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香港工程師學會

Structural Division
結構分部

A Practical Guide
to the Code of Practice on Wind Effects In Hong Kong 2019

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Acknowledgment

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Disclaimer

The content of this Handbook is an expression of opinion only. The guidance and recommendations given in this Handbook should always be reviewed by those using the handbook in the light of their particular case. The Structural Division of the Hong Kong Institution of Engineers, the members of the Working Group and their servants of agents assume no responsibility to any party for the whole or any part of this Handbook and its content.

1. Introduction

This handbook is intended to provide engineers with a guide to calculate the wind loads effectively in accordance with the Code of Practice on Wind Effects in Hong Kong 2019 (the Code) for the design of standard buildings.

The handbook should be read in conjunction with the Code and Explanatory Notes to the Code of Practice on Wind Effects in Hong Kong 2019 (EN). It does not override the recommendation of the Code or the EN.

2. Calculation Procedure

The calculation of wind loads for standard structures shall follow the procedure shown in Figure 2-1 of the Code, which is referred as the “Standard Method” by the Code.

As a preliminary judgement for the use of the Standard Method, the building shall fulfil the following requirements:

- $H \leqslant 200$m,
- Regular building shape covered by the Code
- Not in complex topography or surroundings which adversely affect the site wind condition.

Wind forces on buildings fulfil the requirements from Section 1.1 can be determined using the Standard Method. The total wind load following the Standard Method consist of four components:

- Determination of along-wind forces
- Determination of torsional wind forces
- Determination of across-wind base moment, if required
- Load combination of the wind forces in the two orthogonal and torsional directions

The procedure of calculating of wind loading on building elements is given in the flowchart in Figure 2-2 of the Code.

The calculation of wind loads on buildings and building elements shall start with correct estimation of the design wind reference pressure, which is the wind reference pressure calculated at the effective height Z_e considering the topographic effect, sheltering effect and wind directionality as described in Section 3. The structural wind load calculation and the cladding wind load calculation are demonstrated in Section 4 and Section 5 respectively. Section 6 will discuss in detail about the wind tunnel test requirements. Section 7 shows the working examples for the Code application.

3. Reference Wind Pressure

3.1 Directionality

3.1.1 Principle

The reference wind pressure may be adjusted using the directionality factor provided by Table A1-1 in the Code to account the reduced probability that the strongest wind direction coincides the direction with the strongest building responses aerodynamically.

The directionality factor does not apply to circular buildings as it has uniform force coefficient for all directions.

The directional factors can be directly adopted in the wind tunnel tests to adjust the reference pressure if the Sector Method is adopted. For Up-crossing Method, Storm Passage Method, or other similar methods, $S_\theta = 1.0$ shall be used for forces and pressures.

3.1.2 Procedure and Example

The user of the Standard Method of the Code may follow the steps outlined below to get the directionality factor S_θ. Alternatively it is safe to take $S_\theta = 0.85$ for all wind directions.

For buildings with non-rectangular shapes, an enclosed rectangle can be synthetically created to envelope the original building plan, which shall keep the maximum of the breadth of windward face of the building from each wind direction. Some examples are given in Figure 3-1.

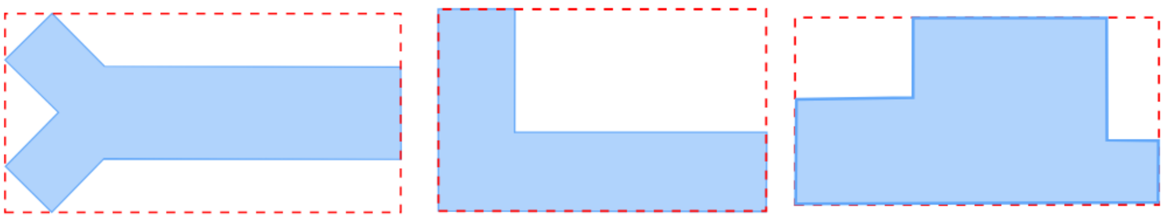


Figure 3-1 Examples of the equivalent rectangles for non-rectangular building plan shapes

The building plan, a synthetically generated enclosed rectangle, is shown in **Figure 3-2** . The polar diagram shows the wind directionality factors from Appendix A of the Code. For each wind direction, the wind directionality factor should be identified as the maximum of the section, which covers ±45° from the centre of the rectangle as shown by the red dash line in **Figure 3-2** . The values of the wind directionality factor at the edge (red dash line) are calculated using interpolation as marked in **Figure 3-2**. For each section, the directionality factor shall be taken as the maximum value of the directionality factors taken from the interpolated values at the section edges and the values from any of the 8 standard wind directions within that section as shown in **Table 3-1**.

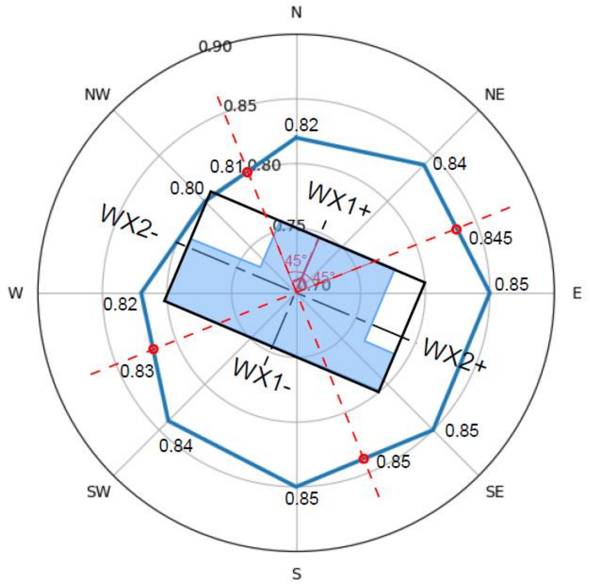


Figure 3-2 Determination of Directionality Factor

Table 3-1 Determined Directionality Factors

Sector	Wind Directionality factors in the Sector	S_θ
WX1+	Max (0.81,0.82,0.84,0.845)	0.845
WX1-	Max (0.83,0.84,0.85,0.85)	0.85
WX2+	Max (0.845,0.85,0.85,0.85)	0.85
WX2-	Max (0.81,0.80,0.82,0.83)	0.83

3.2 Topography factor

3.2.1 Principle

The topographic multiplier shall be calculated for buildings located in the topographic significant zones. The calculation procedure applies to hills and ridges, cliffs, and escarpments, which can accelerate the mean wind speed over the summit or crest as shown in Figure 3-3.

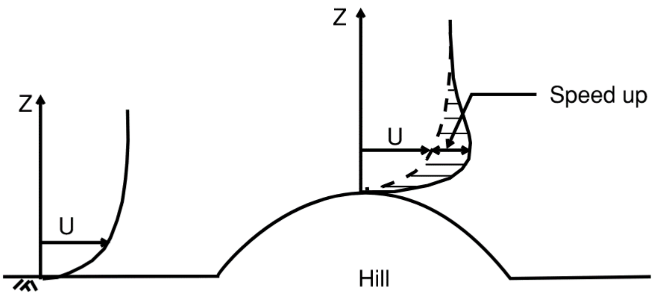


Figure 3-3 Wind speed-up over hills

Topographic impact is considered significant when the maximum slope for a quarter of the hill in the top half of the hill on the wind ward side is bigger than 0.05 and when the site is located in a topographic significant zone as shown in the shaded areas in Figure 3-4 and Figure 3-5. The topographic multiplier shall be determined according to the procedure described in Section 3.2.2 next.

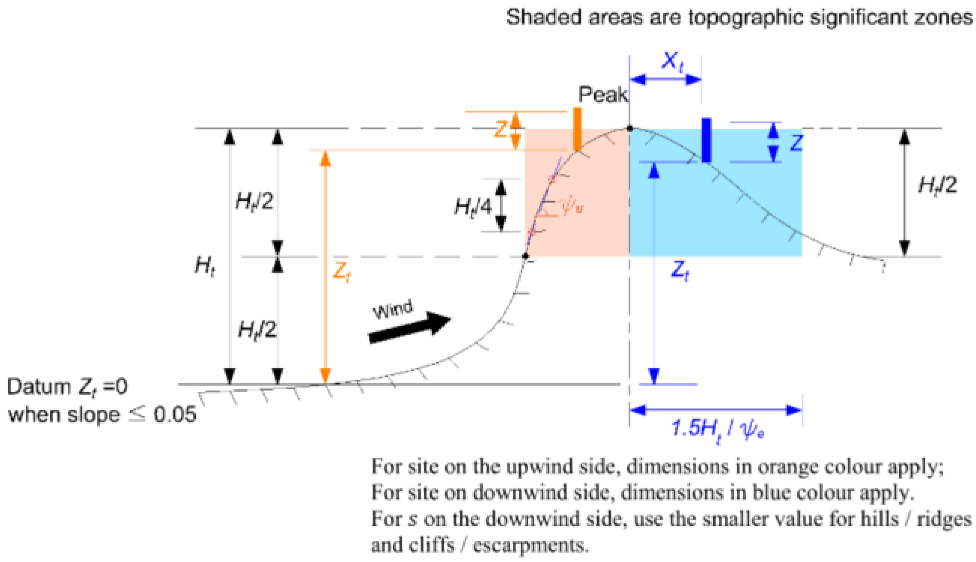


Figure 3-4 Topographic significant zone for hills/ridges

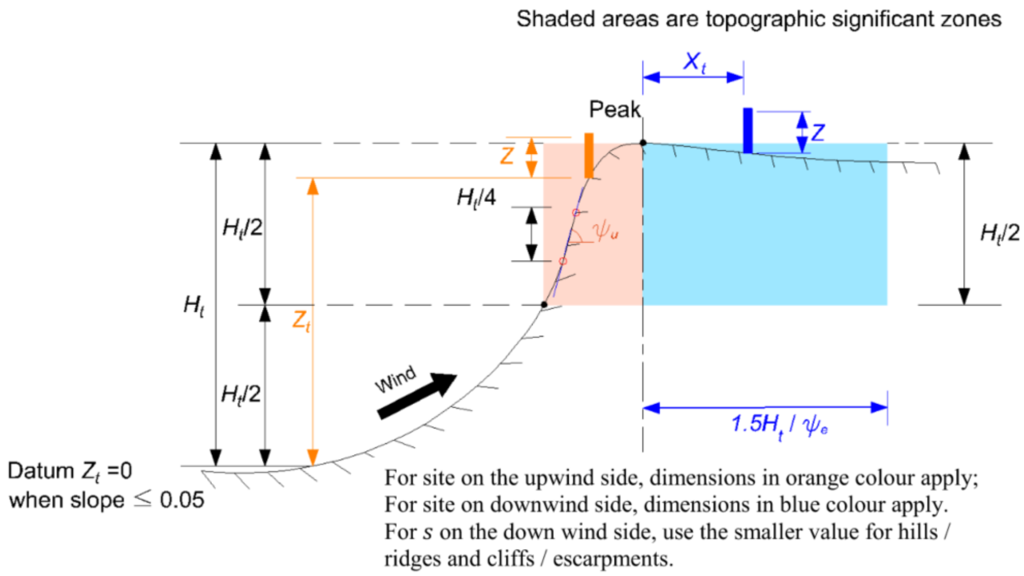


Figure 3-5 Topographic significant zone for cliffs/escarpments

3.2.2 Procedure

Part A: Determine if the site is located in the topographic significant zone

1) Requirements of the upwind slope >0.05

The maximum slope for a quarter of the hill height in the top half of the wind on the wind ward side bigger than 0.05 is the first requirement to determine if the site is topographically significant. The upwind slope can be determined following the procedures below.

Divide the approaching wind directions into 4 sectors, each sector is generated as the ±45° from the orthogonal direction of each building face. In each sector, draw a cross section through the site at an appropriate angular interval, e.g., every 22.5°, as shown in Figure 3-6. Then evaluate the topography factor for all the sections, such as S1-1, S1-2 and S1-3, for example. Pick up the section give the biggest S_t. An example for S1-3 is shown in Figure 3-7. The cross-section of the hill is then shown in Figure 3-6. The slope shall be determined as the maximum slope of each quarter height of the hill section (from ½ H_t, 5/8H_t, 3/4H_t) of the top half height of the hill. For this case,

$\psi_u = max\ (\psi_{u1}, \psi_{u2}, \psi_{u3}) = 0.4663 > 0.05$

where

ψ_{u1} represents the slope from ½ H_t to 3/4H_t as shown by the yellow line in Figure 3-7;

ψ_{u2} represents the slope from 5/8 H_t to 7/8 H_t as shown by the green line in Figure 3-7;

ψ_{u3} represents the slope from 3/4 H_t to H_t as shown by the red line in Figure 3-7.

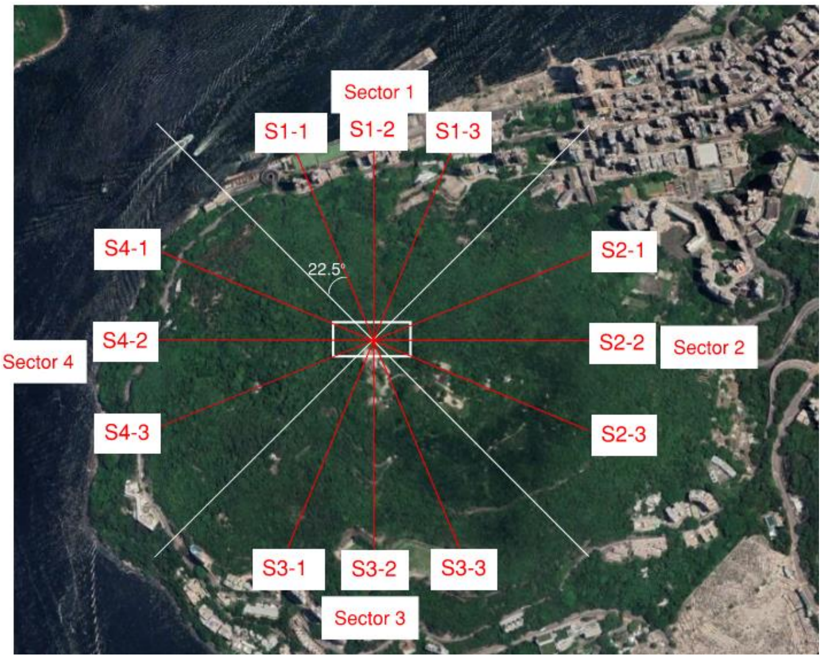


Figure 3-6 Hill sections

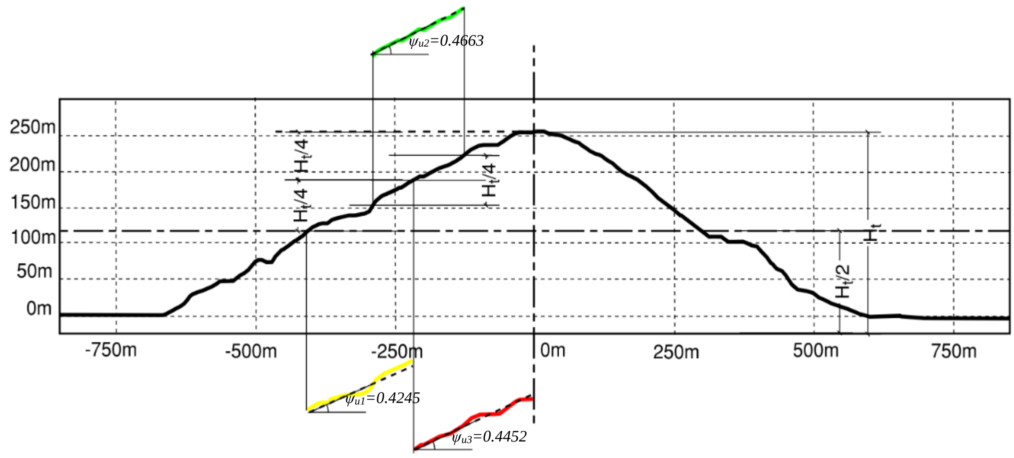


Figure 3-7 Upwind slope at S1-3

2)Requirement of the site located in the topography significant zone

The criteria shall be used to determine if the site is located within the topographic significant zone, for which the topographic multiplier shall be applied.

If the site falls in any of the topographic zones as listed in Case 1 to Case 3 as shown in Figure 3-8, the site is considered located in the topography significant zone.

- Case 1: For the upslope of hills and ridges or cliffs and escarpments, the site must be at the top half of the topographic feature.
- Case 2: Downwind of hills and ridges, the site should be above the top half height of the crest and within a distance of $1.5H_t/\psi_e$ from the top of the feature.
- Case 3: Downwind of cliffs and escarpments, the site should be above the top half height of the crest and within a distance of $1.5H_t/\psi_e$ from the top of the feature.

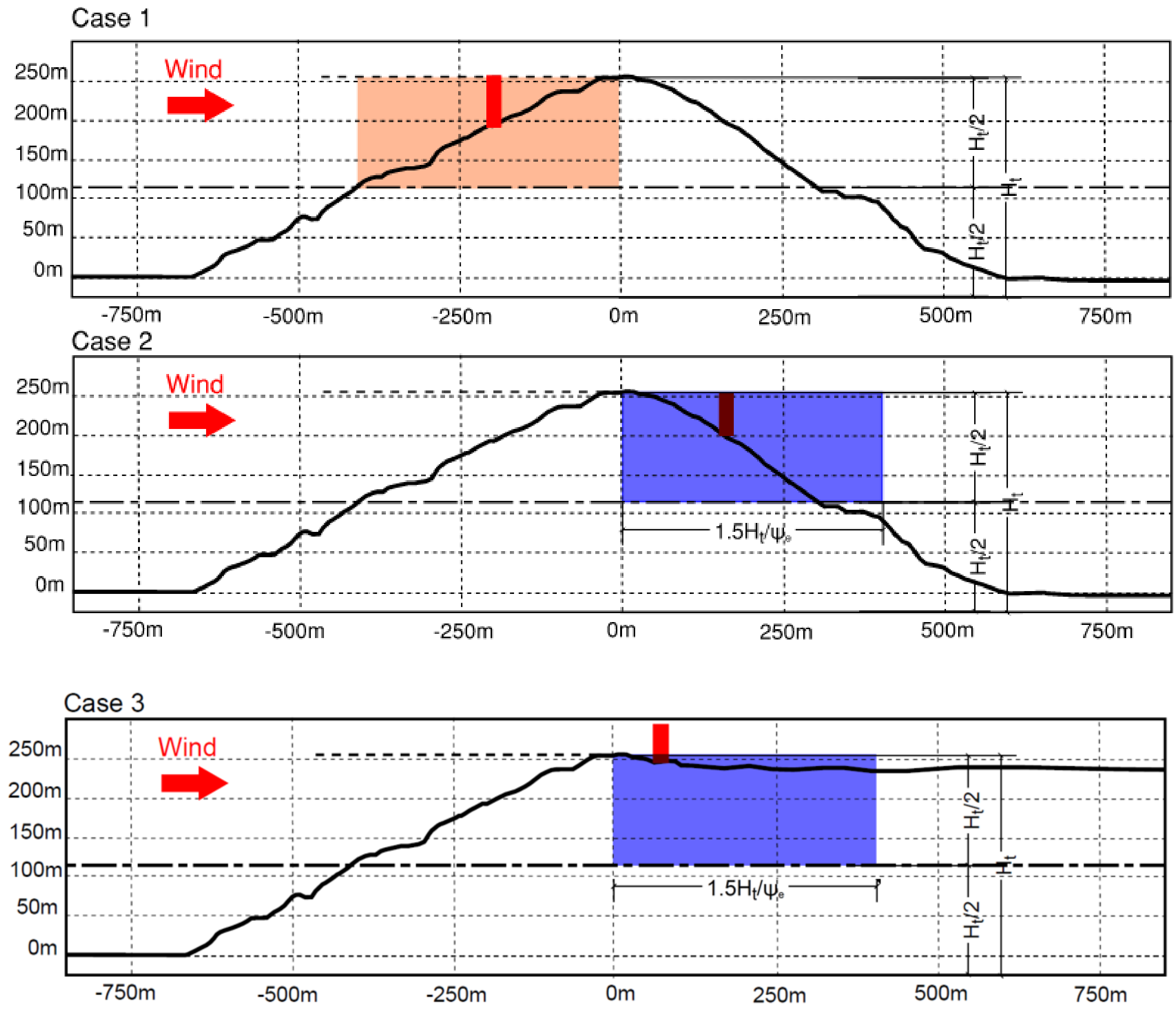


Figure 3-8 Site location

Part B: Calculation of Topographic multiplier for a site located in the topographic significant zone

Following Part A, if the site is located in the topographic significant zone, the following procedures can be followed to calculate the topographic multiplier.

1) For each of the four sectors, further cut a section through the site at an appropriate angular interval as a way, as shown in Figure 3-6.
2) At each section, e.g. S1-1, determine the upwind slope ψ_u as introduced in Section3.2.2. The value of ψ_e=min (ψ_u, 0.3).
3) Determine the topographic dimensions.
4) Determine H_t, the height of the hill from the windward side above surrounding ground with a mean slope of less than or equal to 5%.
5) Determine Z_t, the height of the highest part of the site measured from the same datum as H_t.
6) If the site is located on the downwind side, determine X_t, the distance from the crest of the hill to the site.
7) Calculate the topographic location factor s following the flow chart in Figure 3-9.
8) Calculate $I_{v,z}$ by Equation 3-3 of the Code.
9) Calculate the topographic multiplier of wind pressure by

$$S_t = \left[1 + \frac{2\psi_e s}{1 + 3.7 I_{v,z}}\right]^2$$

   Note that s and $I_{v,z}$ should be calculated at height Z=2/3H.

10) Take the most onerous St from S1-1 to S1-3 as the St for Sector 1.
11) Repeat steps 1) to 10) for all the four sectors.

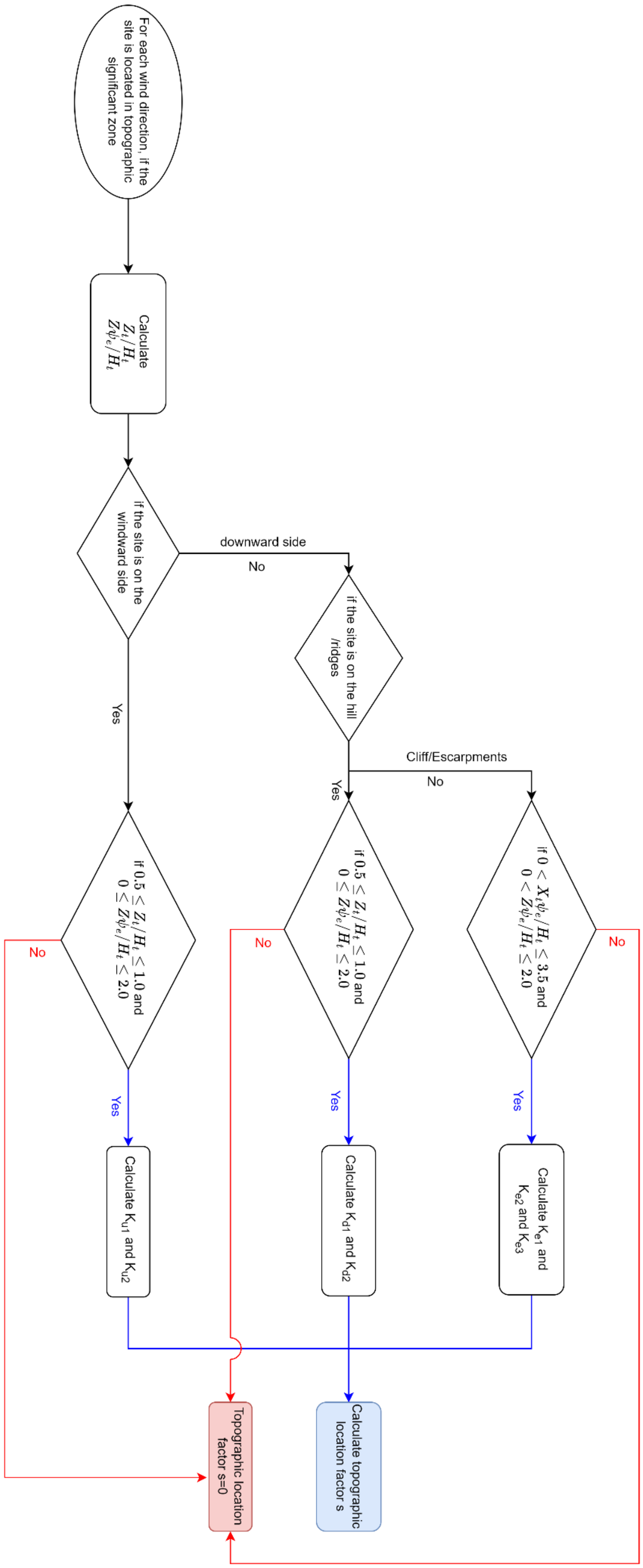


Figure 3-9 Flowchart for topographic multiplier

3.2.3 Example

This section will demonstrate the procedure of topographic factor calculation. The example is a construction site in the hilly area of Hong Kong. The building geometries are given in Figure 3-11. Only the topographic condition of Section S1-3 for WX1 direction is selected for demonstration purpose.

Step 1:

Divide the approaching wind directions into 4 sectors, each sector is generated as the ±45° from the orthogonal direction of each building face as shown in Figure 3-10. The most significant slope through the site is searched to represent the topographic condition in that direction and assume it is S1-2 within all the sections (S1-1 to S1-3).

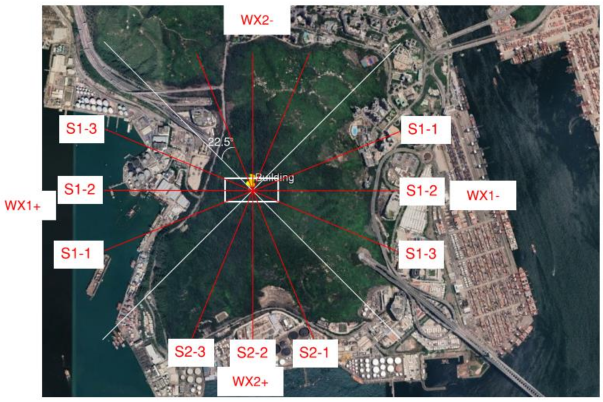


Figure 3-10 Site location of the example (not to scale)

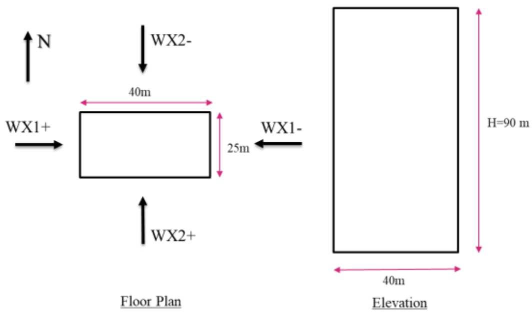


Figure 3-11 Building geometry of the example

Step 2: Calculation of St for S1-1 at wind direction WX1+ and WX1-

For Section S1-2 in direction WX1+ and WX1-, the topographic profile is shown in Figure 3-12. For each topographic condition, the slopes at the three different heights are measured to derive the maximum slope representing this topographic feature. And the topographic significance could be determined as below.

WX1+: Building is located on the upwind slope

$$\psi_u = \max(\psi_{u1}, \psi_{u2}, \psi_{u3}) = \max(0.36, 0.45, 0.40) = 0.45 > 0.05$$

where

ψ_{u1} represents the slope from ½ H_t to 3/4H_t

ψ_{u2} represents the slope from 5/8 H_t to 7/8 H_t

ψ_{u3} represents the slope from 3/4 H_t to H_t

The local topographic is considered as significant.

$Z_t/H_t=192/286=0.67>0.5$

$$\psi_e = \min(\psi_u, 0.3) = \min(0.45, 0.3) = 0.3$$

WX1-: Building is located on the downwind slope (ridge)

$\psi_u = \max(\psi_{u4}, \psi_{u5}, \psi_{u6}) = \max(0.53, 0.55, 0.42) = 0.55 > 0.05$

where

ψ_{u6} represents the upwind slope from ½ H_t to 3/4H_t

ψ_{u5} represents the upwind slope from 5/8 H_t to 7/8 H_t

ψ_{u4} represents the upwind slope from 3/4 H_t to H_t

The local topographic is considered as significant.

Z_t/H_t=192/286=0.67>0.5

$\psi_e = \min(\psi_u, 0.3) = \min(0.55, 0.3) = 0.3$

$$X_t = 235m < \frac{1.5H_t}{\psi_e} = 1430m$$

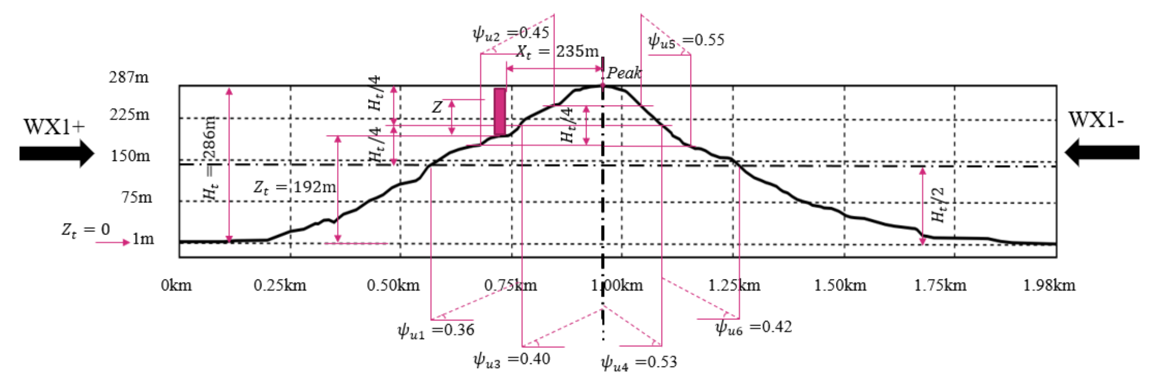


Figure 3-12 Topographic dimensions for WX1

Step 3:

As for both WX1+ and WX1-, the local topographic are considered as topographic significant. The topographic multipliers are calculated as below.

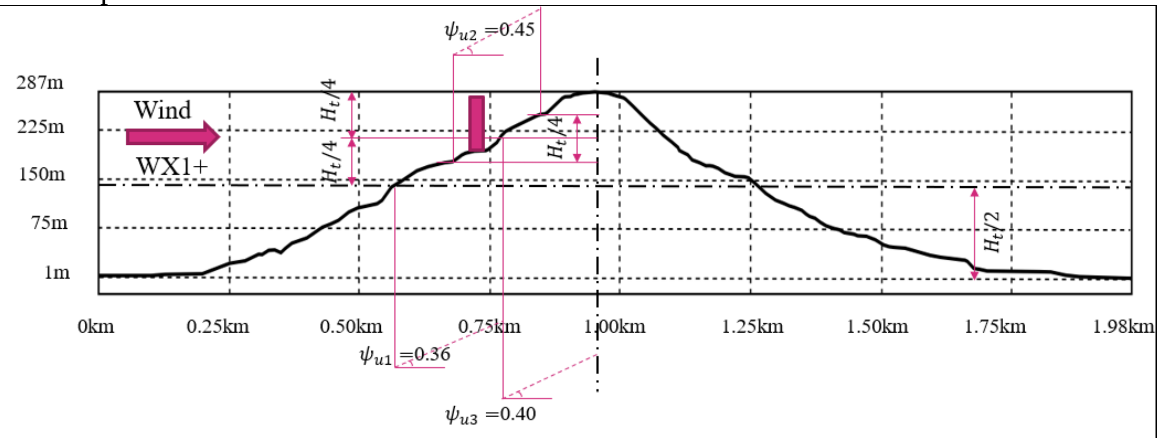


Figure 3-13 Building located on the upwind section for both hills and ridges

WX1+: The site is on the upwind section for both hills or ridges,

$0.5 \le Z_t/H_t = 192/286 = 0.67 \le 1.0$

s and $I_{v,z}$ are calculated at height, $Z = 2/3\,H$=60m

$0 \le \frac{Z\psi_e}{H_t} = \frac{60\times0.3}{286} \approx 0.07 \le 2$

s, K_{u1} and K_{u2} shall be calculated using Equation A3-2 to A3-4 of the Code.

$$K_{u1} = 0.1552\left(\frac{Z\psi_e}{H_t}\right)^4 - 0.8575\left(\frac{Z\psi_e}{H_t}\right)^3 + 1.8133\left(\frac{Z\psi_e}{H_t}\right)^2 - 1.9115\left(\frac{Z\psi_e}{H_t}\right) + 1.0124 = 0.90$$

$$K_{u2} = 0.3542\left(\frac{Z\psi_e}{H_t}\right)^2 - 1.0577\left(\frac{Z\psi_e}{H_t}\right) + 2.6465 = 2.58$$

$$I_{v,z} = 0.087\left(\frac{Z}{500}\right)^{-0.11} = 0.11$$

$$s = K_{u1}\cdot e^{\left[-K_{u2}\left(1-\frac{Z_t}{H_t}\right)\right]} = 0.90\times e^{[-2.58(1-0.67)]} = 0.38$$

$$S_t = \left[1 + \frac{2\psi_e s}{1+3.7I_{v,z}}\right]^2 = 1.36$$

Z	**K_{u1}**	**K_{u2}**	**s**	**S_t**
60	0.90	2.58	0.38	1.36

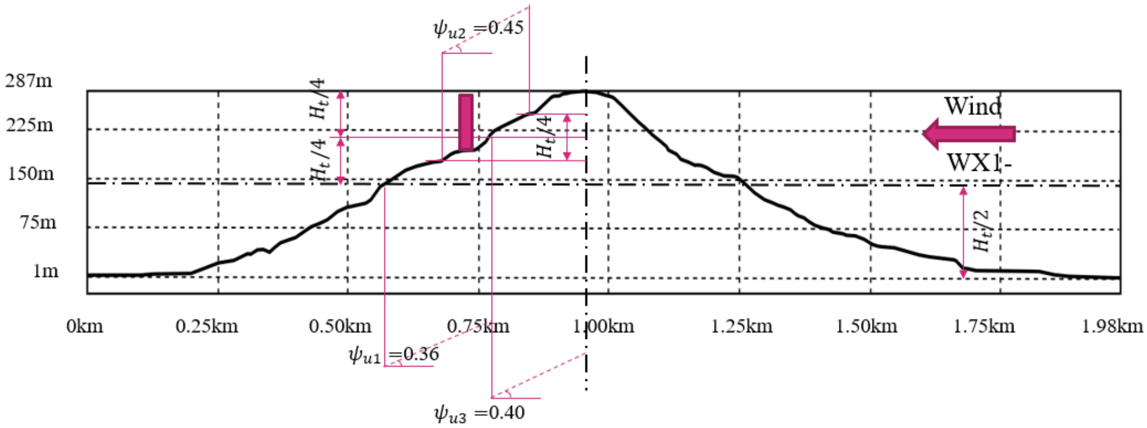


Figure 3-14 Building located on the downwind section for both hills and ridges

WX1-: The site is on the downwind section on the hills or ridges

s and $I_{v,z}$ are calculated at height, $Z = 2/3\,H$=60m

$Z_t/H_t = 192/286 = 0.67$

$$\frac{Z\psi_e}{H_t} = \frac{60\times0.3}{286} \approx 0.07$$

$$K_{d1} = 0.1552\left(\frac{Z\psi_e}{H_t}\right)^4 - 0.8575\left(\frac{Z\psi_e}{H_t}\right)^3 + 1.8133\left(\frac{Z\psi_e}{H_t}\right)^2 - 1.9115\left(\frac{Z\psi_e}{H_t}\right) + 1.0124 = 0.90$$

$$K_{d2} = -0.3056\left(\frac{Z\psi_e}{H_t}\right)^2 + 1.0212\left(\frac{Z\psi_e}{H_t}\right) - 1.7637 = -1.70$$

$$s = K_{d1} \cdot e^{\left[K_{d2}\left(1-\frac{Z_t}{H_t}\right)\right]} = 0.90 \times e^{[-1.70(1-0.67)]} = 051$$

$$I_{v,z} = 0.087\left(\frac{Z}{500}\right)^{-0.11} = 0.11$$

$$S_t = \left[1 + \frac{2\psi_e s}{1+3.7I_{v,z}}\right]^2 = 1.49$$

Z	K_{d1}	K_{d2}	s	S_t
60	0.90	-1.70	0.51	1.49

Step 4:

Because it has assumed S1-2 has the most onerous St between S1-1 to S1-3 in both WX1+ and WX1- directions. The St of WX1+ is 1.36 and is 1.49 for WX1-.

3.3 Direct Sheltering

3.3.1 Principles

The exposure adjustment for direct shelter shall be considered using the concept of displacement height and the corresponding reduced effective height. Standard method and Simplified method are introduced in Appendix A2 of the EN.

Several rules shall be followed when applying sheltering effects.

- The benefit due to the most significant sheltering building should not be considered. The same concept applies to both the code based sheltering effect calculation and the determination of building removal for the removal configuration of wind tunnel tests. While one building could be the most beneficial building in one division, it could be retained in another division if it is not the most beneficial building there.
- Buildings in the same building lot shall be treated as a whole, when evaluating the direct sheltering effect for the determination of the most beneficial building/buildings to be removed. Here the building lot may refer to the Lot layer in iC1000 map from Land's Department as shown by the yellow blocks in Figure 3-15.*
- If there is level differences of the site and the surrounding buildings, the rules are given in Appendix A2 of the EN. Two examples are given in Figure 3-16 and Figure 3-17 to demonstrate the application of the rules for buildings on a slope.
    - Example 1:

      For T1, the building height used for direct sheltering is calculated as 50m-30m=20m

      For T2, the building height for direct sheltering is calculated as 100m-20m=80m, as the obstructing height shall be taken as less than or equal to the height of the proposed building, the building height for sheltering calculation is min(H_{T1}, $H_{ProposedBuilding}$)=min(80,40)=40m.

- Example 2:

  For T1, the building height is 40m

  For T2, the original building height is 100m. However, as the obstructing height shall be taken as less than or equal to the height of the proposed building, the building height used for sheltering efeect calculation shall be taken as min(H_{T2}, $H_{ProposedBuilding}$)=min(100,50)=50m.

*It should also be noted that when replying HKIE's query on the definition of "building lot" in APSEC Discussion Forum in May 2021, BD advised that "buildings issued with the same occupation permit within a cluster could be treated as "buildings in the same building lot" when evaluating the direct sheltering effect and determining the most beneficial building/buildings". This definition is believed to lead to bigger sheltering benefit than that of land lot.

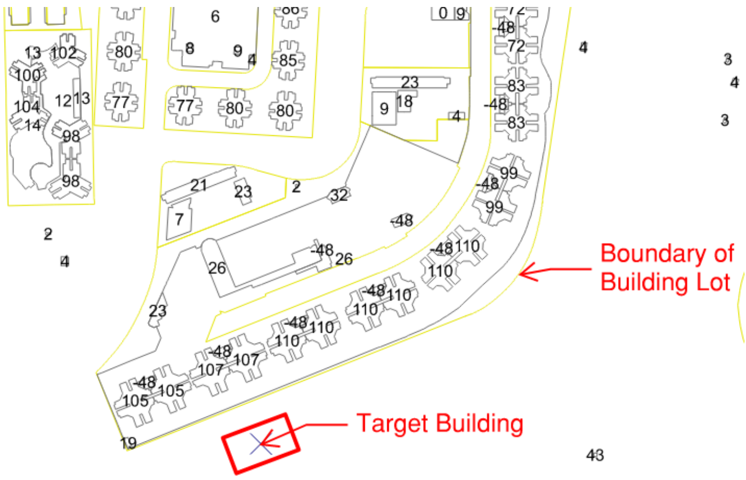


Figure 3-15 Example of the map showing building lot

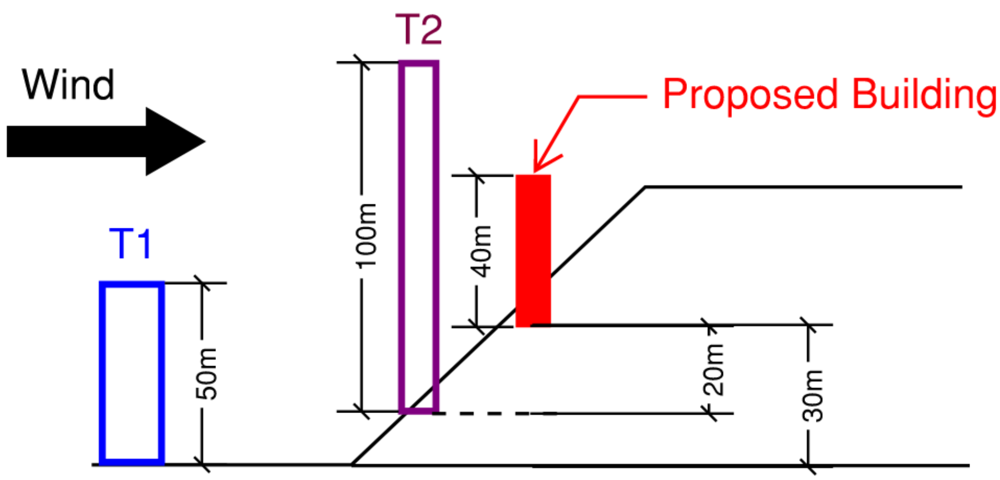


Figure 3-16 Site on a sloped terrain

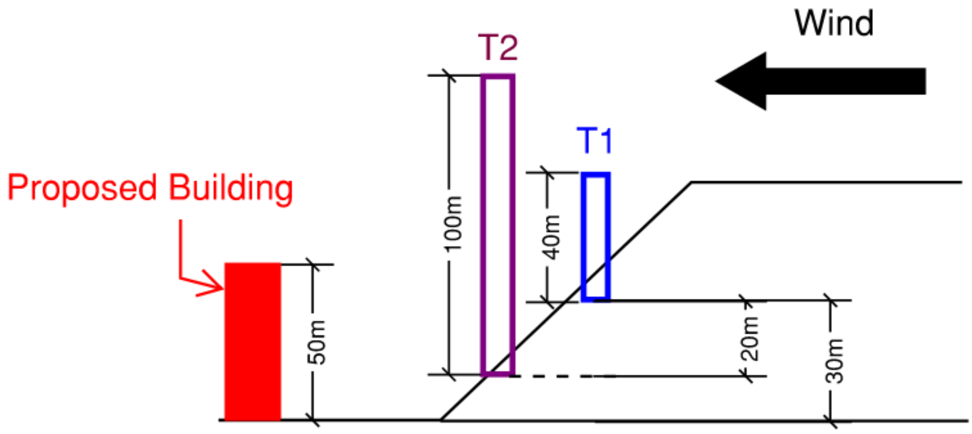


Figure 3-17 Surrounding buildings on a sloped terrain

3.3.2 Procedure and Examples

The standard procedure of the sheltering effect calculation is described in more detail in the EN, which is applicable to most of the site surroundings. A simplified approach is also demonstrated in the EN with a case example.

4. Structural wind loads & responses

The wind loads acting on a standard building have been updated to incorporate the along wind loads, across wind loads and torsional wind loads, which is not only more in line with the other international standard, but also more reflective of the physical nature of the wind induced loading.

4.1 Along-wind Loads

A uniform approach using a size and dynamic factor, $S_{q,z}$, has been adopted in the Code to replace the "Static Approach" and "Dynamic Approach of the 2004 Code. The along wind force per unit height at a height, Z, for a building on level ground is calculated from the product of wind reference pressure, force coefficient, size and dynamic factor and the breadth of the building:

$$W_z = Q_z C_f S_{q,z} B$$

where

W_z along wind load per unit height, at height, Z

Q_z wind reference pressure adjusted for effects from sheltering, topography and wind direction

C_f force coefficient

$S_{q,z}$ size and dynamic factor

B Breadth of building

The wind reference pressure adjustment is discussed in Section 3. The force coefficient will be introduced in Section 4.1.1 and the size and dynamic factor will be covered in Section 4.1.2.

4.1.1 Force coefficients

The force coefficients are determined based on the building shapes and dimensions. The Code has introduced an equation and a chart for calculating force coefficients of buildings which can be treated as rectangles based on the aspect ratio H_e/D and plan ratio B/D. The following rules shall be followed:

1) When calculating the force coefficient in each direction, the effective height corresponding to that direction can be used. A simple example in Figure 4-1 is shown as below:

   a. When calculating along wind force from direction WX1+, H_e/D =1.05. B/D = 0.6, the force coefficient C_f = 1.128

   b. When calculating along wind force from direction WX1-, H_e/D = 1.5, B/D = 0.6, the force coefficient C_f = 1.120

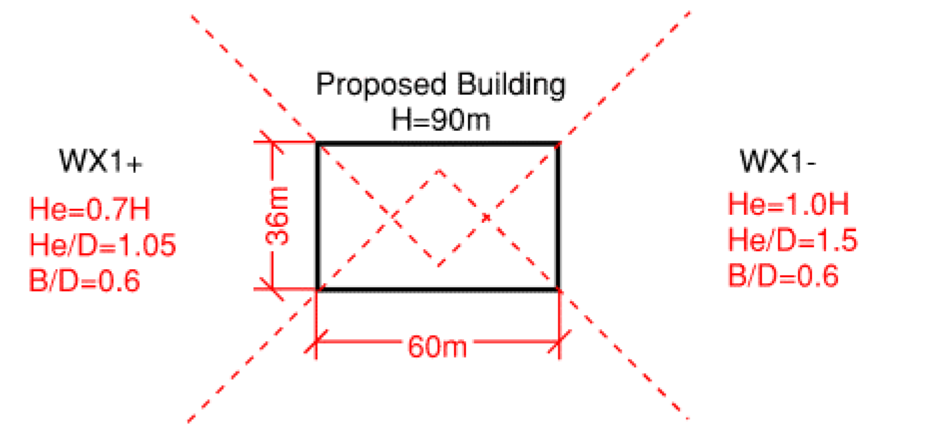


Figure 4-1 Example of force coefficient in differect wind directions

For the buildings could be treated as rectangular, the rules below shall be followed.

2) Force Coefficients variation along elevations

For buildings with plan shape variation along the building height, Section 4.2.2 shall be followed. If the plan variation affecting less than 10% of H, the plan variation can be ignored.

Example:

The tower is about 110m as shown in Figure 4-2. It consists of 3 parts, Part A: the roof top structure of 15m, Part B: main tower of 75m and Part C: podium of 20m. Considering the sheltering effect, the effective height in wind direction WX1 is He=0.7H=77m.

For Part A, the portion over the total height is about 15/110=13.6% > 10 %, the force coefficient shall be calculated using the local plan dimension and the total effective height as below :

$$\frac{H_e}{D} = \frac{77}{15} = 5.13$$

$$\frac{B}{D} = \frac{10}{15} = 0.67$$

$$C_f = 1.1 + \frac{0.055H_e/D}{\exp\left\{\left|log_e\left[\left(\frac{0.6B}{D}\right)\left(1 - \frac{0.011H_e}{D}\right)\right]\right|^{\left[1.7-0.0013\left(\frac{H_e}{D}\right)^2\right]}\right\}} = 1.21$$

For Part B, the force coefficient shall be calculated using the local plan dimension of the main tower and the total effective height as below:

$$\frac{H_e}{D} = \frac{77}{20} = 3.85$$

$$\frac{B}{D} = \frac{35}{20} = 1.75$$

$$C_f = 1.1 + \frac{0.055H_e/D}{\exp\left\{\left|\log_e\left[\left(\frac{0.6B}{D}\right)\left(1-\frac{0.011H_e}{D}\right)\right]\right|^{\left[1.7-0.0013\left(\frac{H_e}{D}\right)^2\right]}\right\}} = 1.311$$

For Part C, as a podium, the force coefficient shall be calculated using the plan dimension of the podium and the total effective height as below:

$$\frac{H_e}{D} = \frac{77}{30} = 2.57$$

$$\frac{B}{D} = \frac{50}{30} = 1.67$$

$$C_f = 1.1 + \frac{0.055H_e/D}{\exp\left\{\left|\log_e\left[\left(\frac{0.6B}{D}\right)\left(1-\frac{0.011H_e}{D}\right)\right]\right|^{\left[1.7-0.0013\left(\frac{H_e}{D}\right)^2\right]}\right\}} = 1.241$$

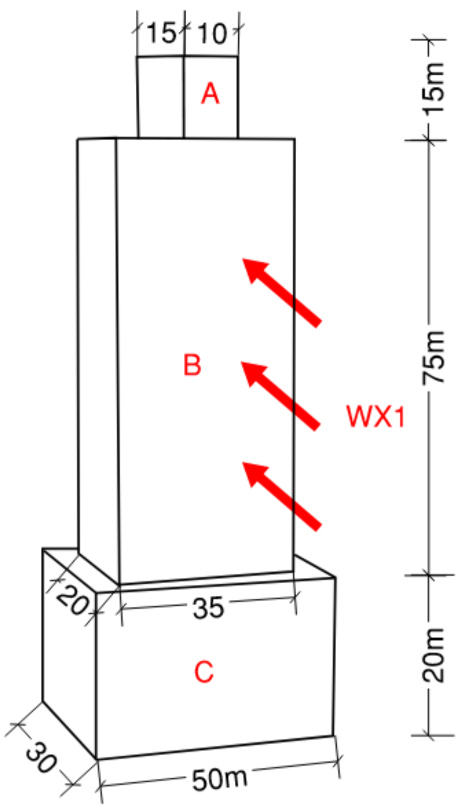
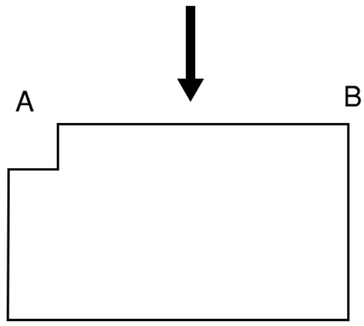


Figure 4-2 Example of a tower sitting on a podium

3) Force Coefficients for buildings with corner cuts/ round corners

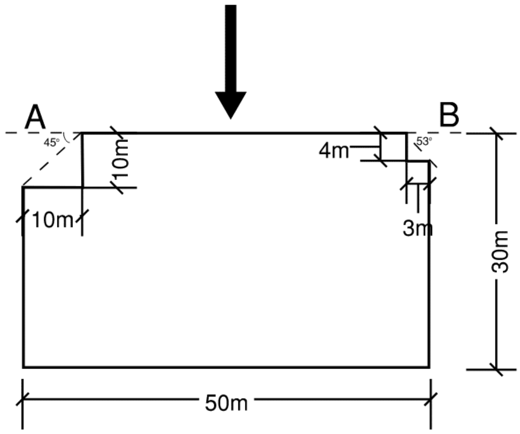
For the buildings with the symmetrical corners cuts or round corners, Section 4.2.3 of the Code shall be followed to consider the effects from the corner shapes. The corner modifications, either corner cut or round corner, are considered to provide beneficiary reduction on the wind loading and the Code has reflected this impact by applying a corner reduction factor on the force coefficients. It shall be noted that for only single corner cut/ single round corner on building plan, the corner reduction is not applicable. An example of the building shapes to use this rule is given as below.



Case 1:

Only corner cut at Corner A of the windward face

No corner reduction shall be applied.



Case 2:

Corner A: corner reduction with size 10m x 10m;

Corner B: corner reduction with size 4m x 3m;

As both corners of the windward face have corner cut, the corner cut effect shall be calculated as below:

Corner A:

$$1 - 2\frac{w}{B}(1 - cos\theta)$$

$$= 1 - 2 \times 10/50 \times (1 - \cos(45°)) = 0.883$$

Corner B:

$$1 - 2\frac{w}{B}(1 - cos\theta)$$

$$= 1 - 2 \times 3/50 \times (1 - \cos(53°)) = 0.952$$

Conservatively, the corner effect factor is max(0.883, 0.952)=0.952

Similar rules shall also be applied to the rectangular shapes with round corners using Equation 4-3 of the Code

4) Special shapes in considering force coefficient (U, X, double Y, L and Z)

Normally, a rectangle with corner cut-outs (Shape 1) in Figure 4-3 shall adopt the approach in clause 3). But if the w/B value exceeds 0.31 (Shape 2), it shall also be considered as an X-shaped building following Section 4.2.4 of the Code. The equivalent rectangle leading to smaller wind loads between the two options can be selected for calculation.

For the shapes such as Y-shaped, L-shaped, Z-shaped, it shall be noted that the equivalent rectangle may be different from different wind approaching angles referring to Figure 4-4 of the Code.

5) For the plan shapes not covered by the Code, the main principle in Section 4.2.4 of the EN.

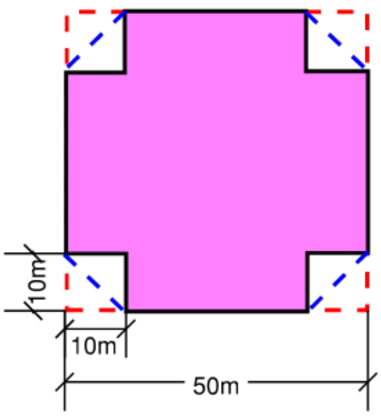
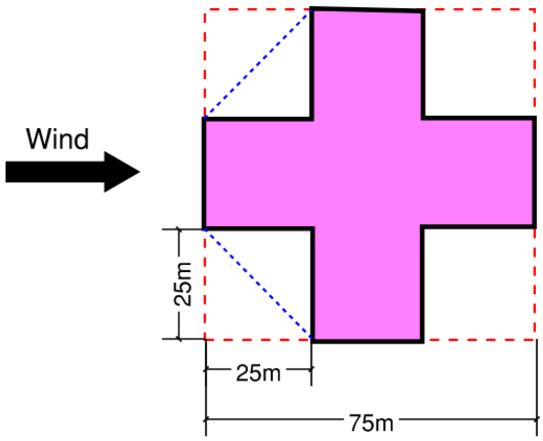
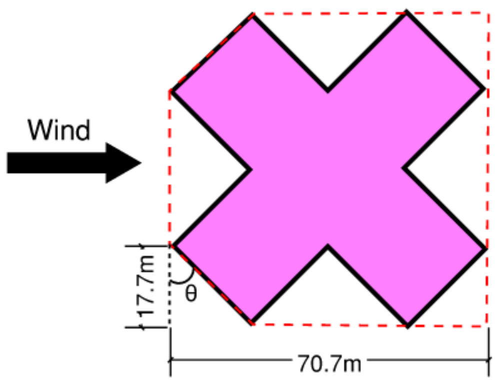
Shape 1: w/B <0.31	
	w/B=10/50=0.2<0.31 → it can be treated as a rectangle shape (red dash line) with corner cut (blue dash line)
Shape 2: w/B ≥ 0.31	
 Option 1	 Option 2
w/B=25/75=0.33>0.31 → take w/B=0.31, it can be treated as a rectangle shape (red dash line) with corner cut (blue dash line)	OR it can be treated as an X-shape.

Figure 4-3 Rectangles with corner cuts

For buildings of circular plan with height to diameter ratio not larger than 6, the force coefficient can be taken as 0.75.

4.1.2 Size and dynamic factors

The size and dynamic factors is applied to the peak gust pressures following the Code rather than the mean pressure in the 2004 Code. It is first calculated at the top height of the building and then reduced linearly along the height. It will directly result in an appropriate shear and base moment and a reasonable distribution of loading with height. The calculation procedure is summarized in Figure 4-4 as below. It shall be noted that in the calculation of $S_{q,h}$, the actual building height shall be used.

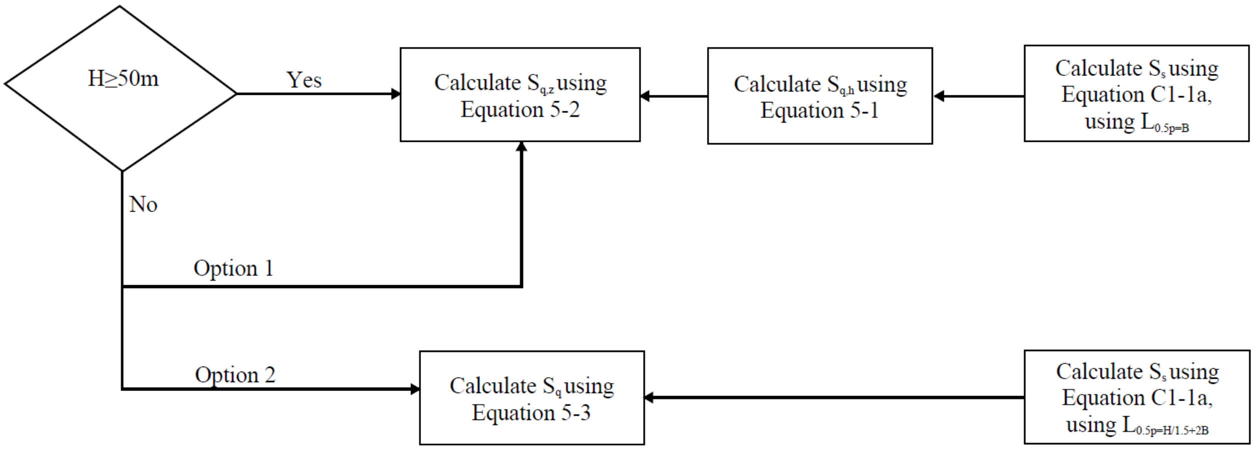


Figure 4-4 Flow chart of size and dynamic factors calculation

Size factor is incorporated in the Code to address the effect of the size and the location of the loading area to get in line with other international wind codes. Generally, the size factor will increase with smaller area, particularly in the corners or edges where flow separation will exist. In the Code, S_s will be used in the cladding wind load calculation as demonstrated in Section 5.3 and in the calculation of the size and dynamic factor $S_{q,h}$ for the along-wind load as described below.

$$S_{s(L_{0.5p}=B)} = e^{(0.17-0.07L_{0.5p}{}^{0.32})}$$

This equation applies to the size factor for the "other" zones and the over-all wind loads.

The $L_{0.5p}$ shall be directly adopted as the breadth of the building. If the building breadth varies with the height, the breadth shall be the one at the top of the main structure.

For the tall buildings, size and dynamic factor shall be calculated using Equation 5-1 of the Code.

$$S_{q,h} = 0.5 + \sqrt{\left(S_{s(L_{0.5p}=B)} - 0.5\right)^2 + \frac{0.25}{B^{0.5}HN_x^2\xi_x}}$$

For the short buildings that less than 50m in the Code, it is less dependent on the dynamic effect. The simplified equation as below (Equation 5-3 of the Code), which is independent on the natural frequency, can be used.

$$S_q = 1.1S_{s(L_{0.5p}=\frac{H}{1.5}+2B)}$$

4.2 Torsional loads and exemptions

Torsional force usually is generated due to the non-uniform wind pressure distribution on the surface or the unsymmetric building geometry. The Code has provided a simplified rule to calculate the torsional force by, in each orthogonal direction, shifting the along wind load from the geometric centre of the area by a horizontal distance e, which is defined as:

$e = \pm 0.05\ B$ for $B/D \leq 1$

$e = \pm 0.20\ B$ for $B/D = 6$

Interpolation can be applied for e when $1 < B / D < 6$.

For non-rectangular buildings that may be treated as rectangular, the same methodology of treating irregular plan shapes in force coefficient calculation in Section 4.1.1 shall be adopted to generate a synthetic rectangle to obtain the dimensions B and D.

4.3 Across-wind Loads

The across wind loads are normally generated by vortex shedding and act in the direction perpendicular to the approaching wind. It is an indispensable part of wind loading for those relative flexible buildings with large aspect ratio. In the Code, the across-wind loads checking can only be exempted if the building could fulfil all the following three requirements:

- $H<100m$
- $Max(H/B) < 5$
- The fundamental frequencies greater than 0.5Hz

Otherwise, the across-wind base moment for the two orthogonal wind directions shall be assessed using Equation 2-2 of the Code.

4.3.1 Wind Loading Scale up and Judgement on the Necessity of Wind Tunnel Tests

After calculating the across-wind base moment, it shall be compared with the along wind base moment acting in the same direction. Table 4-1 shows the wind loading direction for each approaching angle.

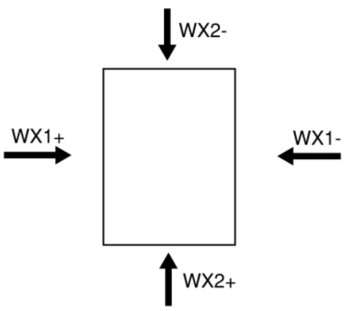
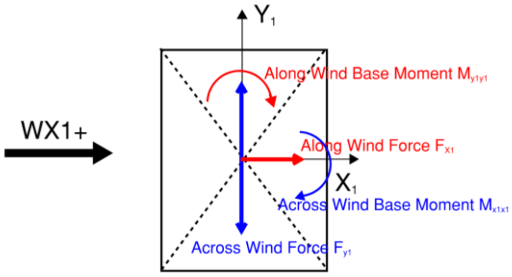
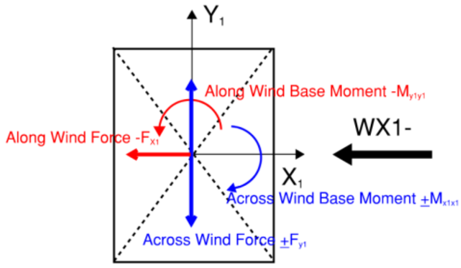
The across wind base moment (M_{x1x1}) from WX1+ and WX1- shall be compared with the along wind base moment (M_{y2y2}) as X1 and Y2 are in the same direction. If $\max(M_{-x1x1}, M_{+x1x1})/ M_{y2y2} \leqslant 1$, the along wind force F_{x1} shall not be changed.

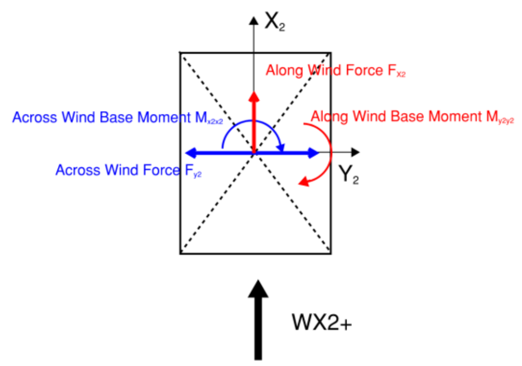
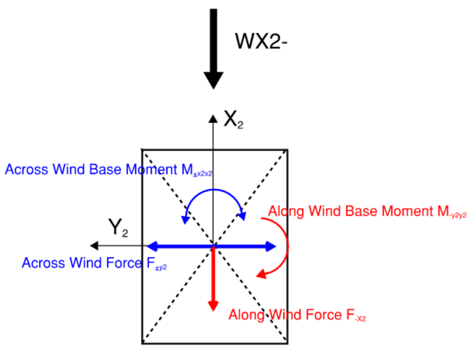
If $1<\max(M_{-x1x1}, M_{+x1x1})/ M_{y2y2} \leqslant 1.5$, the along wind force F_{x1} shall be factored up by $\max(M_{-x1x1}, M_{+x1x1})/ M_{y2y2}$, to make the scaled along-wind force match with the across wind force.

If $\max(M_{-x1x1}, M_{+x1x1})/ M_{y2y2} >1.5$, according to the Code, the building needs to be wind tunnel tested, because the across-wind impact is very substantial and it needs a more accurate assessment of the across wind load and responses.

The comparison shall be applied to each wind approaching direction to adjust the corresponding along wind load. An example is given in Section 2.2.3 of the EN.

Table 4-1 Crosswind load judgment

<table>
<tr><td>
</td><td>wind is approaching from four directions (WX1+, WX1-, WX2+, WX2-) normal to each side of the building as shown in the left</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

<table>
<tr><td colspan="2">For WX_1+, the along wind and across wind force and base moment are marked in left. Y_1, implying the across wind load due to wind in X_1 direction, is in the same direction as X_2 (the approaching wind direction in next case).</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">For WX_2+, the along wind and across wind force and base moment are marked in left. Y_2 is in the same direction with X_1.</td></tr>
</table>

A parametric study is conducted to investigate the across wind and along wind load relationship for various buildings. The building height varies from 90m to 200m with an aspect ratio from 4 to 8. The natural frequencies are calculated using 46/H for simplicity. The results are presented in terms of the ratio of the across-wind base moment divided by the corresponding along-wind base moment as shown in Table 4-2. From the table, the highlighted cells represent the conditions in which the 1.5 base moment ratio is exceeded and those conditions in general covers buildings with high aspect ratio and bigger building heights.

Under the studied parameters, it could be concluded that:

- Unless in very dense urban center, wind tunnel testing will be required for buildings with H/min(B,D) >=7. This includes exposed (He/H=1) or mildly sheltered conditions (He/H=0.75).
- In significantly sheltered condition (He/H<0.5) due to exceeding the 1.5 ratio, such normal buildings in extremely dense urban center, compulsory wind tunnel test due to exceeding the 1.5 ratio is very rare, except for very limited buildings with very big slenderness ratio.

However, it should be noted that the conclusions in this parametric study are valid under the adopted natural frequencies only, but they are expected still give some indicative information for general cases.

Table 4-2 Overturning Moment Comparison (M_{across}/M_{along} of the same loading direction)

		He/H=1.0					He/H=0.75					He/H=0.45				
		H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B
H (m)	H/D	8	7	6	5	4	8	7	6	5	4	8	7	6	5	4
90	8	1.84	1.54	1.26	1.01	0.79	1.88	1.59	1.31	1.05	0.83	1.39	1.19	0.99	0.80	0.63
90	7	1.81	1.52	1.24	0.99	0.75	1.83	1.55	1.28	1.02	0.79	1.33	1.14	0.95	0.76	0.59
90	6	1.73	1.46	1.20	0.95	0.72	1.74	1.47	1.22	0.97	0.74	1.25	1.07	0.89	0.72	0.55
90	5	1.63	1.38	1.14	0.91	0.69	1.62	1.38	1.15	0.92	0.70	1.15	0.99	0.82	0.67	0.51
90	4	1.48	1.27	1.05	0.84	0.64	1.46	1.25	1.04	0.84	0.64	1.03	0.88	0.74	0.60	0.46
120	8	1.92	1.61	1.32	1.05	0.82	1.96	1.66	1.37	1.10	0.87	1.46	1.25	1.04	0.84	0.67
120	7	1.88	1.58	1.30	1.03	0.79	1.91	1.62	1.33	1.07	0.83	1.40	1.20	1.00	0.81	0.63
120	6	1.81	1.53	1.26	1.00	0.76	1.82	1.54	1.28	1.02	0.78	1.32	1.13	0.94	0.76	0.59
120	5	1.71	1.45	1.20	0.95	0.72	1.70	1.45	1.20	0.96	0.74	1.22	1.04	0.87	0.70	0.54
120	4	1.56	1.33	1.10	0.89	0.67	1.54	1.32	1.10	0.89	0.68	1.09	0.93	0.78	0.64	0.49
150	8	1.97	1.66	1.36	1.08	0.85	2.02	1.71	1.41	1.14	0.90	1.51	1.29	1.08	0.88	0.69
150	7	1.94	1.63	1.34	1.07	0.82	1.97	1.67	1.38	1.10	0.85	1.45	1.24	1.04	0.84	0.65
150	6	1.87	1.58	1.30	1.03	0.78	1.88	1.59	1.32	1.06	0.81	1.37	1.17	0.98	0.79	0.61
150	5	1.76	1.50	1.24	0.99	0.75	1.76	1.50	1.25	1.00	0.76	1.26	1.08	0.91	0.73	0.57
150	4	1.61	1.38	1.15	0.92	0.70	1.59	1.36	1.14	0.92	0.71	1.13	0.98	0.82	0.66	0.51
180	8	2.02	1.69	1.39	1.11	0.87	2.06	1.75	1.44	1.16	0.92	1.55	1.33	1.11	0.90	0.71
180	7	1.98	1.67	1.37	1.09	0.84	2.01	1.71	1.41	1.13	0.88	1.49	1.28	1.07	0.86	0.67
180	6	1.91	1.62	1.33	1.06	0.81	1.92	1.63	1.35	1.09	0.83	1.41	1.20	1.01	0.81	0.63
180	5	1.81	1.54	1.27	1.01	0.77	1.80	1.54	1.28	1.03	0.79	1.30	1.12	0.94	0.76	0.59
180	4	1.66	1.42	1.18	0.95	0.72	1.64	1.40	1.17	0.95	0.73	1.17	1.01	0.85	0.69	0.53
200	8	2.04	1.71	1.41	1.12	0.88	2.09	1.77	1.46	1.18	0.93	1.58	1.35	1.12	0.92	0.72
200	7	2.01	1.69	1.39	1.11	0.85	2.04	1.73	1.43	1.15	0.89	1.52	1.30	1.08	0.88	0.69
200	6	1.94	1.64	1.35	1.07	0.82	1.95	1.66	1.37	1.10	0.85	1.43	1.22	1.02	0.83	0.64
200	5	1.84	1.56	1.29	1.03	0.78	1.83	1.56	1.30	1.04	0.80	1.33	1.14	0.95	0.77	0.60
200	4	1.68	1.44	1.20	0.96	0.73	1.66	1.43	1.19	0.96	0.74	1.19	1.03	0.86	0.70	0.54

4.4 Load Combination

4.4.1 Torsional loads exemptions

The torsional load cases can be exempted if the structural system are proved well resistant to the lateral loads. The Code has given the below conditions, where torsional load cases could be exempted.

(a) Buildings of single storey up to 10m height;

(b) Buildings of up to 70 m height with a peripheral lateral load resisting construction;

(c) Buildings which pass the torsional regularity check. The check that in each lateral direction X1 and X2 in turn, the maximum inter-storey drift in each storey due to the torsional load must be less than 25% of that due to the lateral load (for buildings with a vertically continuous lateral and torsional resisting structure, this check may be made only at the base and at higher storeys where the resisting capacity reduces by more than 25% when compared with nearby storeys); or

(d) Where the torsional inter-storey drift calculated above are not greater than 50% of the lateral drift, the Case 3 in Table 2-1 of the Code, (primarily torsion) load cases do not need to be calculated.

If the torsional load case exemption rules (a) to (c) is fulfilled, only 8 load cases by the lateral wind loads in the two orthogonal directions shall be considered as shown in Table 4-3 Load combination factors for lateral wind loads only.

Table 4-3 Load combination factors for lateral wind loads only

Case	$W_{z,x1} = Max(W_{z,+x1}, W_{z,-x1})$	$W_{z,x2} = Max(W_{z,+x2}, W_{z,-x2})$
1	±1.00	±0.55
2	±0.55	±1.00

If the torsional load case exemption rules (a) to (c) is not fulfilled but the check in (d) is passed, totally 16 load cases as shown in Table 4-4 Load combination factors with torsion shall be considered.

Table 4-4 Load combination factors with torsion

Case	$W_{z,x1} = Max(W_{z,+x1}, W_{z,-x1})$	$W_{z,x2} = Max(W_{z,+x2}, W_{z,-x2})$	ΔT_z
1	±1.00	±0.55	±0.55
2	±0.55	±1.00	±0.55

4.4.2 An example of application of Item (c) of torsional exemption

We consider a 156m high building with a rectangle plan shape (32.3m x 36.4m) as shown in Figure Figure 4-5. It is located in a flat terrain without any other buildings sheltered. A frame-shear wall is modeled in the ETABS as shown in Figure 4-6. The lateral load is resisted by the moment frames and the inner core walls. The mass of the building composed of dead load, superimposed dead load and 25% of the imposed loads is added to the model for the modal analysis. Through the modal analysis, the natural frequencies of the building for the lateral X1 (X direction in Figure 4-6) and X2 (Y direction in Figure 4-6) and torsional (Rz in Figure 4-6) directions are summarized in Table 4-5.

Since it is over 70m, the building torsional regularity check is required if taking the load clause to exempt the torsion load cases. Three wind load cases following the Code are added to the model as listed below and tabulated in Table 4-6:

- WIND X1: maximum lateral wind loading in X1 direction;
- WIND X2: maximum lateral wind loading in X2 direction;
- WIND T (Rz direction): the torsional wind loading.

The eccentricity e is calculated using B/D ratio as below:

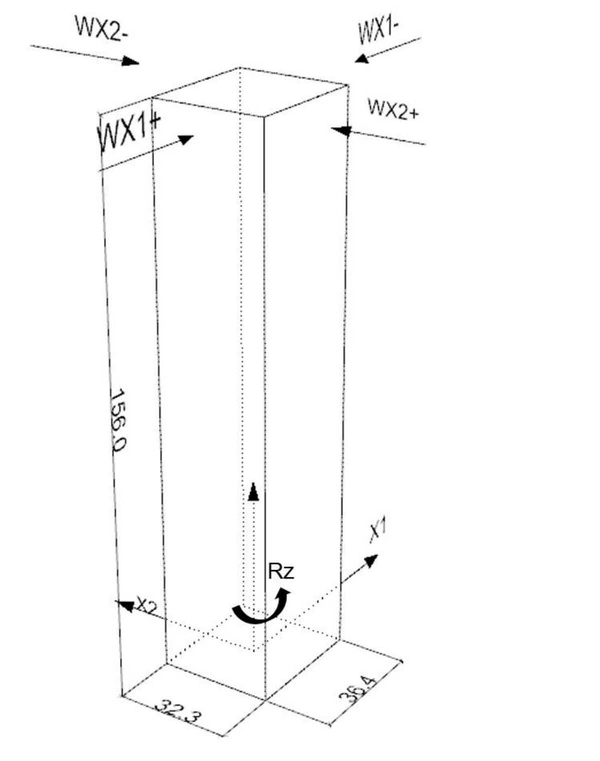
WX1: B/D= 32.3/36.4 < 1, e = 0.05

WX2: B/D = 36.4/32.3 = 1.13, e = 0.0539

The inter-storey drift for each storey under WIND X1, WIND X2 and WIND T is tabulated in Table 4-7. It could be observed that the maximum inter-storey drift due to torsion (WIND T) is less than

25% of that due to the lateral load, fulfills the requirement (c) in Section 4.4.1. Only the load cases in Table 4-3 need to be considered in the structural design.

Figure 4-5 A Case Study for Torsional Regularity Check



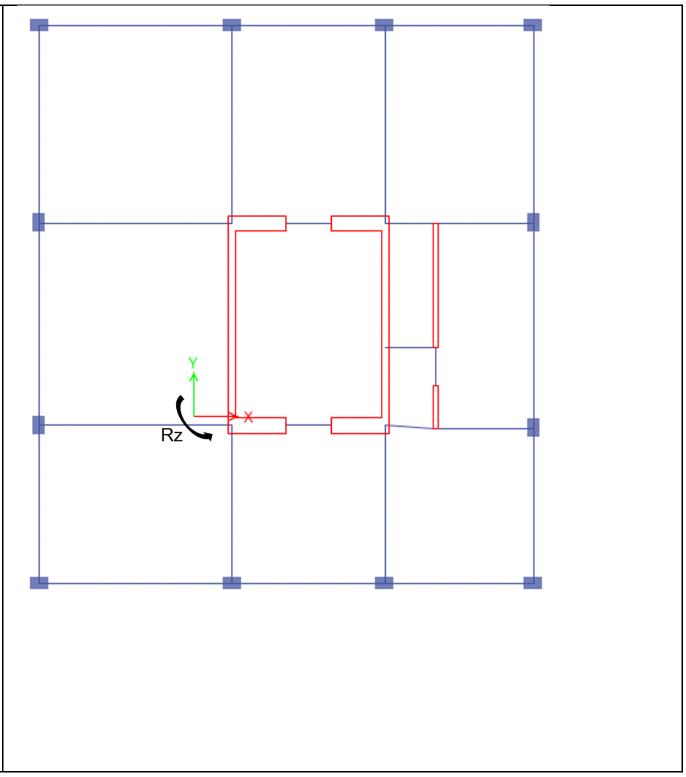


Figure 4-6 Structural System in ETABS

Table 4-5 Modal Properties

Mode	Direction	Natural Frequency (Hz)
1	X-X	0.237
2	Y-Y	0.269
3	Rz	0.482

Table 4-6 Input Wind Load to Etabs Model

	Wind X1 (kN)	Wind X2 (kN)	Wind T (kNm)
ROOF	402	327	787
32/F	586	477	1147
31/F	609	496	1192
30/F	597	487	1170
29/F	582	475	1141
28/F	565	461	1106
27/F	550	450	1078
26/F	539	441	1057
25/F	528	433	1035
24/F	517	424	1014
23/F	506	415	992
22/F	495	407	970

21/F	484	398	949
20/F	473	389	927
19/F	462	381	906
18/F	451	372	884
17/F	440	363	862
16/F	429	355	841
15/F	418	346	819
14/F	407	337	797
13/F	396	328	775
12/F	384	319	753
11/F	407	338	797
10/F	444	370	871
9/F	427	356	836
8/F	400	334	783
7/F	391	328	767
6/F	359	302	703
5/F	307	259	602
4/F	273	230	534
3/F	250	211	489
2/F	261	221	511
1/F	259	220	507
G/F	150	128	294

Table 4-7 Inter Storey Drift Output From the Etabs Model

Story	Max Inter storey drift in X1 direction		Inter storey drift ratio (due to WIND T/ due to WIND X1)	Max Inter storey drift in X2 direction		Inter storey drift ratio (due to WIND T/ due to WIND X2)
	Inter storey drift due to WIND X1 (lateral load)	Inter storey drift due to WIND T (Torsion)		Inter storey drift due to WIND X2 (lateral load)	Inter storey drift due to WIND T (Torsion)	
ROOF	9.3E-04	2.0E-06	0%	6.3E-04	2.0E-06	0%
32/F	9.4E-04	4.0E-06	0%	6.4E-04	4.0E-06	1%
31/F	9.5E-04	5.0E-06	1%	6.5E-04	5.0E-06	1%
30/F	9.7E-04	7.0E-06	1%	6.6E-04	7.0E-06	1%
29/F	9.8E-04	9.0E-06	1%	6.6E-04	9.0E-06	1%
28/F	9.9E-04	1.1E-05	1%	6.7E-04	1.1E-05	2%
27/F	1.0E-03	1.3E-05	1%	6.8E-04	1.2E-05	2%
26/F	1.0E-03	1.5E-05	1%	6.9E-04	1.4E-05	2%
25/F	1.0E-03	1.7E-05	2%	6.9E-04	1.6E-05	2%
24/F	1.0E-03	1.8E-05	2%	7.0E-04	1.8E-05	3%
23/F	1.0E-03	2.0E-05	2%	7.0E-04	1.9E-05	3%
22/F	1.1E-03	2.2E-05	2%	7.1E-04	2.1E-05	3%
21/F	1.1E-03	2.3E-05	2%	7.1E-04	2.2E-05	3%
20/F	1.1E-03	2.5E-05	2%	7.1E-04	2.4E-05	3%
19/F	1.1E-03	2.7E-05	3%	7.1E-04	2.5E-05	4%
18/F	1.1E-03	2.8E-05	3%	7.0E-04	2.7E-05	4%
17/F	1.0E-03	3.0E-05	3%	7.0E-04	2.8E-05	4%

16/F	1.0E-03	3.1E-05	3%	6.9E-04	3.0E-05	4%
15/F	1.0E-03	3.3E-05	3%	6.8E-04	3.1E-05	5%
14/F	1.0E-03	3.4E-05	3%	6.7E-04	3.2E-05	5%
13/F	9.9E-04	3.5E-05	4%	6.5E-04	3.4E-05	5%
12/F	9.6E-04	3.7E-05	4%	6.3E-04	3.5E-05	6%
11/F	9.4E-04	3.9E-05	4%	6.1E-04	3.7E-05	6%
10/F	9.1E-04	4.3E-05	5%	5.8E-04	4.1E-05	7%
9/F	8.3E-04	3.8E-05	5%	5.2E-04	3.5E-05	7%
8/F	7.5E-04	3.7E-05	5%	4.6E-04	3.4E-05	7%
7/F	7.1E-04	3.7E-05	5%	4.4E-04	3.5E-05	8%
6/F	6.5E-04	3.6E-05	6%	3.9E-04	3.4E-05	9%
5/F	5.7E-04	3.0E-05	5%	3.3E-04	2.8E-05	9%
4/F	5.1E-04	2.9E-05	6%	2.9E-04	2.6E-05	9%
3/F	4.4E-04	2.7E-05	6%	2.4E-04	2.4E-05	10%
2/F	3.8E-04	2.7E-05	7%	1.9E-04	2.5E-05	13%
1/F	3.6E-04	3.4E-05	9%	1.9E-04	3.3E-05	17%

4.5 Acceleration Calculation and Human Comfort Assessment

The 2019 Code specifically requires the human comfort to be assessed by comparing calculated acceleration using Equation 2-4 of the Code with the peak acceleration limits in Section 2.4.2 of the Code. It shall be noted that the damping ratio for checking acceleration is given separately from the one for strength design as tabulated in Appendix C2 of the Code. The peak acceleration limits reflect that human tolerance to building motion is frequency dependent.

$$A_z = \frac{G_{ry}\,\rho_a}{\xi_y{}^{0.5} N_y{}^{1.3} (BD)_b^{0.15}} \left(\frac{0.215\sqrt{2S_r Q_h/\rho_a}}{1 + 3.7 I_{v,h}} \right)^{3.3} \frac{H_b}{3M_h} . \frac{2 + \eta_y}{3} . \left(\frac{Z}{H_b} \right)^{\eta_y}$$

A parametric study is conducted using the same building geometry information and natural frequencies as shown in Section 4.3.1 and two sets of mass densities (400kg/m^3 and 500 kg/m^3) and two sets of return periods (1-year and 10-year). The results summarized in Appendix A are compared with the acceleration limitation introduced in the Code. N/A represents buildings falling out of the standard approach due to $M_{across}/M_{along} \geqslant 1.5$ as shown in Table 4-2. In the legend, red represents conditions that exceed the human comfort limit for office buildings; blue represents conditions that are below the comfort limit for residential building; pink represents conditions exceeding residential but within the office limit.

On analysing results shown in Appendix A, the trend can be observed that, under the same building height, more slender buildings lead to bigger acceleration responses and therefore have bigger possibility to exceed the human comfort criteria. It is also observed that for tall buildings, the residential comfort can be satisfied in most less slender buildings (H/min(B,D)≤6), even under the unsheltered condition. Although a big exceedance of residential comfort limit is observed in short slender buildings, a common understanding is that shorter buildings are relatively easier to get significant sheltering benefit from surroundings so that their residential comfort may not be a big concern in urban city terrain with and without sheltering conditions.

5. Cladding Wind Loads

For the calculation of cladding wind loads, the procedure is summarized in Figure 2-2 of the Code.

The cladding loads calculation shall depend on the different opening conditions of the building envelope.

For the buildings without dominant openings:

$$P = Q_z C_p S_s$$

For the buildings with dominant openings:

$$P = P_e - P_i = Q_z(C_{pe} S_s - C_{pi} S_{s,i})$$

From the equations above, three main factors will affect the cladding wind loads, i.e., reference wind pressure, pressure coefficient and size factor, which will be discussed in the following chapters.

5.1 Reference Wind Pressure

Reference wind pressure is calculated at the reference height using the same procedure as that introduced in the structure wind load calculation. The 2019 Code takes reference height as building top rather than following approaching wind profile, which is different from the requirement of the 2004 Code.

In the CoP 2019, if no sheltering effect is considered, the cladding pressure will be a constant value over the building height. If the sheltering effect is considered, the reference wind pressure will be calculated based on a reduced building height, effective height. And the cladding pressure below a height of $0.5(H-H_e)$ can be reduced by 20%. A simple example for a building with $H_e/H=0.6$ is shown in Figure 5-1. Below the height $0.5(H-H_e)=0.2H$, the cladding pressure could be reduced by 20%.

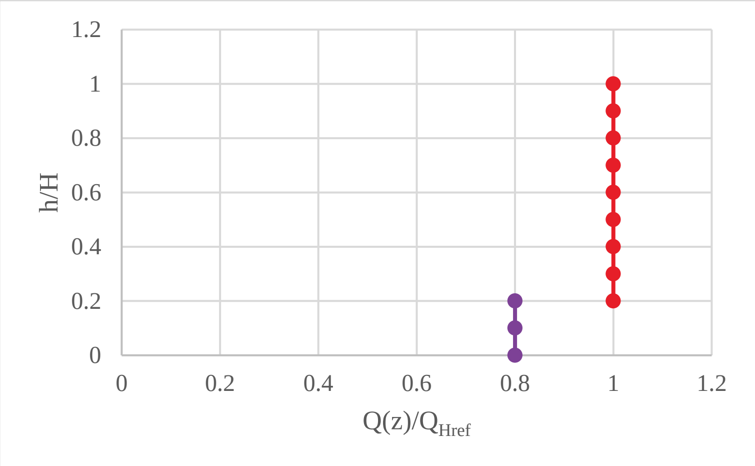


Figure 5-1 Cladding Pressure over heights

For a tower sitting on a podium, the reference wind pressure shall be calculated according to the different locations.

- For the towers sitting more than 0.2b from the podium edge as shown in Figure 4.5(a) of the Code, the calculation of the cladding wind load for the podium shall use the reference wind pressure calculated at the top of the podium, while the cladding wind load for the tower shall be calculated using the reference wind pressure at the top of the tower.

- For the tower at the edge of a podium (gap $\leqslant$ 0.2b), as shown in Figure 4.5(b) of the Code, some podium portion may be affected by tower and therefore the reference height for those portions shall be the tower height.

5.2 Pressure Coefficients

The net pressure coefficients for an enclosed building envelop without dominant openings are provided in Section 4.3.1 of the Code. The net pressure coefficients are derived assuming the internal pressure coefficients as +0.2 or -0.3 with the same values in the 2004 Code. The corresponding external pressures are given in Table B1-1 of Appendix B1 of the Code. It shall be noted that the net pressure coefficients shall be applied together with the wind reference pressure at the top of the building, Q_h.

The pressure coefficients for building envelop with dominant openings are provided in Appendix B1 of the EN.

5.2.1 Guidance for Edge Zone Extent of Irregular Shapes

The zone definitions for rectangular shaped buildings are given in Figure 4-6(a) and (b) of the Code. For the irregular shaped buildings, the definition of the edge zone follows the rule for the rectangles as shown in Figure B-1 of the EN, which is also shown in Figure 5-2 below with a slight expansion of the demonstration on L shape.

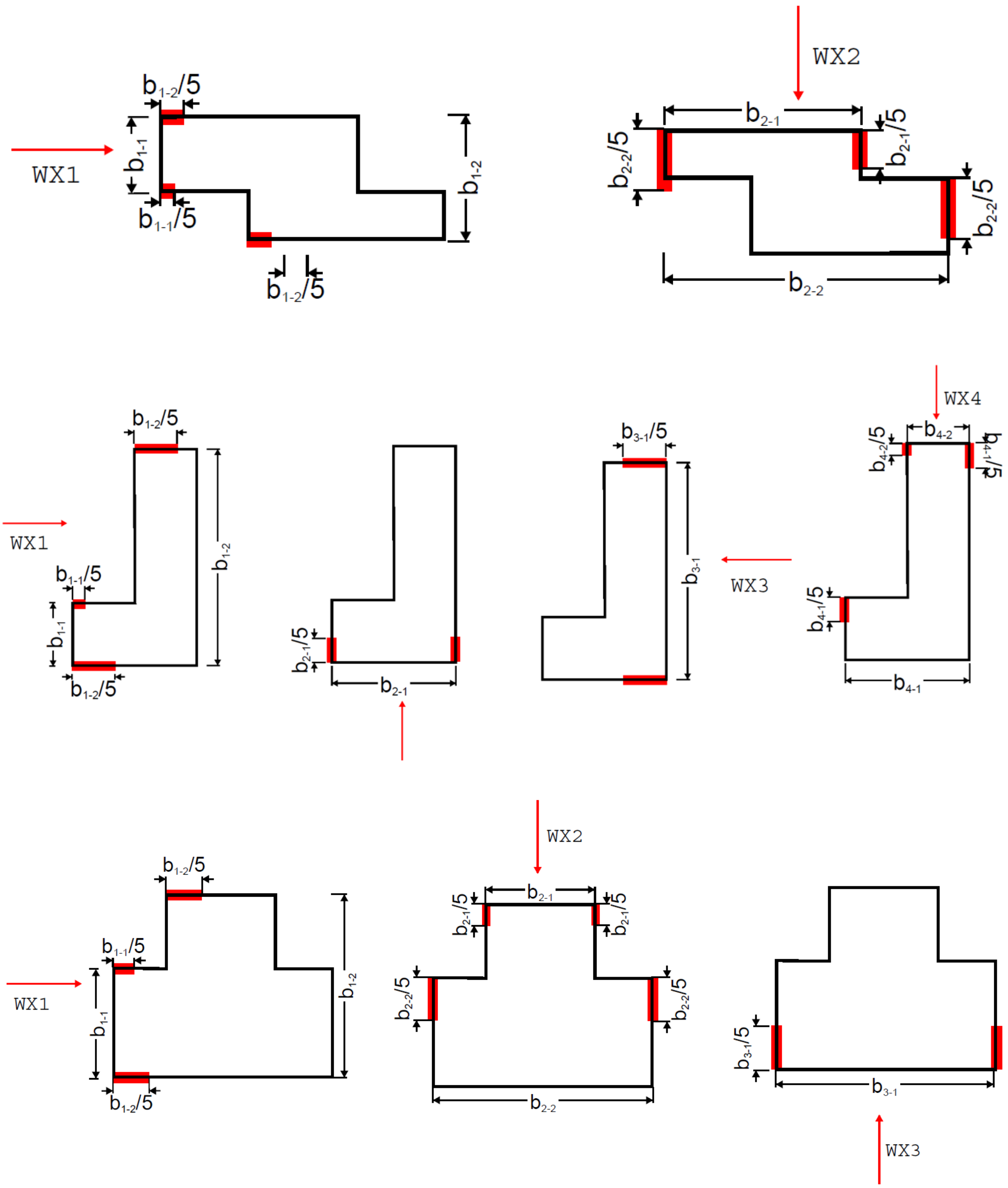


Figure 5-2 definition of the edge zones for some irregular shapes

5.2.2 Podium roof cladding affected by tower

For the towers sitting on the podium, some of the podium areas may be under the influence of the tower and shall adopt the same pressure values from the adjacent elevations of the tower. The zone definitions and dimensions are shown in Figure 5-3 and Figure 5-4.

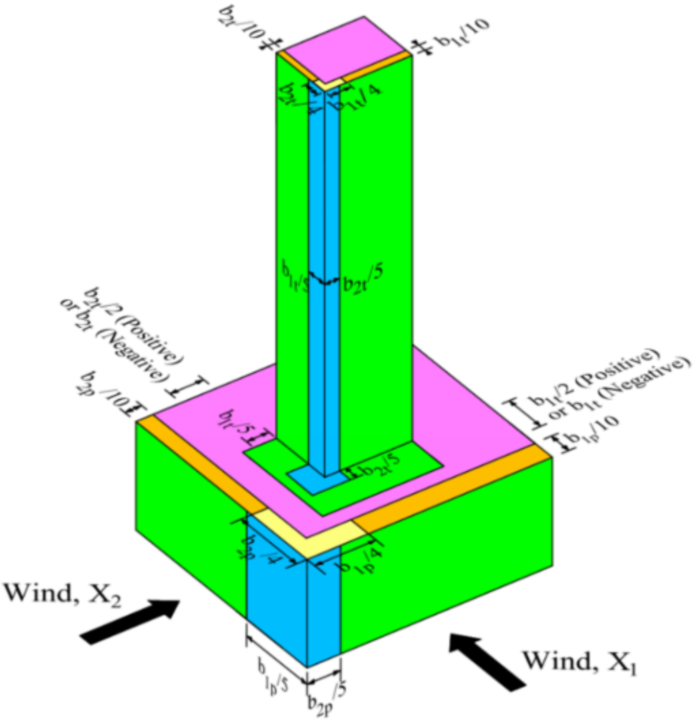


Figure 5-3 Dimension for pressure zones

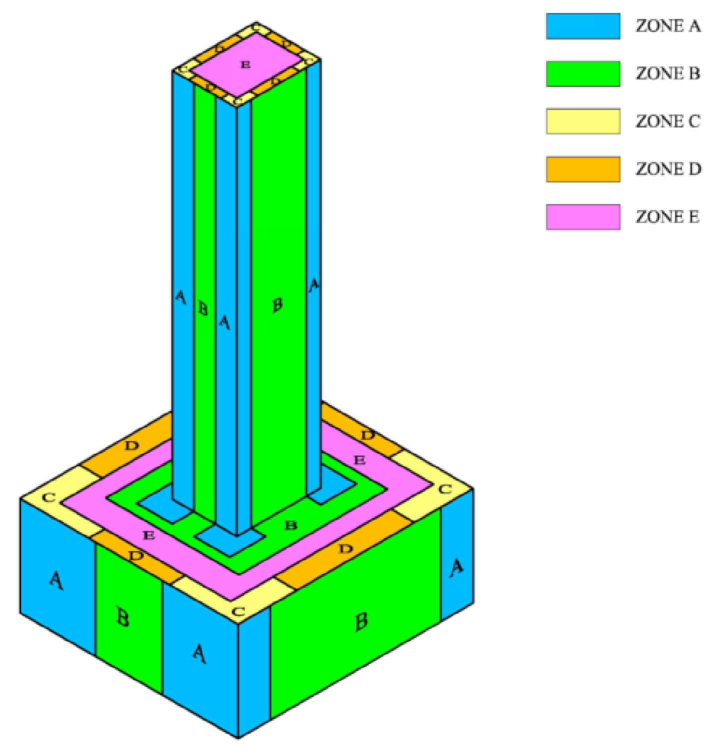


Figure 5-4 Zone key for pressure

5.2.3 Internal Pressure with dominant openings

For the buildings with dominant openings, the cladding wind pressure shall be calculated as the net pressure of the external and internal wind pressure together. The external pressure coefficients for building envelope are provided in Appendix B1.2 of the Code. The internal pressure coefficients shall be calculated following the guidance of Appendix B1.3 of the Code.

If the openings can be justified as dominant openings, the internal pressure coefficient shall be calculated as:

$$C_{pi} = \frac{C_{pe}}{\left[1 + \left(\frac{A_{tot}}{A_0}\right)^2\right]}$$

where

A_{tot} is the sum of areas of openings on other faces, including leakage. The leakage contribution to A_{tot} is defined as 0.1% of the total external surface area of the other surfaces. Other numbers may be used with justification and specialist advice may be sought.

A_0 is the area of the largest opening or sum of areas of openings of similar sizes and within the same or similar pressure zone/zones on the same building face.

If the openings are not qualified as dominant openings, the internal pressure coefficient can be estimated from the balance of flow, using the formula below:

$$o^* = \sum_{All\ j} A_j \left[\sqrt{\frac{2\left|P_{ej} - P_i\right|}{\rho_a}} Sign\left(P_{ej} - P_i\right)\right]$$

where

P_{ej} is the external pressure at the jth opening

P_i is the wanted internal pressure

$\sqrt{\frac{2|P_{ej}-P_i|}{\rho_a}}$ is the air flow speed at the jth opening

$Sign\left(P_{ej} - P_i\right)$ is the direction of flow – inward if positive

A_j is the effective opening size at position j, typically 0.6 of the gross area for a rectangular building.

The Definition of dominant openings

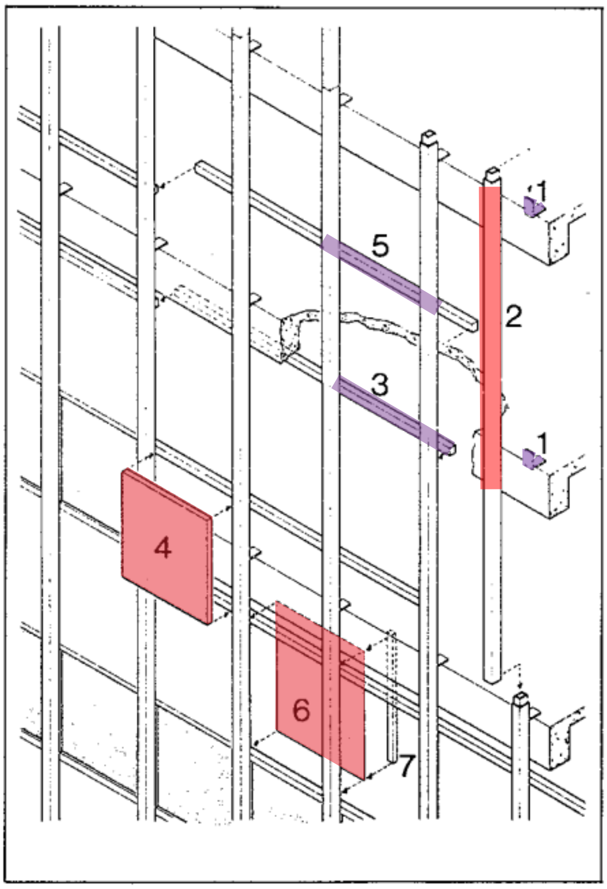
The definition of dominant openings is shown in Appendix B1 of the Code. An example is shown in Section 5.5.2 to demonstrate how to define if the opening is dominant.

5.3 Size Factor

Size factor reflects the correlation between the loading area and the turbulence scales. For a small area, the wind flow will be highly correlated, the peak pressure of the load areas is therefore big. The sensitivity of peak pressure against the size of loading is more obvious in edge and corner zones. This section will introduce the procedure of the size factor calculation for various components.

5.3.1 Size factor for various components

Figure 5-5 shows the typical cladding system for buildings. 4 different elements, i.e., anchors, mullions, horizontal rail, spandrel panel/vision glasses are highlighted with different colours. An example of calculating the half perimeter length of the four elements are shown from Figure 5-6 to Figure 5-9. It is reminded that the example here is for reference only and it should be the responsibility of the designers to make a reasonable judgement of the loading areas of their specific projects.



STICK SYSTEM—Schematic of typical version

1: Anchors. 2: Mullion. 3: Horizontal rail (gutter section at window head). 4: Spandrel panel (may be installed from inside building). 5: Horizontal rail (window sill section). 6: Vision glass (installed from inside building). 7: Interior mullion trim.

Other variations: Mullion and rail sections may be longer or shorter than shown. Vision glass may be set directly in recesses in framing members, may be set with applied stops, may be set in sub-frame, or may include operable sash.

Figure 5-5 Schematic of typical cladding system

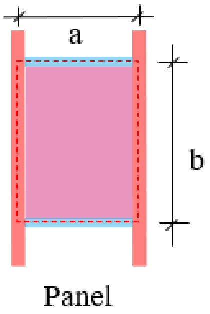


Figure 5-6 $L_{0.5p}$ for a cladding panel

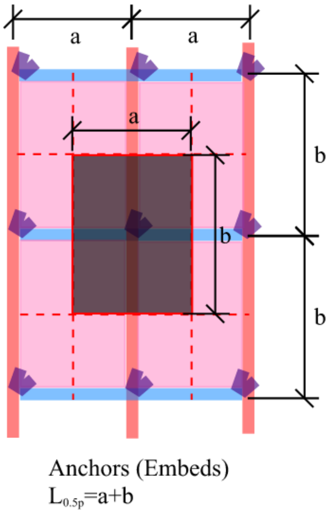
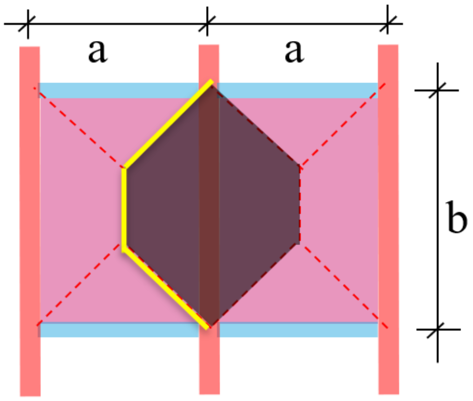
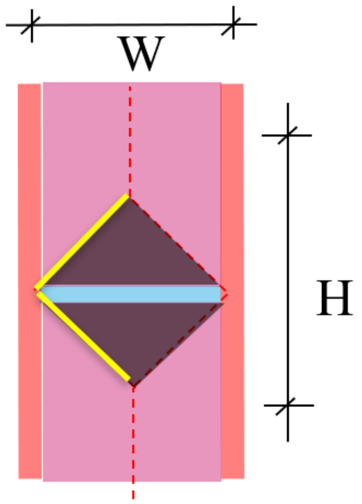


Figure 5-7 $L_{0.5p}$ for an anchor



$L_{0.5p}$ is the half perimer as marked by yellow line.

Figure 5-8 $L_{0.5p}$ for a mullion



$L_{0.5p}$ is the half perimer as marked by yellow line.

Figure 5-9 $L_{0.5p}$ for a transom

5.4 Working Example for Cladding Wind Load Calculation

In this section, two working examples are illustrated to show the procedure of the cladding wind load calculation following HKCOP 2019. The examples show the differences in considering the reference height under different relative positions between the tower and the podium.

5.4.1 General Information

The example is a 90m tower sitting on a 16m podium with different relative positions (total height of 106m). The key dimensions for the tower and the podium are illustrated in Figure 5-10 and Figure 5-11. The building is located on an open flat terrain without any significant topographic features or the complex surroundings. The cladding panel is assumed as a 1.5m × 1.5m size on the tower and a 1.5m × 3m size on the podium.

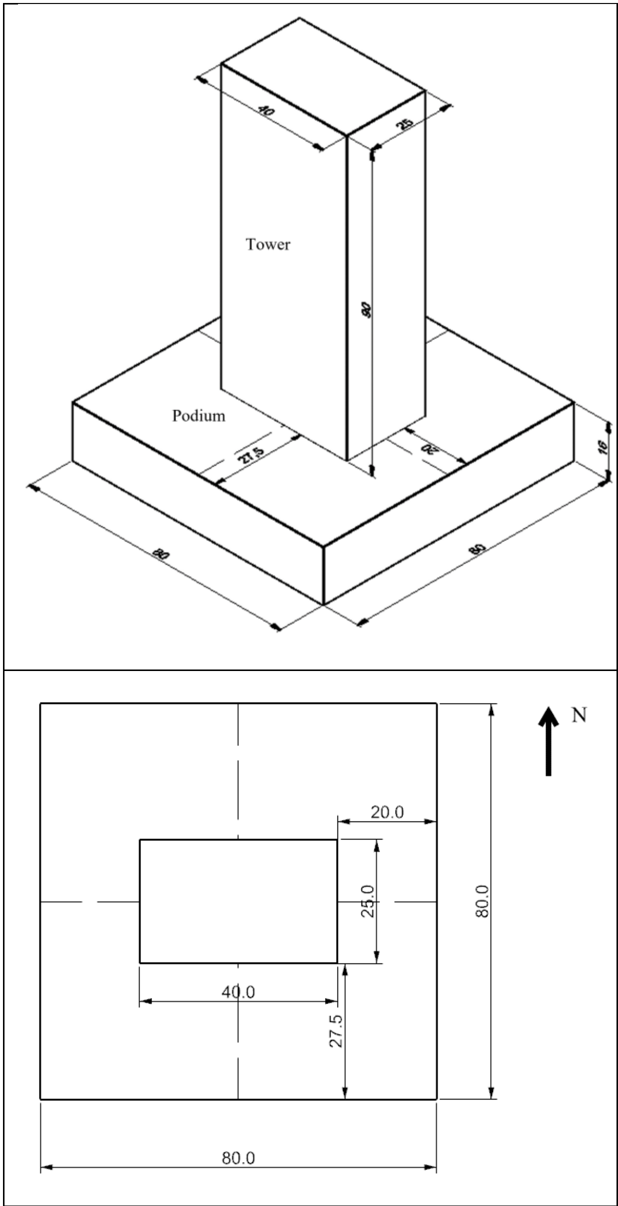


Figure 5-10 Dimensions for Case 1

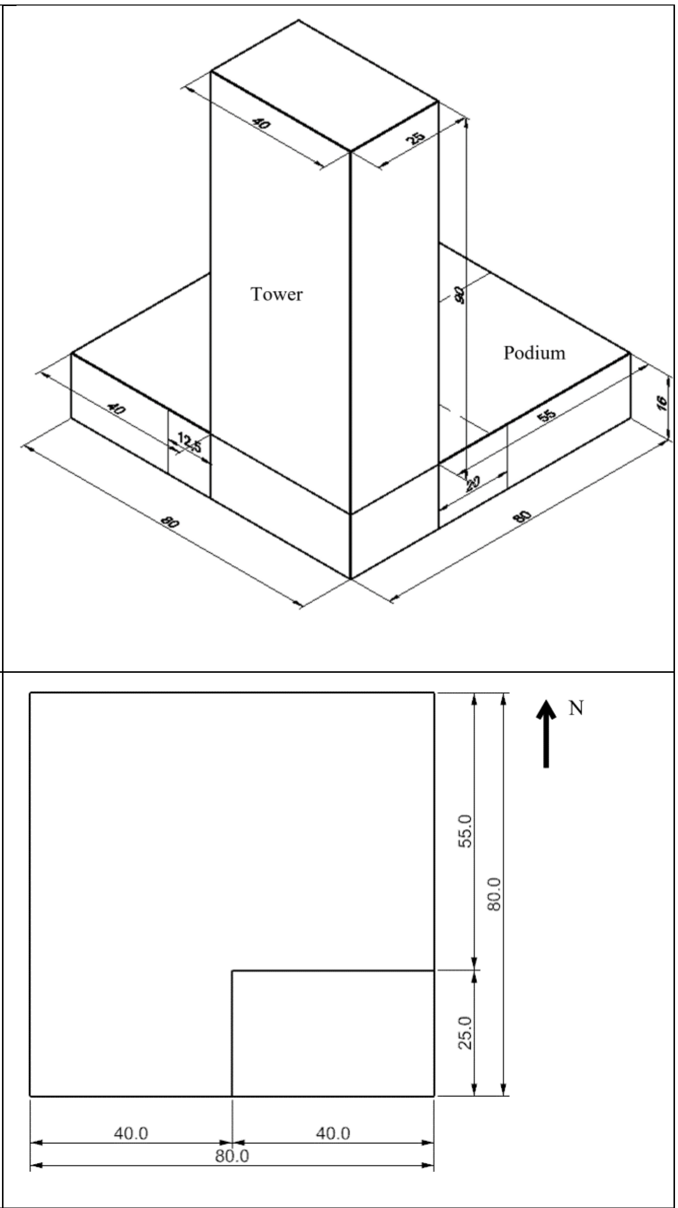


Figure 5-11 Dimensions for Case 2

5.4.2 Calculation of the cladding pressure

Based on the assumption of the topography, the topography factor is 1.0. For remaining steps, the calculation procedure is as follows.

a. Determine the directionality factor on pressure, S_θ

The directionality factor is obtained following the procedure described in Section 3.1.2 as summarized in Figure 5-12. For the easy demonstration, the directionality factor is taken as 0.85 for all the directions conservatively.

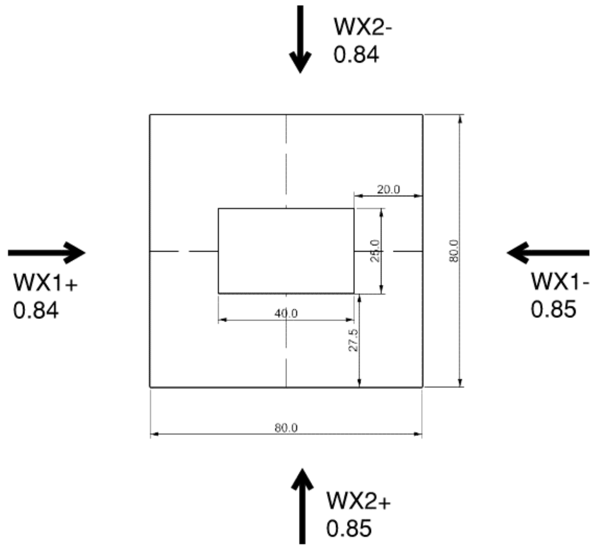


Figure 5-12. Directionality factors

b. Consider the different reference heights

It should be noted that the podium walls close to the tower may be under the impact of the wind flows from the tower. Thus, the reference height in those regions shall be the same as the tower according to the Code, as marked in the blue region on the podium part in Figure 5-13. The dimension of the region extend from the tower footprint ($0.5b_{1t}$ or $0.5b_{2t}$ subject to approaching wind direction) is determined based on cladding zone scaling length b as defined in Figure 4-5 of the Code in the corresponding wind direction. As for the reference wind pressure on the podium roof, it shall follow the pressure zones in Figure 5-4. If the pressure zone is the extension of the pressure zone from the tower wall, the reference wind pressure for the tower shall be used. Otherwise, the reference wind pressure for the podium is adopted.

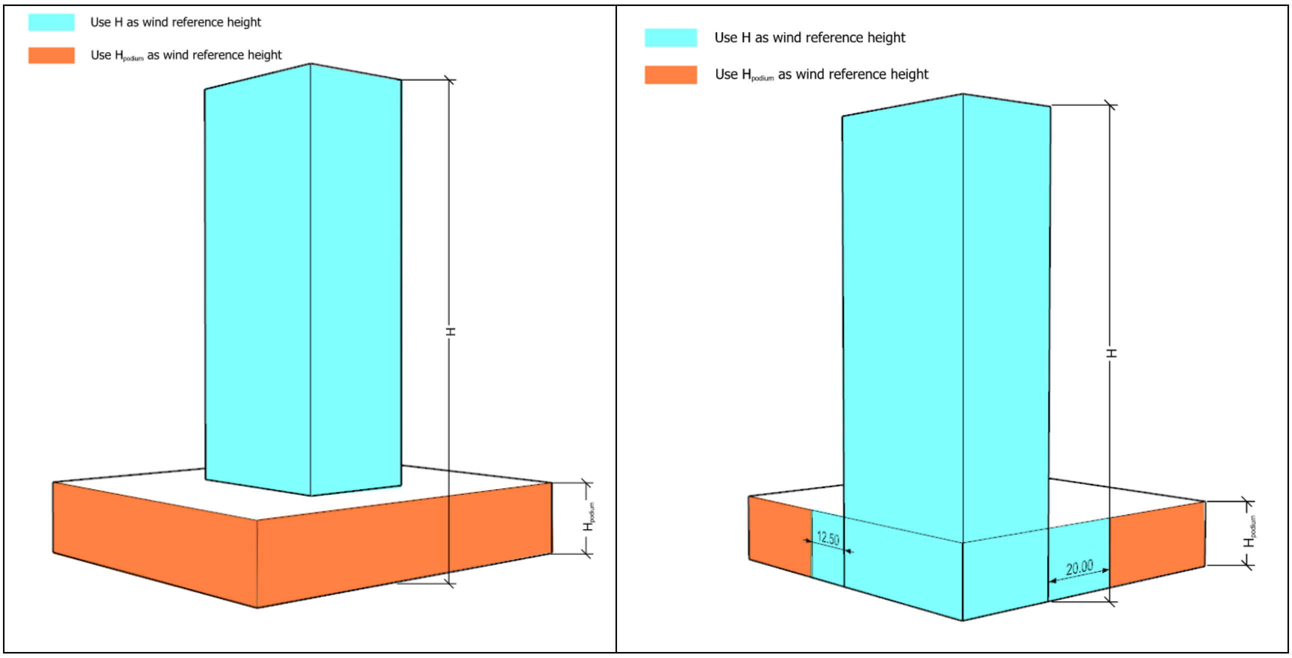


Figure 5-13 Reference Pressure Zone

Table 5-1 Summary of reference wind pressure

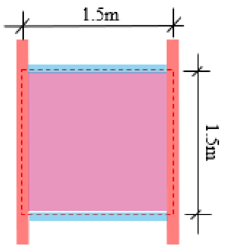
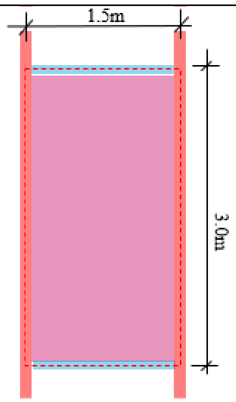
Case 1	Wind Reference Height (m)	Directionality factor	Reference Wind Pressure (kPa)
Tower*	106	0.85	2.45
Podium	16	0.85	1.81
Case 2	Wind Reference Height (m)	Directionality factor	Reference Wind Pressure (kPa)
Tower*	106	0.85	2.45
Podium (elevation of blue zone)	106	0.85	2.45
Podium (roof and elevation of orange zone)	16	0.85	1.81

* Including podium roof zone under influence of the tower as defined in Figure 4-6(a) in the Code.

c. Calculation of size factor

The cladding panel is assumed as a 1.5m × 1.5m size on the tower and a 1.5m × 3m size on the podium. The size factors for the cladding panel design are calculated following Appendix C1 of the Coded and summarized in Table 5-2 depending on the size and the location of a panel.

Table 5-2 Summary of size factors

	Tower		
	Location	$L_{0.5p}$	S_s
	Edge (suction)	3m	1.18
	Corner (suction)	3m	1.30
	Other zones (suction) & all zones for positive pressure	3m	1.07
	Podium		
	Location	$L_{0.5p}$	S_s
	Edge (suction)	4.5m	1.13
	Corner (suction)	4.5m	1.22
	Other zones (suction) & all zones for positive pressure	4.5m	1.06

d. Calculation of the cladding load

For the enclosed buildings, the net pressure coefficients are given in Table 4-1 of the Code. The different wind reference pressures calculated using the reference heights in step b are used. The cladding pressures calculated for Case 1 and Case 2 are summarized in Table 5-4 and Table 5-5 respectively.

For the podium roof, the more onerous values of that following the podium roof rule and that following the tower wall rule, if it is applicable, are adopted conservatively.

e. Calculation of the key zone dimensions

Once the cladding wind pressure are calculated, the loading zones shall be defined on the building envelop. The key dimensions, b_{1t}, b_{2t}, b_{1p}, b_{2p} are taken following the rules in Figure 4-5 of the Code and summarized in Table 5-3. The dimensions of the loading zones are then defined following Figure 4-6 of the Code. For the cladding wind load on the podium roof, the area close to the tower are under the impact of the wind flow around the tower and shall take the wind load same as either Zone A or Zone B of the tower as shown in Figure 4-6 of the Code, for which the dimensions vary for positive and negative pressures.

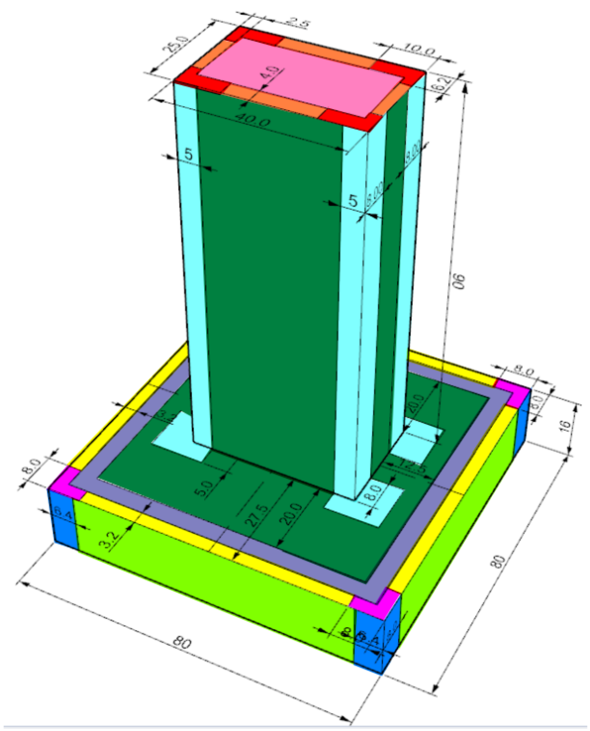
Table 5-3 Key Zone Dimensions

Key Dimensions
$b_{2t} = \min(2H_{tower}, B_{tower-2}) = 40$ m
$b_{2p} = \min\left(2H_{podium}, B_{podium-2}\right) = 32$ m
$b_{1t} = \min(2H_{tower}, B_{tower-1}) = 25$ m
$b_{1p} = \min\left(2H_{podium}, B_{podium-1}\right) = 32$ m

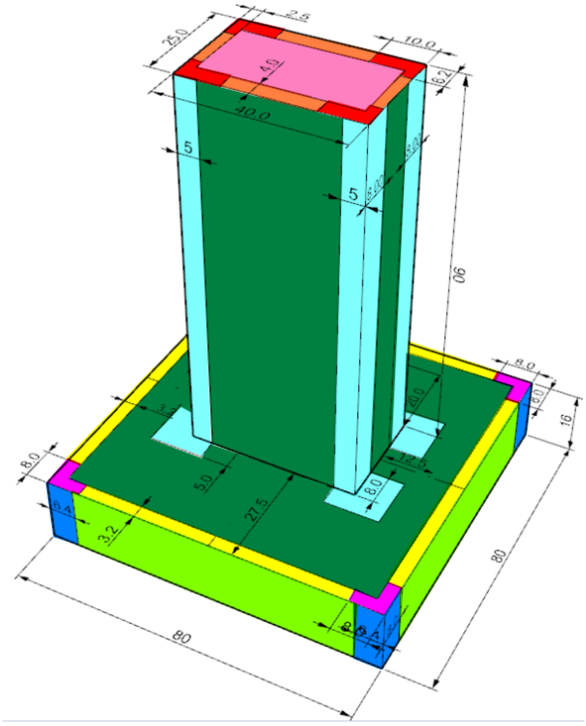
Table 5-4 Cladding Wind Load for Case 1

Tower									
				Negative Cladding Pressure			Positive Cladding Pressure		
Location	Zone	Colour Code	Reference Wind Pressure	Size Factor S_s	C_{p_neg}	Pressure (kPa)	Size Factor S_s	C_{p_pos}	Pressure (kPa)
Wall*	A		2.45kPa	1.18	-1.4	-4.05	1.07	+1.1	2.89
	B		2.45kPa	1.07	-1.0	-2.62	1.07	+1.1	2.89
Roof	C		2.45kPa	1.30	-2.2	-7.01	1.07	+0.3	0.79
	D		2.45kPa	1.18	-1.6	-4.63	1.07	+0.3	0.79
	E		2.45kPa	1.07	-1.0	-2.62	1.07	+0.3	0.79
Podium									
				Negative Cladding Pressure			Positive Cladding Pressure		
Location	Zone	Colour Code	Reference Wind Pressure	Size Factor S_s	C_{p_neg}	Pressure (kPa)	Size Factor S_s	C_{p_pos}	Pressure (kPa)
Wall	A		1.81kPa	1.13	-1.4	-2.86	1.06	+1.1	2.11
	B		1.81kPa	1.06	-1	-1.92	1.06	+1.1	2.11
Roof	C		1.81kPa	1.22	-2.2	-4.86	1.06	+0.3	0.58
	D		1.81kPa	1.13	-1.6	-3.27	1.06	+0.3	0.58
	E		1.81kPa	1.06	-1	-1.92	1.06	+0.3	0.58

* including podium roof if the tower wall clause in Figure 4-6 (b) of the Code is applicable and gives more onerous results.



(a) Positive Cladding Pressure for Case 1



(b) Negative Cladding Pressure for Case 1

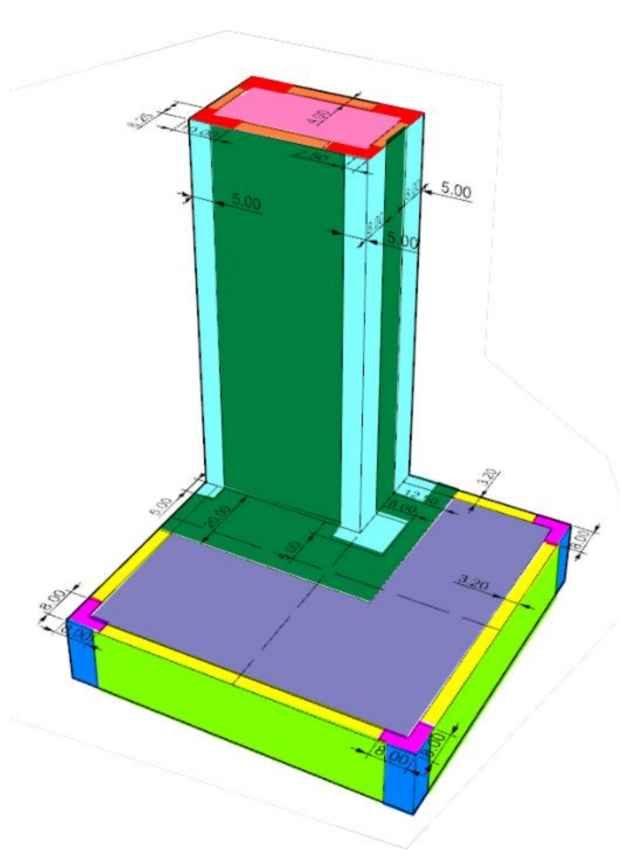
Figure 5-14 Pressure Zone for Case 1

Table 5-5 Cladding Wind Load for Case 2

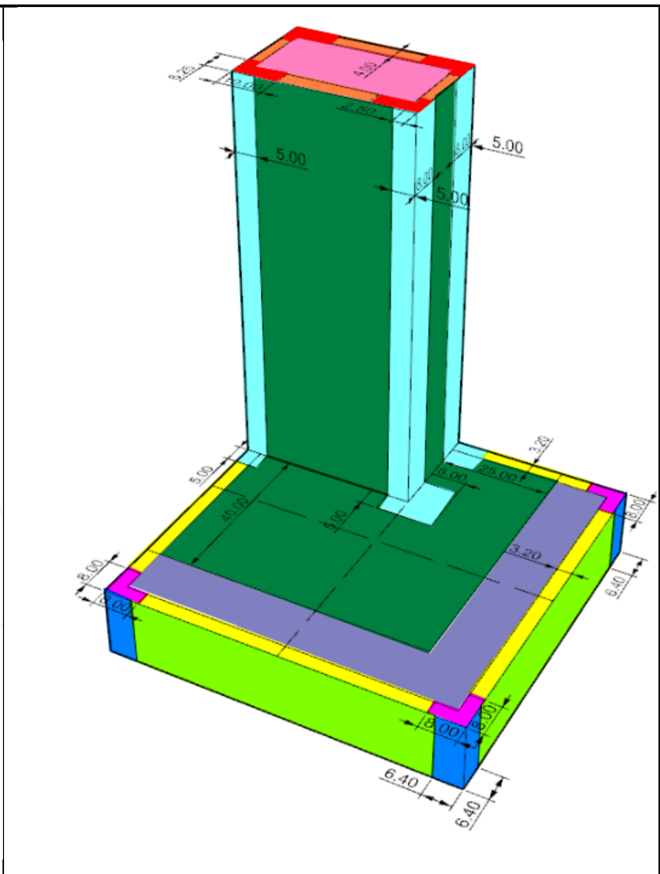
Tower									
				Negative Cladding Pressure			Positive Cladding Pressure		
Location	Zone	Colour Code	Reference Wind Pressure	Size Factor S_s	C_{p_neg}	Pressure (kpa)	Size Factor S_s	C_{p_pos}	Pressure (kpa)
Wall*	A		2.45kPa	1.18	-1.4	-4.05	1.07	+1.1	2.89
	B		2.45kPa	1.07	-1.0	-2.62	1.07	+1.1	2.89
Roof	C		2.45kPa	1.30	-2.2	-7.01	1.07	+0.3	0.79
	D		2.45kPa	1.18	-1.6	-4.63	1.07	+0.3	0.79
	E		2.45kPa	1.07	-1.0	-2.62	1.07	+0.3	0.79
Podium									
				Negative Cladding Pressure			Positive Cladding Pressure		
Location	Zone	Colour Code	Reference Wind Pressure	Size Factor S_s	C_{p_neg}	Pressure (kPa)	Size Factor S_s	C_{p_pos}	Pressure (kPa)
Wall	A		1.81kPa	1.13	-1.4	-2.86	1.06	1.1	2.11
	B		1.81 kPa	1.06	-1	-1.92	1.06	1.1	2.11

	A’		2.45 kPa	1.13	-1.4	-3.88	1.06	1.1	2.86
	B’		2.45 kPa	1.06	-1	-2.60	1.06	1.1	2.86
Roof	C		1.81 kPa	1.22	-2.2	-4.86	1.06	0.3	0.58
	D		1.81 kPa	1.13	-1.6	-3.27	1.06	0.3	0.58
	E		1.81 kPa	1.06	-1	-1.92	1.06	0.3	0.58

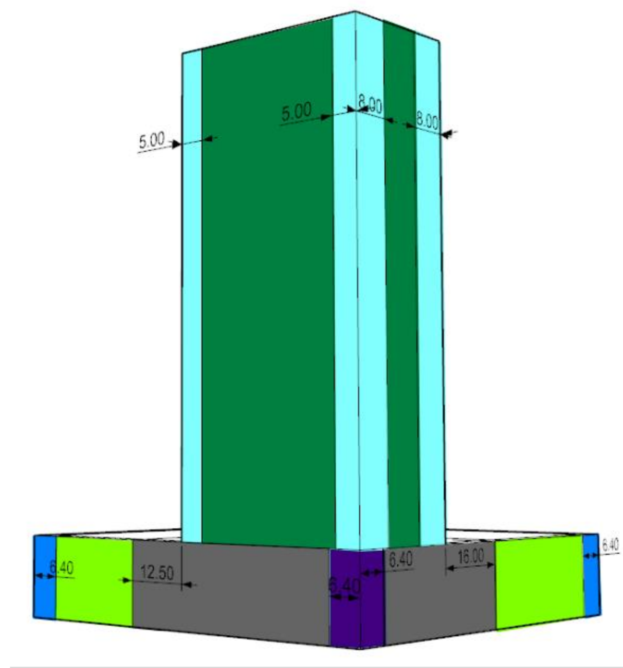
* including podium roof if the tower wall clause in Figure 4-6 (b) of the Code is applicable and gives more onerous results.



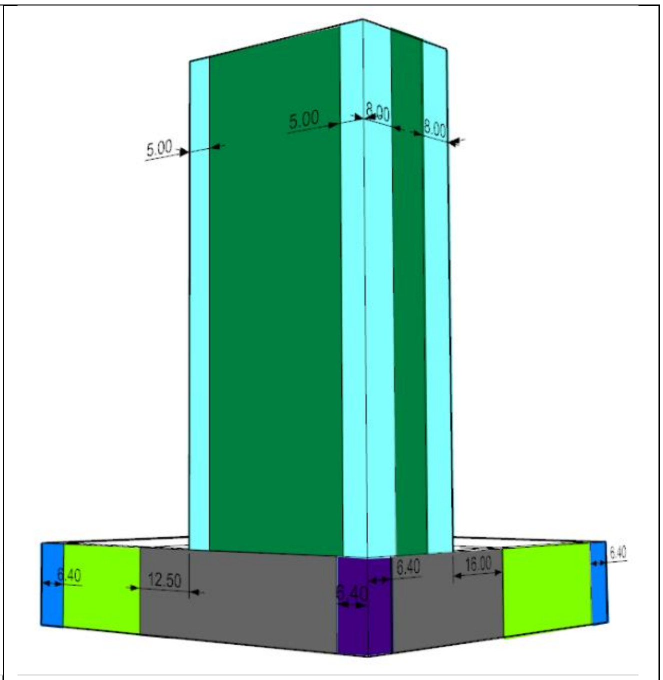
(a) Positive Cladding Pressure for Case 2 (View 1)



(b) Negative Cladding Pressure for Case 2 (View 2)



(c) Positive Cladding Pressure for Case 2 (View 1)



(d) Negative Cladding Pressure for Case 2 (View 2)

Figure 5-15 Pressure Zone for Case 2

5.5 Working Example for Cladding Wind Load Calculation for a building with dominant openings

This example demonstrating how to derive the wind pressure coefficients for the buildings with dominant openings is shown below.

5.5.1 General Information

The example is a 30m low rise building with permanent openings designed on the building envelope as shown in the 3D image of Figure 5-16. As the calculation of wind reference pressure have been demonstrated in the previous example, only the calculation of pressure coefficient will be shown here.

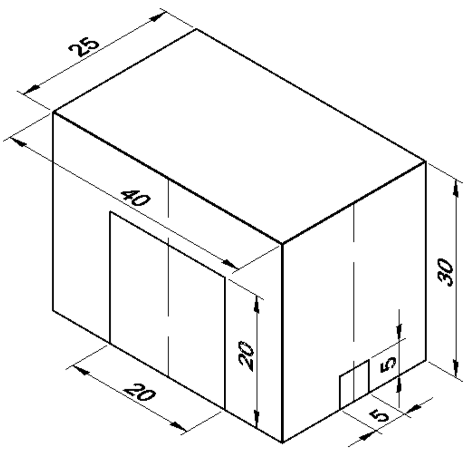


Figure 5-16 Building Geometries

5.5.2 Define the dominant opening

The largest opening area is

$$A_0 = 20m \times 20m = 400m^2$$

The sum of the areas of openings on other faces, including 0.1% leakage of the total external surface area of the other surfaces:

$$A_{tot} = 5 \times 5 + 0.1\%(40 \times 30 + 25 \times 30 \times 2 + 25 \times 40) = 25 + 3.7 = 28.7m^2$$

$$A_0 > 1.5A_{tot}$$

Therefore, this opening is considered as a dominant opening

5.5.3 Calculation of the internal pressure coefficient

The internal pressure coefficient can be calculated using the equation below..

$$C_{pi} = \frac{C_{pe}}{\left[1 + \left(\frac{A_{tot}}{A_0}\right)^2\right]}$$

Depending on the location of the dominant opening and whether the opening is under negative or positive pressures, Table 5-6 summarizes the calculated C_{pi} assuming the dominant opening is on wall edge under negative pressure (Zone A), on wall general zone under negative pressure (Zone B) and under positive pressure respectively.

Table 5-6 Calculation of C_{pi}

		C_{pe}	A_{tot} (m^2)	A_0 (m^2)	C_{pi}
Wall	A (negative)	-1.2	28	400	-1.19
	B (negative)	-0.8	28	400	-0.80
	A&B (positive)	0.8	28	400	0.80

5.5.4 Combination with external pressure

The internal pressure shall be combined with the external pressure aiming at the most critical wind loads on the elements. The example in Figure 5-17 shows the wind pressure directions on the external due to the dominant opening when the wind is approaching towards the dominant opening. According to this figure, the wind pressures on the external walls are summarized as below

- P(Side A)=$sign(P_e)\big||P_e| - |P_i|\big|$
- P(Side B)=$sign(P_e)\big||P_e| - |P_i|\big|$
- P(Side C)=$sign(P_e)\big||P_e| - |P_i|\big|$
- P(Side D)=$sign(P_e)\big||P_e| - |P_i|\big|$

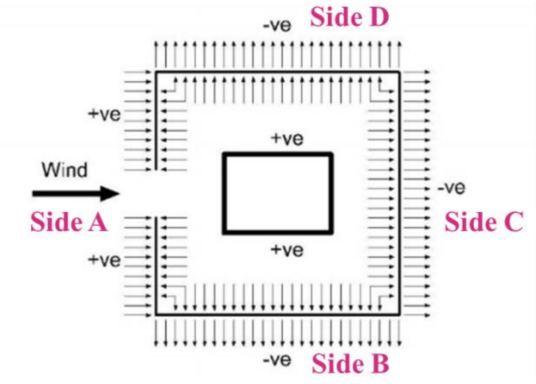


Figure 5-17 Example of internal and external wind pressure combination

6. Wind Tunnel Test Requirements

The necessary provisions for wind tunnel testing are given in Chapter 6 of the Code; further supplementary information is given in the EN.

6.1 Buildings to be wind tunnel tested

For buildings outside the applicability of the Standard Method, as defined in Section 1.1 of the Code, a wind tunnel test is compulsory.

Even if a building may use the Standard Method, a designer can still decide to conduct wind tunnel tests from the safety or economy perspective.

6.2 Reports

6.2.1 Method of statement

There should be a method statement of the wind tunnel tests to describe the facilities (including the information of the wind tunnel), instrumentation and measurement equipment and techniques, analysis methods to be employed and the compliance with the requirement in the Code. It will reduce the risk of different opinions from the designer or the approval authorities, if the method statement report is fully discussed and agreed among the testing laboratory, the designer and the authority prior to the tests.

6.2.2 Testing report/reports

The wind tunnel testing report should include the methodology of testing, referring to the Method Statement report, show how the wind tunnel testing requirements of the code (including quality assurance) are satisfied, and the findings and conclusions. Sufficient information should be included to support the quality of the wind simulation, building modelling, test instrumentation and the test data processing. Intermediate data should be made available if required for the purpose of independent validation and checking.

6.3 Items to be addressed in Reports and the Corresponding Testing Requirement

The following items shall be addressed in the reports mentioned above:

1) Background and testing scope

   The background information of the testing building shall be briefly introduced. The testing scope shall specifically demonstrate the testing scope and items and identify the key outcomes expected from the wind tunnel tests, which could be one or all of the following areas:

   - Wind climate study
   - Topographic tests to identify the impact of the topographic features on the site wind condition
   - Structural wind studies through either a High frequency force balance (HFFB) test or simultaneous pressure integration (SPI) method to derive the structural wind load and responses
   - Pressure measurement for cladding wind load

2) Boundary layer wind flow simulation

Description of simulation method and results of the natural boundary layer wind shall be given. Some key features must be included:

- Geometric testing scale of wind simulation:
- Wind tunnel testing wind speeds and the corresponding full-scale/ model velocity scale
- Mean wind speed profile measured in the wind tunnel and comparison with the target profile
- The longitudinal component of turbulence intensity profile in the wind tunnel and comparison with the target profile, and
- Integral scale of turbulence measured in the wind tunnel, or wind spectrum

Note that this required information applies to both the topography test and the loading tests such as the HFFB or cladding test.

3) Topographic test

The following details of the topographic test (if any) shall be included or satisfied:

- Topographic model extent of coverage, which shall include the major topographic features likely to have an impact on the wind conditions on the site,
- Buildings to be included in the proximity model excluded,
- Proposed levels for profile measurement,
- Measured mean velocity and turbulence intensity profiles at site for all the tested wind directions

4) Surrounding buildings and proximity model

The surrounding buildings are included in the proximity model in the wind tunnel to model the near field impact to site. The following details of the proximity model shall be included:

- Proximity model extent of coverage with a radius not less than 400m
- Calculation details of the blockage ratio*
- The details of the removed buildings and the calculation procedure demonstrating the proposed buildings to be removed are those providing most sheltering effects, if a removal configuration is conducted.

*The estimated maximum value of the blockage ratio during testing should not be over 10% with both the proximity model and the model to be tested included, except that a blockage tolerance wind tunnel is adopted. If a blockage tolerance tunnel is adopted, sufficient information to demonstrate the effectiveness of the blockage tolerance shall be provided.

5) Testing models

The following information about the testing models shall be provided

- Description of the design and construction of the testing models (HFFB or cladding model), including materials, construction method, and any simplification of the model which may affect the accuracy of the test
- For cladding models, demonstration of tapping layout on building plan or elevations or on 3D models, with pressure tap identification labels and description of Code compliance on pressure tap density
- For cladding models, demonstration of tapping layout of the simultaneously instrumented taps, if the SPI approach for structural wind loads is adopted
- For HFFB models, point of location of the sensor of the HFFB
- For HFFB models, evidence that the model/balance assembly is stiff enough to suppress its own vibration, such as by demonstrating the natural frequencies of the model-balance assembly is at least two times of the building natural frequencies when converted to full scale

6) Scaling ratio in wind tunnel tests

    - Topographic model: normally shall be equal to or larger than 1:5000
    - Proximity model: normally shall be not smaller than 1:500
    - Velocity scaling ratio adopted for various tests, with reference height for reference wind speed clearly specified
    - Minimum Reynolds number based on the building dimension shall be not less than 1×10^4 for sharp edges; for rounded shapes, requirement in D1.5 of the EN shall be referred to. The length dimension for calculating the Reynolds number shall be the smallest dimension of the main massing of the building.

7) Measuring directions

    - Topographic test shall be conducted in at least 18 wind directions at 20^o interval.
    - Proximity model shall be measured at least 36 wind directions at 10^o interval for pressures and loads.

8) Requirement to matching of wind pressures

    Where the effect of topography is modelled, the wind profiles determined from the topographic test shall be used to match to the building model tests.

    - The methodology of wind profile matching shall be stated and fulfil the requirements of the Code as stated in Section 6.1.3 and Section 6.1.7 of the Code.
    - Special attention shall be paid on the matching height selection as specified in Section 6.1.7 of the Code, especially the different matching heights on different exposed conditions.

9) Measurement in cladding test

    For cladding test, the following information shall be available:

    - Frequency response of the wind pressure measurement system
    - Information on tubing response correction

- Sampling rate and measurement duration
- Methodology of statistical determination of peak pressure, and
- Methodology to estimate internal pressure, if applicable

10) Requirement on testing data or testing results

Following testing data or testing results are normally required in a cladding test:

- Tabulated data of measured mean, standard deviation, minimum and maximum pressures or pressure coefficients (with clear statement of the reference wind speed or reference wind pressure so that the associated pressures can be calculated easily) for each wind direction and each pressure tap,
- Contour plots or blockage diagrams of peak cladding pressure enveloping all the studied wind directions,
- Pressure time history shall be well recorded and achieved, which may be required per request for checking and peer review purpose.

11) Measurement and required data in HFFB test

For a HFFB test, the following information is normally required:

- Sampling rate and measurement duration
- Information of any single filtering or spectra correction, if applicable
- Mean, root-mean-square values and power spectral densities of the base shear and base moment, with reference wind speed clearly specified
- Time history of base shear and moment shall be well recorded and achieved, which may be required per request for checking and peer review purpose.

12) Dynamic properties

Information on dynamic properties shall be including in the testing report, including

- Natural frequencies of mode shapes of at least the first two translational mode and the first torsional mode,
- Mass distribution along the building height, and
- Assumed damping ratio to be used for the wind-induced response calculation

13) Summary of wind loads or wind induced responses in structural wind loading test

- Wind-induced peak base moment for all the studied wind directions,
- Equivalent static wind load distribution/distributions along the height of the building
- Load combination factors or critical wind load cases covering all the likely critical loading effects with consideration of simultaneous contributions from the torsional and the two lateral loading components
- Peak accelerations at the level of interest at the required return periods, and their comparison against the acceptable criteria

6.4 Rules for removal configuration (principle and example)

The buildings provide the most significant sheltering effect shall be removed under the removal configuration.

The principle is to find the surrounding building with maximum H_d in each wind direction, which is considered as the first beneficial building in the calculation of effective height as demonstrated in Appendix A2 of the Code.

As shown in Figure 6-1, Building 1 to Building 3 are the obstruction buildings in Wind X direction. The height of reduction can be calculated using Equation A2-1 to Equation A2-3 or Figure A2-3 of the Code. As $H_{d2}>H_{d1}>H_{d3}$, building 2 should be removed as it provides the most significant sheltering effect to the target building.

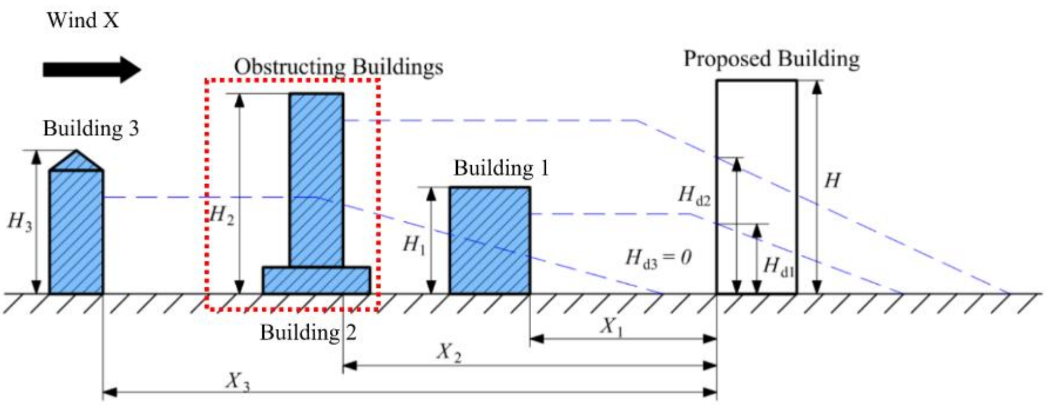


Figure 6-1 Removal Configuration Rules

6.5 Minimum loads

CoP 2019 allows testing only existing configuration by setting a lower bound of testing the results at 80% of Code wind loads, including the across-wind effect if applicable. By contrast, CoP 2004 requires to test both configurations.

If a removal configuration is tested, the lower bound can be relaxed to 70% of the Code along-wind loads.

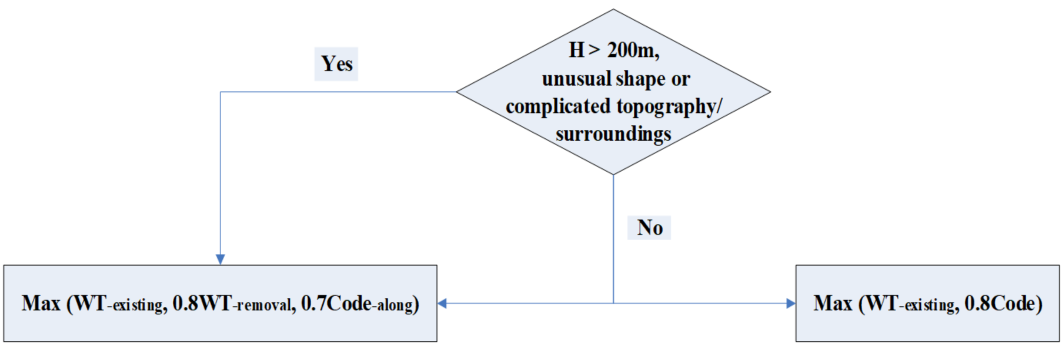


Figure 6-2 Minimum adopted wind loads from a test

7. Working Examples

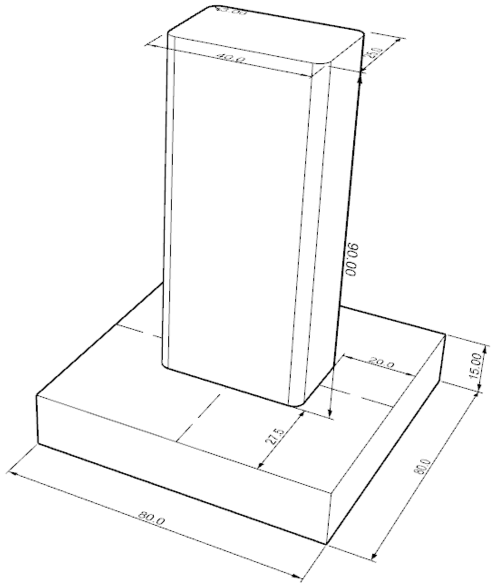
7.1 Single tower sitting on podium for tower structural force calculation

This example is to demonstrate the procedure of structural wind load calculation of a single tower sitting on the podium following the CoP 2019. The basic geometry of the building is shown in Figure 7-1. The total height of the building is 105m. The building is located on the flat terrain. The site surrounding condition is showing in Figure 7-2. The natural frequency is 0.44Hz for both directions.

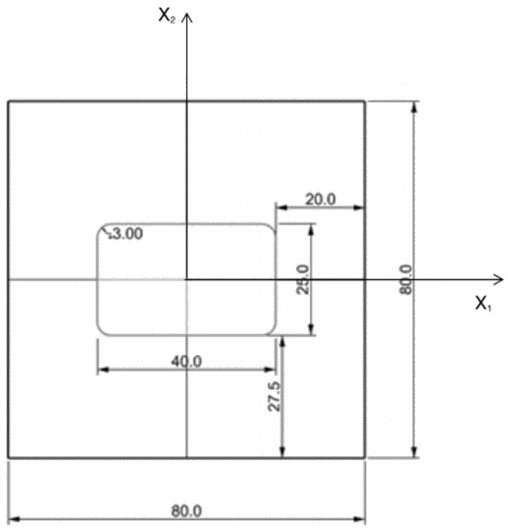
Preliminary judgement on the applicability of the Code:

1) H=105m ⩽ 200m
2) Building shape: rectangular shape with round corners, which is well covered by the Code
3) Topographic condition: flat terrain, topographically insignificant
4) Surrounding condition: surrounding by buildings as shown in Figure 7-2 and the sheltering effect could be addressed using the codified method.

Based on the above judgement, the Standard Method could be used to assess the wind loading and wind responses of the building.



(a) 3D Image



(b) Plan Dimension

Figure 7-1 Building Information

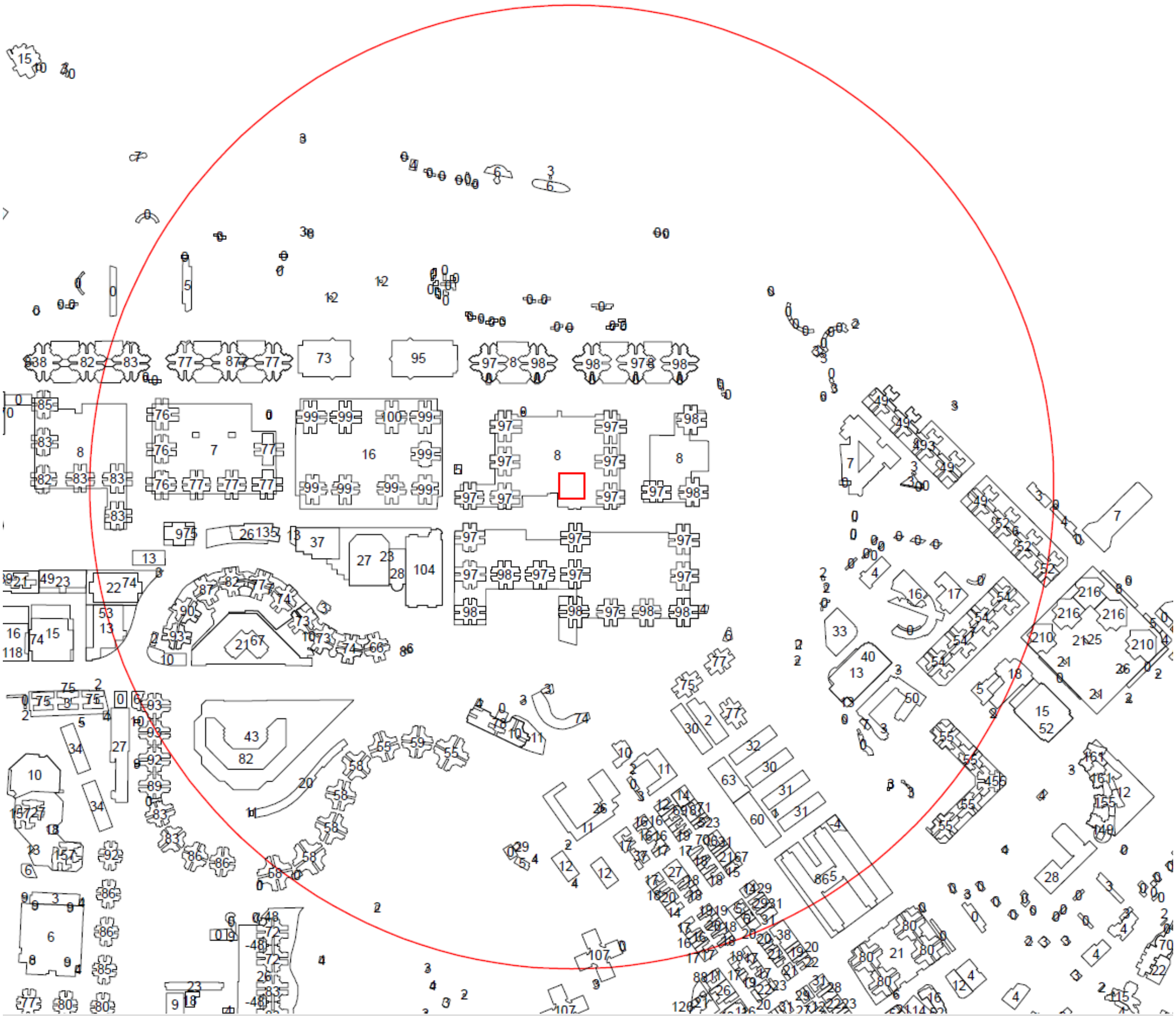


Figure 7-2 Surrounding Buildings within 500m radius from the site.

7.1.1 Determine the reference wind pressure

1) Directionality

   Conservatively, the directionality factor S_θ is taken as 0.85 for all wind directions.

2) Topographic factor

   The site is located in the topographic insignificant zones. The topographic factor is then taken as St=1.0.

3) Effective height

   Following the guidance of Appendix A2 of the Code and the EN, the surrounding building shows similar plan shape and heights, which is applicable to the simplified method.

   Circles with radius from 1H to 4H are drawn on the map for easy identification of the sheltering effect of the buildings. Four sectors are divided representing 4 directions to be considered in the wind load calculation. The alphabetic letters marked represent the name of the building lot. The buildings are named by the combination of an alphabetic letter and a number, i.e. Building A1 means the building No. 1 in Lot A. (In this example, the lot information is from iC 1000 map from Lands Department for demonstration purpose; however, please also note the interpretation of building lot from BD introduced in Section 3.3.1 of the handbook.)

According to the rule of Simplified method, some preliminary judgement could be made by visual checking:

- In Sector 1, buildings in Lot A, Lot B, Lot C and Lot D are taller than 0.9H (94.5m) and sitting within 2H radius, the H_{di}/H could be taken as 0.7.
- In Sector 2, buildings in Lot D, Lot E and Lot F are taller than 0.9H (94.5m) and sitting within 2H radius, the H_{di}/H could be taken as 0.7.
- In Sector 3, buildings in Lot F are taller than 0.9H (94.5m) and sitting within 2H radius, the H_{di}/H could be taken as 0.7.
- In Sector 4, buildings in Lot A, Lot D, Lot H, Lot F and Lot G are taller than 0.9H (94.5m) and sitting within 2H radius, the H_{di}/H could be taken as 0.7.

From this preliminary judgement, the most-sheltering building could be identified as marked by red in Figure 7-3. The dash lines are drawn according to the angle covered by the most-sheltering building to divide each sector into several sub-sectors. From each sub-sector (SS), the second most-sheltering building for the effective calculation as highlighted by blue.

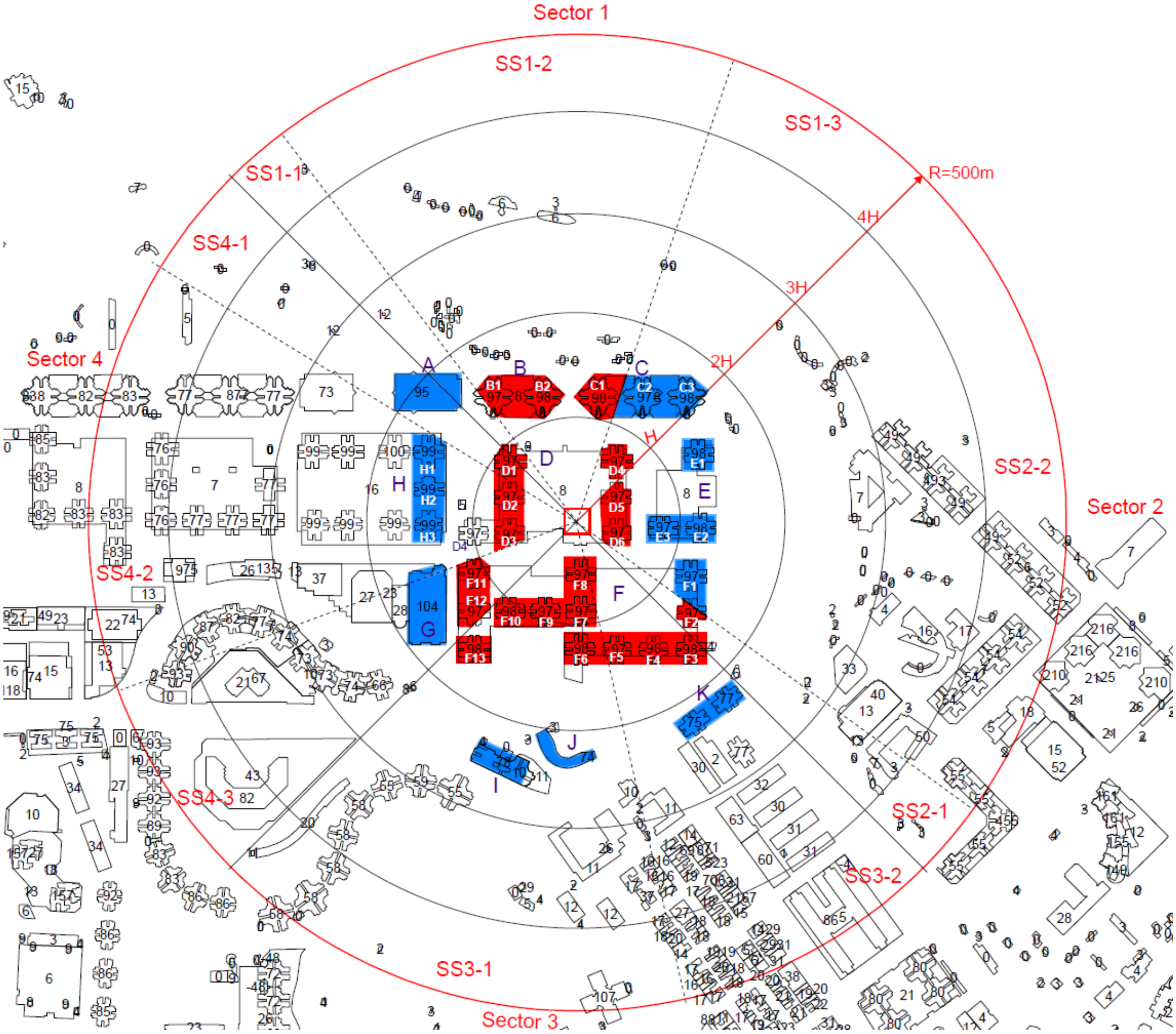


Figure 7-3 Identification of the most and the second most sheltering buildings

Table 7-1 The height of reduction

Sub Section	Lot	Building	H_i (m)	X_i (m)	$0.8H_i$ (m)	1.2Hi-0.2Xi but ≥0 (m)	0.75H (m)	H_d (m)	A (°)	$H_d \times \alpha/90°$ (m)
SS 1-1	A	A	94	159	75.2	81	78.8	75.2	7	5.8
SS 1-2	-	-	-	-	-	-	-	0	56	0.0
SS 1-3	C	C2 C3	98	140	78.4	89.6	78.8	78.4	26	22.6
SS 2-1	-	-	-	-	-	-	-	0	10	0.0
SS 2-2	F	F1 F2	97	112	77.6	94	78.8	77.6	19	16.4
	E	E2 E3	98	62	78.4	105.2	78.8	78.4	22	19.2
	E	E1	98	123	78.4	93	78.8	78.4	14	12.2
SS 3-1	J	J	74	219	59.2	45	78.8	45	16	8.0
	I	I	78	239	62.4	45.8	78.8	45.8	13	6.6
SS 3-2	K	K	77	213	61.6	49.8	78.8	49.8	18	10.0
SS 4-1	A	A	94	169	75.2	79	78.8	75.2	14	11.7
SS 4-2	H	H1 H2 H3	99	133	79.2	92.2	78.8	78.75	40	35.0
SS 4-3	G	G	104	145	83.2	95.8	78.8	78.75	26	22.8

**H: the actual building height of the proposed building*

H_i: the height of the obstructing building above the ground level within ±45 degrees of the considered wind direction, taken as less than or equal to H

X_i: Horizontal distance from the upwind edge of the proposed building to the obstructing building.

H_d: the height of reduction

α: occupied angle of the obstructing building

The final effective height is calculated as Z-H_d, summarized in Figure 7-4.

The corresponding design wind reference pressures for each direction is then tabulated in Table 7-2

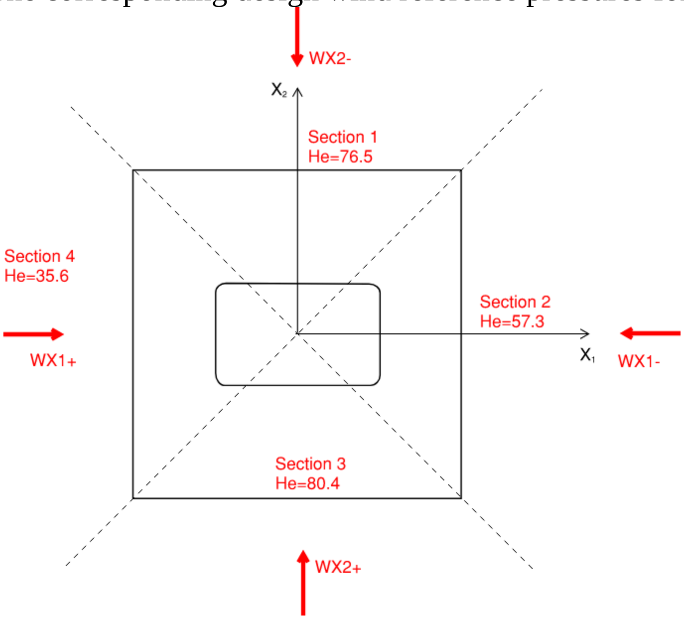


Figure 7-4 Effective Height Summary

Table 7-2 Design wind reference pressure summary

	Direction	H_e (m)	S_θ	S_t	Q_h (kPa)
Section 1	WX2-	76.5	0.85	1.0	2.33
Section 2	WX1-	57.3	0.85	1.0	2.22
Section 3	WX2+	80.4	0.85	1.0	2.35
Section 4	WX1+	35.6	0.85	1.0	2.06

7.1.2 Determine the force coefficient

The building geometry changes significantly between the podium and the tower. The force coefficient shall be calculated for the tower and the podium respectively using the local plan dimensions and overall effective height as tabulated in Table 7-3. The round corner will provide the reduction on the force coefficient by a factor of 1-2.5r/B.

Table 7-3 Summary of force coefficients

Tower	H_e (m)	R (m)	B (m)	D (m)	H_e /D	B/D	C_f	Corner Reduction	C_{f_final}
Section 1	76.5	3	40	25	3.06	1.6	1.266	0.813	1.029
Section 2	57.3	3	25	40	1.43	0.625	1.129	0.75	0.847
Section 3	80.4	3	40	25	3.22	1.6	1.275	0.813	1.306
Section 4	35.6	3	25	40	0.89	0.625	1.118	0.75	0.839
Podium	**H_e (m)**	**r**	**B (m)**	**D (m)**	**H_e /D**	**B/D**	**C_f**	**Corner Reduction**	**C_{f_final}**
Section 1	76.5	N/A	80	80	0.96	1	1.138	N/A	1.138
Section 2	57.3	N/A	80	80	0.72	1	1.128	N/A	1.128
Section 3	80.4	N/A	80	80	1.01	1	1.140	N/A	1.140
Section 4	35.6	N/A	80	80	0.44	1	1.118	N/A	1.118

7.1.3 Determination of the Size and Dynamic Factor

The combined size and dynamic factor at the building height $S_{q,h}$ is calculated using Equation 5-1 of the Code. $S_{q,z}$ is then reduced from $S_{q,h}$ using Equation 5-2 of the Code. An example for $S_{q,h}$ in WX2+ and WX2- direction is given in Table 7-4.

Table 7-4 Calculation of $S_{q,h}$ in WX2+ and WX2-

$L_{0.5p}$	$L_{0.5p}$ = B of the loaded area at the top of the building for buildings over 50m	40m
S_s	Size factor using Equation C1-1a of the Code. S_s =Exp(0.17-0.07 $L_{0.5p}{}^{0.32}$)	0.94
H	Building height	105m
B	Breadth of the building	40m
N_x	Fundamental frequency for the mode mainly aligned with the alongwind direction	0.44Hz
ξ_x	Ratio of the damping to critical damping in the relevant direction of vibration	0.030
$S_{q,h}$	The combined size and dynamic factor at the top of the building	1.01

7.1.4 Calculation of along-wind load and torsional wind load

Through Section 7.1.1 to Section 7.1.3, the three key parameters are calculated for the along wind load using Equation $W_z = Q_z C_f S_{q,z} B$. The spreadsheet for the along wind load in WX2- direction is shown in Table 7-5 for reference. The shear force and the bending moment at each level are further derived as shown in the rightmost two columns.

Table 7-5 Along wind load calculation for WX2-

Level	Z (m)	Z_e (m)	h_i (m)	B (m)	C_f	$Q_{z,flat}$ (kPa)	S_θ	S_t	Q_z (kPa)	S_{qz}	W_z (kN/m)	Design Force (kN)	Torsion (kNm)	Shear Force (kN)	Bending Moment (kNm)
34	105.0	76.5	1.5	40	1.029	2.74	0.85	1.00	2.33	1.01	97	219	595	219	0
33	102.0	73.5	3.0	40	1.029	2.72	0.85	1.00	2.31	1.00	96	287	781	506	656
32	99.0	70.5	3.0	40	1.029	2.70	0.85	1.00	2.30	0.99	94	282	768	788	2174
31	96.0	67.5	3.0	40	1.029	2.69	0.85	1.00	2.28	0.98	92	277	755	1066	4538

30	93.0	64.5	3.0	40	1.029	2.67	0.85	1.00	2.27	0.97	91	273	741	1338	7735
29	90.0	61.5	3.0	40	1.029	2.65	0.85	1.00	2.25	0.96	89	268	728	1606	11749
28	87.0	58.5	3.0	40	1.029	2.62	0.85	1.00	2.23	0.95	88	263	715	1869	16567
27	84.0	55.5	3.0	40	1.029	2.60	0.85	1.00	2.21	0.94	86	258	701	2126	22173
26	81.0	52.5	3.0	40	1.029	2.58	0.85	1.00	2.19	0.93	84	253	688	2379	28552
25	78.0	49.5	3.0	40	1.029	2.56	0.85	1.00	2.17	0.92	83	248	674	2627	35690
24	75.0	46.5	3.0	40	1.029	2.53	0.85	1.00	2.15	0.91	81	243	660	2869	43570
23	72.0	43.5	3.0	40	1.029	2.50	0.85	1.00	2.13	0.90	79	237	646	3107	52179
22	69.0	40.5	3.0	40	1.029	2.47	0.85	1.00	2.10	0.89	77	232	631	3339	61499
21	66.0	37.5	3.0	40	1.029	2.44	0.85	1.00	2.08	0.88	76	227	616	3565	71516
20	63.0	34.5	3.0	40	1.029	2.41	0.85	1.00	2.05	0.87	74	221	601	3786	82212
19	60.0	31.5	3.0	40	1.029	2.38	0.85	1.00	2.02	0.86	72	215	586	4002	93571
18	57.0	28.5	3.0	40	1.029	2.34	0.85	1.00	1.99	0.85	70	209	569	4211	105576
17	54.0	25.5	3.0	40	1.029	2.30	0.85	1.00	1.95	0.84	68	203	553	4414	118209
16	51.0	22.5	3.0	40	1.029	2.25	0.85	1.00	1.91	0.83	66	197	535	4611	131451
15	48.0	19.5	3.0	40	1.029	2.20	0.85	1.00	1.87	0.82	63	190	517	4801	145284
14	45.0	16.5	3.0	40	1.029	2.14	0.85	1.00	1.82	0.81	61	183	497	4984	159688
13	42.0	13.5	3.0	40	1.029	2.08	0.85	1.00	1.76	0.80	58	175	475	5159	174639
12	39.0	10.5	3.0	40	1.029	1.99	0.85	1.00	1.70	0.79	55	166	451	5324	190115
11	36.0	9.0	3.0	40	1.029	1.95	0.85	1.00	1.65	0.78	53	160	434	5484	206087
10	33.0	8.3	3.0	40	1.029	1.92	0.85	1.00	1.63	0.77	52	155	423	5639	222539
9	30.0	7.5	3.0	40	1.029	1.89	0.85	1.00	1.61	0.76	50	151	411	5790	239457
8	27.0	6.8	3.0	40	1.029	1.86	0.85	1.00	1.58	0.75	49	147	399	5937	256828
7	24.0	6.0	3.0	40	1.029	1.82	0.85	1.00	1.55	0.74	47	166	450	6102	274639
6	21.0	5.3	4.0	40	1.029	1.78	0.85	1.00	1.52	0.73	46	194	776	6296	299048
5	16.0	4.0	4.5	80	1.138	1.77	0.85	1.00	1.51	0.71	98	392	1566	6688	327382
4	12.0	3.0	3.5	80	1.138	1.77	0.85	1.00	1.51	0.70	96	312	1249	7000	350790
3	9.0	2.3	3.0	80	1.138	1.77	0.85	1.00	1.51	0.69	95	284	1136	7284	371791
2	6.0	1.5	3.0	80	1.138	1.77	0.85	1.00	1.51	0.68	93	280	1119	7564	393643
1	3.0	0.8	3.0	80	1.138	1.77	0.85	1.00	1.51	0.67	92	207	827	7771	416335
G	0.0	0.0	1.5	80	1.138	1.77	0.85	1.00	1.51	0.66	90	68	271	7838	427990

After the along wind load is derived, the torsional force is considered by shifting the storey along wind force by the eccentricity calculated by B/D ratio as calculated in Table 7-6. The torsional forces are tabulated in the rightmost column of Table 7-5.

Table 7-6 Calculation of eccentricity

	WX1+, WX1-		WX2+, WX2-	
	B/D	e (m)	B/D	e (m)
Tower	0.625	0.05B=1.25	1.6	0.068B=2.72
Podium	1	0.05B=4	1	0.05B=4

7.1.5 Calculation of across-wind base moment and checking

The building is over 100m, thus the across wind base moments shall be checked.

The across wind base moment WX2- is calculated as shown in Table 7-7following Equation 2-2 of the Code.

Table 7-7 Calculation of across-wind base moment

N_y	Fundamental frequency for model mainly aligned with the across-wind direction	0.44Hz
G_{ry}	Peak factor, $G_{ry} = \sqrt{2Log_e(1800N_y)}$	3.65
γ_w	Ultimate wind load factor	1.4
ξ_y	Ratio of damping to critical damping in across-wind direction	0.029
ρ_a	Mass density of air	$1.2\text{x}10^{-3}$ T/m^3

$(BD)_b$	The average plan area of the enclosing rectangle over the top third of the building	$1000m^2$
Q_h	Wind reference pressure at the effective height	2.33kpa
$I_{v,h}$	Wind turbulence intensity	0.107
H_b	Height of building structure above ground level but excluding the height of irregular roof features above the main roof.	105m
M_{x2x2}	Across-wind base moment	213MNm

It shall be noted that for WX1+, He/H = 0.34, the turbulence intensity shall be modified using Equation 3-4 of the Code.

Table 7-8 Summary of lateral wind load

Direction	$M_{\pm x1x1}$ Across wind	$M_{\pm y1y1}$ Along wind	Direction	$M_{\pm x2x2}$ Across wind	$M_{\pm y2y2}$ Along wind
WX1+	69	205	WX2+	217	437
WX1-	191	218	WX2-	213	428

$$\frac{\max(M_{-x1x1}, M_{+x1x1})}{|M_{-y2y2}|} = \frac{\max(69,191)}{428} < 1,\ W_{z,-x2} \text{ no need to scale up}$$

$$\frac{\max(M_{-x1x1}, M_{+x1x1})}{|M_{+y2y2}|} = \frac{\max(69,191)}{437} < 1,\ W_{z,+x2} \text{ no need to scale up}$$

$$\frac{\max(M_{-x2x2}, M_{+x2x2})}{|M_{-y1y1}|} = \frac{\max(217,213)}{218} < 1,\ W_{z,-x1} \text{ no need to scale up}$$

$$\frac{\max(M_{-x2x2}, M_{+x2x2})}{|M_{+y1y1}|} = \frac{\max(217,213)}{205} = 1.06 > 1,\ \underline{W_{z,-x1} \text{ shall be scaled up by the factor of } 1.06}$$

Based on the across wind base moment check, only $W_{z,-x1}$ needs to be adjusted as above.

7.1.6 Acceleration and checking

The acceleration (in m/s^2) for orthogonal wind directions at the top of the building is assessed using Equation 2-4 of the Code. An example for acceleration for 1-year return period is given as below. The ratio of damping for acceleration is adopted using the aspect ratio from Table C2-1 of the Code.

Table 7-9 Calculation of acceleration

N_y	Fundamental frequency for model mainly aligned with the across-wind direction	0.44Hz
G_{ry}	Peak factor, $G_{ry} = \sqrt{2Log_e(1800N_y)}$	3.65
S_r	Factor on wind pressure for different return period	0.25 (1 year return)
ξ_y	Ratio of damping to critical damping in across-wind direction	0.020
ρ_a	Mass density of air	$1.2\text{x}10^{-3}$ T/m^3

$(BD)_b$	The average plan area of the enclosing rectangle over the top third of the building	$1000m^2$
Q_h	Wind reference pressure at the effective height	2.33kPa
$I_{v,h}$	Wind turbulence intensity	0.107
H_b	Height of building structure above ground level but excluding the height of irregular roof features above the main roof.	105m
M_h	Mass of the building above 2/3H, assuming $400kg/m^3$ as the building density for this case	14000000kg
η_y	Parameter used to describe the approximate mode deflection variation with height	1.5
Acceleration	1 year return period acceleration	$0.022m/s^2$

According to Figure 2-6 of the Code, the acceleration limit under 1 year return period for office tower is 0.086 m/s^2 , the acceleration is within the limit.

7.1.7 Load combination

The lateral load and the torsional load calculated in Section 7.1.4 shall be applied simultaneously to the building with combination factors in Table 2-1 of the Code. The resultant of loads from 24 load cases shall be applied at the centre of the area at each level.

7.2 Multi-towers on podium

The example is shown to demonstrate the load combination for multi towers sitting on the same podium. Figure 7-5 shows that 7 towers / blocks share one podium. The global axis XOY follows the axis of the podium, and the local axis *xoy* is based on the individual tower orientation. Here, the local axis for the 7 towers is same as shown in Figure 7-1.

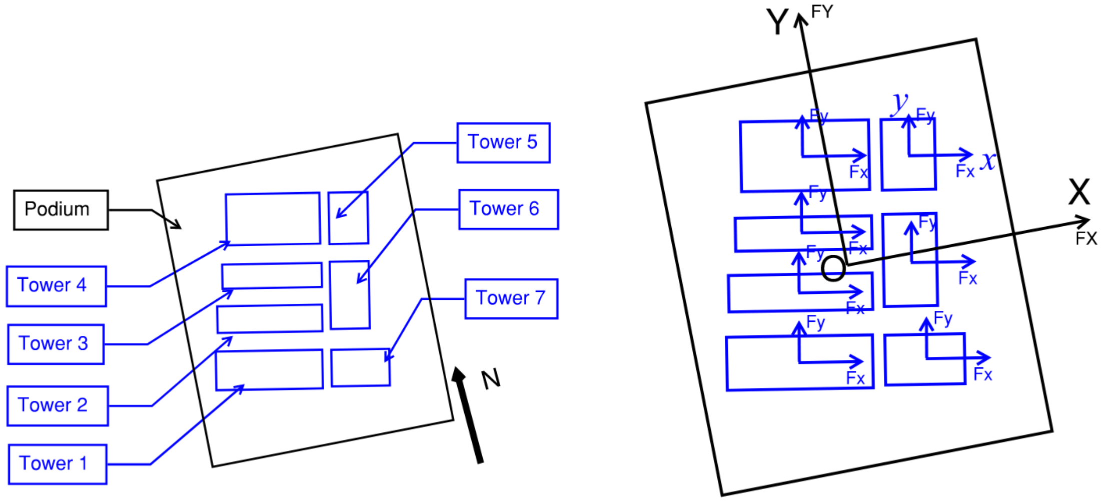


Figure 7-5 Site Plan

Assume the two orthogonal loads and the torsion loads for the towers and podium have been calculated, following the same procedure introduced in the example in Section 7.1; Table 7-10 summarized the calculated wind loading for the podium and the blocks in their own calculation axis.

Table 7-10 Wind Loads for the towers and the podium

	F_X (MN)	M_{YY} (MNm)	T_X(MNm)	F_Y (MN)	M_{XX} (MNm)	T_Y(MNm)	T(MNm)
Podium to Base	4.0	47.6	36.6	1.9	17.5	9.3	36.6
	Fx (MN)	Myy (MNm)	Tx(MNm)	Fy (MN)	Mxx (MNm)	Ty(MNm)	T(MNm)
Tower 1 to Podium	2.6	64.2	3.1	6.9	169.9	51.8	51.8
Tower 2 to Podium	3.1	120.9	2.6	11.1	437.0	109.6	109.6
Tower 3 to Podium	3.1	119.6	2.6	10.8	422.9	98.9	98.9
Tower 4 to Podium	6.1	237.4	10.9	10.5	407.9	47.2	47.2
Tower 5 to Podium	6.8	264.1	14.3	4.7	185.2	6.4	14.3
Tower 6 to Podium	8.3	321.6	24.9	4.4	178.2	6.0	24.9
Tower 7 to Podium	2.7	66.3	3.3	4.1	102.5	11.0	11.0

7.2.1 Critical Translational Load Cases

This step aims to generate the maximum translational wind load from all the towers in each checking direction.

Step 1: Under global axis, which is defined as the main axis of the podium in this case, 8 subzones (Zone 1 to Zone 8 as shown in Figure 7-6) are defined representing 8 main checking directions. The selection of the global axis is independent from the local axis of the tower and the podium.

Step 2: For each tower and the podium, the translation loads (F_x and F_y) are combined using the combination factors of Case 1 and Case 2 ,which are the governing translational load cases of Table 2-1 of the Code, are generated and summarized in Table 7-11 for each tower. The calculated load vectors for each tower and the podium are shown in Table 7-12. The combined translation forces, presented as a load vector under the local axis for each tower and the podium, are plotted into the 8 zones in global axis in Figure 7-6.

An example of the vector summation for Zone 1 is shown in Figure 7-7

Step 3: For each zone,

- pick up a load vector from each tower and the podium and do a vector summation; this vector sum correspond to a specific series of load vectors from each other in this zone. (An example of a possible vector summation for Zone 1 is shown in Figure 7-7.)
- there could be many such series of load vectors; as an example all the series of load vectors in Zone 1 are listed in Table 7-13. However, only the specific series of load vectors giving the maximum magnitude of the vector sum in the studied zone will finally be selected to represent the governing global translational loads of this zone; as an example, for Zone 1, this can be selected based on the magnitude of the resultant force are shown in the last row of Table 7-13.

Step 4: Repeat the same procedure in Step 3 for all the 8 zones. Finally 8 global load cases giving the biggest translational loads in each of the 8 zones are decided, as summarized in Table 7-14. For example, Case 1 in the table represent the series of load vectors giving the biggest translational loads in Zone 1.

Step 5: For each of the global load cases in Table 7-14, individual torsions of each tower and podium should be added simultaneously, with the factor of ±0.55. This gives totally 16 load cases.

Table 7-11 Combined translational load cases for individual block

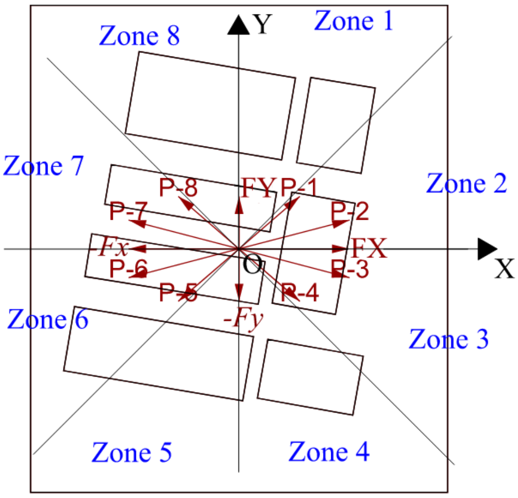
Combined Force	Load	Combined Force	Load
X-1	0.55Fx+Fy	**X-5**	-0.55Fx-Fy
X-2	Fx+0.55Fy	**X-6**	-Fx-0.55Fy
X-3	Fx-0.55Fy	**X-7**	-Fx+0.55Fy
X-4	0.55Fx-Fy	**X-8**	-0.55Fx+Fy
X represents either any of the individual tower or the podium.			

Table 7-12 Calculated combined translational forces

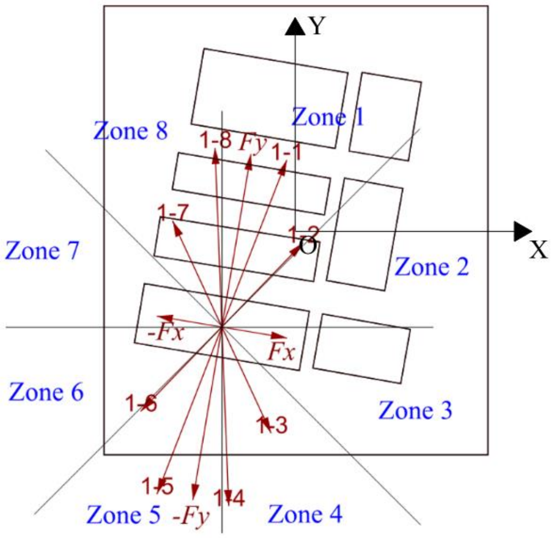
	X-1		X-2		X-3		X-4	
	$0.55F_X$	F_Y	F_X	$0.55F_Y$	F_X	$-0.55F_Y$	$0.55F_X$	$-F_Y$
Podium to Base (MN)	2.2	1.9	4.0	1.0	4.0	-1.0	2.2	-1.9
	0.55Fx	Fy	Fx	0.55Fy	Fx	-0.55Fy	0.55Fx	-Fy
Tower 1 to Podium (MN)	1.4	6.9	2.6	3.8	2.6	-3.8	1.4	-6.9
Tower 2 to Podium (MN)	1.7	11.1	3.1	6.1	3.1	-6.1	1.7	-11.1
Tower 3 to Podium (MN)	1.7	10.8	3.1	5.9	3.1	-5.9	1.7	-10.8
Tower 4 to Podium (MN)	3.4	10.5	6.1	5.8	6.1	-5.8	3.4	-10.5

Tower 5 to Podium (MN)	3.7	4.7	6.8	2.6	6.8	-2.6	3.7	-4.7
Tower 6 to Podium (MN)	4.6	4.4	8.3	2.4	8.3	-2.4	4.6	-4.4
Tower 7 to Podium (MN)	1.5	4.1	2.7	2.3	2.7	-2.3	1.5	-4.1
	X 5		**X 6**		**X 7**		**X 8**	
	$-0.55F_X$	$-F_Y$	$-F_X$	$-0.55F_Y$	$-F_X$	$0.55F_Y$	$-0.55F_X$	F_Y
Podium to Base (MN)	-2.2	-1.9	-4.0	-1.0	-4.0	1.0	-2.2	1.9
	0.55Fx	Fy	Fx	0.55Fy	Fx	-0.55Fy	0.55Fx	-Fy
Tower 1 to Podium (MN)	-1.4	-6.9	-2.6	-3.8	-2.6	3.8	-1.4	6.9
Tower 2 to Podium (MN)	-1.7	-11.1	-3.1	-6.1	-3.1	6.1	-1.7	11.1
Tower 3 to Podium (MN)	-1.7	-10.8	-3.1	-5.9	-3.1	5.9	-1.7	10.8
Tower 4 to Podium (MN)	-3.4	-10.5	-6.1	-5.8	-6.1	5.8	-3.4	10.5
Tower 5 to Podium (MN)	-3.7	-4.7	-6.8	-2.6	-6.8	2.6	-3.7	4.7
Tower 6 to Podium (MN)	-4.6	-4.4	-8.3	-2.4	-8.3	2.4	-4.6	4.4
Tower 7 to Podium (MN)	-1.5	-4.1	-2.7	-2.3	-2.7	2.3	-1.5	4.1

Podium

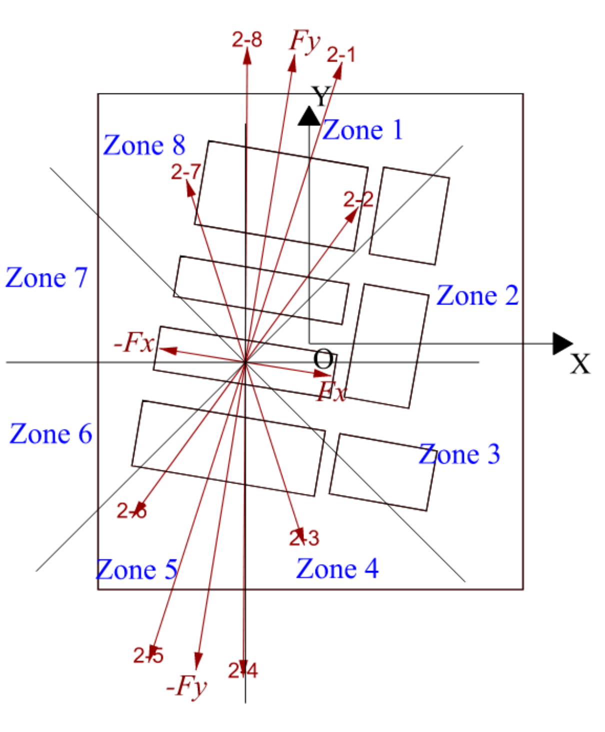
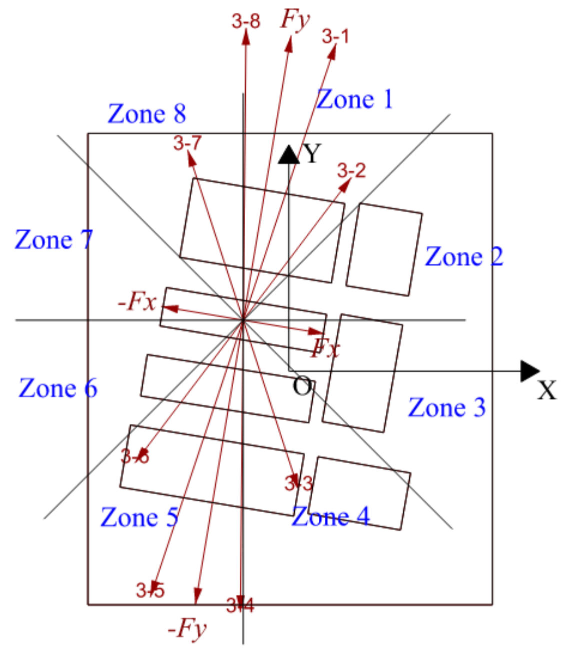
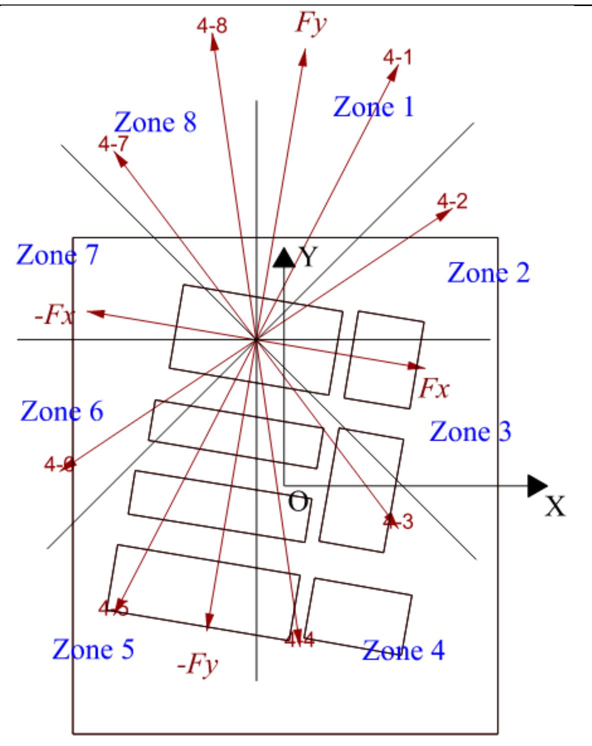
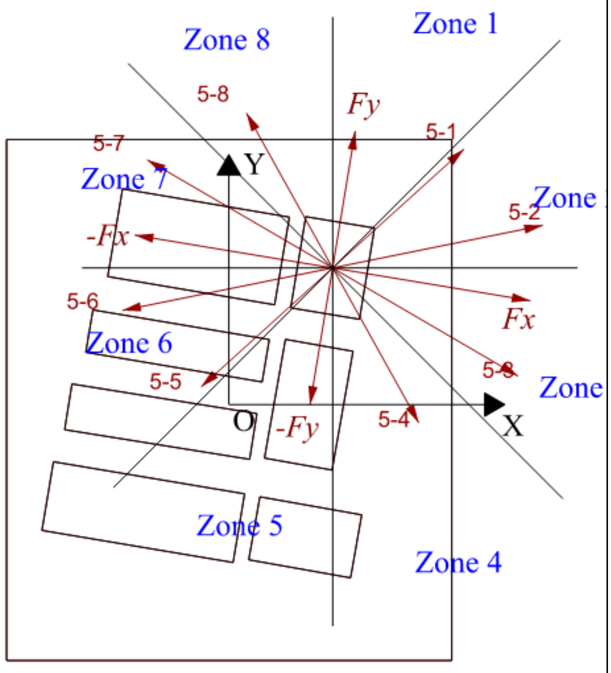


Tower 1



Tower 2

Tower 3

	
Tower 4	Tower 5
	
Tower 6	Tower 7

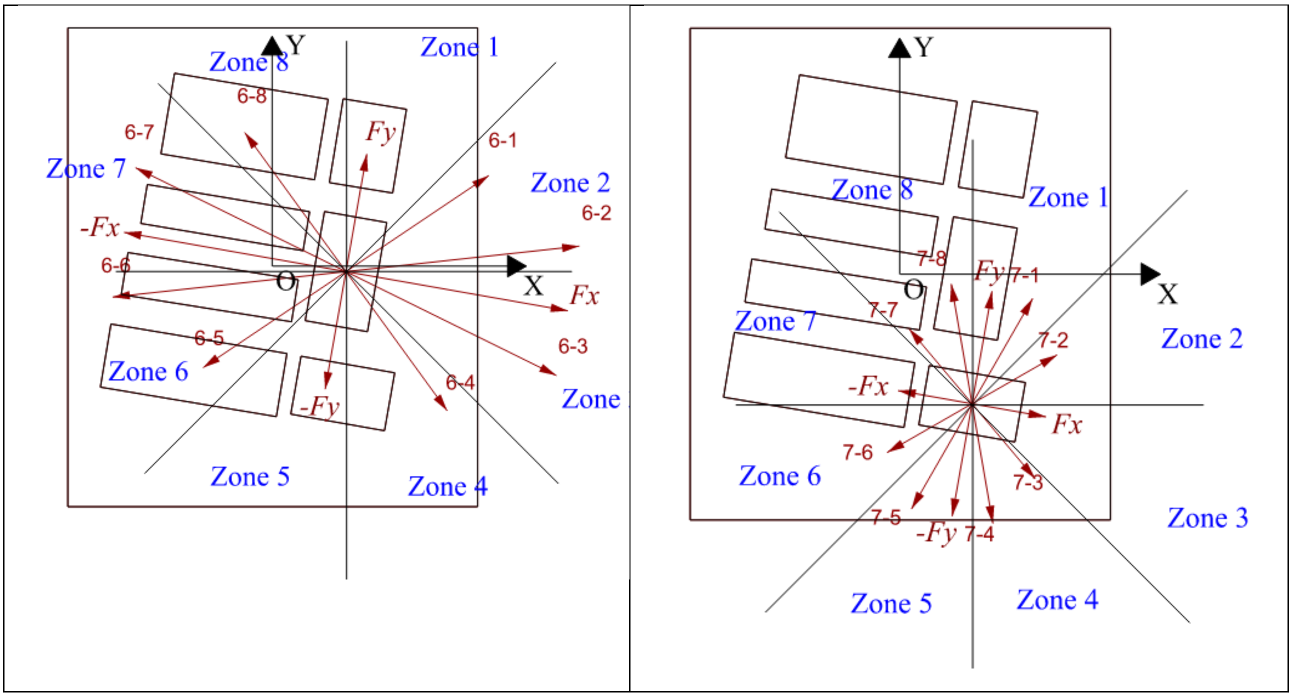


Figure 7-6 Detailed combined force vectors for each block

Table 7-13 Pick up the load combination in Zone 1

Zone 1									
Case	1	2	3	4	5	6	7	8	9
P	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T1	T1-1	T1-2	T1-1	T1-2	T1-1	T1-2	T1-1	T1-2	T1-1
T2	T2-1	T2-1	T2-2	T2-2	T2-8	T2-8	T2-1	T2-1	T2-2
T3	T3-1	T3-1	T3-1	T3-1	T3-1	T3-1	T3-2	T3-2	T3-2
T4	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1
T5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T7	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1
Magnitude (MN)	44.45	41.72	39.98	37.37	43.82	40.94	40.09	37.48	35.79
Case	10	11	12	13	14	15	16	17	18
P	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T1	T1-2	T1-1	T1-2	T1-1	T1-2	T1-1	T1-2	T1-1	T1-2
T2	T2-2	T2-8	T2-8	T2-1	T2-1	T2-2	T2-2	T2-8	T2-8
T3	T3-2	T3-2	T3-2	T3-8	T3-8	T3-8	T3-8	T3-8	T3-8
T4	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1	T4-1
T5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T7	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1	T7-1
Magnitude (MN)	33.36	39.26	36.48	43.84	40.97	39.17	36.40	43.46	40.46

Table 7-14 Final Load Cases

Zone	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
P	N/A	P-2	P-3	N/A	N/A	P-6	P-7	N/A
T1	T1-1	N/A	N/A	T1-4	T1-5	N/A	N/A	T1-8
T2	T2-1	N/A	N/A	T2-3	T2-5	N/A	N/A	T2-7
T3	T3-1	N/A	N/A	T3-3	T3-5	N/A	N/A	T3-7
T4	T4-1	T4-2	N/A	T4-4	T4-5	T4-6	N/A	T4-8
T5	N/A	T5-2	T5-3	T5-4	N/A	T5-6	T5-7	T5-8
T6	N/A	T6-2	T6-3	T6-4	N/A	T6-6	T6-7	T6-8
T7	T7-1	T7-2	N/A	T7-4	T7-5	T7-6	N/A	T7-8
Magnitude (MN)	44.45	31.34	19.96	47.44	44.45	31.34	19.96	47.44

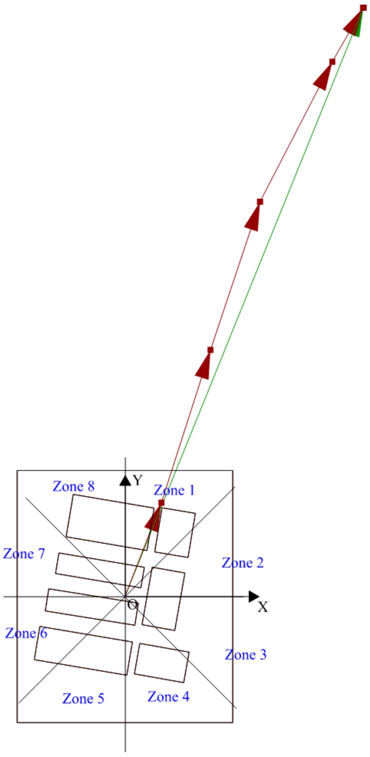


Figure 7-7 Vector summation for Zone 1.

7.2.2 Critical Torsional Load Cases

The critical torsional load cases can be obtained following the steps as below:

Step 1: For each zone, the resultant translational governed lateral forces are calculated through vector summation as described in Section 7.2.1 and shown in Table 7-13. Totally 8 resultant lateral forces can be obtained, summarized as $F_{lateral}$ in Table 7-15 .

Step 2: For each lateral force, it is plotted in the global axis and the maximum projecting diagonal breadth B_i can be identified. An example of Zone 1 is shown in Figure 7-8.

Step 3: For each subzone, the overall torsion can be calculated as $M^*_i = F_{lateral\_i} * 0.1B_i$, as summarized in Table 7-15.

Step 4: The maximum torsion is chosen as the overall torsional loads due to partial tower load as $M^* = \max(M^*_i)$ = 744.8MNm, and it will be applied as a concentrated torque with full value on the podium roof.

Step 5: All the local/individual torsions on the tower and the podium, as shown in the last column of Table 7-10 shall be applied with full value to the model as well, and their total value M is 394.3MNm.

Step 6: The load vectors corresponding to the 8 $F_{lateral}$ cases in Table 7-14, representing the largest translational loading effect in each zone, shall also be applied to the model with reduced magnitude (factor of 0.55).

Step 7: Figure 7-9 is an example demonstrating an overall critical torsional load case, including the load vectors for reduced translational loads in Step 6, the full concentrated torque in Step 4 and the full individual torsions in Step 5.

Step 8: The overall loading effects are summarized in Table 7-16. With consideration the opposite directions of M and M*, there are another 16 load cases.

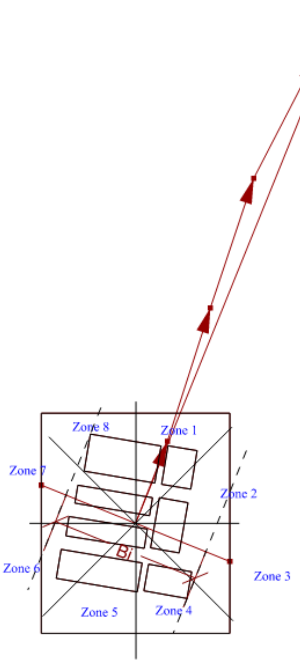


Figure 7-8 Example of B_i

Table 7-15 Resultant Lateral Forces Summary and Calculation of M^*_i

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
$F_{lateral\_i}$ (MN)	44.45	31.34	19.96	47.44	44.45	31.34	19.96	47.44
B_i (m)	163	186	195	157	163	186	195	157
M^*_i(MNm)	724.5	582.9	389.2	744.8	724.5	582.9	389.2	744.8

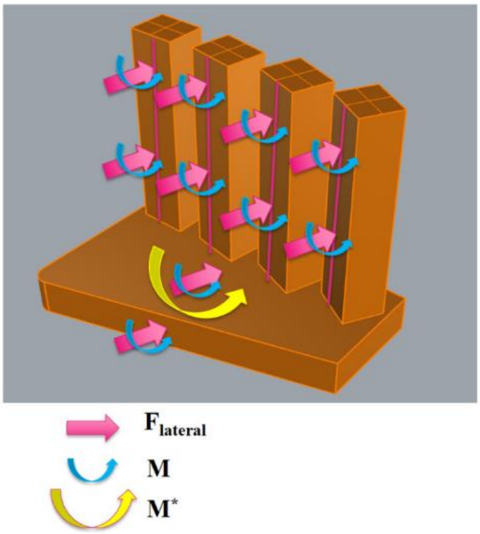


Figure 7-9 Critical torsional load cases (copy from the Code)

Table 7-16 Summary of the Overall Loading Effect of the Critical Torsional Load Cases

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
$F_{lateral\_i}$ (MN)	24.4	17.2	11.0	26.1	24.4	17.2	11.0	26.1
M (MNm)	±394.3	±394.3	±394.3	±394.3	±394.3	±394.3	±394.3	±394.3
M^* (MNm)	±744.8	±744.8	±744.8	±744.8	±744.8	±744.8	±744.8	±744.8

Appendix A: Parametric Study for Acceleration

	Calculated Acc > Office Limit
	Residential Limit< Calculated Acc <Office Limit
	Calculated Acc < Residential Limit

Assumed density 500kg/m^3, unit: milli-g

1 year acceleration		He/H=1.0					He/H=0.7					He/H=0.45					Limit (COP 2019)	
		H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B		
H (m)	H/D	8.0	7.0	6.0	5.0	4.0	8.0	7.0	6.0	5.0	4.0	8.0	7.0	6.0	5.0	4.0	Residential	Office
90	8	N/A	N/A	13.0	10.6	8.2	N/A	N/A	11.4	9.3	7.2	10.2	8.7	7.3	5.9	4.6	5.5	8.3
90	7	N/A	N/A	10.6	8.6	6.7	N/A	N/A	9.3	7.6	5.9	8.7	6.7	5.6	4.5	3.5	5.5	8.3
90	6	N/A	10.6	8.2	6.7	5.1	N/A	9.3	7.2	5.8	4.5	7.3	5.6	4.3	3.5	2.7	5.5	8.3
90	5	N/A	8.6	6.7	4.9	3.8	N/A	7.6	5.8	4.3	3.3	5.9	4.5	3.5	2.6	2.0	5.5	8.3
90	4	8.2	6.7	5.1	3.8	2.6	7.2	5.9	4.5	3.3	2.3	4.6	3.5	2.7	2.0	1.5	5.5	8.3
120	8	N/A	N/A	10.6	8.6	6.7	N/A	N/A	9.3	7.6	5.8	8.4	7.2	6.0	4.9	3.8	6.3	9.4
120	7	N/A	N/A	8.7	7.0	5.4	N/A	N/A	7.6	6.2	4.8	7.2	5.5	4.6	3.7	2.9	6.3	9.4
120	6	N/A	8.7	6.7	5.4	4.2	N/A	N/A	5.9	4.8	3.7	6.0	4.6	3.5	2.9	2.2	6.3	9.4
120	5	N/A	7.0	5.4	4.0	3.1	N/A	6.2	4.8	3.5	2.7	4.9	3.7	2.9	2.1	1.7	6.3	9.4
120	4	N/A	5.4	4.2	3.1	2.1	N/A	4.8	3.7	2.7	1.9	3.8	2.9	2.2	1.7	1.2	6.3	9.4
150	8	N/A	N/A	9.0	7.3	5.7	N/A	N/A	7.9	6.4	5.0	N/A	6.2	5.2	4.2	3.2	6.9	10.4
150	7	N/A	N/A	7.4	6.0	4.6	N/A	N/A	6.5	5.3	4.1	6.2	4.7	4.0	3.2	2.5	6.9	10.4
150	6	N/A	N/A	5.7	4.6	3.6	N/A	N/A	5.0	4.1	3.1	5.2	4.0	3.0	2.4	1.9	6.9	10.4
150	5	N/A	6.0	4.6	3.4	2.6	N/A	5.3	4.1	3.0	2.3	4.2	3.2	2.4	1.8	1.4	6.9	10.4
150	4	N/A	4.6	3.6	2.6	1.8	N/A	4.1	3.1	2.3	1.6	3.2	2.5	1.9	1.4	1.0	6.9	10.4
180	8	N/A	N/A	7.9	6.4	5.0	N/A	N/A	7.0	5.7	4.4	N/A	5.4	4.5	3.7	2.8	7.5	11.2
180	7	N/A	N/A	6.5	5.3	4.1	N/A	N/A	5.7	4.6	3.6	5.4	4.2	3.5	2.8	2.2	7.5	11.2
180	6	N/A	N/A	5.0	4.1	3.1	N/A	N/A	4.4	3.6	2.8	4.5	3.5	2.7	2.2	1.7	7.5	11.2
180	5	N/A	N/A	4.1	3.0	2.3	N/A	N/A	3.6	2.6	2.0	3.7	2.8	2.2	1.6	1.3	7.5	11.2
180	4	N/A	4.1	3.1	2.3	1.6	N/A	3.6	2.8	2.0	1.4	2.8	2.2	1.7	1.3	0.9	7.5	11.2
200	8	N/A	N/A	7.4	6.0	4.6	N/A	N/A	6.5	5.2	4.1	N/A	5.0	4.2	3.4	2.6	7.9	11.8
200	7	N/A	N/A	6.0	4.9	3.8	N/A	N/A	5.3	4.3	3.3	N/A	3.9	3.2	2.6	2.0	7.9	11.8
200	6	N/A	N/A	4.6	3.8	2.9	N/A	N/A	4.1	3.3	2.6	4.2	3.2	2.5	2.0	1.6	7.9	11.8
200	5	N/A	N/A	3.8	2.7	2.1	N/A	N/A	3.3	2.4	1.9	3.4	2.6	2.0	1.5	1.2	7.9	11.8
200	4	N/A	3.8	2.9	2.1	1.5	N/A	3.3	2.6	1.9	1.3	2.6	2.0	1.6	1.2	0.8	7.9	11.8

Table A 1 Acceleration Comparison (500kg/m^3,1-year return)

	Calculated Acc > Office Limit
	Residential Limit< Calculated Acc <Office Limit
	Calculated Acc < Residential Limit

Assumed density 500kg/m^3, unit: milli-g

10 year acceleration		He/H=1.0					He/H=0.7					He/H=0.45					Limit (COP 2019)	
		H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B		
H (m)	H/D	8	7	6	5	4	8	7	6	5	4	8	7	6	5	4	Residential	Office
90	8	N/A	N/A	47.8	38.8	30.0	N/A	N/A	42.0	34.0	26.3	37.4	32.1	26.9	21.8	16.8	20.2	30.3
90	7	N/A	N/A	39.1	31.7	24.5	N/A	N/A	34.3	27.8	21.5	32.1	24.6	20.6	16.7	12.9	20.2	30.3
90	6	N/A	39.1	30.1	24.4	18.9	N/A	34.3	26.4	21.4	16.6	26.9	20.6	15.7	12.8	9.9	20.2	30.3
90	5	N/A	31.7	24.4	17.9	13.8	N/A	27.8	21.4	15.7	12.1	21.8	16.7	12.8	9.6	7.4	20.2	30.3
90	4	30.0	24.5	18.9	13.8	9.6	26.3	21.5	16.6	12.1	8.4	16.8	12.9	9.9	7.4	5.4	20.2	30.3
120	8	N/A	N/A	39.0	31.6	24.5	N/A	N/A	34.2	27.8	21.5	30.7	26.3	22.1	17.9	13.8	23.0	34.5
120	7	N/A	N/A	31.9	25.8	20.0	N/A	N/A	28.0	22.7	17.6	26.3	20.2	16.9	13.7	10.6	23.0	34.5
120	6	N/A	N/A	24.6	19.9	15.4	N/A	N/A	21.6	17.5	13.5	22.1	16.9	12.9	10.5	8.1	23.0	34.5
120	5	N/A	25.8	19.9	14.6	11.3	N/A	22.7	17.5	12.8	9.9	17.9	13.7	10.5	7.9	6.1	23.0	34.5
120	4	N/A	20.0	15.4	11.3	7.8	N/A	17.6	13.5	9.9	6.8	13.8	10.6	8.1	6.1	4.4	23.0	34.5
150	8	N/A	N/A	33.2	26.9	20.8	N/A	N/A	29.2	23.7	18.3	N/A	22.6	18.9	15.3	11.9	25.4	38.1
150	7	N/A	N/A	27.2	22.0	17.0	N/A	N/A	23.9	19.4	15.0	22.6	17.3	14.5	11.8	9.1	25.4	38.1
150	6	N/A	N/A	20.9	17.0	13.1	N/A	N/A	18.4	14.9	11.5	18.9	14.5	11.1	9.0	7.0	25.4	38.1
150	5	N/A	22.0	17.0	12.4	9.6	N/A	19.4	14.9	10.9	8.4	15.3	11.8	9.0	6.8	5.2	25.4	38.1
150	4	N/A	17.0	13.1	9.6	6.6	N/A	15.0	11.5	8.4	5.8	11.9	9.1	7.0	5.2	3.8	25.4	38.1
180	8	N/A	N/A	29.1	23.6	18.3	N/A	N/A	25.6	20.8	16.1	N/A	19.9	16.7	13.5	10.5	27.5	41.3
180	7	N/A	N/A	23.8	19.3	15.0	N/A	N/A	20.9	17.0	13.1	19.9	15.3	12.8	10.4	8.0	27.5	41.3
180	6	N/A	N/A	18.4	14.9	11.5	N/A	N/A	16.1	13.1	10.1	16.7	12.8	9.8	7.9	6.1	27.5	41.3
180	5	N/A	N/A	14.9	10.9	8.4	N/A	N/A	13.1	9.6	7.4	13.5	10.4	7.9	6.0	4.6	27.5	41.3
180	4	N/A	15.0	11.5	8.4	5.8	N/A	13.1	10.1	7.4	5.1	10.5	8.0	6.1	4.6	3.3	27.5	41.3
200	8	N/A	N/A	27.0	21.9	16.9	N/A	N/A	23.7	19.3	14.9	N/A	18.5	15.5	12.6	9.7	28.8	43.3
200	7	N/A	N/A	22.1	17.9	13.9	N/A	N/A	19.4	15.7	12.2	N/A	14.2	11.9	9.6	7.5	28.8	43.3
200	6	N/A	N/A	17.0	13.8	10.7	N/A	N/A	15.0	12.1	9.4	15.5	11.9	9.1	7.4	5.7	28.8	43.3
200	5	N/A	N/A	13.8	10.1	7.8	N/A	N/A	12.1	8.9	6.9	12.6	9.6	7.4	5.5	4.3	28.8	43.3
200	4	N/A	13.9	10.7	7.8	5.4	N/A	12.2	9.4	6.9	4.7	9.7	7.5	5.7	4.3	3.1	28.8	43.3

Table A 2 Acceleration Comparison (500kg/m^3,10-year return)

	Calculated Acc > Office Limit
	Residential Limit< Calculated Acc <Office Limit
	Calculated Acc < Residential Limit

Assumed density 400kg/m^3, unit: milli-g

1 year acceleration		He/H=1.0					He/H=0.7					He/H=0.45					Limit (COP 2019)	
		H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B		
H (m)	H/D	8	7	6	5	4	8	7	6	5	4	8	7	6	5	4	Residential	Office
90	8	N/A	N/A	16.3	13.2	10.2	N/A	N/A	14.3	11.6	9.0	12.7	10.9	9.1	7.4	5.7	5.5	8.3
90	7	N/A	15.9	13.3	10.8	8.3	N/A	N/A	11.7	9.5	7.3	10.9	8.4	7.0	5.7	4.4	5.5	8.3
90	6	N/A	13.3	10.3	8.3	6.4	N/A	11.7	9.0	7.3	5.6	9.1	7.0	5.4	4.3	3.4	5.5	8.3
90	5	N/A	10.8	8.3	6.1	4.7	N/A	9.5	7.3	5.3	4.1	7.4	5.7	4.3	3.3	2.5	5.5	8.3
90	4	10.2	8.3	6.4	4.7	3.3	9.0	7.3	5.6	4.1	2.9	5.7	4.4	3.4	2.5	1.8	5.5	8.3
120	8	N/A	N/A	13.3	10.8	8.3	N/A	N/A	11.6	9.4	7.3	10.5	9.0	7.5	6.1	4.7	6.3	9.4
120	7	N/A	N/A	10.8	8.8	6.8	N/A	N/A	9.5	7.7	6.0	9.0	6.9	5.8	4.7	3.6	6.3	9.4
120	6	N/A	N/A	8.4	6.8	5.2	N/A	N/A	7.3	6.0	4.6	7.5	5.8	4.4	3.6	2.8	6.3	9.4
120	5	N/A	8.8	6.8	5.0	3.8	N/A	7.7	6.0	4.3	3.4	6.1	4.7	3.6	2.7	2.1	6.3	9.4
120	4	N/A	6.8	5.2	3.8	2.7	N/A	6.0	4.6	3.4	2.3	4.7	3.6	2.8	2.1	1.5	6.3	9.4
150	8	N/A	N/A	11.3	9.2	7.1	N/A	N/A	9.9	8.1	6.2	N/A	7.7	6.4	5.2	4.0	6.9	10.4
150	7	N/A	N/A	9.2	7.5	5.8	N/A	N/A	8.1	6.6	5.1	7.7	5.9	4.9	4.0	3.1	6.9	10.4
150	6	N/A	N/A	7.1	5.8	4.5	N/A	N/A	6.3	5.1	3.9	6.4	4.9	3.8	3.1	2.4	6.9	10.4
150	5	N/A	7.5	5.8	4.2	3.3	N/A	6.6	5.1	3.7	2.9	5.2	4.0	3.1	2.3	1.8	6.9	10.4
150	4	N/A	5.8	4.5	3.3	2.3	N/A	5.1	3.9	2.9	2.0	4.0	3.1	2.4	1.8	1.3	6.9	10.4
180	8	N/A	N/A	9.9	8.0	6.2	N/A	N/A	8.7	7.1	5.5	N/A	6.8	5.7	4.6	3.6	7.5	11.2
180	7	N/A	N/A	8.1	6.6	5.1	N/A	N/A	7.1	5.8	4.5	6.8	5.2	4.4	3.5	2.7	7.5	11.2
180	6	N/A	N/A	6.2	5.1	3.9	N/A	N/A	5.5	4.5	3.4	5.7	4.4	3.3	2.7	2.1	7.5	11.2
180	5	N/A	N/A	5.1	3.7	2.9	N/A	N/A	4.5	3.3	2.5	4.6	3.5	2.7	2.0	1.6	7.5	11.2
180	4	N/A	5.1	3.9	2.9	2.0	N/A	4.5	3.4	2.5	1.7	3.6	2.7	2.1	1.6	1.1	7.5	11.2
200	8	N/A	N/A	9.2	7.5	5.8	N/A	N/A	8.1	6.6	5.1	N/A	6.3	5.3	4.3	3.3	7.9	11.8
200	7	N/A	N/A	7.5	6.1	4.7	N/A	N/A	6.6	5.4	4.1	N/A	4.8	4.0	3.3	2.5	7.9	11.8
200	6	N/A	N/A	5.8	4.7	3.6	N/A	N/A	5.1	4.1	3.2	5.3	4.0	3.1	2.5	1.9	7.9	11.8
200	5	N/A	N/A	4.7	3.4	2.7	N/A	N/A	4.1	3.0	2.3	4.3	3.3	2.5	1.9	1.5	7.9	11.8
200	4	N/A	4.7	3.6	2.7	1.8	N/A	4.1	3.2	2.3	1.6	3.3	2.5	1.9	1.5	1.1	7.9	11.8

Table A 3 Acceleration Comparison (400kg/m^3,1-year return)

	Calculated Acc > Office Limit
	Residential Limit< Calculated Acc <Office Limit
	Calculated Acc < Residential Limit

Assumed density 400kg/m^3, unit: milli-g

10 year acceleration		He/H=1.0					He/H=0.7					He/H=0.45					Limit (COP 2019)	
		H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B	H/B		
H (m)	H/D	8	7	6	5	4	8	7	6	5	4	8	7	6	5	4	Residential	Office
90	8	N/A	N/A	59.8	48.5	37.5	N/A	N/A	52.4	42.5	32.9	46.7	40.1	33.6	27.2	21.1	20.2	30.3
90	7	N/A	N/A	48.9	39.6	30.7	N/A	N/A	42.9	34.8	26.9	40.1	30.7	25.7	20.9	16.2	20.2	30.3
90	6	N/A	48.9	37.7	30.5	23.6	N/A	42.9	33.0	26.8	20.7	33.6	25.7	19.7	16.0	12.4	20.2	30.3
90	5	N/A	39.6	30.5	22.3	17.3	N/A	34.8	26.8	19.6	15.1	27.2	20.9	16.0	12.0	9.3	20.2	30.3
90	4	37.5	30.7	23.6	17.3	11.9	32.9	26.9	20.7	15.1	10.5	21.1	16.2	12.4	9.3	6.7	20.2	30.3
120	8	N/A	N/A	48.7	39.5	30.6	N/A	N/A	42.8	34.7	26.8	38.4	32.9	27.6	22.4	17.3	23.0	34.5
120	7	N/A	N/A	39.8	32.3	25.0	N/A	N/A	35.0	28.4	21.9	32.9	25.3	21.2	17.2	13.3	23.0	34.5
120	6	N/A	N/A	30.7	24.9	19.3	N/A	N/A	27.0	21.9	16.9	27.6	21.2	16.2	13.1	10.1	23.0	34.5
120	5	N/A	32.3	24.9	18.2	14.1	N/A	28.4	21.9	16.0	12.4	22.4	17.2	13.1	9.8	7.6	23.0	34.5
120	4	N/A	25.0	19.3	14.1	9.7	N/A	21.9	16.9	12.4	8.6	17.3	13.3	10.1	7.6	5.5	23.0	34.5
150	8	N/A	N/A	41.5	33.7	26.1	N/A	N/A	36.5	29.6	22.9	N/A	28.2	23.7	19.2	14.8	25.4	38.1
150	7	N/A	N/A	34.0	27.5	21.3	N/A	N/A	29.8	24.2	18.7	28.2	21.7	18.1	14.7	11.4	25.4	38.1
150	6	N/A	N/A	26.2	21.2	16.4	N/A	N/A	23.0	18.6	14.4	23.7	18.1	13.9	11.2	8.7	25.4	38.1
150	5	N/A	27.5	21.2	15.5	12.0	N/A	24.2	18.6	13.6	10.5	19.2	14.7	11.2	8.4	6.5	25.4	38.1
150	4	N/A	21.3	16.4	12.0	8.3	N/A	18.7	14.4	10.5	7.3	14.8	11.4	8.7	6.5	4.7	25.4	38.1
180	8	N/A	N/A	36.4	29.5	22.9	N/A	N/A	32.0	26.0	20.1	N/A	24.9	20.8	16.9	13.1	27.5	41.3
180	7	N/A	N/A	29.8	24.2	18.7	N/A	N/A	26.2	21.2	16.4	24.9	19.1	16.0	13.0	10.0	27.5	41.3
180	6	N/A	N/A	23.0	18.6	14.4	N/A	N/A	20.2	16.4	12.7	20.8	16.0	12.2	9.9	7.7	27.5	41.3
180	5	N/A	N/A	18.6	13.6	10.5	N/A	N/A	16.4	12.0	9.3	16.9	13.0	9.9	7.4	5.8	27.5	41.3
180	4	N/A	18.7	14.4	10.5	7.3	N/A	16.4	12.7	9.3	6.4	13.1	10.0	7.7	5.8	4.2	27.5	41.3
200	8	N/A	N/A	33.8	27.4	21.2	N/A	N/A	29.7	24.1	18.6	N/A	23.1	19.4	15.7	12.2	28.8	43.3
200	7	N/A	N/A	27.6	22.4	17.3	N/A	N/A	24.3	19.7	15.2	N/A	17.7	14.9	12.0	9.3	28.8	43.3
200	6	N/A	N/A	21.3	17.2	13.3	N/A	N/A	18.7	15.2	11.7	19.4	14.9	11.4	9.2	7.1	28.8	43.3
200	5	N/A	N/A	17.2	12.6	9.8	N/A	N/A	15.2	11.1	8.6	15.7	12.0	9.2	6.9	5.4	28.8	43.3
200	4	N/A	17.3	13.3	9.8	6.7	N/A	15.2	11.7	8.6	5.9	12.2	9.3	7.1	5.4	3.9	28.8	43.3

Table A 4 Acceleration Comparison (400kg/m^3,10-year return)