



### Slenderness Effects for Columns in Non-Sway Frame - Moment Magnification Method (CSA A23.3-19)







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Evaluate slenderness effect for columns in a non-sway frame multistory reinforced concrete building (Q is computed to be much less than 0.05) by designing a two-story high column in the middle of an atrium opening at the second-floor level. The design forces obtained from a first-order analysis are provided in the design data section below. The story height is 4.3 m. it is assumed that the column only resists gravity loads. Compare the calculated results with exact values from <u>spColumn</u> engineering software program from <u>StructurePoint</u>.









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#### Code

Design of Concrete Structures (CSA A23.3-19)

#### References

- Concrete Design Handbook, Fourth Edition, 2016, Cement Association of Canada (CAC), Example 8.1.
- spColumn Engineering Software Program Manual v10.10, STRUCTUREPOINT, 2023
- "<u>Slenderness Effects for Columns in Sway Frame Moment Magnification Method (CSA A23.3-19)</u>" Design Example, <u>STRUCTUREPOINT</u>, 2023

#### **Design Data**

Concrete  $f_c' = 40 \text{ MPa}$   $\rho_c = 2,400 \text{ kg/m}^3$ Steel  $f_y = 400 \text{ MPa}$ Slab:  $h_s = 150 \text{ mm}$ ,  $b_{eff} = 1800 \text{ mm}$ Beams: h = 500 mm,  $b_w = 400 \text{ mm}$ , l = 7 mColumns: h = 500 mm, b = 500 mm

Additional service design forces obtained from first-order analysis will be considered in this example to outline and discuss the evolution of CSA A23.3 provisions in slenderness calculations for non-sway columns where the largest first-order moment,  $M_{2}$ , is less than the minimum moment,  $M_{2,min}$ :

Table 1 – Additional column service load cases						
Lood Coso	Axial Load,	Bending Moment, kN-m				
Load Case	kN	Тор	Bottom			
Dead, D	1,776	48	-8			
Live, L	1,320	30	-5			







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#### 1. Factored Axial Loads and Bending Moments

#### 1.1. Load Combinations - Factored Loads

#### CSA A23.3-19 (Annex C, Table C.1a)

Table 2 - Column factored loads									
CEA A22.2.10	No	Load Combination	Axial Load,	Bending Moment, kN-m		M <sub>Top,ns</sub>	M <sub>Bottom,ns</sub>		
CSA A25.5-19	INO.	Load Combination	kN	Тор	Bottom	kN-m	kN-m		
Annex C	1	1.4D	2,486	67.2	11.2	67.2	11.2		
Table C.1a	2	1.25D + 1.5L	4,200	105.0	17.5	105.0	17.5		

#### 2. Slenderness Effects and Sway or Non-sway Frame Designation

Columns and stories in structures are considered as non-sway frames if the stability index for the story (Q) does not exceed 0.05. <u>CSA A23.3-19 (10.14.4)</u>

The Q value is assumed much less than 0.05. Therefore, the frame is considered as a non-sway frame.

#### 3. Effective Length Factor (k)

$$I_{column} = 0.7 \times \frac{c^4}{12} = 0.7 \times \frac{500^4}{12} = 3.65 \times 10^9 \text{ mm}^4$$

$$E_c = (3,300 \times \sqrt{f_c'} + 6,900) \left(\frac{\gamma_c}{2,300}\right)^{1.5}$$

$$E_c = (3,300 \times \sqrt{40} + 6,900) \left(\frac{2,400}{2,300}\right)^{1.5} = 29,602 \text{ MPa}$$
For solumn being designed.

For column being designed:

$$\frac{E_c \times I_{column}}{l_c} = \frac{29,602 \times 3.65 \times 10^9}{8,600} = 1.25 \times 10^{10} \text{ N-mm}$$

For other columns:

$$\frac{E_c \times I_{column}}{l_c} = \frac{29,602 \times 3.65 \times 10^9}{4,300} = 2.51 \times 10^{10} \text{ N-mm}$$

For beams framing into the columns:

$$\frac{E_b \times I_{beam}}{l_b} = \frac{29,602 \times 2.69 \times 10^9}{7,000} = 1.14 \times 10^{10} \text{ N-mm}$$

Where:

spcolumn

## $I_{beam} = 0.35 \times 7.698 \times 10^9 = 2.694 \times 10^9 \text{ mm}^4$

#### CSA A.23.3-19 (10.14.1.2)





$$\Psi_{R} = \Psi_{A} = 1.652$$

Using the following figure  $\rightarrow k = 0.835$  for the exterior column.



Figure 5 – Effective Length Factor (k) (Non-Sway Frame)

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#### 4. Check if Slenderness can be Neglected

CSA A23.3-19 allows to neglect the slenderness in a non-sway frame if:

$$\frac{k \times l_{u}}{r} \leq \frac{25 - 10 \left(\frac{M_{1}}{M_{2}}\right)}{\sqrt{\frac{P_{f}}{f_{c}^{\prime} \times A_{g}}}}$$

$$r = \sqrt{\frac{I_{g}}{A_{g}}} = \sqrt{\frac{c^{2}}{12}} = \sqrt{\frac{500^{2}}{12}} = 144.34 \text{ mm}$$

$$\frac{k \times l_{u}}{r} = \frac{0.835 \times (8,600 - 500)}{144.34} = 46.86$$

$$\frac{k \times l_{u}}{r} \leq \frac{25 - 10 \left(\frac{M_{1}}{M_{2}}\right)}{\sqrt{\frac{P_{f}}{f_{c}^{\prime} \times A_{g}}}}$$

$$CSA \ A23.3 - 19 \ (Eq. \ 10.16)$$

per CSA A23.3-19:

- $M_1/M_2$  is not taken less than -0.5.
- $M_1/M_2$  shall be taken positive if the member is bent in single curvature and
- shall be taken as 1.0 if M<sub>2</sub> is less than M<sub>2,min</sub>

Check minimum moment:

$$(M_2)_{\min} = P_f (15 + 0.03h)$$
  
 $(M_2)_{\min} = 4,200 \times (15 + 0.03 \times 500) / 1,000 = 126.00 \text{ kN-m} > M_2 = 105.00 \text{ kN-m}$ 

Since  $M_2 < M_{2,min}$ ,  $M_1/M_2$  ratio shall be taken as 1.0.

CSA A23.3-19 (10.15.2)

<u>CSA A23.3-19 (10.15.3.1)</u>

$$\frac{M_1}{M_2} = 1.0$$

$$\frac{25 - 10 \left(\frac{M_1}{M_2}\right)}{\sqrt{\frac{P_f}{f_c' \times A_g}}} = \frac{25 - 10(1.0)}{\sqrt{\frac{4,200 \times 1,000}{40 \times (500 \times 500)}}} \frac{25 - 10}{0.648} = 23.15$$

$$\frac{k \times l_u}{r} = 46.86 > \frac{25 - 10 \left(\frac{M_1}{M_2}\right)}{\sqrt{\frac{P_f}{f_c' \times A_g}}} = 23.15 \quad \therefore \text{ slenderness can't be neglected.}$$

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Where:

## There are two options for calculating the effective flexural stiffness of slender concrete columns (EI)eff. The first equation provides accurate representation of the reinforcement in the section and will be used in this example and is also used by the solver in spColumn. Further comparison of the available options is provided in "Effective

#### 5.1. Calculation of Critical Load (Pc)

 $(EI)_{eff} = \begin{cases} (a) \frac{0.2E_c I_g + E_s I_{st}}{1 + \beta_d} \\ (b) \frac{0.4E_c I_g}{1 + \beta_s} \end{cases}$ 

$$r = \sqrt{\frac{I_g}{A_g}} = \sqrt{\frac{500^4 / 12}{500^2}} = 144.34 \text{ mm}$$
 CSA A23.3-19 (10.14.2)

With 12 - 25M reinforcement equally distributed on all sides and 500 mm  $\times$  500 mm column section

$$I_{\rm st} = 0.176 \times \frac{12 \times 500}{100} \times 500 \times 500^3 \times 0.75^2 = 1.485 \times 10^{-10}$$

$$\beta_d = \frac{P_{f,sustained}}{P_f} = \frac{2,220}{4,200} = 0.529$$

$$(EI)_{eff} = \frac{0.2E_c I_g + E_s I_{st}}{1 + \beta_d}$$
CSA A23.3-19 (Eq. 10-19)

5. Moment Magnification - Non-Sway Frame

$$M_{c} = \frac{C_{m}M_{2}}{1 - \frac{P_{f}}{\phi_{m}P_{c}}} \ge M_{2}$$
CSA A23.3-19 (10.15.3.1)

Where:

 $C_m = 0.6 + 0.4 \frac{M_1}{M_2} \ge 0.4$ CSA A23.3-19 (10.15.3.2)

And, the member resistance factor would be  $\phi_m = 0.75$ 

 $P_{c} = \frac{\pi^{2} \left( EI \right)_{eff}}{\left( kl_{u} \right)^{2}}$ CSA A23.3-19 (Eq. 10.18)

Flexural Stiffness for Critical Buckling Load of Concrete Columns" technical note.

$$I_{st} = 0.176 \times \rho_t \times b \times h^3 \times \gamma^2$$

 $8 \text{ mm}^4$  $500 \times 500$ 

CSA A23.3-19 (10.15.3.1)

CSA A23.3-19 (10.15.3.1)

Concrete Design Handbook (Table 8.2(b))







$$(EI)_{eff} = \frac{0.2 \times (29,602) \times (5.21 \times 10^9) + (200,000) \times (1.485 \times 10^8)}{1+0.529} = 3.96 \times 10^{13} \text{ N-mm}^2$$

$$P_c = \frac{\pi^2 (EI)_{eff}}{(kl_u)^2}$$

$$P_c = \frac{\pi^2 \times (3.96 \times 10^{13})}{(kl_u)^2} = 8,544.34 \text{ kN}$$

$$=\frac{1}{(0.835 \times (8.600 - 500))^2} = 0$$

#### 5.2. Calculation of Magnified Moment (Mc)

$$C_m = 0.6 + 0.4 \frac{M_1}{M_2} \ge 0.4$$
   
CSA A23.3-19 (10.15.3.2)

CSA A23.3-04, clause 10.15.3.1 stated that " $M_2$  in Equation 10.16 shall not be taken as less than  $P_f(15+0.03h)$  about each axis separately."

CSA A23.3-14, clause 10.15.3.1 stated that " $M_2$  in Equation 10.17 shall not be taken as less than  $P_f(15+0.03h)$ about each axis separately with the member bent in single curvature with  $C_m$  taken as 1.0."

The CSA A23.3-14, clause 10.15.3.1 provides unclear guidance implying the M<sub>2</sub> shall not be taken less than the minimum moment,  $P_f(15+0.03h)$  with members bent in single curvature only. This provision is revised entirely and clarified in CSA A23.3-19 as follows to consistently require C<sub>m</sub> = 1.0 in all cases where M<sub>2,min</sub> exceeds M<sub>2</sub>.

CSA A23.3-19, clause 10.15.3.1 states that " $M_2$  in Equation 10.17 shall not be taken as less than  $M_{2,min}$  about each axis separately. <u>If  $M_{2,min}$  exceeds  $M_2$ ,  $C_m$  shall be taken as equal to 1.0."</u>

Check minimum moment:

CSA A23.3-19 (10.15.3.1)

 $(M_2)_{\min} = P_f (15 + 0.03h) = 126.00 \text{ kN-m} > M_2 = 105.00 \text{ kN-m}$ 

Therefore,  $C_m = 1.0$ 

<u>CSA A23.3-19 (10.15.3.1)</u>

$$M_{c} = \frac{C_{m}M_{2}}{1 - \frac{P_{f}}{\phi_{m}P_{c}}} \ge M_{2}$$
CSA A23.3-19 (Eq. 10.17)

$$M_{c} = \frac{1.0 \times 126.00}{1 - \frac{4,200}{0.75 \times 8,544.34}} = \frac{1.0 \times 126}{1 - 0.655} = 2.902 \times 126.00 = 365.65 \text{ kN-m} \ge 126.00 \text{ kN-m}$$

The slenderness effects resulted in a 248% increase of the first-order moment.





#### 6. Column Design

Based on the factored axial loads and magnified moments considering slenderness effects, the capacity of the assumed column section (500 mm  $\times$  500 mm with 12 – 25M bars distributed all sides equal) will be checked and confirmed to finalize the design. A column interaction diagram will be generated using strain compatibility analysis, the detailed procedure to develop column interaction diagram can be found in "Interaction Diagram - Tied Reinforced Concrete Column (CSA A23.3-19)" example.



Figure 6 – Designed Column Interaction Diagram



#### 7. Column Design - spColumn Software

<u>spColumn</u> is a StructurePoint software program that performs the analysis and design of reinforced concrete sections subjected to axial force combined with uniaxial or biaxial bending. Using the provisions of the Strength Design Method and Unified Design Provisions, slenderness considerations are used for moment magnification due to second order effect (P-Delta) for sway and non-sway frames.

For this column section, investigation mode is used, service loads are defined, and slenderness effects are considered using CSA A23.3-19 provisions.



Figure 7 – spColumn Interface

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Figure 8 – spColumn Model Editor



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sp	Sler	nderness						×
≣↓	~	✓ Columns Design Column - X Avis	Design Column					
=↑		Design Column - Y Axis Columns Above/Below	Design column clear height (Ix)	8.1	m			
	~	<ul> <li>✓ Beams</li> <li>X - Beams</li> <li>Y - Beams</li> <li>✓ Properties</li> </ul>	Sway Criteria					
	~		Nonsway frame	(Σ Pc) / (Pc)				
		Slenderness Factors	Sway frame	(Σ Pu) / (Pu)				
			Effective Length Factors					
			Compute 'k' factors	End conditions:	~			
			Input 'k' factors      k(ns)     0.834505			Ď	Ĭ	
			k(s) 1.498917	•	0	0	O py to Y -	O Axis
					0	K	С	ancel

Figure 9 – Defining Slenderness (spColumn)

Structure Point

CONCRETE SOFTWARE SOLUTIONS



sp	Slen	derness				×
≣↓ =↑	*	Columns Design Column - X Axis	Columns Above/Below		.v	
	*	Design Column - Y Axis Columns Above/Below Beams X - Beams Y - Beams Properties Slenderness Factors	Copy to ↓ Column Rectau Height(c/c) Width (W) Depth (D) f'c Ec ✔	ngular    4.3  M  500  mm  500  mm  29601.55  MPa		nn - Above
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			Depth (D)	500 mm	i ↓ <sup>±</sup>	Ч.
			f'c	40 MPa	Li t	ŧ
		Ec 🗸	29601.55 MPa			
					ОК	Cancel

Figure 10 – Defining Columns Above / Below (spColumn)

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Figure 11 – Defining Beams in X - Direction (spColumn)

spcolumn



CONCRETE SOFTWARE SOLUTIONS



sp	Loads							—		×
≣↓	Ƴ Lo	ads Factored Loads	Service L	pads						
-1		Service Loads	Load	Case	Р	Мх (Тор)	Mx (Bot)	Му (Тор)	My (Bo	it)
	~ м	odes (No Loads) Axial Load Points	Nam	e	kN	kNm	kNm	kNm	kNr	m
			Dead		1776	48	-8	0		0
			Live		1320	30	-5	0		0
			Wind		0	0	0	0		0
			EQ		0	0	0	0		0
			Snow		0	0	0	0		0
			+ New	×	Delete 🛛 🔬 Clear	≣× Remove Dup	plicates	Impor	t / Export	
			No.	[P, M	x (Top), Mx (Bot), I	My (Top), My (Bot	t)] for each case			•
	Pc (Top	by My Mx My Mx My Mx								4
								ОК	Cancel	

Figure 12 – Defining Loads / Modes (spColumn)



CONCRETE SOFTWARE SOLUTIONS



sp	Defi	nitions									×
≣↓	~	Properties Concrete	Load Com	binations							
-T		Reinforcing Steel	+ New	× Delete	⊖ Defau	lt					
		Reduction Factors Design Criteria	Comb	o Dead	Live	Wind	EQ	Snow			
		Bar Set	>	U1 1.4	0	0	0	0			
		Load Cases Load Combinations									
									ОК	С	ancel

Figure 13 – Defining Load Combinations (spColumn)



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Figure 14 - Column Section Interaction Diagram about X-Axis (spColumn)







spColumn v10.10 (TM) Computer program for the Strength Design of Reinforced Concrete Sections Copyright - 1988-2023, STRUCTUREPOINT, LLC. All rights reserved



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#### 1. General Information

File Name	E:\StructureP\Slenderness-Non- Sway-CSA-19.colx		
Project	Slenderness-Non-Sway		
Column	Interior		
Engineer	StructurePoint		
Code	CSA A23.3-19		
Bar Set	CSA G30.18		
Units	Metric		
Run Option	Investigation		
Run Axis	X - axis		
Slenderness	Considered		
Column Type	Structural		
Capacity Method	Moment capacity		

#### 2. Material Properties

#### 2.1. Concrete

Туре	Standard
f'c	40 MPa
Ec	29601.6 MPa
f <sub>c</sub>	31.6 MPa
٤ <sub>u</sub>	0.0035 mm/m
β1	0.87

#### 2.2. Steel

Туре	Standard	
f <sub>y</sub>	400	MPa
Es	200000	MPa
ε <sub>ty</sub>	0.002	mm/mm

#### 3. Section

#### 3.1. Shape and Properties

Туре	Rectangular	
Width	500	mm
Depth	500	mm
Ag	250000	mm <sup>2</sup>
l <sub>x</sub>	5.20833e+009	mm <sup>4</sup>
l <sub>y</sub>	5.20833e+009	mm <sup>4</sup>
r <sub>x</sub>	144.338	mm
r <sub>y</sub>	144.338	mm
Xo	0	mm
Yo	0	mm





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#### 3.2. Section Figure



Figure 1: Column section

#### 4. Reinforcement

#### 4.1. Bar Set: CSA G30.18

Bar	Diameter	Area	Bar	Diameter	Area	Bar	Diameter	Area
	mm	mm <sup>2</sup>		mm	mm <sup>2</sup>		mm	mm <sup>2</sup>
 #10	11.30	100.00	#15	16.00	200.00	#20	19.50	300.00
#25	25.20	500.00	#30	29.90	700.00	#35	35.70	1000.00
#45	43.70	1500.00	#55	56.40	2500.00			

#### 4.2. Confinement and Factors

Confinement type	Tied
For #55 bars or less	#10 ties
For larger bars	#15 ties
Material Resistance Factors	
Axial compression, (a)	0.8
Steel (¢s)	0.85
Concrete (¢c)	0.65
Minimum dimension, h	500 mm

#### 4.3. Arrangement

Pattern	All sides equal		
Bar layout	Rectangular		
Cover to	Longitudal bars		
Clear cover	50 mm		





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Bars	12 #25		
Total steel area, A <sub>s</sub>	6000	mm <sup>2</sup>	
Rho	2.40	%	
Minimum clear spacing	100	mm	

#### 5. Loading

5.1. Load Cases

Case	Туре	Sustained Load
		%
A	Dead	100
В	Live	0
С	Wind	0
D	EQ	0
E	Snow	0

#### 5.2. Load Combinations

	Combination	Dead	Live	Wind	EQ	Snow
_	U1	1.400	0.000	0.000	0.000	0.000
	U2	1.250	1.500	0.000	0.000	0.000

#### 5.3. Service Loads

No.	Load Case	Axial Load	Axial Load Mx @ Top	Mx @ Bottom	Му @ Тор	My @ Bottom	
		kN	kN	kNm	kNm	kNm	kNm
1	Dead	1776.00	48.00	-8.00	0.00	0.00	
1	Live	1320.00	30.00	-5.00	0.00	0.00	
1	Wind	0.00	0.00	0.00	0.00	0.00	
1	EQ	0.00	0.00	0.00	0.00	0.00	
1	Snow	0.00	0.00	0.00	0.00	0.00	

#### 6. Slenderness

#### 6.1. Sway Criteria

X-Axis Non-sway column

#### 6.2. Columns

Column	Axis	Height	Width	Depth/Dia.	l	f'c	Ec
		m	mm	mm	mm <sup>4</sup>	MPa	MPa
Design	х	8.1	500	500	5.20833e+009	40	29601.6
Above	х	4.3	500	500	5.20833e+009	40	29601.6
Below	х	4.3	500	500	5.20833e+009	40	29601.6

#### 6.3. X - Beams

Beam	Length	Width	Depth	1	f' <sub>c</sub>	Ec
	m	mm	mm	mm <sup>4</sup>	MPa	MPa
Above Left	7	740	500	7.69761e+009	40	29601.6
Above Right	7	740	500	7.69761e+009	40	29601.6
Below Left	7	740	500	7.69761e+009	40	29601.6
Below Right	7	740	500	7.69761e+009	40	29601.6





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#### 7. Moment Magnification 7.1. General Parameters

Factors	Code defaults
Stiffness reduction factor, $\phi_K$	0.75
Cracked section coefficients, cl(beams)	0.35
Cracked section coefficients, cl(columns)	0.7
$0.2 E_c I_g + E_s I_{se}$ (X-axis)	6.05e+010 kNmm <sup>2</sup>
Minimum eccentricity, exmin	30.00 mm
k'	$(P_{t} / (f_{a}^{*}A_{a}))^{0.5}$

#### 7.2. Effective Length Factors

Axis	$\Psi_{top}$	$\Psi_{\text{bottom}}$	k (Nonsway)	k (Sway)	kl <sub>u</sub> /r
X	1.652	1.652	0.835	(N/A)	46.84

#### 7.3. Magnification Factors: X - axis

Load Combo			Ends		Along Length							
		∑Pr	Pc	∑P₀	$\beta_{ds}$	δs	Pf	k'l <sub>u</sub> /r	Pc	$\beta_{dns}$	Cm	δ
		kN	kN	kN			kN		kN			
1	U1	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)	2486.40	(N/A)	6530.83	1.000	1.000	2.031
1	U2	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)	4200.00	(N/A)	8545.02	0.529	1.000	2.902

#### 8. Factored Moments

NOTE: Each loading combination includes the following cases: Top - At column top Bot - At column bottom

#### 8.1. X - axis

Load			1	<sup>st</sup> Order				2 <sup>nd</sup> Order		Ratio
Combo			M <sub>ns</sub>	Ms	Mr	M <sub>min</sub>	Mi		Mc	2 <sup>nd</sup> /1 <sup>st</sup>
			kNm	kNm	kNm	kNm		kNm	kNm	
1	U1	Тор	67.20	(N/A)	67.20	74.59	M <sub>2</sub> =	67.20	151.49	(N/A)
1	U1	Bot	11.20	(N/A)	11.20	74.59	M1=	11.20	151.49	(N/A)
1	U2	Тор	105.00	(N/A)	105.00	126.00	M <sub>2</sub> =	105.00	365.59	(N/A)
1	U2	Bot	17.50	(N/A)	17.50	126.00	M1=	17.50	365.59	(N/A)

#### 9. Control Points

About	Point	Р	X-Moment	Y-Moment	NA Depth	d <sub>t</sub> Depth	ε <sub>t</sub>
		kN	kNm	kNm	mm	mm	
Х	@ Max compression	7051.8	0.00	0.00	1021	437	-0.00200
х	@ Allowable comp.	5641.4	267.94	0.00	489	437	-0.00037
Х	@ $f_s = 0.0$	5015.8	363.79	0.00	437	437	0.00000
Х	@ $f_s = 0.5 f_y$	3633.5	505.90	0.00	340	437	0.00100
Х	@ Balanced point	2546.6	583.19	0.00	278	437	0.00200
X	@ Pure bending	0.0	398.46	0.00	104	437	0.01124
X	@ Max tension	-2040.0	0.00	0.00	0	437	9.99999
-X	@ Max compression	7051.8	0.00	0.00	1021	437	-0.00200
-X	@ Allowable comp.	5641.4	-267.94	0.00	489	437	-0.00037
-X	@ f <sub>s</sub> = 0.0	5015.8	-363.79	0.00	437	437	0.00000
-X	@ $f_s = 0.5 f_y$	3633.5	-505.90	0.00	340	437	0.00100
-X	@ Balanced point	2546.6	-583.19	0.00	278	437	0.00200
-X	@ Pure bending	0.0	-398.46	0.00	104	437	0.01124





STRUCTUREPOINT - spColumn v Licensed to: StructurePoint, LLC. L E:\StructurePoint\spColumn\Slend	10.10 (TM) .icense ID: 00000-0000000- erness-Non-Swav-CSA-19.(	-4-20FC1-20FC1 colx				Page   <b>7</b> 8/7/2023 10:51 AM
About Point	P	X-Moment	Y-Moment	NA Depth	d. Denth	F.
About Foint	kN	kNm	kNm	mm	mm	-1

0.00

0.00

437

0

9.99999

# **10. Factored Loads and Moments with Corresponding Capacity Ratios** NOTE: Calculations are based on "Moment Capacity" Method. Each loading combination includes the following cases: Top - At column top Bot - At column bottom

-2040.0

-X @ Max tension

No. Load				Demand		Capacit	Y	Parameters a	Capacity	
Combo			Pr	M <sub>fx</sub>	Pr	M <sub>rx</sub>	NA Depth	ε <sub>t</sub>	Ratio	
				kN	kNm	kN	kNm	mm		
1	1	U1	Тор	2486.40	151.49	2486.40	583.06	274	0.00209	0.26
2	1	U1	Bot	2486.40	151.49	2486.40	583.06	274	0.00209	0.26
3	1	U2	Тор	4200.00	365.59	4200.00	455.21	379	0.00054	0.80
4	1	U2	Bot	4200.00	365.59	4200.00	455.21	379	0.00054	0.80





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#### 11. Diagrams 11.1. PM at θ=0 [deg]

• •	• • •									
	Y									
	+×									
•	•					1.5E+0	04 T P [kN]			
•										
50	00 x 500 mm									
				fs=0					fs=0	
General Informatio	n Olandarraa Nan Ourau				(Pmax)			(Pma	x	
Project	Siendemess-Non-Sway	fs=0.5	5fv	1				`/		fs=0.5fv
Engineer	StructurePoint			1	fs=0		-	fs=(		le elely
Code	CSA A23 3-19		f.	-0.56			-	X	fe=0 55	
Bar Set	CSA G30 18		1	5-0.51y	$\checkmark$			+8	13-0.01y	
Units	Metric		1							1
Run Option	Investigation		1	(			+2			
Run Axis	X - axis								1 1	
Slenderness	Considered			1		_		/	M [k	(Nm]
Column Type	Structural		-	1		<hr/>		1	-	1
Capacity Method	Moment capacity		-800			and and a second			8	00
					(D. 1.)		and a			
f.	40 MPa				(Pmin)			(Pmir	1)	
E.	29601.6 MPa									
						500	n 1			
f.	400 MPa		DM	at 0.0 f	daal	-500	J0 —			
És.	200000 MPa		FIV	at 0.0 [	uegj					
Section	Destensular									
Type Width	Fectangular									
Depth	500 mm	No.	Loa	ad Comb	0	Pr	M <sub>fx</sub>	P,	Mrx	Capacity
Δ	250000 mm <sup>2</sup>					kN	kNm	kN	kNm	Ratio
l.	5.20833e+009 mm <sup>4</sup>	3	1	U2	Top	4200.0	365.6	4200.00	455.21	0.80
l.	5.20833e+009 mm <sup>4</sup>	4	1	U2	Top	4200.0 2486.4	365.6	4200.00 2486 40	455.21 583.06	0.80
,		2	1	U1	Bot	2486.4	151.5	2486.40	583.06	0.26
Reinforcement	All states sound									
Pattern	All sides equal								Max. Capac	tity Ratio: 0.80
Cover to	Rectangular									
Clear cover	50 mm									
Bars	12 #25									
	TE HEO									
Confinement type	Tied									
Total steel area, As	6000 mm <sup>2</sup>									
Rho	2.40 %									
Min. clear spacing	100 mm									





#### 8. Summary and Comparison of Design Results

Analysis and design results from the hand calculations above are compared with the exact values obtained from <u>spColumn</u> model.

Table 3 – Parameters for Moment Magnification of Column in Non-Sway Frame											
	k EI, N-mm <sup>2</sup>		P <sub>f</sub> , kN P <sub>c</sub> , kN		Magnification Factor	M <sub>2,min</sub> , kN-m	M <sub>c</sub> , kN-m				
Hand	0.835	6.05×10 <sup>13</sup>	4,200.00	8,544.34	2.902	126.00	365.65				
<u>spColumn</u>	0.835	6.05×10 <sup>13</sup>	4,200.00	8,545.02	2.902	126.00	365.59				

All the results of the hand calculations illustrated above are in precise agreement with the automated exact results obtained from the <u>spColumn</u> program.



#### 9. Conclusions & Observations

The analysis of the reinforced concrete section performed by <u>spColumn</u> conforms to the provisions of the Strength Design Method and Unified Design Provisions with all conditions of strength satisfying the applicable conditions of equilibrium and strain compatibility and includes slenderness effects using moment magnification method for sway and nonsway frames.

CSA A23.3 provides multiple options for calculating values of  $(EI)_{eff}$  and magnification factor leading to variability in the determination of the adequacy of a column section. Engineers must exercise judgment in selecting suitable options to match their design condition. The <u>spColumn</u> program utilizes the exact methods whenever possible and allows user to override the calculated values with direct input based on their engineering judgment wherever it is permissible.

In the case where the larger first-order moment (M<sub>2</sub>) is less than the minimum moment (M<sub>2,min</sub>) for a column in non-sway frame, significantly higher magnification is expected when using CSA A23.3-19 as compared to the prior editions of CSA A23.3. The first-order moment increased by 248% (compared to 93.5% increase when using CSA A23.3-14)<sup>\*</sup> due to the adjustment on clause 10.15.3.1 in CSA A23.3-19 where C<sub>m</sub> shall be taken as equal to 1.0 when M<sub>2,min</sub> exceeds M<sub>2</sub>. [M<sub>2</sub> = 105.00 kN-m, M<sub>2,min</sub> = 126.00 kN-m, M<sub>c</sub> = 365.60 kN-m (CSA A23.3-19) and M<sub>c</sub> = 243.80 kN-m (CSA A23.3-14)<sup>\*</sup>]

Detailed calculations are shown in "<u>Slenderness Effects for Columns in Non-Sway Frame - Moment Magnification</u> <u>Method (CSA A23.3-14)</u>" design example.