Ultimate limit state under normal stresses (ACI 318S-14, 22.4)

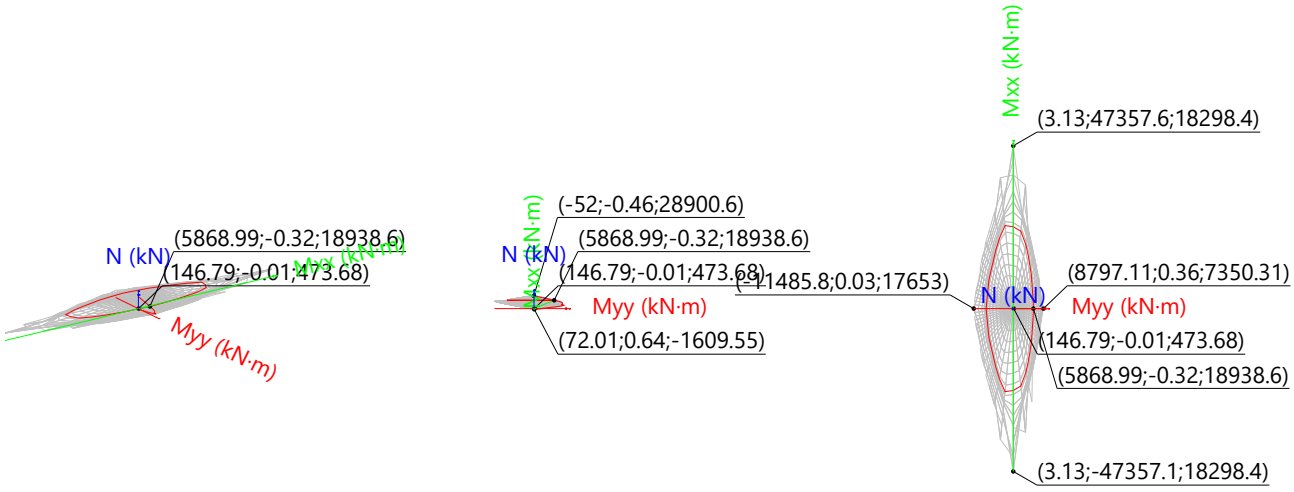
The worst case forces to be withstood from the analysis are produced at "Elevation 49.00 (Base)", in the combination of loadcase "1.4·SW+1.4·DL".

The following criteria must be satisfied:

$$\eta_1 = \sqrt{\frac{P_u^2 + M_{u,x}^2 + M_{u,y}^2}{(\phi \cdot P_n)^2 + (\phi \cdot M_{n,x})^2 + (\phi \cdot M_{n,y})^2}} \leq 1$$

η : ***0.025*** ✓

$P_u \leq \phi \cdot P_{n,max}$ **473.68 kN** ≤ **19745.49 kN** ✓



Capacity volume | View N, M | View Mx, My

Resistance check of the section (η_1)

P_u,M_u are the first order design forces.

P_u: Design normal force. **P_u** : *473.68* kN

M_u: First order design moment. **$M_{u,x}$** : *-0.01* kN·m

$M_{u,y}$: *146.79* kN·m

$\phi \cdot P_n$,$\phi \cdot M_n$ are the forces that cause the section to fail with the same eccentricities as the worst-case design forces.

ϕ**·P_n**: Ultimate axial resistance. ϕ**·P_n** : *18938.59* kN

ϕ**·M_n**: Bending resistance. ϕ**·$M_{n,x}$** : *-0.32* kN·m

ϕ**·$M_{n,y}$** : *5868.99* kN·m

Instability limit status check

In the x-axis:

It shall be permitted to ignore slenderness effects for compression members that satisfy (Article 6.2.5):

$$\frac{k \cdot l_u}{r} \leq 22$$ **1.3** ≤ **22.0** ✓

Where:

kl_u: Effective length. **kl_u** : *3.000* m

r: Radius of gyration of cross section of a compression member. **r** : *237.91* cm

In the y-axis:

It shall be permitted to ignore slenderness effects for compression members that satisfy (Article 6.2.5):

$$\frac{k \cdot l_u}{r} \leq 22$$ **4.5** ≤ **22.0** ✓

Where:

kl_u: Effective length. **kl_u** : *3.000* m

r: Radius of gyration of cross section of a compression member. **r** : *67.20* cm

Design axial strength check

Factored axial force P_u of compression members shall not be taken greater than $\phi \cdot P_{n,max}$ (Article 22.4.2).

$$\phi \cdot P_{n,max} = 0.80 \cdot \phi \cdot \left[0.85 \cdot f'_c \cdot \left(A_g - A_{st}\right) + f_y \cdot A_{st}\right]$$

$\phi \cdot P_{n,max}$: *19745.49* kN

Where:

f'_c: Specified compressive strength of concrete. f'_c : *24.53* MPa

f_y: Specified yield strength of reinforcement. f_y : *420.00* MPa

A_g: Gross area of concrete section. A_g : *17400.00* cm²

A_{st}: Total area of nonprestressed longitudinal reinforcement. A_{st} : *42.58* cm²

Resistance capacity calculation

The calculation of the ultimate resistance capacity of the sections is carried out using the following general hypothesis (Article 22.2.2):

(a) Strength design of members for flexure and axial loads shall be based on satisfaction of applicable conditions of equilibrium and compatibility of strains.

(b) Strain in reinforcement and concrete shall be assumed directly proportional to the distance from the neutral axis.

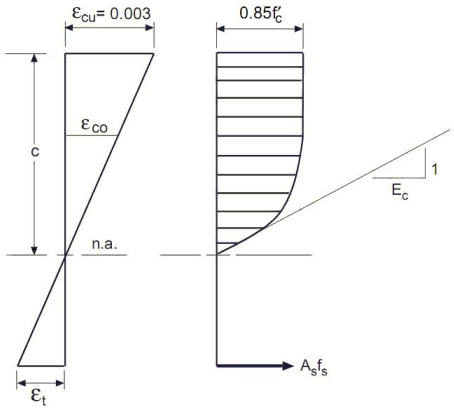
(c) Maximum usable strain at extreme concrete compression fiber shall be assumed equal to 0.003.

(d) Stress in reinforcement below f_y shall be taken as E_s times steel strain. For strains greater than that corresponding to f_y, stress in reinforcement shall be considered independent of strain and equal to f_y.

(e) Tensile strength of concrete shall be neglected in axial and flexural calculations of reinforced concrete.

(f) The relationship between concrete compressive stress distribution and concrete strain shall be assumed to be rectangular, trapezoidal, parabolic, or any other shape that results in prediction of strength in substantial agreement with results of comprehensive tests.

The concrete stress-deformation calculation diagram is of the parabola-rectangle type. The tensile resistance of the concrete is not considered.

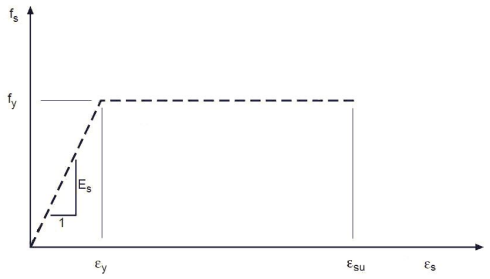


f'_c: Specified compressive strength of concrete. f'_c : *24.53* MPa

ε_{cu}: Maximum usable strain at extreme concrete compression fiber. ε_{cu} : *0.0030*

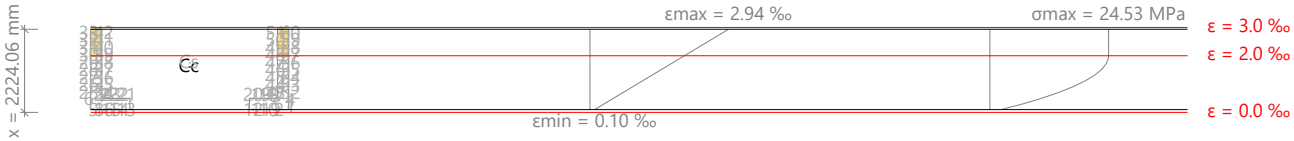
ε_{c0}: Strain at reaching the maximum strength. ε_{c0} : *0.0020*

The following stress-deformation calculation diagram of the steel is adopted for the passive reinforcement.



f_y: Specified yield strength of reinforcement. **f_y** : *420.00* MPa

Ultimate force balance of the section, calculated with the same eccentricities as the worst-case design forces:



Bar	Designation	X Coord. (mm)	Y Coord. (mm)	f_s (MPa)	ε
1	1	-767.68	-2605.71	+37.53	+0.000188
2	2	-767.68	-2394.29	+37.53	+0.000188
3	3	-580.06	-2394.29	+87.07	+0.000435
4	4	-603.88	-2605.71	+80.78	+0.000404
5	5	-791.49	2581.90	+31.25	+0.000156
6	6	-580.06	2581.90	+87.08	+0.000435
7	7	-580.06	2394.29	+87.08	+0.000435
8	8	-791.49	2418.10	+31.25	+0.000156
9	9	-791.49	-2300.00	+31.24	+0.000156
10	10	-791.49	-2100.00	+31.24	+0.000156
11	11	-791.49	-1900.00	+31.24	+0.000156
12	12	-791.49	-1700.00	+31.24	+0.000156
13	29	-791.49	1700.00	+31.25	+0.000156
14	30	-791.49	1900.00	+31.25	+0.000156
15	31	-791.49	2100.00	+31.25	+0.000156
16	32	-791.49	2300.00	+31.25	+0.000156
17	33	-580.06	-2300.00	+87.07	+0.000435
18	34	-580.06	-2100.00	+87.07	+0.000435
19	35	-580.06	-1900.00	+87.07	+0.000435
20	36	-580.06	-1700.00	+87.07	+0.000435
21	53	-580.06	1700.00	+87.08	+0.000435
22	54	-580.06	1900.00	+87.08	+0.000435
23	55	-580.06	2100.00	+87.08	+0.000435
24	56	-580.06	2300.00	+87.08	+0.000435
25	57	-418.04	2605.71	+129.86	+0.000649

Bar	Designation	X Coord. (mm)	Y Coord. (mm)	f_s (MPa)	ε
26	58	-218.04	2605.71	+182.67	+0.000913
27	59	-18.04	2605.71	+235.48	+0.001177
28	60	181.96	2605.71	+288.29	+0.001441
29	61	381.96	2605.71	+341.11	+0.001706
30	62	581.96	2605.71	+393.92	+0.001970
31	63	781.96	2605.71	+420.00	+0.002234
32	64	981.96	2605.71	+420.00	+0.002498
33	65	1181.96	2605.71	+420.00	+0.002762
34	66	-418.04	2394.29	+129.86	+0.000649
35	67	-218.04	2394.29	+182.67	+0.000913
36	68	-18.04	2394.29	+235.48	+0.001177
37	69	181.96	2394.29	+288.29	+0.001441
38	70	381.96	2394.29	+341.11	+0.001706
39	71	581.96	2394.29	+393.92	+0.001970
40	72	781.96	2394.29	+420.00	+0.002234
41	73	981.96	2394.29	+420.00	+0.002498
42	74	1181.96	2394.29	+420.00	+0.002762
43	75	-418.04	-2394.29	+129.86	+0.000649
44	76	-218.04	-2394.29	+182.67	+0.000913
45	77	-18.04	-2394.29	+235.48	+0.001177
46	78	181.96	-2394.29	+288.29	+0.001441
47	79	381.96	-2394.29	+341.10	+0.001705
48	80	581.96	-2394.29	+393.91	+0.001970
49	81	781.96	-2394.29	+420.00	+0.002234
50	82	981.96	-2394.29	+420.00	+0.002498
51	83	1181.96	-2394.29	+420.00	+0.002762
52	84	-418.04	-2605.71	+129.85	+0.000649
53	85	-218.04	-2605.71	+182.67	+0.000913
54	86	-18.04	-2605.71	+235.48	+0.001177
55	87	181.96	-2605.71	+288.29	+0.001441
56	88	381.96	-2605.71	+341.10	+0.001705
57	89	581.96	-2605.71	+393.91	+0.001970
58	90	781.96	-2605.71	+420.00	+0.002234
59	91	981.96	-2605.71	+420.00	+0.002498
60	92	1181.96	-2605.71	+420.00	+0.002762

	Resultant (kN)	e.x (mm)	e.y (mm)
Cc	28231.36	306.52	0.02
Cs	904.94	415.19	-1.31
T	0.00	0.00	0.00

$$P_n = C_c + C_s - T$$ **P_n** : *29136.30* kN

$$M_{n,x} = C_c \cdot e_{cc,y} + C_s \cdot e_{cs,y} - T \cdot e_{T,y}$$ **$M_{n,x}$** : *-0.49* kN·m

$$M_{n,y} = C_c \cdot e_{cc,x} + C_s \cdot e_{cs,x} - T \cdot e_{T,x}$$ **$M_{n,y}$** : *9029.21* kN·m

Where:

C_c: Resultant of concrete compressive forces. **C_c** : *28231.36* kN

C_s: Resultant of steel compressive forces. **C_s** : *904.94* kN

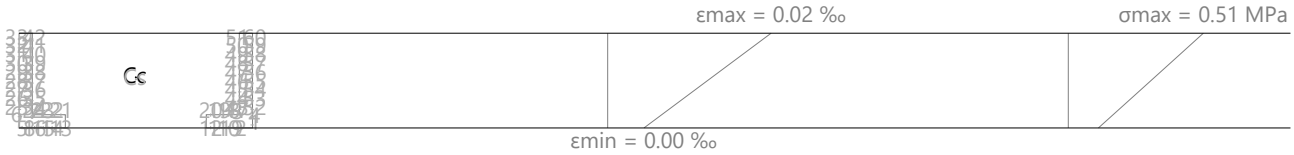
T: Resultant of steel tensile forces. **T** : *0.00* kN

e_{cc}: Eccentricity of the concrete compressive forces in the direction of the X and Y axes. **$e_{cc,x}$** : *306.52* mm

$e_{cc,y}$: *0.02* mm

e_{cs}: Eccentricity of the steel compressive forces in the direction of the X and Y axes.	**$e_{cs,x}$** :	*415.19*	mm
	$e_{cs,y}$:	*-1.31*	mm
e_T: Eccentricity of the steel tensile forces in the direction of the X and Y axes.	**e_T** :	*0.00*	mm
ε_{cmax}: Deformation of the most compressed concrete fibre.	ε_{cmax} :	*0.0029*	
ε_{smax}: Deformation of the steel bar with greatest tension.	ε_{smax} :	*0.0000*	
σ_{cmax}: Stress of the most compressed concrete fibre.	σ_{cmax} :	*24.53*	MPa
σ_{smax}: Stress of the steel bar with greatest tension.	σ_{smax} :	*0.00*	MPa

Worst-case force balance of the section:



Bar	Designation	X Coord. (mm)	Y Coord. (mm)	f_s (MPa)	ε
1	1	-767.68	-2605.71	+1.03	+0.000005
2	2	-767.68	-2394.29	+1.03	+0.000005
3	3	-580.06	-2394.29	+1.31	+0.000007
4	4	-603.88	-2605.71	+1.27	+0.000006
5	5	-791.49	2581.90	+0.99	+0.000005
6	6	-580.06	2581.90	+1.31	+0.000007
7	7	-580.06	2394.29	+1.31	+0.000007
8	8	-791.49	2418.10	+0.99	+0.000005
9	9	-791.49	-2300.00	+0.99	+0.000005
10	10	-791.49	-2100.00	+0.99	+0.000005
11	11	-791.49	-1900.00	+0.99	+0.000005
12	12	-791.49	-1700.00	+0.99	+0.000005
13	29	-791.49	1700.00	+0.99	+0.000005
14	30	-791.49	1900.00	+0.99	+0.000005
15	31	-791.49	2100.00	+0.99	+0.000005
16	32	-791.49	2300.00	+0.99	+0.000005
17	33	-580.06	-2300.00	+1.31	+0.000007
18	34	-580.06	-2100.00	+1.31	+0.000007
19	35	-580.06	-1900.00	+1.31	+0.000007
20	36	-580.06	-1700.00	+1.31	+0.000007
21	53	-580.06	1700.00	+1.31	+0.000007
22	54	-580.06	1900.00	+1.31	+0.000007
23	55	-580.06	2100.00	+1.31	+0.000007
24	56	-580.06	2300.00	+1.31	+0.000007
25	57	-418.04	2605.71	+1.55	+0.000008
26	58	-218.04	2605.71	+1.86	+0.000009
27	59	-18.04	2605.71	+2.16	+0.000011
28	60	181.96	2605.71	+2.46	+0.000012

Bar	Designation	X Coord. (mm)	Y Coord. (mm)	f_s (MPa)	ε
29	61	381.96	2605.71	+2.76	+0.000014
30	62	581.96	2605.71	+3.06	+0.000015
31	63	781.96	2605.71	+3.36	+0.000017
32	64	981.96	2605.71	+3.67	+0.000018
33	65	1181.96	2605.71	+3.97	+0.000020
34	66	-418.04	2394.29	+1.55	+0.000008
35	67	-218.04	2394.29	+1.86	+0.000009
36	68	-18.04	2394.29	+2.16	+0.000011
37	69	181.96	2394.29	+2.46	+0.000012
38	70	381.96	2394.29	+2.76	+0.000014
39	71	581.96	2394.29	+3.06	+0.000015
40	72	781.96	2394.29	+3.36	+0.000017
41	73	981.96	2394.29	+3.67	+0.000018
42	74	1181.96	2394.29	+3.97	+0.000020
43	75	-418.04	-2394.29	+1.55	+0.000008
44	76	-218.04	-2394.29	+1.86	+0.000009
45	77	-18.04	-2394.29	+2.16	+0.000011
46	78	181.96	-2394.29	+2.46	+0.000012
47	79	381.96	-2394.29	+2.76	+0.000014
48	80	581.96	-2394.29	+3.06	+0.000015
49	81	781.96	-2394.29	+3.36	+0.000017
50	82	981.96	-2394.29	+3.67	+0.000018
51	83	1181.96	-2394.29	+3.97	+0.000020
52	84	-418.04	-2605.71	+1.55	+0.000008
53	85	-218.04	-2605.71	+1.86	+0.000009
54	86	-18.04	-2605.71	+2.16	+0.000011
55	87	181.96	-2605.71	+2.46	+0.000012
56	88	381.96	-2605.71	+2.76	+0.000014
57	89	581.96	-2605.71	+3.06	+0.000015
58	90	781.96	-2605.71	+3.36	+0.000017
59	91	981.96	-2605.71	+3.67	+0.000018
60	92	1181.96	-2605.71	+3.97	+0.000020

	Resultant (kN)	e.x (mm)	e.y (mm)
Cc	464.67	310.74	0.00
Cs	9.02	266.63	-0.92
T	0.00	0.00	0.00

$$P_u = C_c + C_s - T$$ **P_u** : *473.68* kN

$$M_{u,x} = C_c \cdot e_{cc,y} + C_s \cdot e_{cs,y} - T \cdot e_{T,y}$$ **$M_{u,x}$** : *-0.01* kN·m

$$M_{u,y} = C_c \cdot e_{cc,x} + C_s \cdot e_{cs,x} - T \cdot e_{T,x}$$ **$M_{u,y}$** : *146.79* kN·m

Where:

C_c: Resultant of concrete compressive forces. **C_c** : *464.67* kN

C_s: Resultant of steel compressive forces. **C_s** : *9.02* kN

T: Resultant of steel tensile forces. **T** : *0.00* kN

e_{cc}: Eccentricity of the concrete compressive forces in the direction of the X and Y axes. **$e_{cc,x}$** : *310.74* mm; **$e_{cc,y}$** : *0.00* mm

e_{cs}: Eccentricity of the steel compressive forces in the direction of the X and Y axes. **$e_{cs,x}$** : *266.63* mm; **$e_{cs,y}$** : *-0.92* mm

e_T: Eccentricity of the steel tensile forces in the direction of the X and Y axes. **e_T** : *0.00* mm

ε_{cmax}: Deformation of the most compressed concrete fibre.	ε_{cmax} :	*0.0000*	
ε_{smax}: Deformation of the steel bar with greatest tension.	ε_{smax} :	*0.0000*	
σ_{cmax}: Stress of the most compressed concrete fibre.	σ_{cmax} :	*0.51*	MPa
σ_{smax}: Stress of the steel bar with greatest tension.	σ_{smax} :	*0.00*	MPa