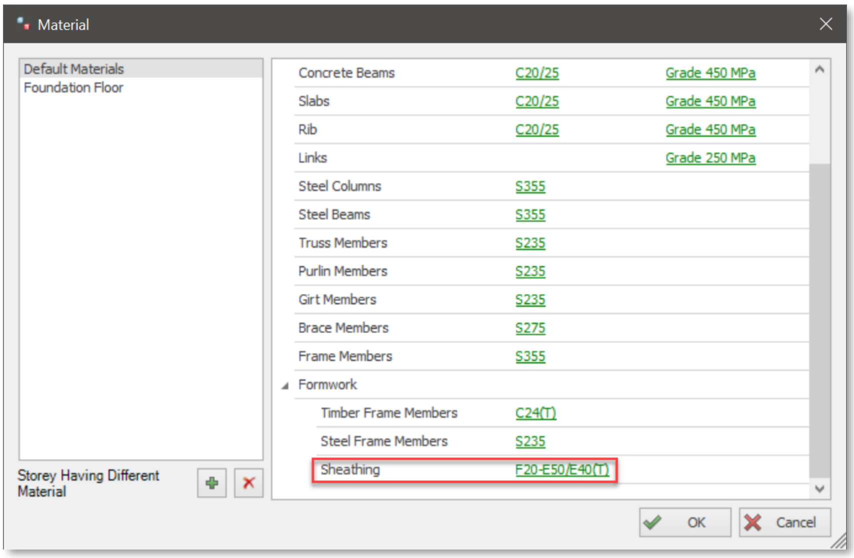

Figure 3: PS 2022 Material Selection Window View-1

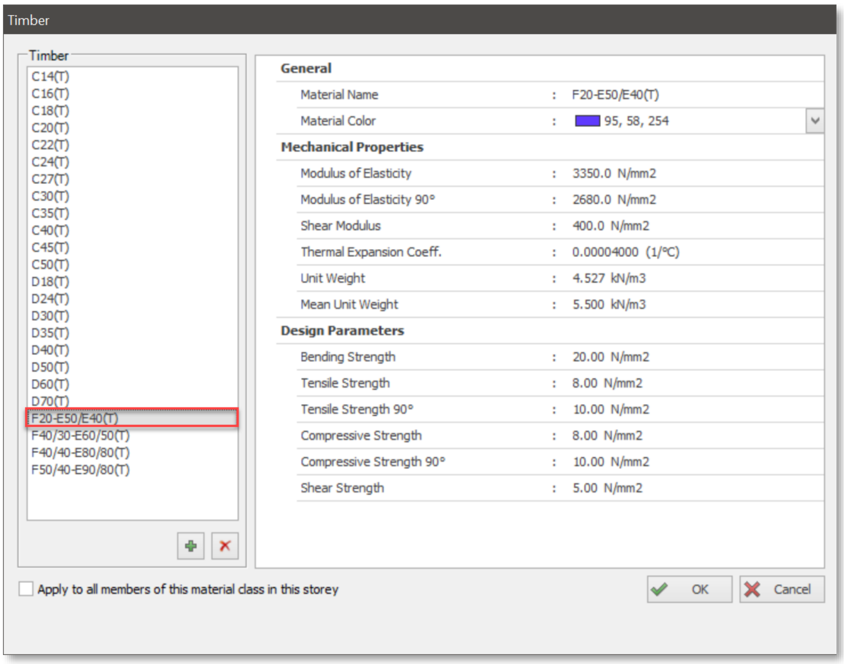

Figure 4: PS 2022 Material Selection Window View-2

Sectional properties of sheating are calculated as follows.

1.	$Material = Plywood$	
2.	$Thickness = t = 18\ mm$	
3.	$b_l = 1000\ mm$	cl.1.3.3(a)
4.	$A_l = \ 18 \times 1000 = 18000\ mm^4$	
5.	$E_l = 3350\ N/mm^2$	
6.	$f_{el} = 20\ MPa$	
7.	$f_{kl} = 5\ MPa$	
8.	$I_l = \frac{1}{12}\ b_l\ t^3 = \frac{1}{12} \times 1000 \times 18^3 = \ 486000\ mm^4$	
9.	$S_l = \frac{I_l}{\frac{t}{2}} = \frac{486000}{\frac{18}{2}} = 54000\ mm^3$	
10.	$Gk = 2$	

Joist Properties

Joist properties and calculations of joist sectional properties are given below. Joist properties are taken from EN 338 and TS EN 13377 specifications. In this document C24(T) is used. Joist properties can be reached from Building Analysis/Edit Materials in ProtaStructure 2022.

		Softwood species												Hardwood species							
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D18	D24	D30	D35	D40	D50	D60	D70
Strength properties (in N/mm^2)																					
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	18	24	30	35	40	50	60	70
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30	11	14	18	21	24	30	36	42
Tension perpendicular	$f_{t,90,k}$	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29	18	21	23	25	26	29	32	34
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	7,5	7,8	8,0	8,1	8,3	9,3	10,5	13,5
Shear	$f_{v,k}$	3,0	3,2	3,4	3,6	3,8	4,0	4,0	4,0	4,0	4,0	4,0	4,0	3,4	4,0	4,0	4,0	4,0	4,0	4,5	5,0
Stiffness properties (in kN/mm^2)																					
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	9,5	10	11	12	13	14	17	20
5 % modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	8	8,5	9,2	10,1	10,9	11,8	14,3	16,8
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	0,63	0,67	0,73	0,80	0,86	0,93	1,13	1,33
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	0,59	0,62	0,69	0,75	0,81	0,88	1,06	1,25
Density (in kg/m^3)																					
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460	475	485	530	540	550	620	700	900
Mean density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550	570	580	640	650	660	750	840	1080

NOTE 1 Values given above for tension strength, compression strength, shear strength, 5 % modulus of elasticity, mean modulus of elasticity perpendicular to grain and mean shear modulus, have been calculated using the equations given in Annex A.
NOTE 2 The tabulated properties are compatible with timber at a moisture content consistent with a temperature of 20 °C and a relative humidity of 65 %.
NOTE 3 Timber conforming to classes C45 and C50 may not be readily available.
NOTE 4 Characteristic values for shear strength are given for timber without fissures, according to EN 408. The effect of fissures should be covered in design codes.

Figure 5: Formwork Material Characteristic Properties

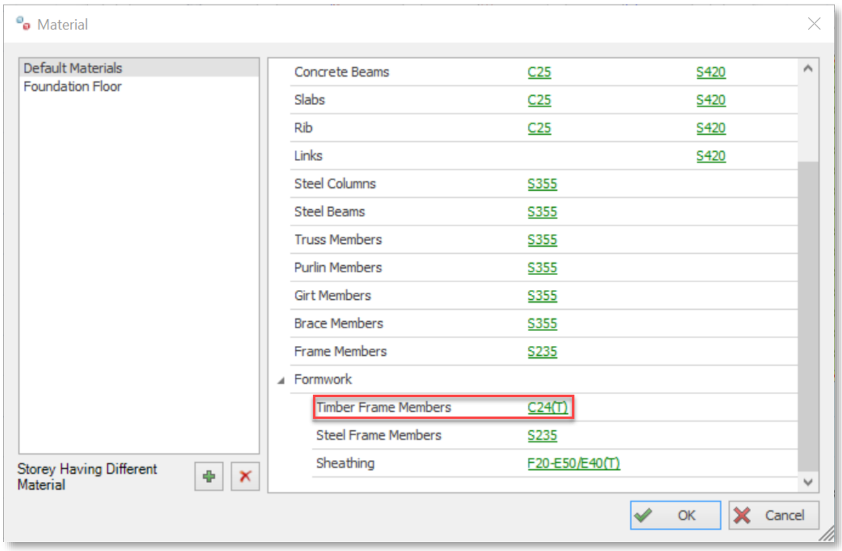

Figure 6:PS 2022 Material Selection Window View-1

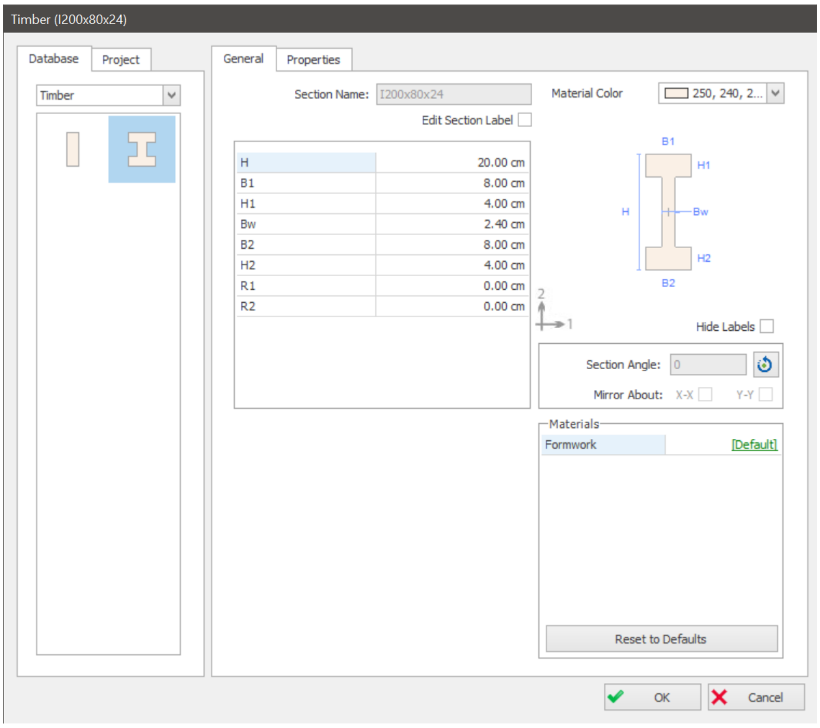

Figure 7: PS 2022 Material Selection Window View-2

1.	$Material = H20\ Timber\ (C24)$
2.	$B(1,2) = 80\ mm$
3.	$H(1,2) = 40\ mm$
4.	$Bw = \ 24\ mm$
5.	$H = 200\ mm$
6.	$A_{bk} = \ 2 \times 80 \times 40 + 24 \times (200 - 40 \times 2) = 9280\ mm^2$
7.	$f_{kbk} = 4\ MPa$
8.	$f_{ebk} = 24\ MPa$
9.	$E_{bk} = 7400\ N/mm^2$
10.	$I_{bk} = 45270000\ mm^4$
11.	$S_{bk} = \frac{I_{bk}}{\frac{h}{2}} = \frac{45270000}{\frac{200}{2}} = 452700\ mm^3$
12.	$Gk = 2$

Stringer Properties

Stringer properties and calculations of stringer sectional properties are given below. Stringer properties are taken from EN 338 and TS EN 13377 specifications. In this document C24(T) is used. Stringer properties can be reached from Building Analysis/Edit Materials in ProtaStructure 2022. Stringer properties are taken as the same as the joist properties.

1.	$Material = H20\,Timber\,(C24)$
2.	$B(1,2) = 80\,mm$
3.	$H(1,2) = 40\,mm$
4.	$Bw = \ 24\,mm$
5.	$H = 200\,mm$
6.	$A_{ik} = \ 2 \times 80 \times 40 + 24 \times (200 - 40 \times 2) = 9280\,mm^2$
7.	$f_{kik} = 4\,MPa$
8.	$f_{eik} = 24\,MPa$
9.	$E_{ik} = 7400\,N/mm^2$
10.	$I_{ik} = 45270000\,mm^4$
11.	$S_{ik} = \frac{I_{bk}}{\frac{h}{2}} = \frac{45270000}{\frac{200}{2}} = 452700\,mm^3$
12.	$Gk = 2$

Shore Properties

Properties of telescopic props are given below.

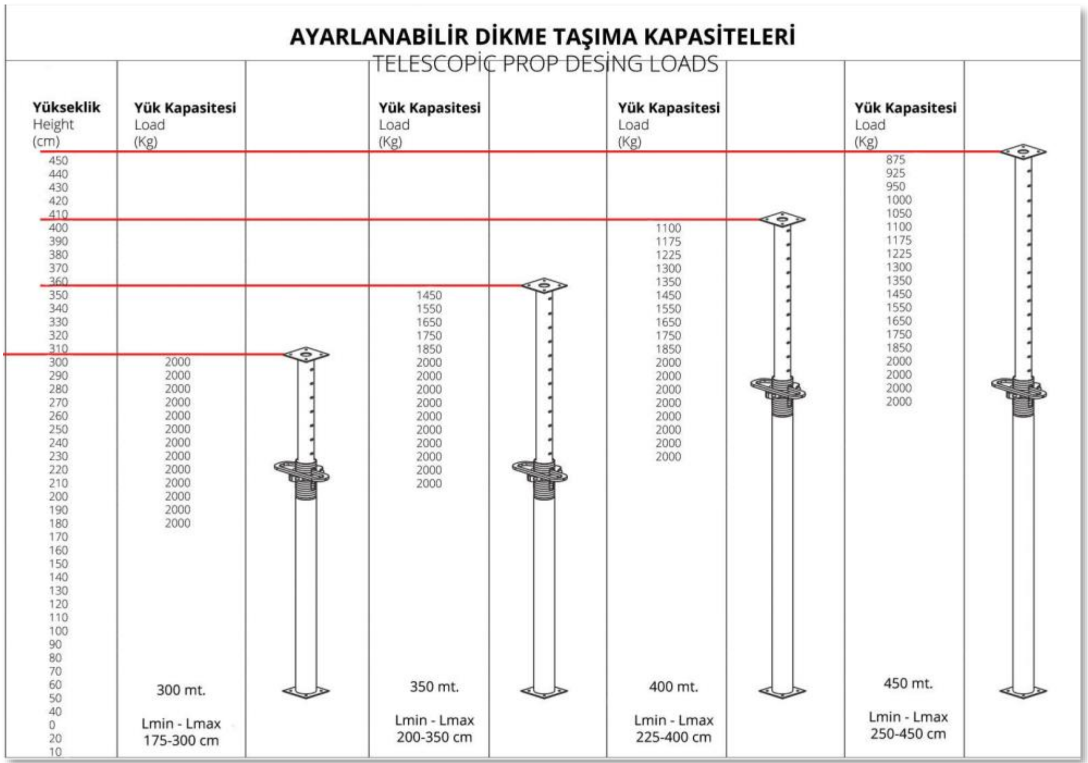

Figure 8: Telescopic Prop Design Loads

Load Calculations

Load calculations can be seen below.

1.	$\gamma_c = 25\ kN\ /\ m^3$	
2.	$Concrete\ Class = C30$	
3.	$Slab\ Thickness = 180\ mm$	
4.	$G_{concrete} = 25 \times \frac{180}{1000} = 4.5\ kN/m^2 = 0.0045\ N/mm^2$	
5.	$G_{formwork} = 0.0004\ N\ /\ mm^2\ \ (Assumption.)$	
6.	$G = \ G_{formwork} + \ G_{concrete} = 0.0049\ N\ /\ mm^2$	
7.	$Q = 0.0025\ N\ /\ mm^2$	cl.1.2.1
8.	$Successive\ Shore\ Number = n = 2$	
9.	$p = G + Q = 0.0074\ N\ /\ m^2$	
10.	$p_d = nG + Q = 2 \times 0.0049 + 0.0025 = 0.0123\ N\ /\ m^2$	

Joist Spacing Calculations

Joist spacing and the number of joists are calculated below.

1.	$L_{bk} = min\left(3.16\sqrt{\frac{f_{el}\,S_l}{p\,b_l\,GK}},\ 0.835\sqrt[3]{\frac{E_l\,I_l}{p\,b_l}},\frac{f_{kl}\,A_l}{0.9\,p\,b_l\,GK}\right)$
2.	$3.16\sqrt{\frac{20\times54000}{0.0074\times1000\times2}} = 853.62\ mm$
3.	$0.835\sqrt[3]{\frac{3350\times486000}{0.0074\times1000}} = 504.08\ mm$
4.	$\frac{5\times18000}{0.9\times0.0074\times1000\times2} = 6756.75\ mm$
5.	$min(853.62,\ 504.08,\ 6756.75) = 504.08\ mm$
6.	$Number\ of\ Joists\ (n) = 11$
7.	$Corner\ Gap\ (l_{corner}) = 0\ mm$
8.	$Effective\ Surface\ Length\ (l) = 4750\ mm$
9.	$Effective\ Surface\ Width\ (b) = 80\ mm$
10.	$Provided\ Spacing\ (l_{bk,provided}) = \frac{l-2\,l_{corner}-b}{n-1} = \frac{4750-80}{11-1} = 467\ mm$
11.	$l_{bk} \geq l_{bk,provided}$ ✓

Stringer Spacing Calculations

Stringer spacing and number of stringers are calculated as below.

1.	$L_{ik} = min\left(3.16\sqrt{\frac{f_{ebk}\,S_{bk}}{p\,L_{bk}\;GK}},\;0.835\sqrt[3]{\frac{E_{bk}\,I_{bk}}{p\,L_{bk}}},\frac{f_{kbk}\,A_{bk}}{0.9\,p\,L_{bk}\,GK}\right)$
2.	$3.16\sqrt{\frac{24\times452700}{0.0074\times467\times2}} = 3961.94\;mm$
3.	$0.835\sqrt[3]{\frac{7400\times45270000}{0.0074\times467}} = 3835.75\;mm$
4.	$\frac{4\times9280}{0.9\times0.0074\times467\times2} = 5967.42\;mm$
5.	$Min(3961.94,\;3835.75,\;5967.42) = 3835.75\;mm$
6.	$Number\ of\ Stringers\ (n) = 3$
7.	$Corner\ Gap\ (l_{corner}) = 0\;mm$
8.	$Effective\ Surface\ Length\ (l) = 4750\;mm$
9.	$Effective\ Surface\ Width\ (b) = 80\;mm$
10.	$Provided\ Spacing\ (l_{ik,provided}) = \frac{l-2\,l_{corner}-b}{n-1} = \frac{4750-80}{3-1} = 2335\;mm$
11.	$l_{ik} \geq l_{ik,provided}$ ✓

Shore Spacing Calculations

Shore spacing and the number of shores are calculated as below.

1.	$L_d = \min\left(3.16\sqrt{\frac{f_{eik}\,S_{ik}}{p_d\,L_{ik}\,GK}},\ 0.835\sqrt[3]{\frac{E_{ik}\,I_{ik}}{p_d\,L_{ik}}},\frac{f_{kik}\,A_{ik}}{0.9\,p_d\,L_{ik}\,GK},\frac{N_d}{1.1\,p_d\,L_{ik}\,GK}\right)$
2.	$N_d = 27200\ N\ (Assumption.)$
3.	$3.16\sqrt{\frac{24\times452700}{0.0123\times2335\times2}} = 1374.31\ mm$
4.	$0.835\sqrt[3]{\frac{7400\times4527000}{0.0123\times2335}} = 1893.66\ mm$
5.	$\frac{4\times9280}{0.9\times0.0123\times2335\times2} = 718.03\ mm$
6.	$\frac{27200}{1.1\times0.0123\times2335\times2} = 430.48\ mm$
7.	$Min(1374.31,\ 1893.66,\ 718.03,\ 430.48) = 430.48\ mm$
8.	$Number\ of\ Shores\ (n) = 11$
9.	$Corner\ Gap\ (l_{corner}) = 0.0\ mm$
10.	$Effective\ Surface\ Length\ (l) = 4750\ mm$
11.	$Provided\ Spacing\ (l_{d,provided}) = \frac{l-2\,l_{corner}}{n+1} = \frac{4750}{11+1} = 396\ mm$
12.	$l_d \geq l_{d,provided}$ ✓

Beam Formwork Design

Beam Properties

Plan view and properties of beam K110, which will be used in the case study can be seen below.

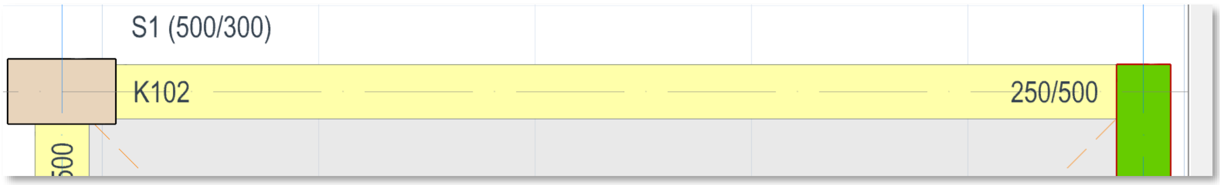

Figure 9: Beam Plan View

Sheating, joist, and stringer properties will be the same as the ones given in the slab formwork design part.

Load Calculations

Load calculations can be seen below.

1.	$\gamma_c = 25\ kN\ /\ m^3$	
2.	$Beam\ Height = 500\ mm$	
3.	$G_{concrete} = \frac{25}{1000000} \times 500 = 0.0125\ N\ /\ mm^2$	
4.	$G_{formwork} = 0.0004\ N\ /\ mm^2\ \ (Assumption.)$	
5.	$Q = 0.0025\ N\ /\ mm^2$	cl.1.2.1
6.	$p = G + Q = 0.0129 + 0.0025 = 0.0154\ N\ /\ mm^2$	
7.	$Successive\ Shore\ Number = n = 2$	
8.	$p_d = nG + Q = 2 \times 0.0129 + 0.0025 = 0.0283\ N\ /\ mm^2$	

Joist Spacing Calculations for the Side Surface

It is assumed that joists will be placed perpendicular to the beam axis. Therefore, b_l will be used as beam height in the calculation of the beam side formwork panels.

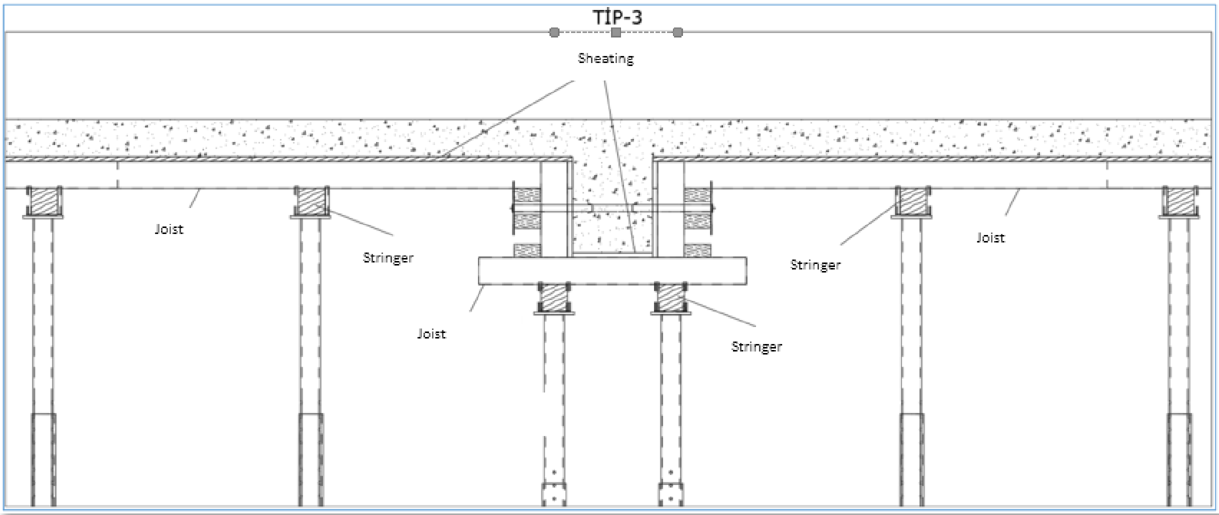

Figure 10: Typical Formwork

1.	$L_{bk} = \min\left(3.16\sqrt{\frac{f_{el}\,S_l}{p\,b_l\,GK}},\ 0.835\sqrt[3]{\frac{E_l\,I_l}{p\,b_l}},\frac{f_{kl}\,A_l}{0.9\,p\,b_l\,GK}\right)$
2.	$3.16\sqrt{\frac{20\times54000}{0.0154\times500\times2}} = 836.83\ mm$
3.	$0.835\sqrt[3]{\frac{3350\times486000}{0.0154\times500}} = 497.45\ mm$
4.	$\frac{5\times18000}{0.9\times0.0154\times500\times2} = 6493.5\ \mathrm{mm}$
5.	$min(836.83,\ 497.45,\ 6493.5) = 497.45\ mm$
6.	$Number\ of\ Joists\ (n) = 11$
7.	$Corner\ Gap\ (l_{corner}) = 0\ \ mm$
8.	$Effective\ Surface\ Length\ (l) = 4625\ mm$
9.	$Effective\ Surface\ Width\ (b) = 80\ mm$
10.	$Provided\ Spacing\ (l_{bk,provided}) = \frac{l-b-2\,l_{corner}}{n-1} = \frac{4625-80}{11-1} = 454.5\ mm$
11.	$l_{bk}\ \ \geq l_{bk,provided}$ ✓

Stringer Spacing Calculations for the Side Surface

Stringer spacing and number of stringers are calculated as below.

1.	$L_{ik} = \min\left(3.16\sqrt{\frac{f_{ebk}\,S_{bk}}{p\,L_{bk}\,GK}},\ 0.835\sqrt[3]{\frac{E_{bk}\,I_{bk}}{p\,L_{bk}}},\frac{f_{kbk}\,A_{bk}}{0.9\,p\,L_{bk}\,GK}\right)$
2.	$3.16\sqrt{\frac{24\times4527000}{0.0154\times454.5\times2}} = 2783.91\ mm$
3.	$0.835\sqrt[3]{\frac{7400\times4527000}{0.0154\times454.5}} = 3031.67\ \mathrm{mm}$
4.	$\frac{4\times9280}{0.9\times0.0154\times454.5\times2} = 2946.32mm$
5.	$Min(2783.91,\ 3021.67,\ 2946.31) = 2783.91\ mm$
6.	*Number of Stringers (n)= 1*
7.	*Corner Gap* (l_{corner}) *=0.0 mm*
8.	*Effective Surface Length* (l)*=500 mm*
9.	*Provided Spacing* ($l_{ik,provided}$) *=500 mm*
10.	$l_{ik} \geq l_{ik,provided}$ ✓

Connection Member Spacing Calculations for the Side Surface

Connection member spacing and the number of stringers are calculated below.

1.	$L_b = \min\left(3.16\sqrt{\frac{f_{eik}\, S_{ik}}{p_d\, L_{ik}\, GK}},\ 0.835\sqrt[3]{\frac{E_{ik}\, I_{ik}}{p_d\, L_{ik}}}, \frac{f_{kik}\, A_{ik}}{0.9\, p_d\, L_{ik}\, GK}, \frac{N_d}{1.1\, p_d\, L_{ik}\, GK}\right)$
2.	$N_d = 22000\ N\ (Assumption.)$
3.	$3.16\sqrt{\frac{24\times452700}{0.0154\times500\times2}} = 2654.22\ mm$
4.	$0.835\sqrt[3]{\frac{7400\times4527000}{0.0154\times500}} = 2936.77\ mm$
5.	$\frac{4\times9280}{0.9\times0.0154\times500\times2} = 2678.21\ mm$
6.	$\frac{22000}{1.1\times0.0154\times500\times2} = 1298.7\ mm$
7.	$Min(2654.22,\ 2936.77,\ 2678.21,\ 1298.7) = 1298.7\ mm$
8.	*Number of Connection Members(n) = 5*
9.	*Corner Gap* $(l_{corner}) = 0.0\ mm$
10.	*Effective Surface Length* $(l) = 4625\ mm$
11.	*Provided Spacing* $(l_{b,provided}) = \frac{l-2\, l_{corner}}{n-1} = \frac{4625}{5-1} = 1156.3\ mm$
12.	$l_b \geq l_{b,provided}$ ✓

Joist Spacing Calculations for the Base

It is assumed that joists will be placed perpendicular to the beam axis. Therefore, b_l will be used as beam width in the calculation of the beam base formwork panels.

1.	$L_{bk} = \min\left(3.16\sqrt{\frac{f_{el}\,S_l}{p\,b_l\,GK}},\ 0.835\sqrt[3]{\frac{E_l\,I_l}{p\,b_l}},\frac{f_{kl}\,A_l}{0.9\,p\,b_l\,GK}\right)$
2.	$3.16\sqrt{\frac{20\times54000}{0.0154\times250\times2}} = 1183.46\,mm$
3.	$0.835\sqrt[3]{\frac{3350\times486000}{0.0154\times250}} = 626.74\,mm$
4.	$\frac{5\times18000}{0.9\times0.0154\times250\times2} = 12987\text{ mm}$
5.	$min(1183.46,\ 626.74,\ 12987) = 626.74\,mm$
6.	$Number\ of\ Joists\ (n)=9$
7.	$Corner\ Gap\ (l_{corner}) = 0\ mm$
8.	$Effective\ Surface\ Length\ (l) = 4625\ mm$
9.	$Effective\ Surface\ Width\ (b) = 80\,mm$
10.	$Provided\ Spacing\ (l_{bk,provided}) = \frac{l-b-2\,l_{corner}}{n-1} = \frac{4625-80}{9-1} = 568.125\,mm$
11.	$l_{\text{bk}} \geq l_{bk,provided}$ ✓

Stringer Spacing Calculations for the Base

Stringer spacing and number of stringers are calculated as below.

1.	$L_{ik} = \min\left(3.16\sqrt{\frac{f_{ebk}\,S_{bk}}{p\,L_{bk}\,GK}},\ 0.835\sqrt[3]{\frac{E_{bk}\,I_{bk}}{p\,L_{bk}}},\frac{f_{kbk}\,A_{bk}}{0.9\,p\,L_{bk}\,GK}\right)$
2.	$3.16\sqrt{\frac{24\times452700}{0.0154\times568.125\times2}} = 2490\ mm$
3.	$0.835\sqrt[3]{\frac{7400\times4527000}{0.0154\times568.125}} = 2814.35\ mm$
4.	$\frac{4\times9280}{0.9\times0.0154\times568.125\times2} = 2357\ \text{mm}$
5.	$Min(2490,\ 2814.35,\ 2357) = 2357\ mm$
6.	*Number of Stringers (n) = 2*
7.	*Corner Gap* (l_{corner})*=0.0 mm*
8.	*Effective Surface Length (l) =250 mm*
9.	*Effective Surface Width (b) =80 mm*
10.	*Provided Spacing* $(l_{ik,provided}) = \frac{l-b-2\,l_{corner}}{n-1} = \frac{250-80}{2-1} = 170\ mm$
11.	$l_{\text{ik}} \geq l_{ik,provided}$ ✓

Shore Spacing Calculations

Shore spacing and the number of shores are calculated below.

1.	$L_d = \min\left(4.5\sqrt{\frac{f_{eik}\,S_{ik}}{p_d\,L_{ik}\,GK}}\;,\sqrt[3]{\frac{E_{ik}\,I_{ik}}{p_d\,L_{ik}}}\,,\frac{2.2\,f_{kik}\,A_{ik}}{p_d\,L_{ik}\,GK}\,,\frac{1.8\,N_d}{p_d\,L_{ik}\,GK}\right)$
2.	$N_d = 27200\,N$ (Assumption.)
3.	$4.5\sqrt{\frac{24\times452700}{0.0283\times170\times2}} = 4781.79\,mm$
4.	$\sqrt[3]{\frac{7400\times45270000}{0.0283\times170}} = 4114.04\,mm$
5.	$\frac{2.2\times9280\times4}{0.0283\times170\times2} = 8487.21\,mm$
6.	$\frac{1.8\times27200}{0.0283\times170\times2} = 5088.33\,mm$
7.	$Min(4781.9,\ 4114.04,\ 8487.21,\ 5088.33) = 4114.04\,mm$
8.	*Number of Shores (n)= 2*
9.	*Corner Gap* (l_{corner})*=0.0 mm*
10.	*Effective Surface Length* (l)*=4625 mm*
11.	*Provided Spacing* $(l_{d,provided}) = \frac{l-b-2\,l_{corner}}{n+1} = \frac{4625}{2+1} = 1542\,mm$
12.	$l_d \geq l_{d,provided}$ ✓

Column Formwork Design

Column Properties

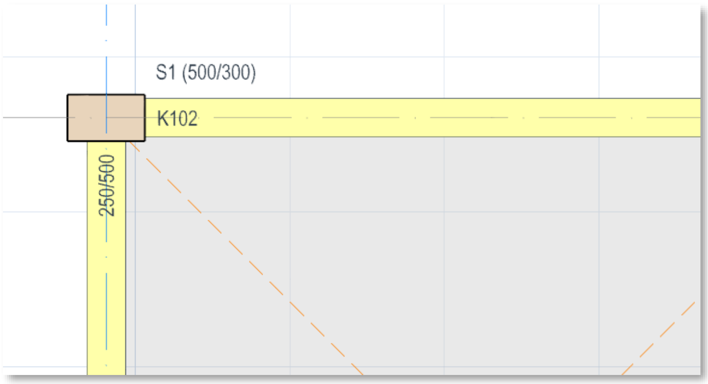

Figure 11: Plan View of the Column

Sheating, joist, and stringer properties will be the same as the ones given in the slab formwork design part. The calculations will be done using the properties of the S1 column.

Load Calculations

Load calculations can be seen below.

Concrete Hydrostatic Pressure Calculation:

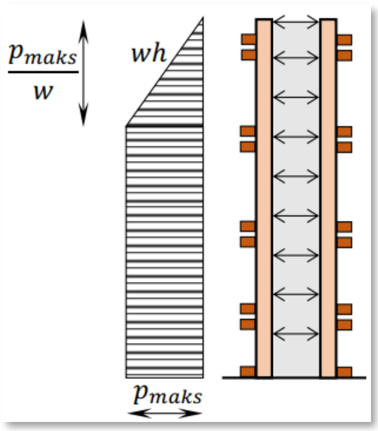

Figure 12:Concrete Hydrostatic Load Diagram

1.	$Concrete\ Class = C30$
2.	$T\ = 20°$
3.	$Total\ Pouring\ Time = 1.5\ hr$
4.	$R\ = \frac{3}{1.5} = 2\ m/hr$
5.	$p_{max} = 8.5 + \frac{950R}{T+18} = 8.5 + \frac{950\times2}{20+18} = 58.5\ \ [kPa] = 0.0585\ Mpa$

Wind Load Calculation:

Wind load is calculated as per TS-498 Section 11 as follows.

Height (m)	Velocity (m/s)	Q (kN/m2)	C
0	28	0.5	1.6
8	36	0.8	
20	42	1.1	
100	46	1.3	

1.	$Column\ Top\ Elevation = 3\ m$
2.	$Column\ Bottom\ Elevation = -1.1\ m$
3.	$Coefficient\ of\ Suction\ (C_f) = 1.6$
4.	$q = 0.5\ kN/m^2$
5.	$W = C_f\ q\ H\ \ = 1.6 \times 0.5 \times 0.5 =\ 0.4\ kN/m\ acting\ on\ 50\ cm\ section.$
6.	$Total\ Wind\ Load = 0.4 \times 4.1 = 1.64\ kN\ for\ the\ whole\ surface.$
7.	$W = C_f\ q\ H\ \ = 1.6 \times 0.3 \times 0.5 =\ 0.24\ kN/m\ acting\ on\ 30\ cm\ section.$
8.	$Total\ Wind\ Load = 0.24 \times 4.1 = 0.984\ kN\ for\ the\ whole\ surace.$

Joist Spacing Calculations

Joist spacing and the number of joists are calculated as below.

1.	$L_{bk} = \min\left(3.16\sqrt{\frac{f_{el}\,S_l}{p\,b_l\,GK}},\ 0.835\sqrt[3]{\frac{E_l\,I_l}{p\,b_l}},\frac{f_{kl}\,A_l}{0.9\,p\,b_l\,GK}\right)$
2.	$3.16\sqrt{\frac{20\times54000}{0.0585\times1000\times2}} = 303.6\ mm$
3.	$0.835\sqrt[3]{\frac{3350\times486000}{(0.0585\times1000}} = 253.04\ mm$
4.	$\frac{5\times18000}{0.9\times0.0585\times1000\times2} = 854.7\ mm$
5.	$Min(303.6,\ 253.04,\ 854.7) = 253.04\ mm$

Surface Number	*Number of Joists*	L_{corner} *(mm)*	*l (mm)*	*b (mm)*	$L_{bk,provided}$ *(mm)*	$l_{bk} \geq l_{bk,provided}$
1	3	0	500	80	210	✓
2	2	0	300	80	220	✓
3	3	0	500	80	210	✓
4	2	0	300	80	220	✓

Stringer Spacing Calculations

Stringer spacing and number of stringers are calculated as below.

1.	$L_{ik} = \min\left(3.16\sqrt{\frac{f_{ebk}\,S_{bk}}{p\,L_{bk}\,GK}},\ 0.835\sqrt[3]{\frac{E_{bk}\,I_{bk}}{p\,L_{bk}}},\frac{f_{kbk}\,A_{bk}}{0.9\,p\,L_{bk}\,GK}\right)$
2.	$3.16\sqrt{\frac{24\times45700}{0.0585\times210\times2}} = 2101.33\ mm$
3.	$0.835\sqrt[3]{\frac{7400\times4570000}{0.0585\times210}} = 2513.28\ mm$
4.	$\frac{4\times9820}{0.9\times0.0585\times210\times2} = 1678.65\ \text{mm}$
5.	$Min(2101.33,\ 2513.28,\ 1678.65) = 1678.65\ mm$

Surface Number	*Number of Stringers*	L_{corner} *(mm)*	*l (mm)*	*b (mm)*	$L_{ik,provided}$ *(mm)*	$l_{ik} \geq l_{ik,provided}$
1	4	0	4100	200	1300	✓
2	4	0	4100	200	1300	✓
3	4	0	4100	200	1300	✓
4	4	0	4100	200	1300	✓

Connection Member Spacing Calculations

Connection member spacing and the number of connection members are calculated below.

1.	$L_b = \min\left(3.16\sqrt{\frac{f_{eik}\,S_{ik}}{p\,L_{ik}\,GK}},\ 0.835\sqrt[3]{\frac{E_{ik}\,I_{ik}}{p\,L_{ik}}},\frac{f_{kik}\,A_{ik}}{0.9\,p\,L_{ik}\,GK},\frac{N_d}{1.1\,p\,L_{ik}\,GK}\right)$
2.	$N_d = 22000\ N\ (Assumption.)$
3.	$3.16\sqrt{\frac{24\times452700}{0.0585\times1300\times2}} = 844.56\ mm$
4.	$0.835\sqrt[3]{\frac{7400\times45270000}{0.0585\times1300}} = 1368.78\ mm$
5.	$\frac{4\times9280}{0.9\times0.0585\times1300\times2} = 271.16\ mm$
6.	$\frac{22000}{1.1\times0.0585\times1300\times2} = 131.49\ m$
7.	$Min(844.56, 1368.78, 271.16, 131.49) = 131.49\ mm$

Surface Number	*Number of Connection Members*	L_{corner} *(mm)*	*l (mm)*	*b (mm)*	$L_{b,provided}$ *(mm)*	$l_b \geq l_{b,provided}$
1	5	0	500	0	125	✓
2	4	0	300	0	100	✓
3	5	0	500	0	125	✓
4	4	0	300	0	100	✓

Brace Calculations

Brace capacity calculations are presented in this section.

1.	$N_{brace} = 272000\ N\ (Assumption.)$
2.	$\alpha = 45.00°\ (Assumption.)$
3.	$N_1 = N_{brace} \cos(\alpha)\ \mathrm{n_{Horizontal}}$

Surface Number	$\mathrm{n_{Horizontal}}$	N_1	$N_1 \geq W$
1	1	19233.304	✓
2	1	19233.304	✓
3	0	19233.304	✓
4	0	19233.304	✓

Note: For surfaces 3 and 4, there is a brace on the same axis but on a different surface. Total capacity is equal to the total capacity of all braces on the same axis.

Shearwall Formwork Design

Shearwall Properties

View and properties of shear wall P1, which will be used in the case study can be seen below.

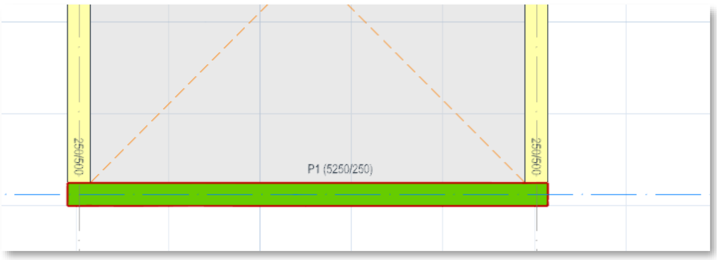

Figure 13: Plan View of the Shearwall

Sheating, joist, and stringer properties will be the same as the ones given in the slab formwork design part.

Load Calculations

Loads are calculated as follows.

Concrete Hydrostatic Pressure Calculation:

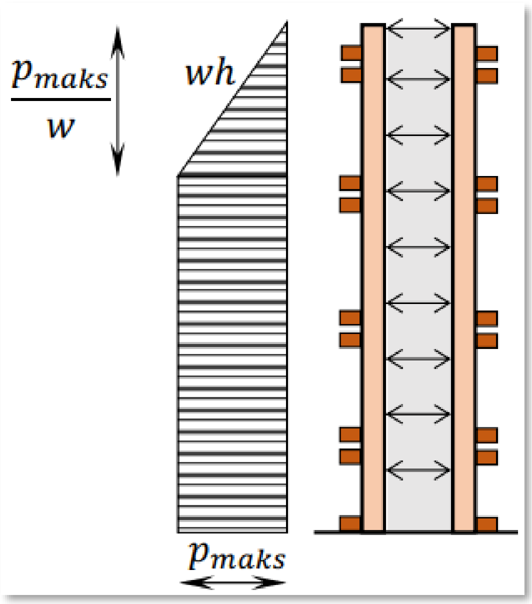

Figure 14: Concrete Hydrostatic Load Diagram

1.	$\gamma_c = 25\ kN\ /\ m^3$
2.	$Concrete\ Class = C30$
3.	$Concrete\ Pouring\ Temperature\ (T) = 20°$
4.	$Total\ pouring\ Duration = 2\ hr$
5.	$Pouring\ Rate\ (R) = \frac{3}{2} = 1.5\ m/hr$
6.	$p_{maks} = 8.5 + \frac{950R}{T+18} = 8.5 + \frac{950\times1.5}{20+18} = 46\ \ [kPa]$

Wind Load Calculations:

Wind load is calculated as per TS-498 Section 11 as follows.

Height(m)	Velocity (m/s)	Q (kN/m2)	C
0	28	0.5	1.6
8	36	0.8	
20	42	1.1	
100	46	1.3	

1.	$Shearwall\ Top\ Elevation = 3\ m$
2.	$Shearwall\ Bottom\ Elevation = -1.1\ m$
3.	$Coefficient\ of\ Suction\ (C_f) = 1.6$
4.	$q = 0.5\ kN/m^2$
5.	$W = C_f\ q\ H\ \ = 1.6 \times 0.5 \times 5.25 =\ 4.2\ kN/m\ acting\ on\ 525\ cm\ section.$
6.	$Total\ Wind\ Load = 4.2 \times 4.1 = 12.6\ kN\ for\ the\ whole\ surface.$
7.	$W = C_f\ q\ H\ \ = 1.6 \times 0.5 \times 0.25 =\ 0.2\ kN/m\ acting\ on\ 25\ cm\ section.$
8.	$Total\ Wind\ Load = 0.2 \times 4.1 = 0.82\ kN\ for\ the\ whole\ surface.$

Joist Spacing Calculations

Joist spacing and the number of joists are calculated as below.

1.	$L_{bk} = \min\left(3.16\sqrt{\frac{f_{el}\,S_l}{p\,b_l\,GK}},\ 0.835\sqrt[3]{\frac{E_l\,I_l}{p\,b_l}},\frac{f_{kl}\,A_l}{0.9\,p\,b_l\,GK}\right)$
2.	$3.16\sqrt{\frac{20\times54000}{0.0585\times1000\times2}} = 303.6\ mm$
3.	$0.835\sqrt[3]{\frac{3350\times486000}{0.0585\times1000}} = 253.04\ mm$
4.	$\frac{5\times18000}{0.9\times0.0585\times1000\times2} = 854.7\ mm$
5.	$Min(303.6,\ 253.04,\ 854.77) = 253.04\ mm$

Surface Number	*Number of Joists*	L_{corner} *(mm)*	*l (mm)*	*b (mm)*	$L_{bk,provided}$ *(mm)*	$l_{bk} \geq l_{bk,provided}$
1	22	0	5250	80	246	✓
2	2	0	250	80	170	✓
3	22	0	5250	80	246	✓
4	2	0	250	80	170	✓

Stringer Spacing Calculations

Stringer spacing and number of stringers are calculated as below.

1.	$L_{ik} = \min\left(3.16\sqrt{\frac{f_{ebk}\,S_{bk}}{p\,L_{bk}\,GK}},\ 0.835\sqrt[3]{\frac{E_{bk}\,I_{bk}}{p\,L_{bk}}},\frac{f_{kbk}\,A_{bk}}{0.9\,p\,L_{bk}\,GK}\right)$
2.	$3.16\sqrt{\frac{24\times452700}{0.0585\times170\times2}} = 2335.5\ mm$
3.	$0.835\sqrt[3]{\frac{7400\times45270000}{0.0585\times170}} = 2696.69\ mm$
4.	$\frac{4\times9280}{0.9\times0.0585\times170\times2} = 2073.62\ \mathrm{mm}$
5.	$Min(2335.5,\ 2696.69,\ 2073.62) = 2073.62\ mm$

Surface Number	*Number of Stringers*	L_{corner} *(mm)*	*l (mm)*	*b (mm)*	$L_{ik,provided}$ *(mm)*	$l_{ik} \geq l_{ik,provided}$
1	3	0	4100	100	2000	✓
2	3	0	4100	100	2000	✓
3	3	0	4100	100	2000	✓
4	3	0	4100	100	2000	✓

Connection Member Spacing Calculations

Connection member spacing and the number of connection members are calculated below.

1.	$L_b = \min\left(3.16\sqrt{\frac{f_{eik}\,S_{ik}}{p\,L_{ik}\,GK}},\ 0.835\sqrt[3]{\frac{E_{ik}\,I_{ik}}{p\,L_{ik}}}, \frac{f_{kik}\,A_{ik}}{0.9\,p\,L_{ik}\,GK}, \frac{N_d}{1.1\,p\,L_{ik}\,GK}\right)$
2.	$N_d = 22000\ N\ (Assumption.)$
3.	$3.16\sqrt{\frac{24\times452700}{0.0585\times1950\times2}} = 689.58\ mm$
4.	$0.835\sqrt[3]{\frac{7400\times4570000}{0.0585\times1950}} = 1195.74\ mm$
5.	$\frac{4\times9280}{0.9\times0.0585\times1950\times2} = 180.77\ mm$
6.	$\frac{22000}{1.1\times0.0585\times1950\times2} = 87.66\ mm$
7.	$Min(689.58,\ 1195.74, 180.77,\ 87.66) = 87.66\ mm$

Surface Number	*Number of Connection Members*	L_{corner} *(mm)*	*l (mm)*	*b (mm)*	$L_{b,provided}$ *(mm)*	$l_b \geq l_{b,provided}$
1	61	0	5250	0	87.5	✓
2	4	0	250	0	83.5	✓
3	61	0	5250	0	87.5	✓
4	4	0	250	0	83.5	✓

Brace Calculations

Brace calculations are presented in this section.

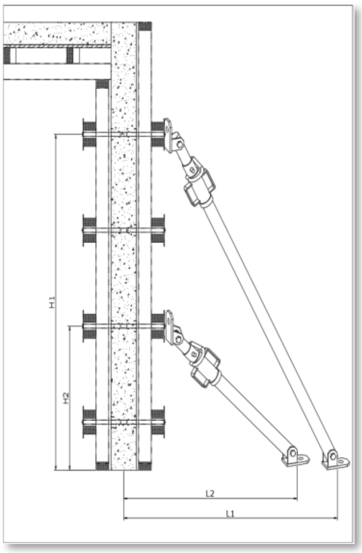

Figure 15: Diagram of Braces Supporting Foundation

1.	$N_{brace} = 272000\ N\ (Assumption.)$
2.	$\alpha = 45.00°\ (Assumption.)$
3.	$N_1 = N_{brace}\cos(\alpha)\,\mathrm{n}_{\mathrm{Horizontal}}$

Surface Number	$n_{Horizontal}$	N_1	$N_1 \geq W$
1	1	19233.304	✓
2	1	19233.304	✓
3	0	19233.304	✓
4	0	19233.304	✓

Note: For surfaces 3 and 4, there is a brace on the same axis but on a different surface. Total capacity is equal to the total capacity of all braces on the same axis.

Creating 2B Formwork Drawings

Formwork detailed drawings can be drawn via ProtaDetails/Formwork section with the user-defined preferences. In order to draw the detailed drawings, right-click on Formwork, which is located in the Details window, and select Draw Formwork Details. Then, the formwork details will be drawn on the specified point.

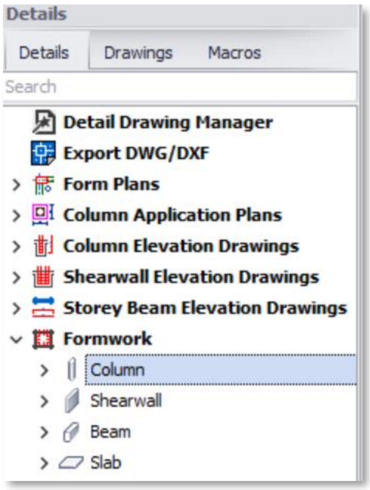

Figure 16: ProtaDetails Structural Tree

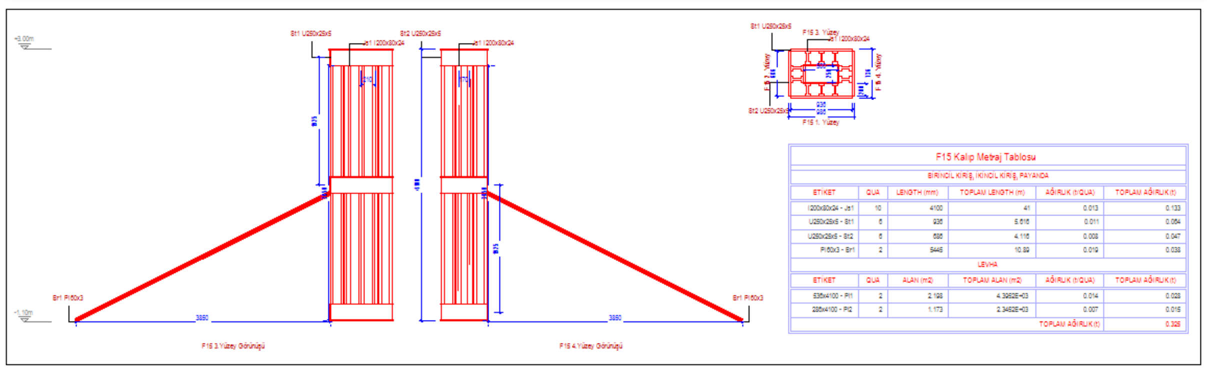

Figure 17: Column 2B Formwork Drawing

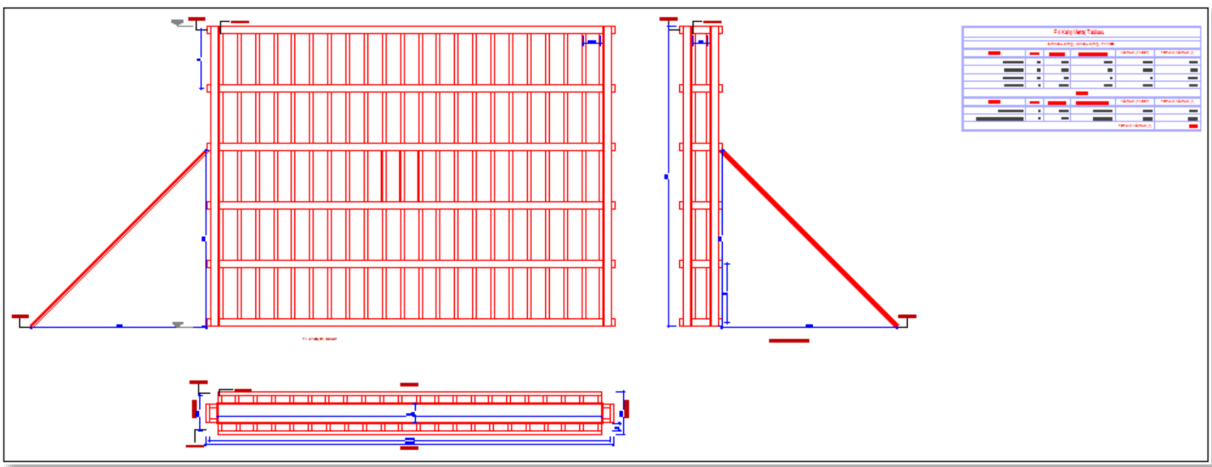

Figure 18: Shearwall 2B Formwork Drawing

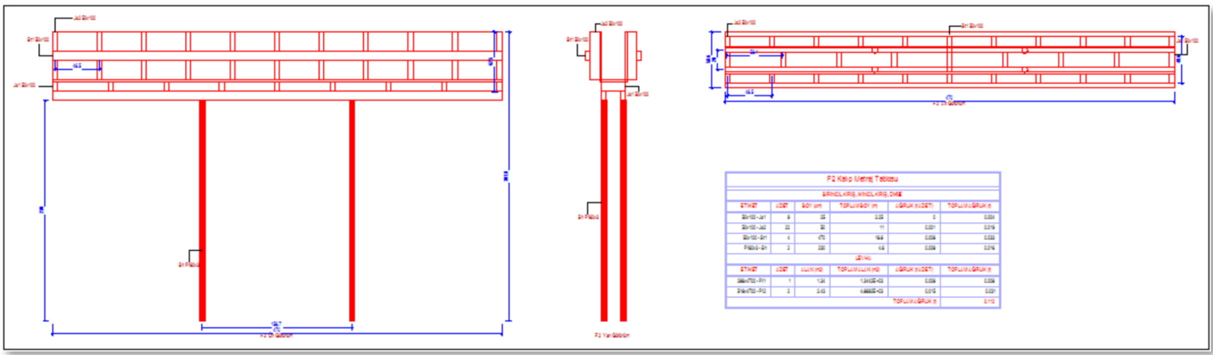

Figure 19: Beam 2B Formwork Drawing

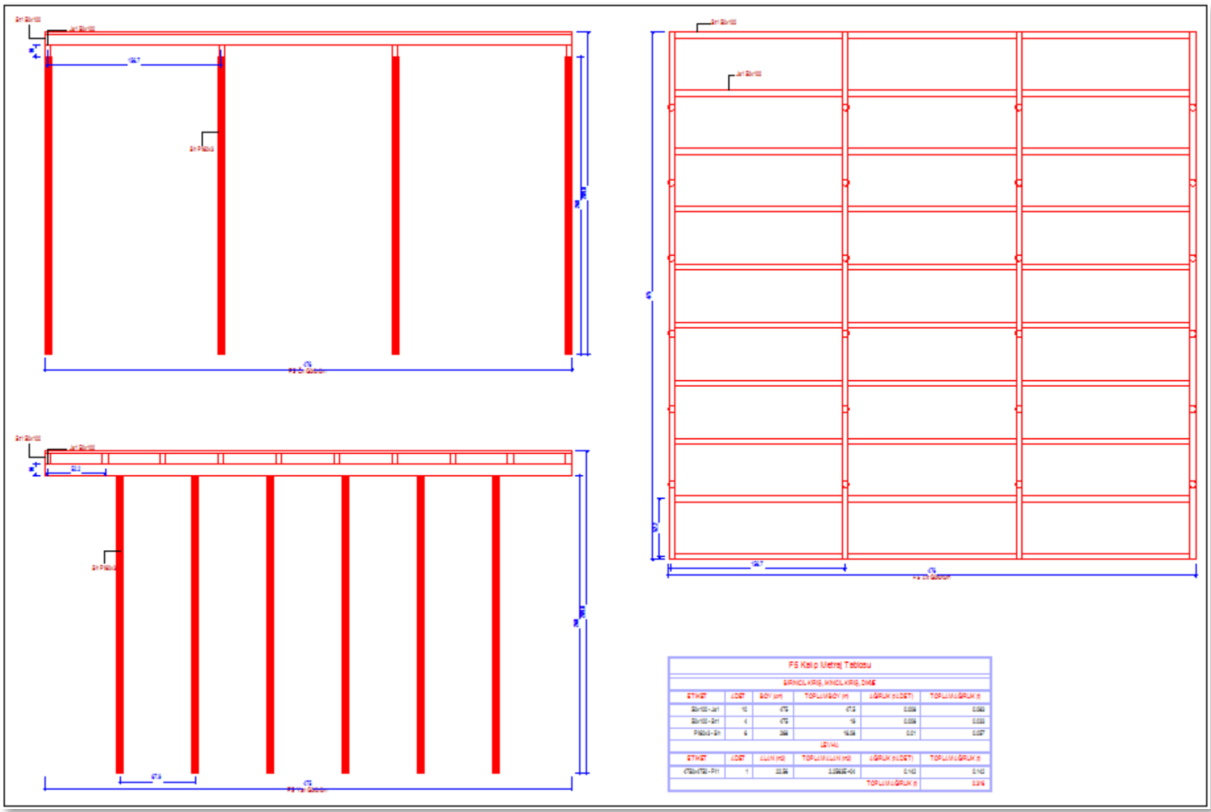

Figure 20: Slab 2B Formwork Drawing

Creating 3B Formwork Model

3B Formwork model can be created from Views/3D Formwork Model. In the 3D Formwork model, the user can filter certain elements and formworks from the 3D model by using the buttons on the ribbon.

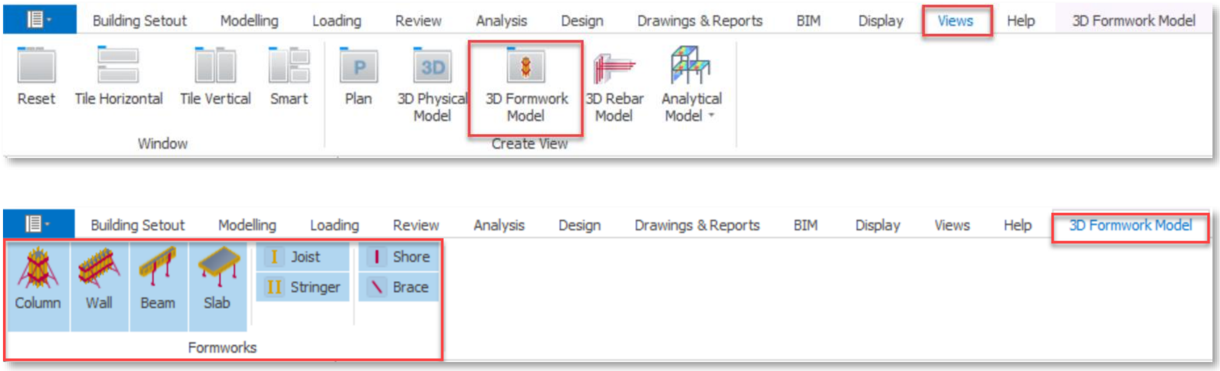

Figure 21: 3B Formwork Model PS2022 Ribbon Buttons

Figure 22: Formwork 3B Model

Thank You…

Thank you for choosing the ProtaStructure Suite product family.

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Our dedicated online support center together with our responsive technical support team is available to help you get the most out of Prota's technology solutions.

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