Sample RKALC Structure

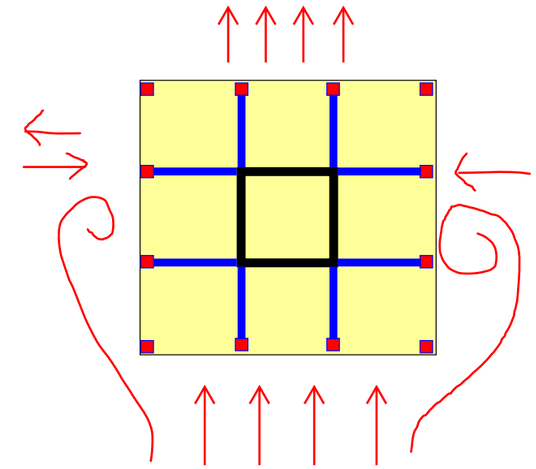
Structure in question is slender tall building with the following characteristics:

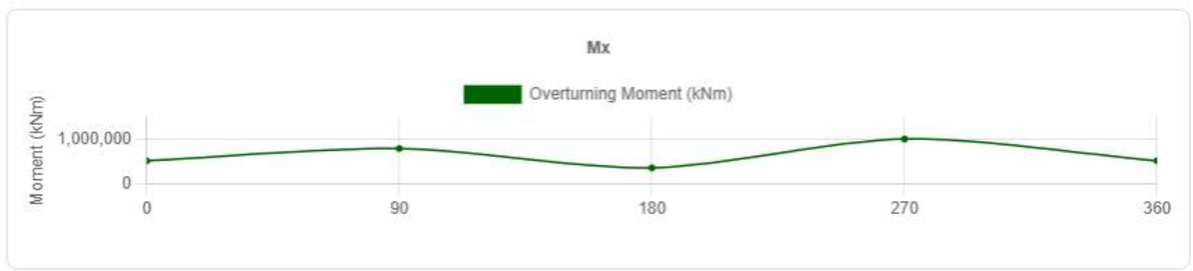
1-Office building of 27x27m² floor plate, central core of 9x9m² footprint

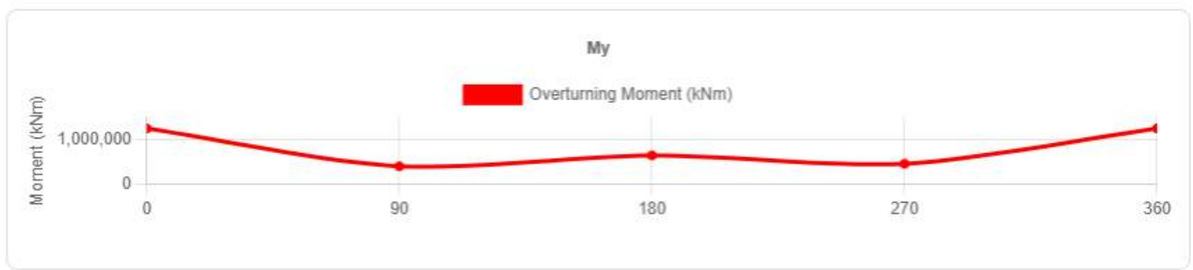
2-46 storeys, with total height of 150m from footings to roof.

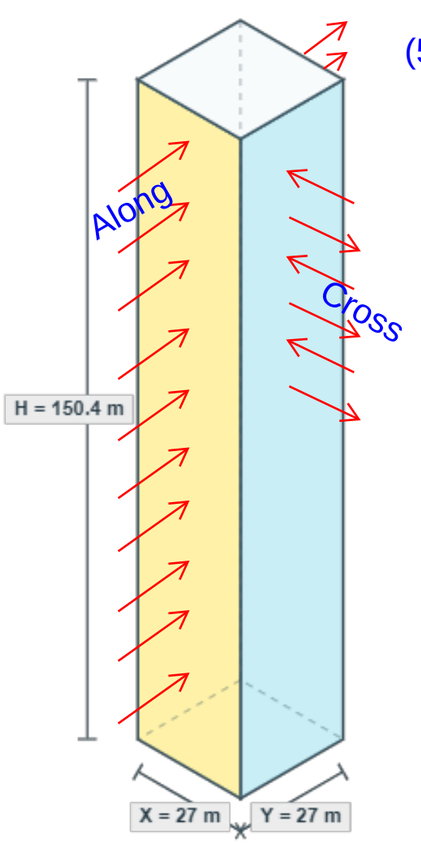
3-Aspect ratio of the building =~ 5.6 (slender)

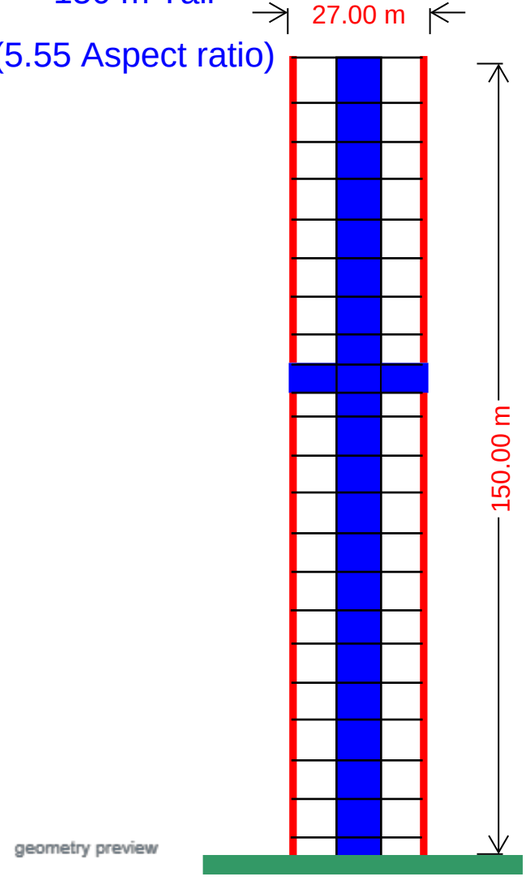
4-Wind loads to be estimated, together with building response











Description of Building

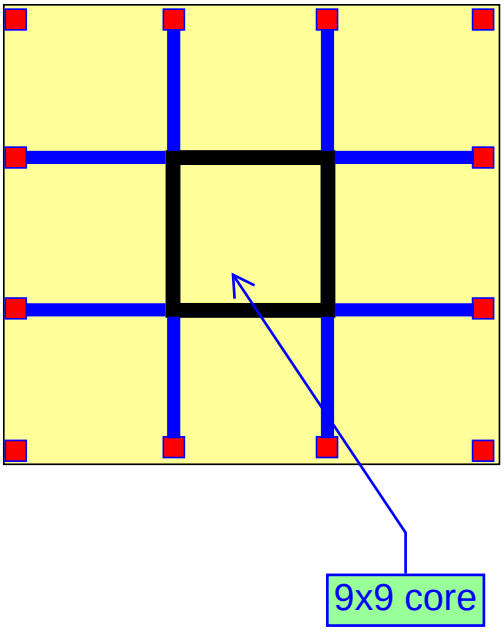
A- Gravity System and loads

This is an office building with typical loads as follows

1- Loads : SDL = 2 KPa and

LL = 3 KPa

2- Slab system is PT with thickness = 240 mm (6KPa)



Therefore

ULS = (2+6) * 1.2 + 3 * 1.5 = 14.1 KPa

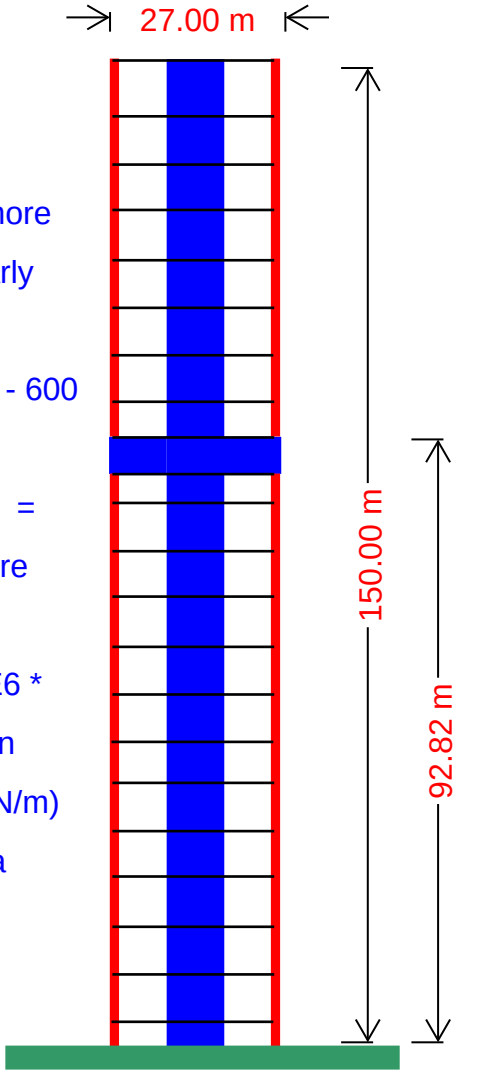
SLS = 2 + 6 + 3 = 11 KPa

for dynamic proeprties

participating mass = 2 + 6 + 0.3 * 3 =~ 9 KPa

average storey mass = 27x27x9 * 1.3 = 852,930 kg

(note the 1.30 factor allows for verticals)



Core

1- For building like this one, footprint of the core should be more than 15% of floor plate, here the core is at circa 10%, so clearly needs big thickness.

2- thickness of walls is roughly = number of levels * 10 = 500 - 600 mm.

so if the core is 9 x 9 and thickness = 600mm, inertia of core = (9^ 4 - 7.8^4) / 12 = 238 m ^4 (gross simplified closed-box core inertia)

-Deflection at top = W * H^ 4 / (8EI) = 75 * 150^4 / (8 * 32.8E6 * 238) = 608 mm (For this preliminary stiffness check, adopt an equivalent uniformly distributed lateral wind load of W = 75 kN/m)

-Assume Cracked section = 0.6 * full section, effective inertia becomes = 0.6 * I - deflection becomes 608 / 0.6 = 1013

-Deflection ratio = 150 000 / 1013 = H/150 at ULS state

-for Service, wind loading roughly becomes 0.65 of ULS, and also effective section is say 0.8 therefore deformation at tip = (608mm * 0.65) / 0.8 = 494 ~ H/300

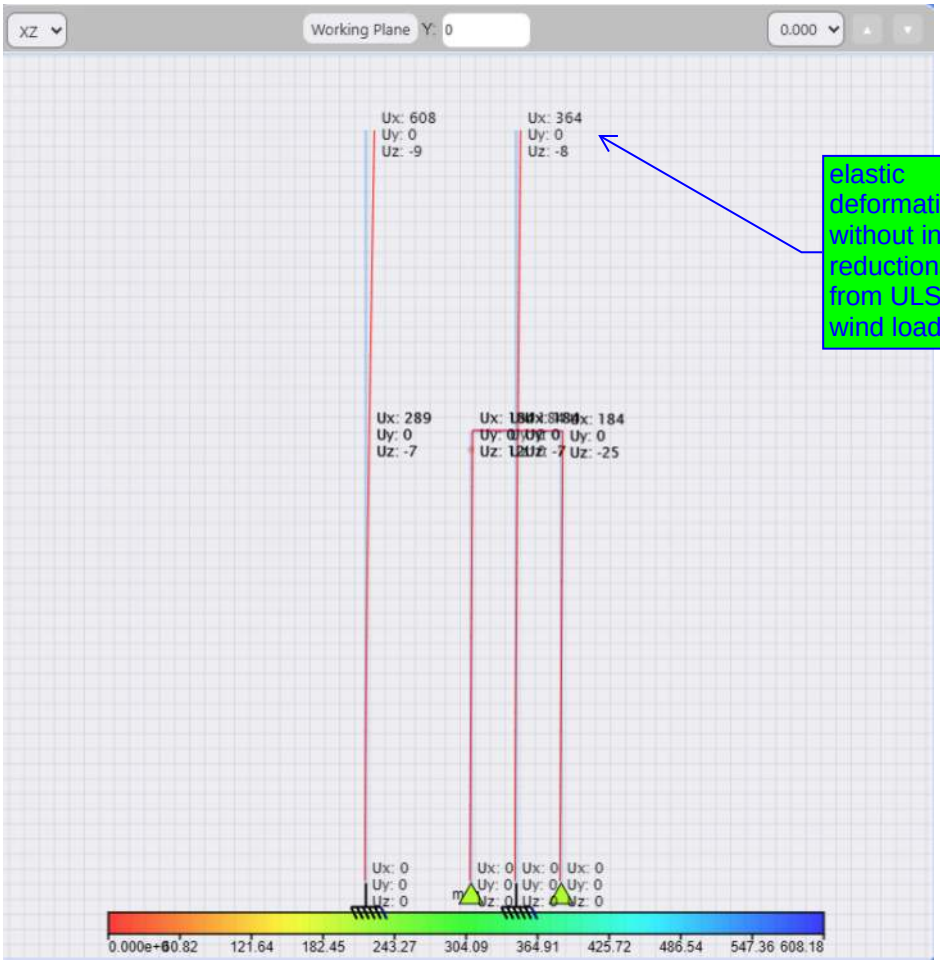
Both are not acceptable metrics..For this example, adopt a target total SLS building drift of H/400. Therefore, the target SLS roof displacement is 150,000 / 400 = 375 mm.

If we use outrigger, see below figure, deflection reduces to 364 (reduction by 40%)

ΔSLS≈364 * 0.65 / 0.8 ≈296 mm

(0.65 converts ULS wind to SLS and 0.8 is inertia reduction at SLS)

and therefore: 150000/296≈H/507

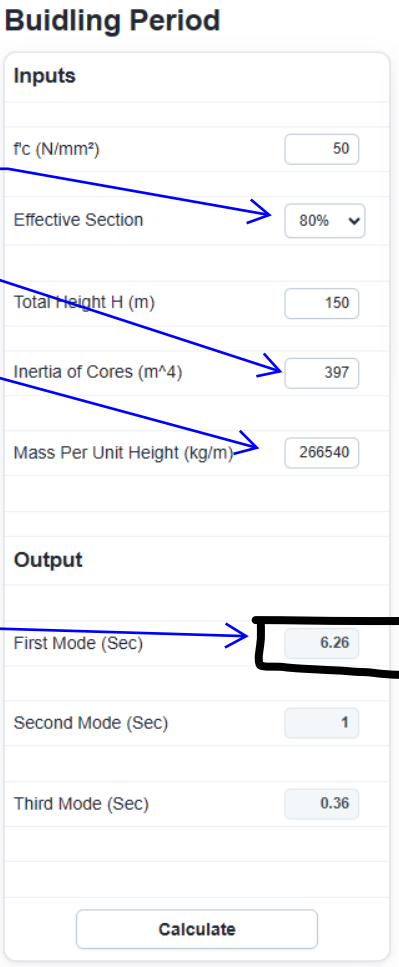


Therefore equivalent global inertia becomes 238 / 0.6 = 396.66 m^4 (this is the inertia that results in deflection = 364)

Building Period should be obtained from modal analysis, however for this example we will work the period using the formula

$$\omega_n = 1.875^2 \sqrt{\frac{EI}{\rho A L^4}}$$

Use this RKALC App



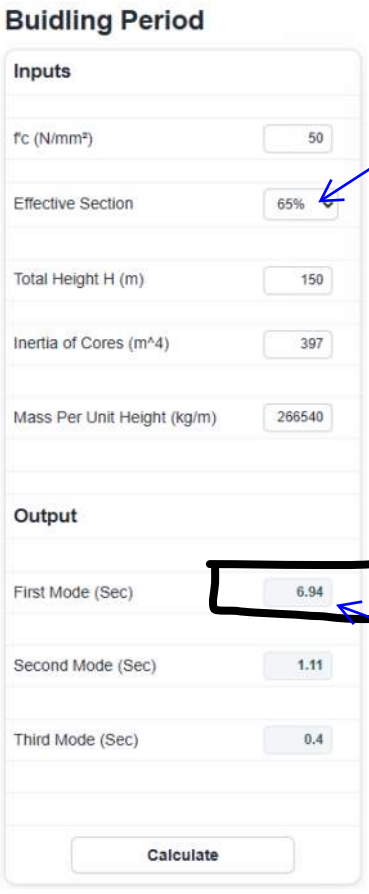
Inertia Reduction SLS

Inertia

floor mass / storey height

$$\omega_n = 1.875^2 \sqrt{\frac{EI}{\rho A L^4}}$$

SLS Period



Inertia Reduction ULS

ULS Period

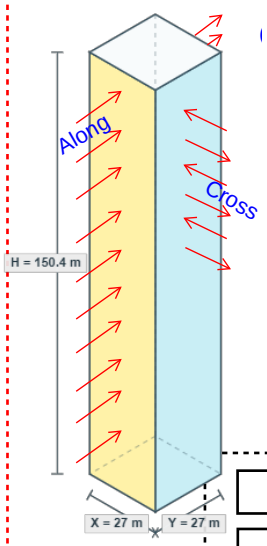
Typical Workflow

Review Lateral System

Analyse the structure for Both SLS and ULS

Participating Mass
Mass Per Floor

Nominate Wind Region and Terrain Category



ULS

Return Period :
1/500 or 1/1000 etc

Damping Ratio
2~3% for Concrete
1.5~2% Steel

Pressure Factors +
Directional Factors +
Shielding +
Building Period
in both directions

SLS

Return Period :
1/5 to 1/10

Damping Ratio
1~1.5% for Concrete
1~1.2% Steel

Pressure Factors +
Directional Factors +
Shielding +
Building Period
in both directions

WindKALC

Along and Cross Wind Loads

ETABS

Bad Results

Good Results

END

WindKALC

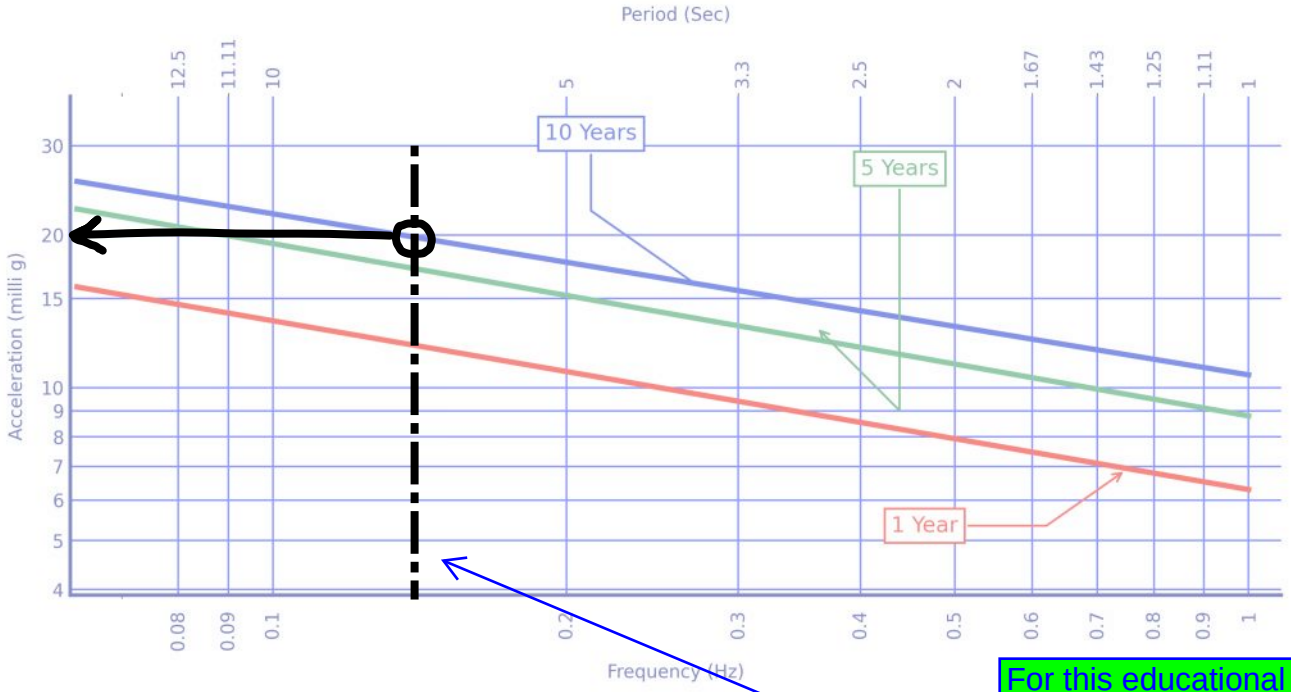
Along and Cross Wind Loads
Acceleration **(important)**

Comfort Criteria
SLS to ETABS (Drift)

Bad Results

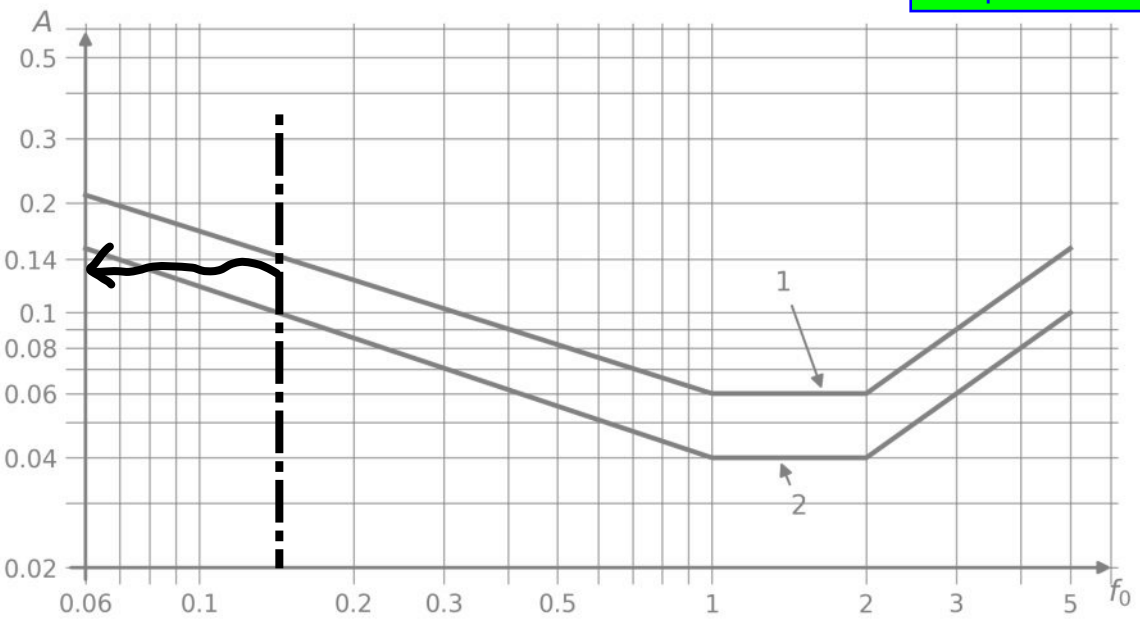
Good Results

END



For this educational example, the Melbourne (1988) criterion is adopted for acceleration acceptance.

Melbourne's (1988) maximum peak horizontal acceleration criteria based on Irwin (1986) and Chen and Robertson (1973), for T = 600 seconds, and return period R years



Evaluation curves for wind-induced vibrations in buildings in a horizontal (x, y) direction for a one-year return period

Key

A peak acceleration, m/s^2

f_0 first natural frequency in a structural

1 offices

2 residences

ISO can be followed but conservative

ES ISO 10137:2012(E)

Following table provides guidance for human perception levels for wind acceleration

Human perception levels		
Level	*Acceleration (m/s^2)*	*Effect*
1	< 0.05	Humans cannot perceive motion
2	0.05 - 0.1	a) Sensitive people can perceive motion; b) hanging objects may move slightly
3	0.1 - 0.25	a) Majority of people will perceive motion; b) level of motion may affect desk work; c) long-term exposure may produce motion sickness
4	0.25 - 0.4	a) Desk work becomes difficult or almost impossible; b) ambulation still possible
5	0.4 - 0.5	a) People strongly perceive motion; b) difficult to walk naturally; c) standing people may lose balance.
6	0.5 - 0.6	Most people cannot tolerate motion and are unable to walk naturally
7	0.6 - 0.7	People cannot walk or tolerate motion.
8	> 0.85	Objects begin to fall, and people may be injured

Human perception levels are informative and should not be confused with the adopted occupant-comfort acceptance criterion

Ultimate Wind Calculation

Wind Loads on Buildings

WindKALC Example

By RK | Sheet No. 8 | Date 8/26

Project inputs

Criteria	
Region	A
Return Period	1/500
Terrain Category	TC3
Global/base-response Cdyn: s = 0 m	0
Storey Height (m)	3.2
No. of Storeys	47
Total Height H (m)	150.4
Bldg. X Dimension (m)	27
Bldg. Y Dimension (m)	27
Site Wind Speed Vr	45
Damping	0.03
Average Storey Mass (kg)	852930
M z,cat (H)	1.21
Table 6.3 principal / companion factor	0.80

Important Design Notes

Analysis Package is valid until 30/03/2030 10:44:38 PM

Directional inputs

Along Y direction

Building Period (sec)	7
CPe Windward	0.8
CPe Leeward suction magnitude	0.5
Combination Factor Kc	0.9
Md Dir Factor +Y	0.9
Md Dir Factor -Y	0.8
Ms Shielding Factor +Y	1
Ms Shielding Factor -Y	0.95
Cfs reference (h:b:d) facing load	6:1:1

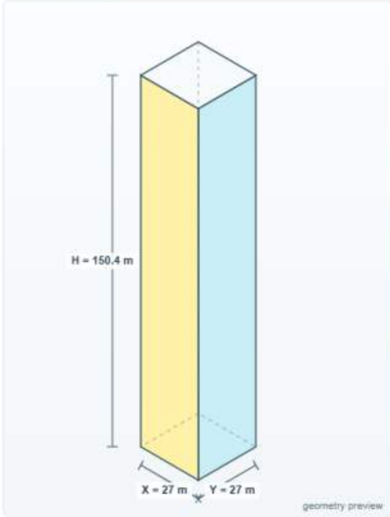
Directional inputs

Along X direction

Building Period (sec)	7
CPe Windward	0.8
CPe Leeward suction magnitude	0.5
Combination Factor Kc	0.9
Md Dir Factor +X	1
Md Dir Factor -X	0.85
Ms Shielding Factor +X	0.8
Ms Shielding Factor -X	1
Cfs reference (h:d:b) perpendicular	6:1:1

3D building view

Live geometry preview



Height H	X dimension	Y dimension
150.4 m	27 m	27 m

Preview updates from the project geometry fields.

Dynamic factor

Peak Factor gv			3.4
Turbulence Factor Ih			0.15
Lh	167	Hs	1
Y Direction Calcs		+Y	-Y
Size Red. Fctr. S		0.204	0.171
N		0.737	0.873
Et		0.108	0.097
Gust Factor		2.17	2.1
Dynamic Response Factor - Cdyn		1.076	1.04
Peak Factor gR		3.178	
Background Factor Bs		0.68	
X Direction Calcs		+X	-X
Size Red. Fctr. S		0.181	0.193
N		0.829	0.78
Et		0.101	0.104
Gust Factor		2.12	2.15
Dynamic Response Factor - Cdyn		1.05	1.063
Peak Factor gR		3.178	
Background Factor Bs		0.68	

Wind response – Y direction

Y Direction	+Y	-Y
Total Base Shear	6020	4148
Overturning Moment	509169	350850
Resonant Moment	200009	123659
Crosswind Base Shear (Perp. to Y Axis)	11887.73	6091.89
Crosswind Overturning M (About Y Axis)	1243829.48	637401.59
Reduced Wind Speed	8.41	7.11
Log10(Cfs)	-1.37	-1.657
Mode Pwr. Exponent k (	1.5	1.5
Mode Shape Correction Km	1.12	1.12
Along-wind peak acceleration (Y axis, milli-g)	10.14	6.27
Crosswind peak acceleration (X axis, milli-g)	73.6	37.72
Combined peak acceleration — Appendix E.6 (milli-g)	73.6	37.72

Wind response – X direction

X Direction	+X	-X
Total Base Shear	4642	5305
Overturning Moment	392630	448709
Resonant Moment	143189	170140
Crosswind Base Shear (Perp. to X Axis)	7516.94	9570.69
Crosswind Overturning M (About X Axis)	786508.3	1001395.16
Reduced Wind Speed	7.48	7.95
Log10(Cfs)	-1.564	-1.459
Mode Pwr. Exponent k	1.5	1.5
Mode Shape Correction Km	1.12	1.12
Along-wind peak acceleration (X axis, milli-g)	7.26	8.63
Crosswind peak acceleration (Y axis, milli-g)	46.54	59.26
Combined peak acceleration — Appendix E.6 (milli-g)	46.54	59.26

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Ultimate Wind Calculation

DIRECTIONAL LOADING

Wind figures

Select a direction to inspect the generated loading figure.

+Y | −Y | +X | −X

Table 6.3(A) — Load combinations for equivalent static loads for buildings < 70 m

Load cases	Peak load combinations
1 and 2	1.0(along-wind) ± 0.8(crosswind)
3 and 4	0.8(along-wind) ± 1.0(crosswind)

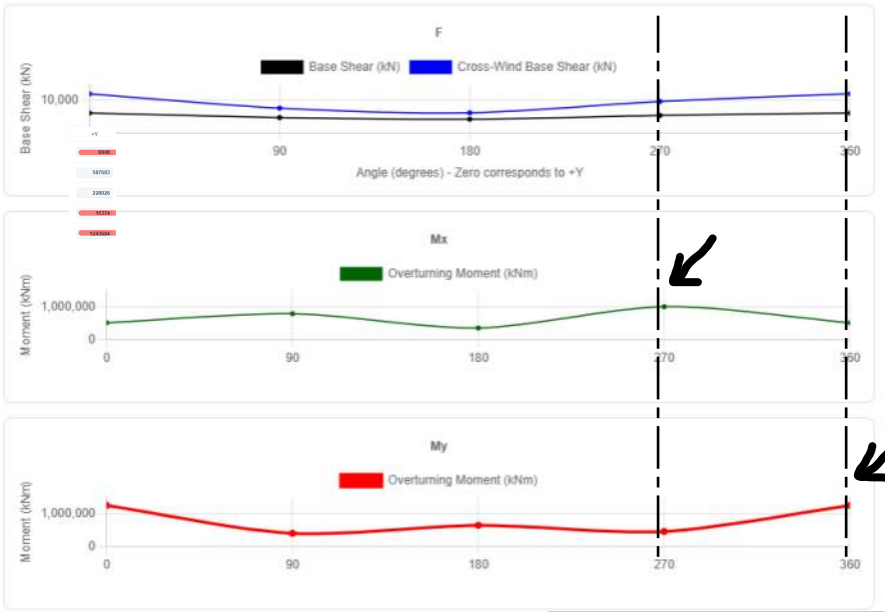
Table 6.3(B) — Load combinations for equivalent static loads for buildings > 70 m

Load cases	Peak load combinations
1 to 4	1.0(along-wind ± 0.15B offset) ± 0.8(crosswind)
5 to 8	0.8(along-wind ± 0.15B offset) ± 1.0(crosswind)
9 to 12	0.8(along-wind ± 0.2B offset) ± 0.8(crosswind)

RESPONSE ENVELOPE

Wind response graphs

Base shear and overturning moment by wind direction.



Export Equivalent Static Wind Loads to Excel / ETABS

Directional sector +Y

Load case 1 — +Y

Along factor 1.00; cross factor +0.80; along-wind offset +4.05 m

Level	Storey Height (m)	Mz Cat	Vdes (m/s)	Fx (kN)	Fy (kN)	Mz (kN.m)
L47	150.4	1.21	49	492.69	156.72	634.7
L46	147.2	1.207	48.88	477.05	155.95	631.59
L45	144	1.204	48.76	461.58	155.18	628.5
L44	140.8	1.201	48.64	446.28	154.42	625.41
L43	137.6	1.198	48.52	431.15	153.66	622.32
L42	134.4	1.194	48.36	416.2	152.65	618.23
L41	131.2	1.191	48.24	401.42	151.89	615.16
L40	128	1.188	48.11	386.82	151.07	611.85
L39	124.8	1.185	47.99	372.41	150.32	608.8
L38	121.6	1.182	47.87	358.18	149.57	605.76
L37	118.4	1.178	47.71	344.14	148.57	601.72
L36	115.2	1.175	47.59	330.28	147.83	598.7
L35	112	1.172	47.47	316.62	147.08	595.68

Load case 2 — +Y

Along factor 1.00; cross factor -0.80; along-wind offset +4.05 m

Level	Storey Height (m)	Mz Cat	Vdes (m/s)	Fx (kN)	Fy (kN)	Mz (kN.m)
L47	150.4	1.21	49	-492.69	156.72	634.7
L46	147.2	1.207	48.88	-477.05	155.95	631.59
L45	144	1.204	48.76	-461.58	155.18	628.5
L44	140.8	1.201	48.64	-446.28	154.42	625.41
L43	137.6	1.198	48.52	-431.15	153.66	622.32
L42	134.4	1.194	48.36	-416.2	152.65	618.23
L41	131.2	1.191	48.24	-401.42	151.89	615.16
L40	128	1.188	48.11	-386.82	151.07	611.85
L39	124.8	1.185	47.99	-372.41	150.32	608.8
L38	121.6	1.182	47.87	-358.18	149.57	605.76
L37	118.4	1.178	47.71	-344.14	148.57	601.72
L36	115.2	1.175	47.59	-330.28	147.83	598.7
L35	112	1.172	47.47	-316.62	147.08	595.68

Ultimate Wind Load Summary

Angle = 0

Case +Y (Peak)

oss = 11887.73 KN
M=1243.8 MN.m

wind

F-Along = 6020 KN
M=509.2 MN.m

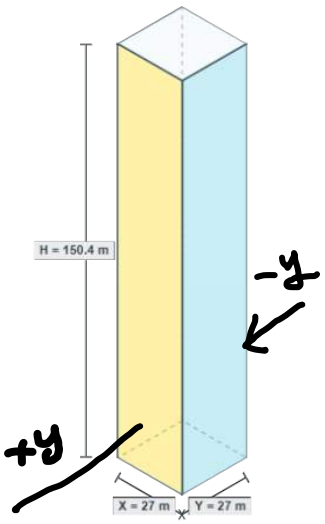
Angle = 180

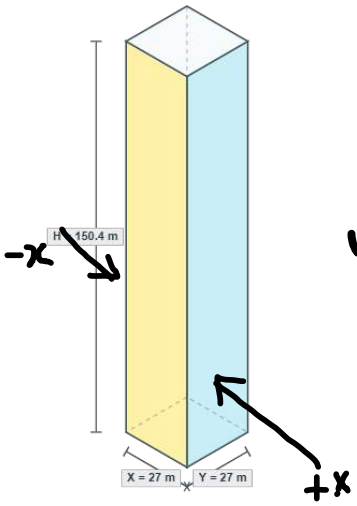
Case -Y (Peak)

F-Along = 4148 KN
M=350.8 MN.m

ross = 6091.89 KN
M=637.4 MN.m

wind





Case +X (Peak)

wind

F-Cross = 7516.94 KN
M=786.5 MN.m

Along = 4642 KN
M=392.6 MN.m

Angle = 90

Case -X (Peak)

F-Cross = 9570.69 KN
M=1001.4 MN.m

wind

F-Along = 5305 KN
M=448.7 MN.m

Angle = 270

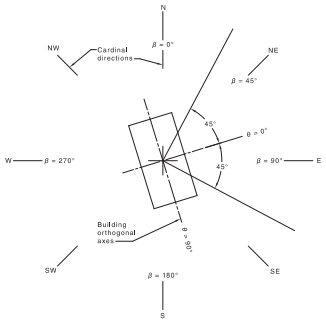
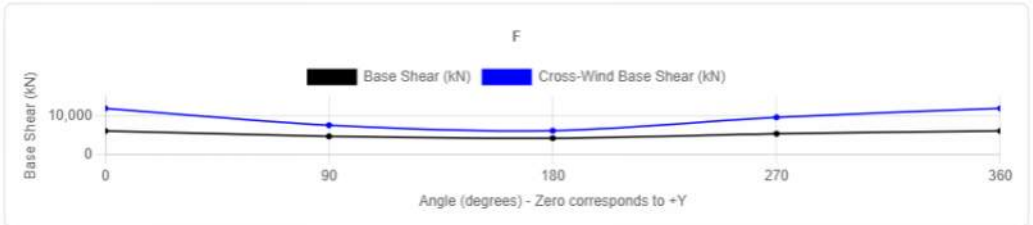


Figure 2.2 — Relationship of wind directions and building orthogonal axes



SLS Wind Calculation

Project inputs

Criteria	
Region	A
Return Period	1/10
Terrain Category	TC3
Global/base-response Cdyn: s = 0 m	0
Storey Height (m)	3.2
No. of Storeys	47
Total Height H (m)	150.4
Bldg. X Dimension (m)	27
Bldg. Y Dimension (m)	27
Site Wind Speed Vr	34
Damping	0.015
Average Storey Mass (kg)	852930
M z,cat (H)	1.21
Table 6.3 principal / companion factor	0.80

Important Design Notes — Analysis Package is valid until 30/03/2030 10:44:38 PM

Directional inputs — Along Y direction

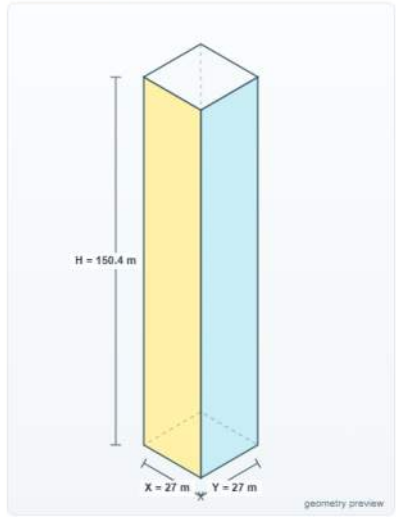
Building Period (sec)	6.26
CPe Windward	0.8
CPe Leeward suction magnitude	0.5
Combination Factor Kc	0.9
Md Dir Factor +Y	0.9
Md Dir Factor -Y	0.8
Ms Shielding Factor +Y	1
Ms Shielding Factor -Y	0.95
Cfs reference (h:b:d) facing load	6:1:1

Directional inputs — Along X direction

Building Period (sec)	6.26
CPe Windward	0.8
CPe Leeward suction magnitude	0.5
Combination Factor Kc	0.9
Md Dir Factor +X	1
Md Dir Factor -X	0.85
Ms Shielding Factor +X	0.8
Ms Shielding Factor -X	1
Cfs reference (h:d:b) perpendicular	6:1:1

3D building view

Live geometry preview



Height H	X dimension	Y dimension
150.4 m	27 m	27 m

Preview updates from the project geometry fields.

Dynamic factor

Peak Factor gv			3.4
Turbulence Factor Ih			0.15
Lh	167	Hs	1
Y Direction Calcs		+Y	-Y
Size Red. Fctr. S		0.133	0.108
N		1.091	1.291
Et		0.084	0.076
Gust Factor		2.18	2.1
Dynamic Response Factor - Cdyn		1.081	1.04
Peak Factor gR		3.213	
Background Factor Bs		0.68	
X Direction Calcs		+X	-X
Size Red. Fctr. S		0.115	0.124
N		1.227	1.155
Et		0.078	0.081

Wind response – Y direction

Y Direction	+Y	-Y
Total Base Shear	3451	2368
Overturning Moment	291919	200319
Resonant Moment	116037	70632
Crosswind Base Shear (Perp. to Y Axis)	4341.34	2260.51
Crosswind Overturning M (About Y Axis)	454241.73	236521.26
Reduced Wind Speed	5.69	4.8
Log10(Cfs)	-2.069	-2.342
Mode Pwr. Exponent k (	1.5	1.5
Mode Shape Correction Km	1.12	1.12
Along-wind peak acceleration (Y axis, milli-g)	5.89	3.58
Crosswind peak acceleration (X axis, milli-g)	26.88	14
Combined peak acceleration — Appendix E.6 (milli-g)	26.88	14

Wind response – X direction

X Direction	+X	-X
Total Base Shear	2653	3037
Overturning Moment	224420	256847
Resonant Moment	82169	98181
Crosswind Base Shear (Perp. to X Axis)	2737.98	3459.47
Crosswind Overturning M (About X Axis)	286480.52	361970.1
Reduced Wind Speed	5.05	5.37
Log10(Cfs)	-2.265	-2.167
Mode Pwr. Exponent k	1.5	1.5
Mode Shape Correction Km	1.12	1.12
Along-wind peak acceleration (X axis, milli-g)	4.17	4.98
Crosswind peak acceleration (Y axis, milli-g)	16.95	21.42
Combined peak acceleration — Appendix E.6 (milli-g)	16.95	21.42

in this example, cross wind and combined acceleration is above acceptance criteria, suggesting review of model for example, period calculations at SLS, exact Mass, better terrain category. but overall the standard gives very conservative numbers by circa 20-30%. so we are very close here

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