



CIVE 3204 Introduction to Structural Design (Fall 2014)

Solution for Assignment #4

Question 1:

Read the live loads from Table 4.1.5.3 of NBCC 2010 as follows:

Level	Occupancy	Live Load (kN/m ²)
6	roof	1
5 thru 3	office	2.4
2 thru 1	retail	4.8
-1 (basement)	garage	2.4

Tributary area of column B3 at each floor = $6 \times 6 = 36 \text{ m}^2$

$$\text{Type B: LLRF} = 0.3 + \sqrt{\frac{9.8}{B}}$$

$$\text{Type A: LLRF} = 0.5 + \sqrt{\frac{20}{A}}$$

Alternate/ Method 1:

Un-factored axial load due to live load only acting on column B3

a) Between floor level 1 and 2 (i.e. under level 2)

$$P_{LL,Reduced} = (36 \times 1 + 36 \times 4.8) \times 1 + (3 \times 36 \times 2.4) \left(0.3 + \sqrt{\frac{9.8}{3 \times 36}} \right) = 364.6 \text{ kN}$$

$$P_{LL,Reduced} = \mathbf{365 \text{ kN}}$$

b) Between floor level -1 and 1 (i.e. under level 1)

$$P_{LL,Reduced} = (36 \times 1) \times 1 + (3 \times 36 \times 2.4) \left(0.3 + \sqrt{\frac{9.8}{3 \times 36}} \right) +$$

$$(2 \times 36 \times 4.8)(1) = 537.4 \text{ kN}$$

$$P_{LL,Reduced} = \mathbf{537 \text{ kN}}$$

Alternate/ Method 2 (Table based):

Level	Occupancy	Tributary Area (m ²)	Live Load Intensity (kN/m ²)	Live Load (kN)			Cumulative Live Load (kN)			Cumulative Tributary Area (m ²)			LLRF		Reduced Live Load (kN)			Total Reduced Live Load (kN)
				Other	Type B	Type A	Other	Type B	Type A	Other	Type B	Type A	Type B	Type A	Other	Type B	Type A	
6	roof	36	1	36			36	0	0	36	0	0	1	1	36	0	0	36.0
5	office	36	2.4		86.4		36	86.4	0	36	36	0	0.8217	1	36	71.00	0	107.0
4	office	36	2.4		86.4		36	172.8	0	36	72	0	0.6689	1	36	115.59	0	151.6
3	office	36	2.4		86.4		36	259.2	0	36	108	0	0.6012	1	36	155.84	0	191.8
2	retail	36	4.8			172.8	36	259.2	172.8	36	108	36	0.6012	1	36	155.84	172.8	364.6
1	retail	36	4.8			172.8	36	259.2	345.6	36	108	72	0.6012	1	36	155.84	345.60	537.4
-1	garage	36	2.4			86.4	36	259.2	432	36	108	108	0.6012	0.9303	36	155.84	401.90	593.7

Un-factored axial load due to live load only acting on column B3

a) Between floor level 1 and 2 (i.e. under level 2)

$$P_{LL,Reduced} = 365 \text{ kN}$$

b) Between floor level -1 and 1 (i.e. under level 1)

$$P_{LL,Reduced} = 537 \text{ kN}$$

Question 2:

In Ottawa, $S_s = 2.4 \text{ kPa}$, $S_r = 0.4 \text{ kPa}$,

let $\gamma = 3 \text{ kN/m}^3$;

$$S = I_s[S_s(C_b C_w C_s C_a) + S_r]$$

a) Snow load profile along section A-A between points P1 and P2:

Assume normal importance structure, $I_s = 1.0$

For flat roof, $C_s = 1.0$

Since “the building is in a setting considered as open terrain” and “has normal importance”,
 $C_w = 0.75$

Check for the size of the main roof: $l_c = w(2-w/l) = 24*(2-24/30) = 28.8 \text{ m} < 200 \text{ m}$

Therefore $C_b = 0.8$

Intensity of snow load on unobstructed roof (or far enough from any obstruction i.e. at a distance $10h'$ away from the obstruction):

$$S = I_s[S_s(C_b C_w C_s C_a) + S_r] = 1*[2.4*(0.8*0.75*1*1) + 0.4] = 1.84 \text{ kPa}$$

How to treat a projection or obstruction or an upper level roof on the main roof?

First assume the main roof is unobstructed, then find the height of snow on the unobstructed roof ($C_b C_w S_s / \gamma$), and check the height and width of any obstruction (sign or parapet) or upper level roofs to see whether they act as objects causing drift on the main roof or not.

To draw snow load distribution near any obstructions (projections), follow figure G-8.

To draw snow load distribution near upper level roofs, follow figure G-5.

Height of snow on unobstructed roof (H_s):

$$H_s = (C_b C_w S_s / \gamma) = 0.8 * 0.75 * 2.4 / 3 = 0.48 \text{ m}$$

$H_{\text{appendage}} = 3 \text{ m} > 0.48 \text{ m} \rightarrow$ The appendage is high enough to be an obstruction

$b_{\text{appendage}} = 12 \text{ m} > 3S_s/\gamma = 3*2.4/3 = 2.4 \text{ m} \rightarrow$ The appendage is wide enough to be an obstruction

$H_{\text{sign}} = 3 \text{ m} > 0.44 \text{ m} \rightarrow$ The commercial sign is high enough to be an obstruction

$b_{\text{sign}} = 12 \text{ m} > 3S_s/\gamma = 3*2.4/3 = 2.4 \text{ m} \rightarrow$ The commercial sign is wide enough to be an obstruction

Dimension of the appendage in plan is $12\text{m} \times 6\text{m}$, which is large enough to be considered as an upper level roof. Therefore, Figure G-5 in the Commentaries can be used to estimate the snow load profile near the upper roof.

Along P1-P2, the snow load profile is affected by both the appendage and the commercial sign. The effect of each of these objects should be calculated separately, and then at each point, maximum value should be taken.

Snow profile along P1-P2 affected by drifting from the appendage (from Commentaries Figure G-5):

h = height of appendage at point P1 = $H_a = 3$ m

$h > [0.8S_s/\gamma = 0.8*2.4/3=0.64$ m] \rightarrow drift should be considered

$$X_d = \min \begin{cases} 5\left(h - \frac{C_b S_s}{\gamma}\right) \\ 5\left(\frac{S_s}{\gamma}\right)(F - C_b) \end{cases}$$

Where,

$$F = \max \begin{cases} 2 \\ 0.35 \sqrt{\frac{\gamma l_c}{S_s} - 6 \left(\frac{\gamma h_p}{S_s}\right)^2} + C_b \end{cases}$$

Where,

l_c = characteristic length of the upper roof = $6(2-6/12) = 9$ m

h_p = height of the parapet for the upper roof = 0

$$F = \max \begin{cases} 2 \\ 0.35 \sqrt{\frac{3 \times 9}{2.4}} + 0.8 = 1.97 \end{cases}$$

$$F = 2$$

$$X_d = \min \begin{cases} 5\left(3 - \frac{0.8 \times 2.4}{3}\right) = 11.8 \text{ m} \\ 5\left(\frac{2.4}{3}\right)(2 - 0.8) = 4.8 \text{ m} \end{cases}$$

$$X_d = 4.8 \text{ m}$$

$$C_a(0) = \min \begin{cases} \frac{\gamma h}{C_b S_s} \\ \frac{F}{C_b} \end{cases}$$

$$C_a(0) = \min \begin{cases} \frac{3 \times 3}{0.8 \times 2.4} = 4.69 \\ \frac{2}{0.8} = 2.5 \end{cases}$$

$$C_a(0) = 2.5$$

$$C_a(0) = 2.5$$

$$h' = h - H_s = 3 - 0.48 = 2.52 \text{ m} \quad \rightarrow 10h' = 25.2 \text{ m}$$

Define X as a distance from P1 toward East.

$$X=0 \quad \rightarrow S = 1 * [2.4 * (0.8 * 1 * 1 * 2.5) + 0.4] = 5.2 \text{ kPa}$$

$$0 < X < (X_d = 4.8 \text{ m}) \quad \rightarrow S = 5.2 - (5.2 - 2.32) X / 4.8 = (5.2 - 0.6X) \text{ kPa}$$

$$X = X_d = 4.8 \quad \rightarrow S = 1 * [2.4 * (0.8 * 1 * 1 * 1) + 0.4] = 2.32 \text{ kPa}$$

$$X_d < X < (10h' = 25.2 \text{ m}) \quad \rightarrow S = 1 * [2.4 * (0.8 * 1 * 1 * 1) + 0.4] = 2.32 \text{ kPa}$$

$$X > (10h' = 25.2 \text{ m}) \quad \rightarrow S = 1 * [2.4 * (0.8 * 0.75 * 1 * 1) + 0.4] = 1.84 \text{ kPa}$$

Snow profile along P1-P2 affected by sliding from the appendage:

Sliding snow load includes 50% of the total weight of the Case I snow load of Figure G-1 of Commentaries from the portion of the upper roof that slopes toward the lower roof.

Case I snow load for the upper roof (from Commentaries Figure G-1):

Check for the size of the upper roof: $l_c = w(2-w/l) = 6*(2-6/12) = 9 \text{ m} < 200 \text{ m}$

Therefore $C_b = 0.8$

Since “the building is in a setting considered as open terrain” and “has normal importance”, $C_w = 0.75$

$$\alpha = \tan^{-1}(1/3) = 18.4^\circ$$

Since the roof is not slippery and $\alpha \leq 30^\circ$, $C_s = 1.0$

Since $0^\circ \leq \alpha \leq 90^\circ$, for load case I: $C_w = 0.75$ and $C_a = 1$

Intensity of snow load for case I on the upper roof (appendage):

$$S_{up} = I_s [S_s (C_b C_w C_s C_a) + S_r] = 1 * [2.4 * (0.8 * 0.75 * 1 * 1) + 0.4] = 1.84 \text{ kPa}$$

Solve for S_{Slide} :

$$(X_d * S_{Slide}) / 2 = 0.5 (S_{up} * b)$$

Where,

b = the width of the portion of the upper roof that slopes toward the lower roof = 3 m

$X_d = X_d$ of the drift portion on the lower roof = 4.8m

$$S_{Slide} = (S_{up} * b) / X_d = (1.84 * 3) / 4.8 = 1.15 \text{ kPa}$$

$$X=0 \quad \rightarrow S_{Total} = 5.2 + 1.15 = 6.35 \text{ kPa}$$

$$0 < X < X_d = 4.8 \text{ m} \quad \rightarrow S = 6.35 - (6.35 - 2.32) X / 4.8 = (6.35 - 0.84X) \text{ kPa}$$

$$X = X_d = 4.88 \text{ m} \quad \rightarrow S = 2.32 \text{ kPa}$$

Check maximum height of the snow load at the edge of the upper roof (at X=0):

In general: $h_s = [(S/I_s) - S_r] / \gamma$

where,

h_s = height of snow (m)

S = snow load intensity (kPa)

I_s = Importance factor

S_r = rain load (kPa)

γ = unit weight of snow (kN/m^3)

Assuming that after the slide, the snow level on the lower roof at the edge of the appendage may not be higher than the edge of the upper roof:

height of the appendage at (X=0) = 3 m

on the lower roof at X=0 $\rightarrow h_{s, \text{Total}} = [(6.35/1) - 0.4]/3 = 1.98 \text{ m} < 3 \text{ m}$

Therefore, the snow level at X=0 on the lower roof (1.98 m) is not higher than the height of the appendage (3 m) and the snow load profile can be plotted based on the values found for the intensity of the snow load.

Snow profile along P1-P2 affected by the commercial sign (from Commentaries Figure G-8):

h = height of obstruction = $H_{\text{sign}} = 3 \text{ m}$

$3 \text{ m} \leq X_d = 2 * h = 6 \text{ m} \leq 9 \text{ m} \rightarrow X_d = 6 \text{ m}$

$h' = h - H_s = 3 - 0.48 = 2.52 \text{ m} \rightarrow 10h' = 25.2 \text{ m}$

$C_a(0) = 0.67 * \gamma * h / (C_b * S_s) = 0.67 * 3 * 3 / (0.8 * 2.4) = 3.14$

$0.8/C_b \leq C_a(0) \leq 2/C_b \rightarrow 1 \leq C_a(0) \leq 2.5 \rightarrow C_a(0) = 2.5$

Define X as a distance from the commercial sign toward west.

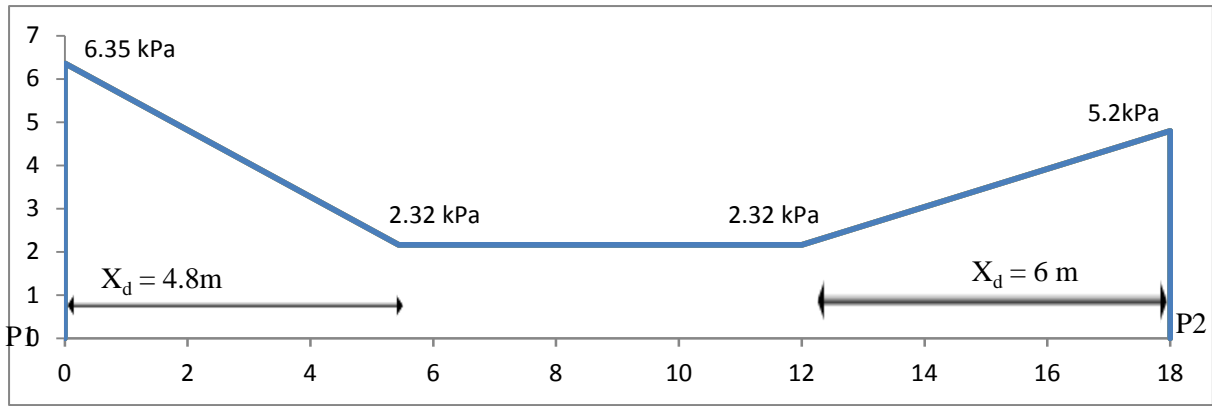
X=0 $\rightarrow S = 1 * [2.4 * (0.8 * 1 * 1 * 2.5) + 0.4] = 5.2 \text{ kPa}$

$0 < X < X_d = 6 \text{ m} \rightarrow S = 5.2 - (5.2 - 2.32) X/6 = (5.2 - 0.48X) \text{ kPa}$

X = $X_d = 6 \text{ m} \rightarrow S = 1 * [2.4 * (0.8 * 1 * 1 * 1) + 0.4] = 2.32 \text{ kPa}$

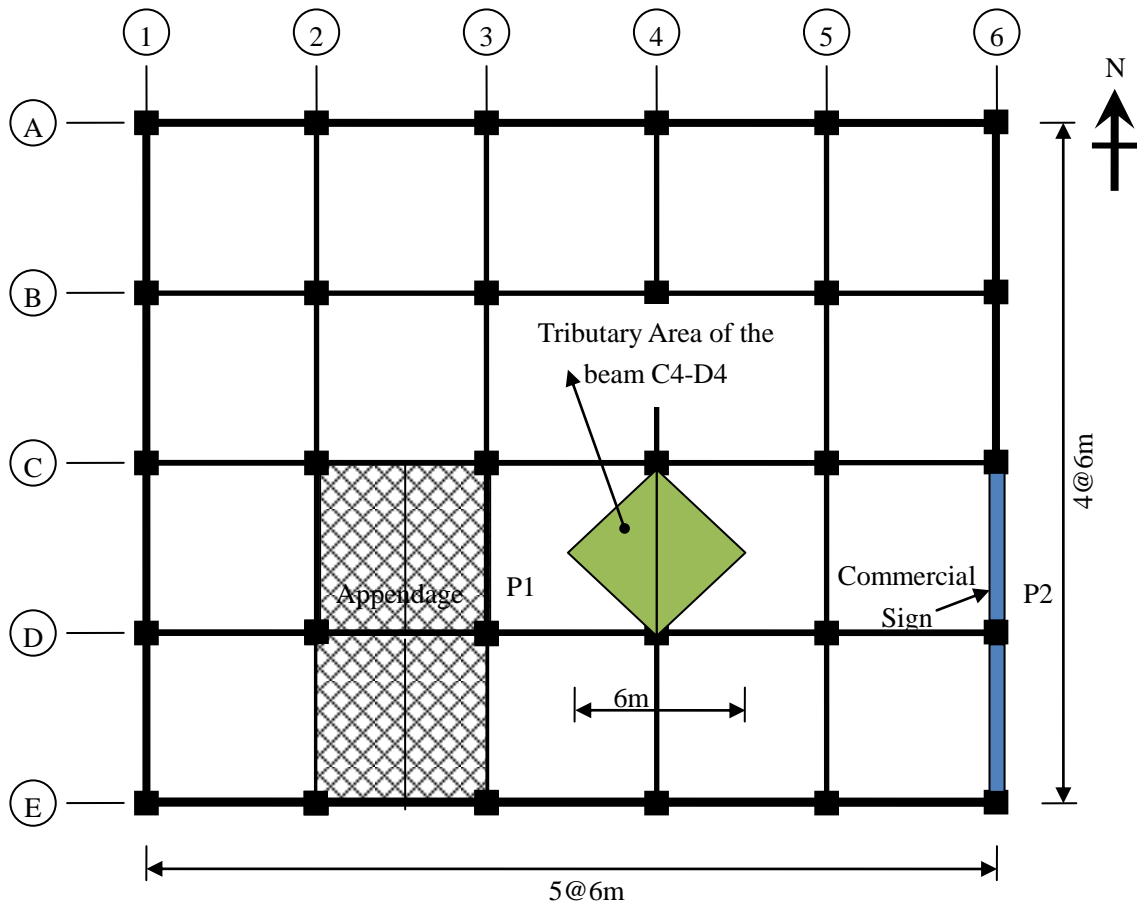
$X_d < X < 10h' = 25.2 \text{ m} \rightarrow S = 1 * [2.4 * (0.8 * 1 * 1 * 1) + 0.4] = 2.32 \text{ kPa}$

X > $10h' = 25.2 \text{ m} \rightarrow S = 1 * [2.4 * (0.8 * 0.75 * 1 * 1) + 0.4] = 1.84 \text{ kPa}$

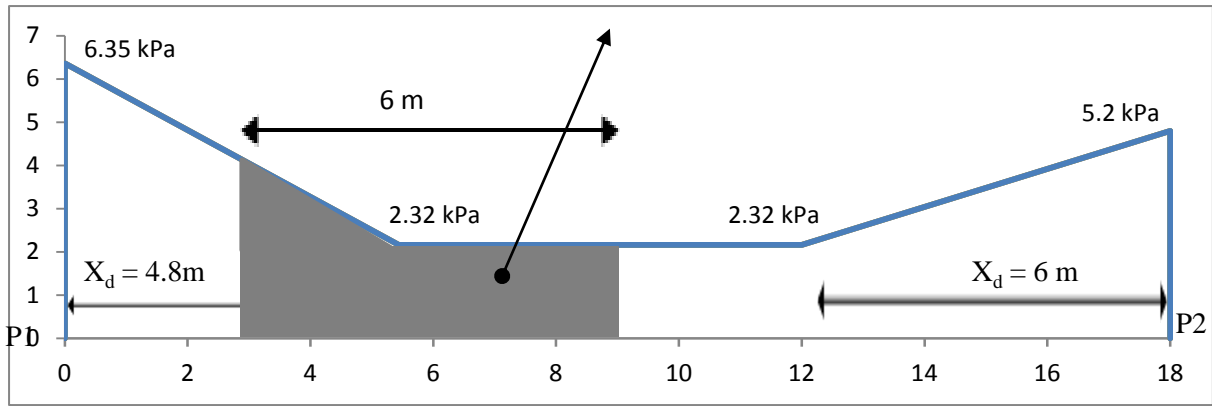


Snow load profile along P1- P2

b) Load pattern on the beam between C4 and D4 due to snow load:



This shaded area is equal to the intensity of the snow load in kN/m acting at the mid-span of the beam C4-D4 due to snow load.

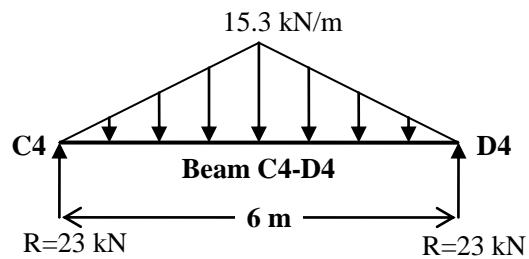


Snow load profile along P1- P2

$$X = 3 \text{ m} \quad \rightarrow \quad S = (6.35 - 0.84X) = 3.83 \text{ kPa}$$

$$UDL_{\text{Snow}} = 2.32 * 6 + (3.83 - 2.32) * (4.8 - 3) / 2 = 15.3 \text{ kN/m}$$

$$R = 6 * 15.3 / 2 = 23 \text{ kN/m}$$



Question 3:

$$P = I_w q C_e C_g C_p$$

Reference wind pressure q :

In Ottawa, the 1/50 years wind pressure, $q = 0.41$ kPa

Gust factor C_g :

For the building as a whole and main structural members: $C_g = 2.0$

Importance factor I_w :

Assume normal importance structure, $I_w = 1.0$

Exposure factor C_e :

Since the height of the structure from the ground level, $H = [5 \times 4.2 = 21 \text{ m}] > 20 \text{ m}$, the building should be considered as high rise.

For structures exposed to open terrain: $C_e = \left(\frac{h}{10}\right)^{0.2} \geq 0.9$

Where,

h = reference height above grade (m)

For windward face, h = actual height of that point above ground

$$C_e = \left(\frac{h}{10}\right)^{0.2} \geq 0.9$$

For leeward face, $h = H/2$

$$C_e = \left(\frac{21/2}{10}\right)^{0.2} = 1.0098 \geq 0.9$$

For roof, $h = H$

$$C_e = \left(\frac{21}{10}\right)^{0.2} = 1.16 \geq 0.9$$

External pressure coefficient C_p :

For the buildings where $H/D_s \geq 1$ or $H > 20 \text{ m}$ read C_p from I-15.

D_s = smaller plan dimension

Here, $H = 21 > 20 \text{ m} \rightarrow$ read C_p from I-15

$D = 4 \times 6 = 24 \text{ m}$

$H/D = 21/24 = 0.875 \rightarrow 0.25 < H/D < 1$

For windward face, $C_p = 0.27 (H/D + 2) = 0.776$

For leeward face, $C_p = -0.27 (H/D + 0.88) = -0.474$

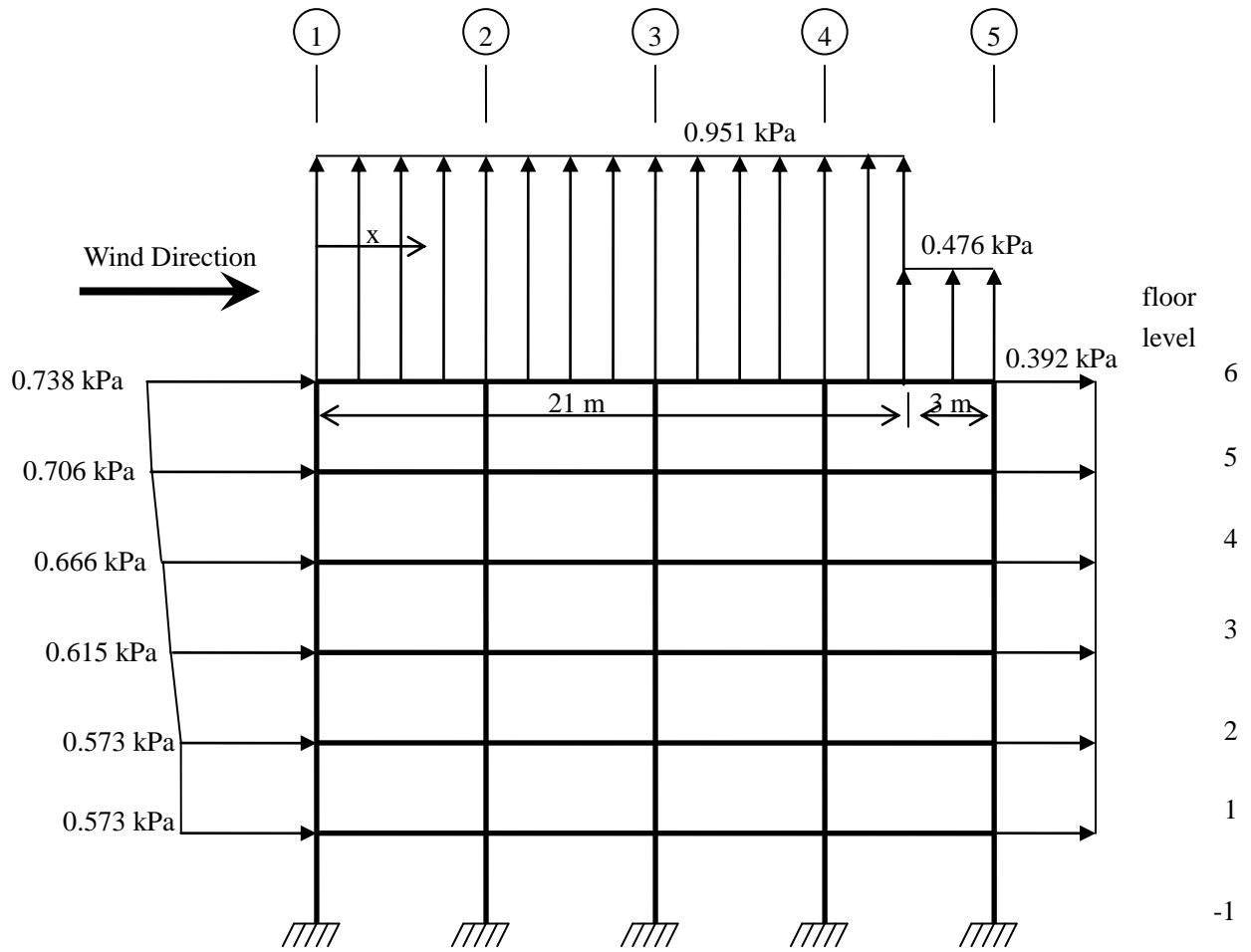
For roof, $C_p = -1.0; 0 < x < (H = 21 \text{ m})$
 $= -0.5; (H = 21 \text{ m}) < x < (D = 24 \text{ m})$

Note: x is the distance in plan from point A3 towards South

External Wind Pressure (P) on the Windward Face					
Floor	h (m)	C_e	C_p	C_g	Pressure (kPa)
6	21	1.160	0.776	2	0.738
5	16.8	1.109			0.706
4	12.6	1.047			0.666
3	8.4	0.966			0.615
2	4.2	0.9			0.573
1	0	0.9			0.573

External Wind Pressure (P) on the Leeward Face					
Floor	h (m)	C_e	C_p	C_g	Pressure (kPa)
6	21	1.0098	-0.474	2	-0.392
5	16.8				-0.392
4	12.6				-0.392
3	8.4				-0.392
2	4.2				-0.392
1	0				-0.392

External Wind Pressure (P) on the Roof					
Floor	x range (m)	C_e	C_p	C_g	Pressure (kPa)
6	0 < x < 21	1.160	-1	2	-0.951
	21 < x < 24	1.160	-0.5	2	-0.476



External wind pressure profile acting on frame 3 N-S Direction