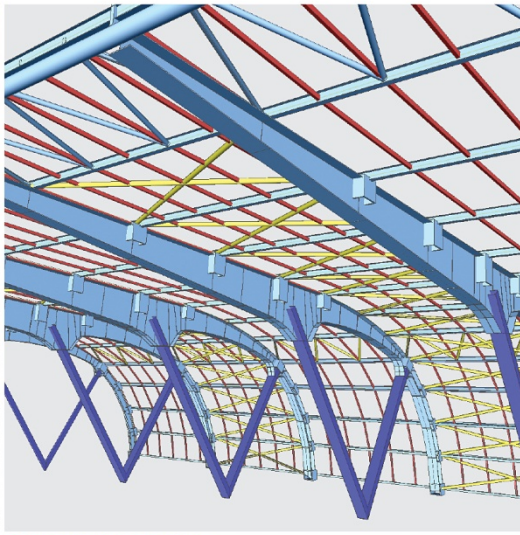
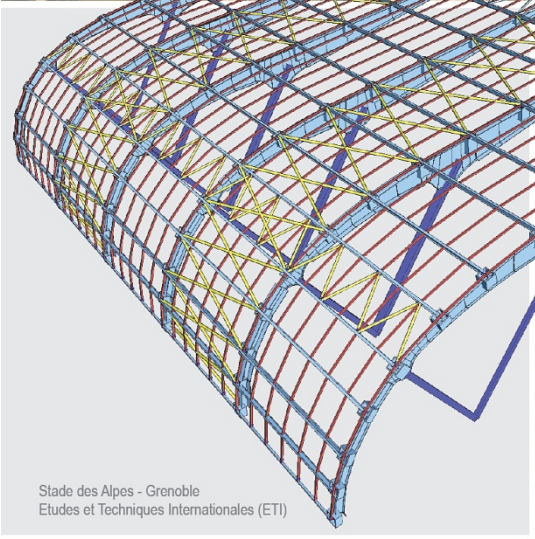
NEMETSCHEK Scia





Stade des Alpes - Grenoble
Etudes et Techniques Internationales (ETI)

ASCE 7-10

3D Wind Loading

Scia Engineer

Introduction

This document briefly explains the upgrade to the 3D wind loading module for IBC code in Scia Engineer versions 14.1 or later. This document should be read in conjunction with the 3D wind loading - Theoretical Background which gives the basis of the calculation along with the scope and the assumptions.

The American Society of Civil Engineers (ASCE) released a new *Minimum Design Loads for Buildings and Other Structures* document in 2010 and the code went into effect with the adoption of IBC 2012. The ASCE 7-10 document includes changes to the determination and application of wind loading on structures as well as the load combinations used for these loads. Scia Engineer 2014.1 supports wind load generation to ASCE 7-10 enabling users to design for the most current wind loading code. The working of the new method is explained in the subsequent sections.

The major differences between ASCE 7-05 and ASCE 7-10 in the context of wind loading are:

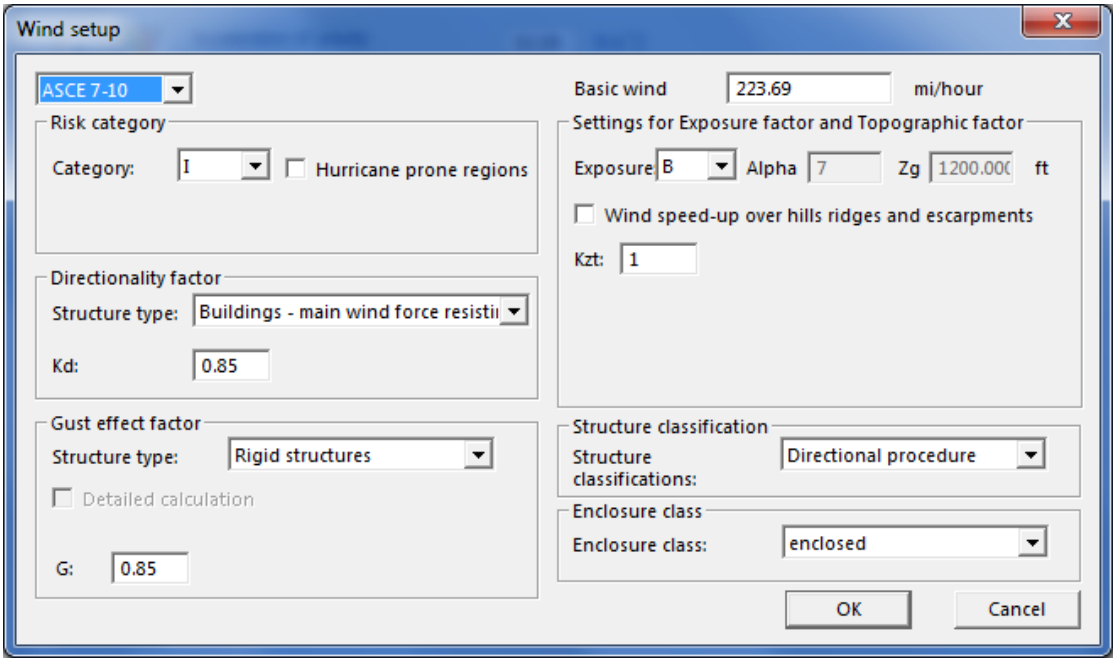
- Low rise method is now referred to as Envelope procedure;
- All heights method is now referred to as Directional procedure;
- New wind speed maps with increased wind speeds for most areas;
- Use of Gust factor, G = 0.85 for all structures within both the low rise and all heights methods;
- The Importance factor, I, based on the occupancy category of the structure is no longer included in the calculation of the velocity pressure;
- For Low Rise method (Envelope procedure), the external pressure coefficients (GCpf) and the wind zones have changed and are now included in two wind load cases:

  Load case ‘A’ (wind perpendicular to the roof ridge) and Load case ‘B’ (wind parallel to roof ridge).
- Changes to load combinations for wind loading for both Load and Resistance factor Design (LRFD) and Allowable Stress Design (ASD).

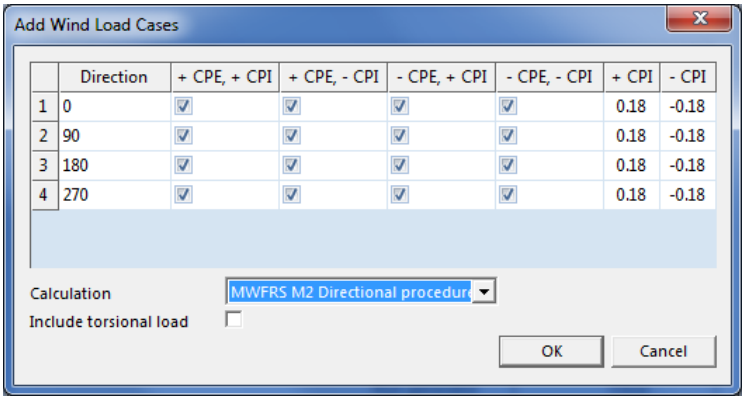
The items which have been implemented in Scia Engineer are, the change of method names, new calculation procedure for Envelope Procedure and new set of load combinations for ASCE 7-10.

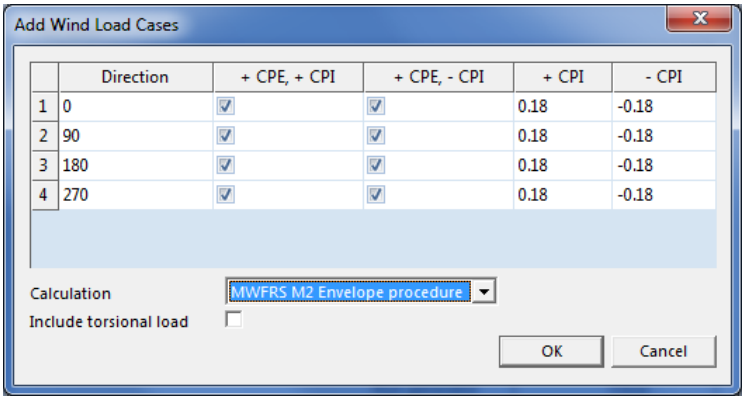
Wind setup

The wind setup data has a new option to select between ASCE 7-05 and ASCE 7-10.



Based on the code selected the structure classification will point to the appropriate method (Directional / Envelope Vs All heights / Low rise). The calculation methods in *Add Wind Load Cases* dialog also uses the corresponding name.



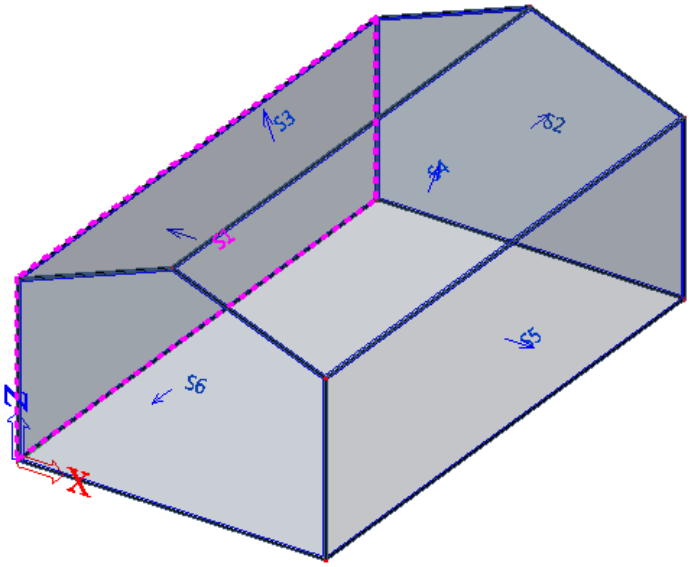


Importance factor 'I' is available with ASCE 7-05 only as required by the code.

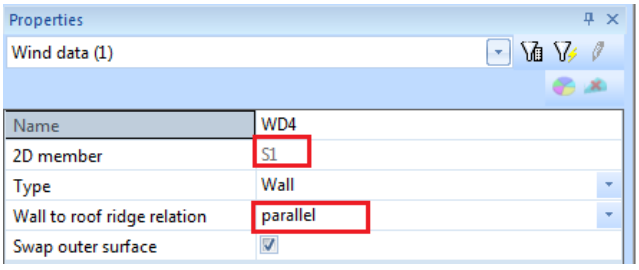
Wind data

In order to facilitate expected external pressure zones generation new inputs are added in the wind data of a 2D member / Load panel with ASCE 7-10 Envelope Procedure.

Wind data on a *Wall*, has an input for *Wall to roof ridge relation*. The user can select between *perpendicular* and *parallel* options depending upon how the building is modelled. Wind data on a *Flat roof* has an option to *Swap longitudinal direction.* The inputs are particularly useful for complex building shapes where the data is not readily accessible from the model. The zones generated will vary depending upon the inputs. This is explained through an example in the subsequent sections of this document.



The picture above shows an example of a duo-pitch roof model where the wall to roof ridge relation is set to parallel for ‘S1’ and ‘S5’ and perpendicular for ‘S6’ and ‘S2’



Directional procedure – External pressure zones

The Directional Procedure (ASCE 7-10 Chapter 27) is applicable for building of all heights. The external pressure coefficients for this method are based on past wind tunnel testing of prototypical building models for the corresponding direction of wind.

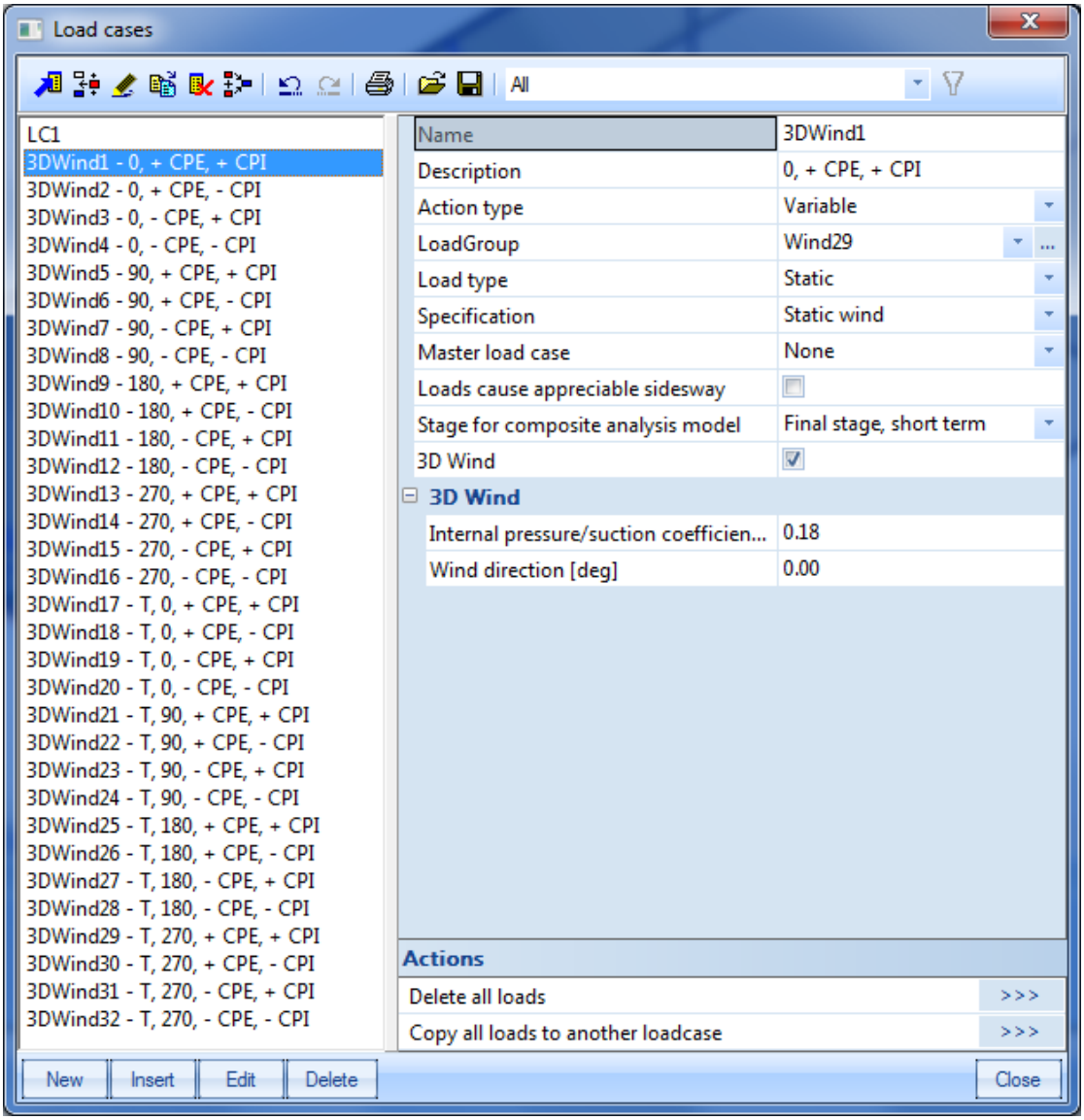
The Directional Procedure implemented in Scia Engineer is based on Section 27.4.1 of the code applicable for enclosed and partially enclosed buildings only.

Chapter 26 of ASCE 7-10 defines a partially enclosed building as a building that complies with both of the following conditions:

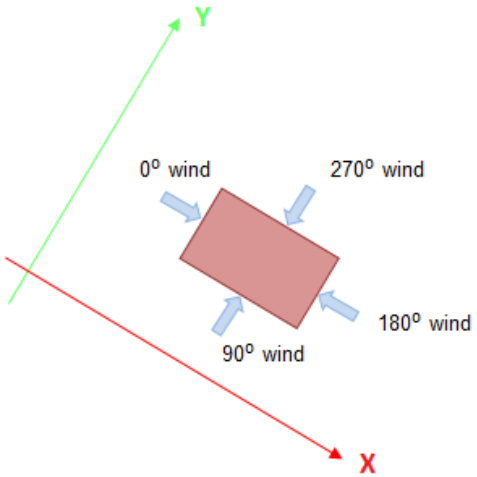
- The total area of openings in a wall that receives positive external pressure exceeds the sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10%.
- The total area of openings in a wall that receives positive external pressure exceeds 4 ft^2 (0.37 m^2) or 1% of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20%.

An open building is defined to have each wall at least 80% open. A building that does not comply with the requirements for open or partially enclosed building is classified as enclosed building.

It is possible to include up to 32 wind load cases considering positive and negative external and internal pressure coefficients and torsional load cases. This is the same as in ASCE 7-05.



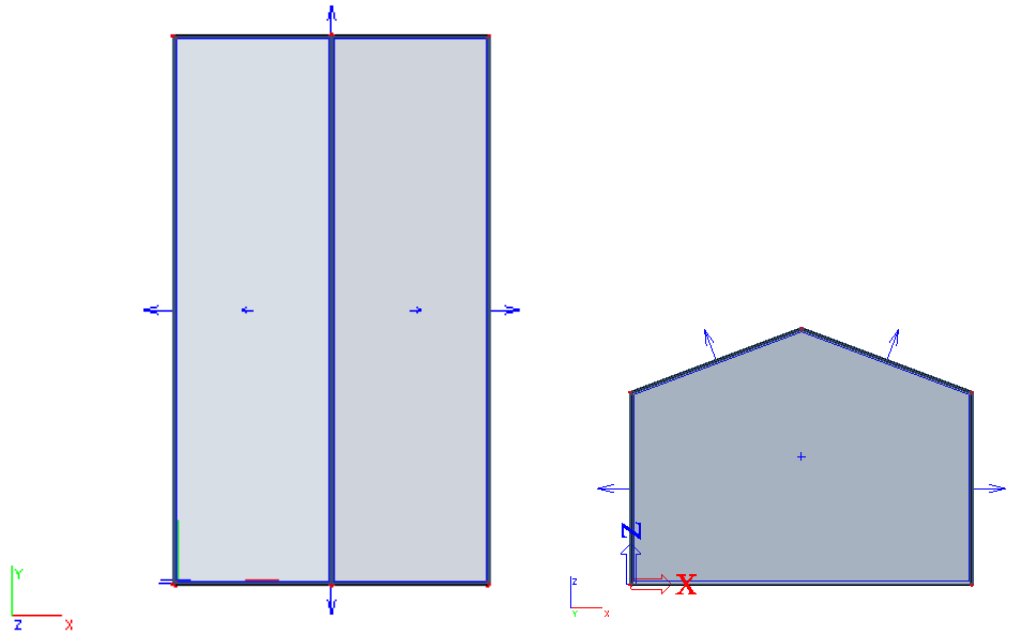
The above picture shows all the possible 32 load cases where 0°, 90°, 180° and 270° represents the wind direction and 'T' represents Torsional load cases.
Note that a 0^{o} wind represents wind along the global X axis (positive direction).



The external pressure zoning by the software is explained through an example below.

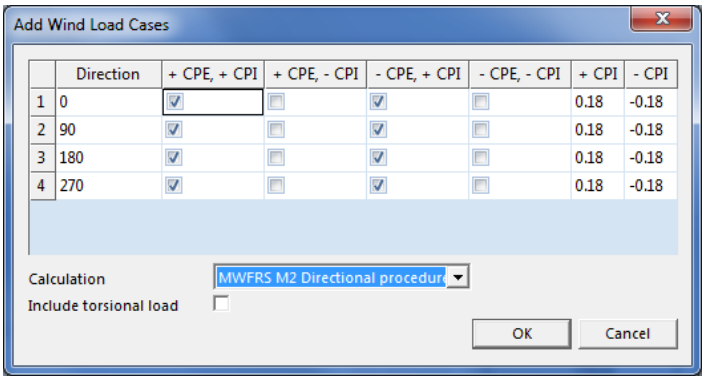
Directional Procedure example:

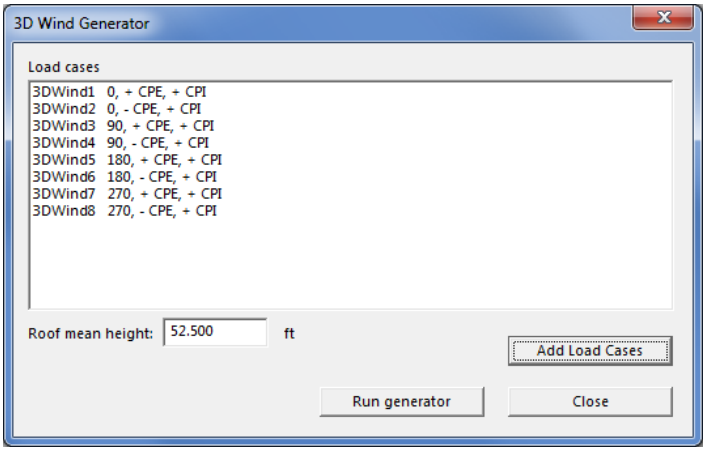
A building with duo pitch roof is modelled as shown below.



Building length = 140 ft
Building width = 80 ft
Height to eaves = 45 ft
Height to ridge = 60 ft

For simplicity 8 load cases will be generated for this example (excluding the torsional load cases and –Cpi combinations)





Roof angle = 20.56^{o}
L/B for wind normal to ridge = 80/140 = 0.57
L/B for wind parallel to ridge = 140/80 = 1.75
h/L for wind normal to ridge = 52.5/80 = 0.65625

External pressure coefficients from figure 27.4-1:

Windward wall coefficient = 0.8
Leeward wall coefficient for wind normal to ridge= -0.5
Leeward wall coefficient for wind parallel to ridge= -0.35
Side wall coefficient = -0.7

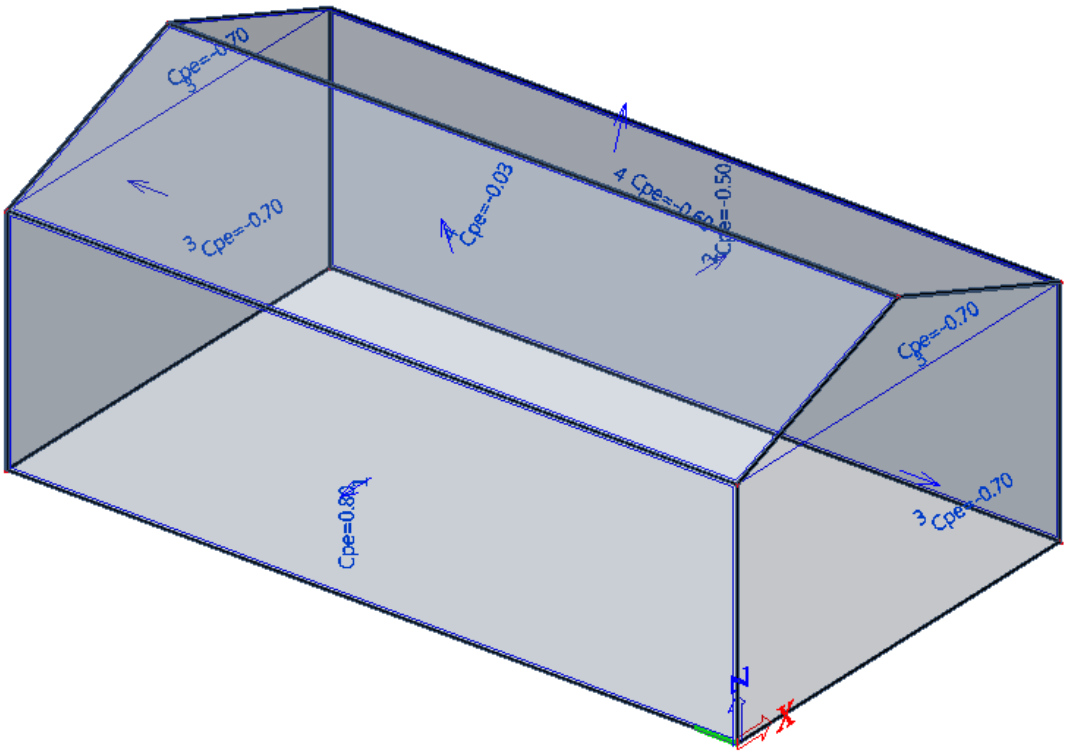
Roof pressure coefficient for wind normal to ridge and windward = -0.48 & -0.03
Roof pressure coefficient for wind normal to ridge and leeward = -0.6

Roof pressure coefficient for wind parallel to ridge:
Zone 1 from 0 to 26.25 ft with Cpe = -0.9 and -0.18
Zone 2 from 26.25 to 52.5 ft with Cpe = -0.9 and -0.18
Zone 3 from 52.5 to 105 ft with Cpe = -0.5 and -0.18
Zone 4 from 105 to 140 ft with Cpe =-0.3 and -0.18

External pressure zones created in Scia Engineer after invoking *Run generator* is shown below:

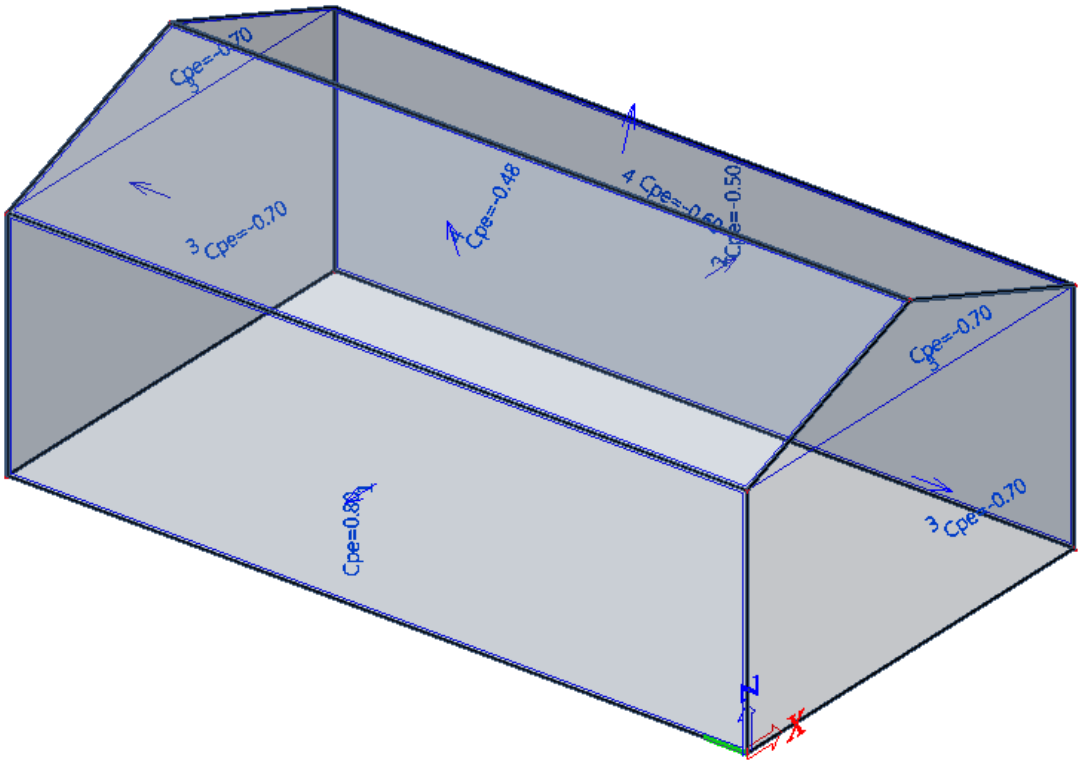
Load case: 3Dwind1, 0, +CPE, +CPI

Wind direction 0 represents wind along global X hence it is wind normal to ridge. Note that this will change if the building is rotated.



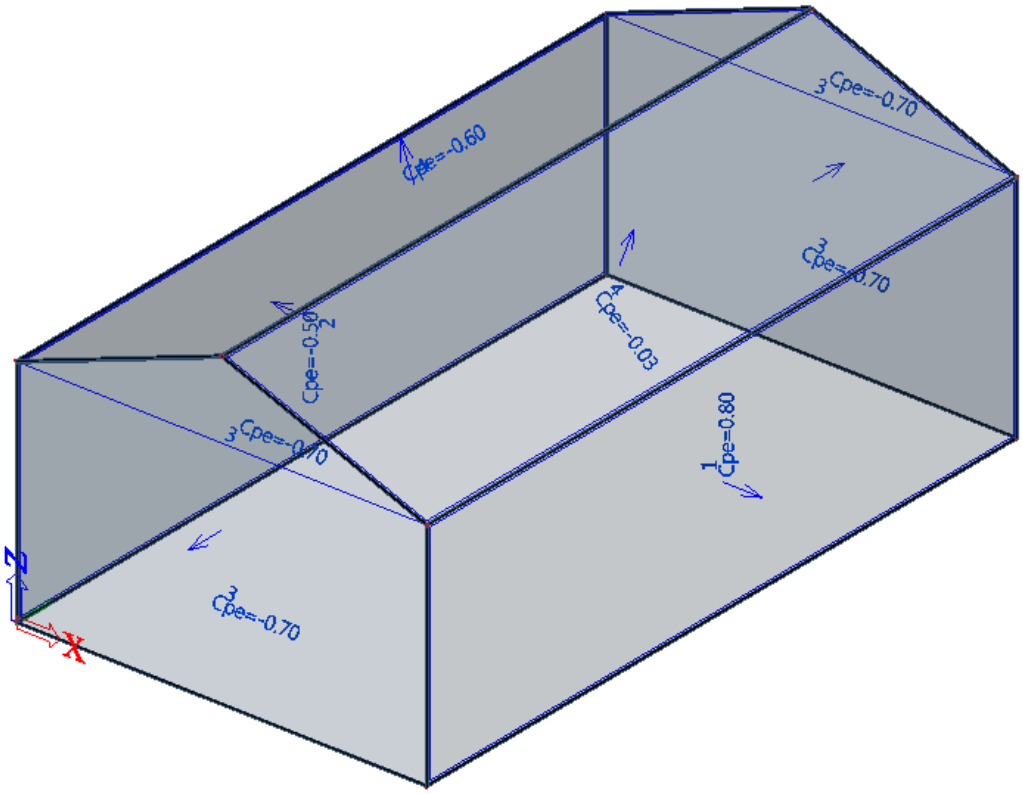
Load case: 3Dwind2, 0, -CPE, +CPI

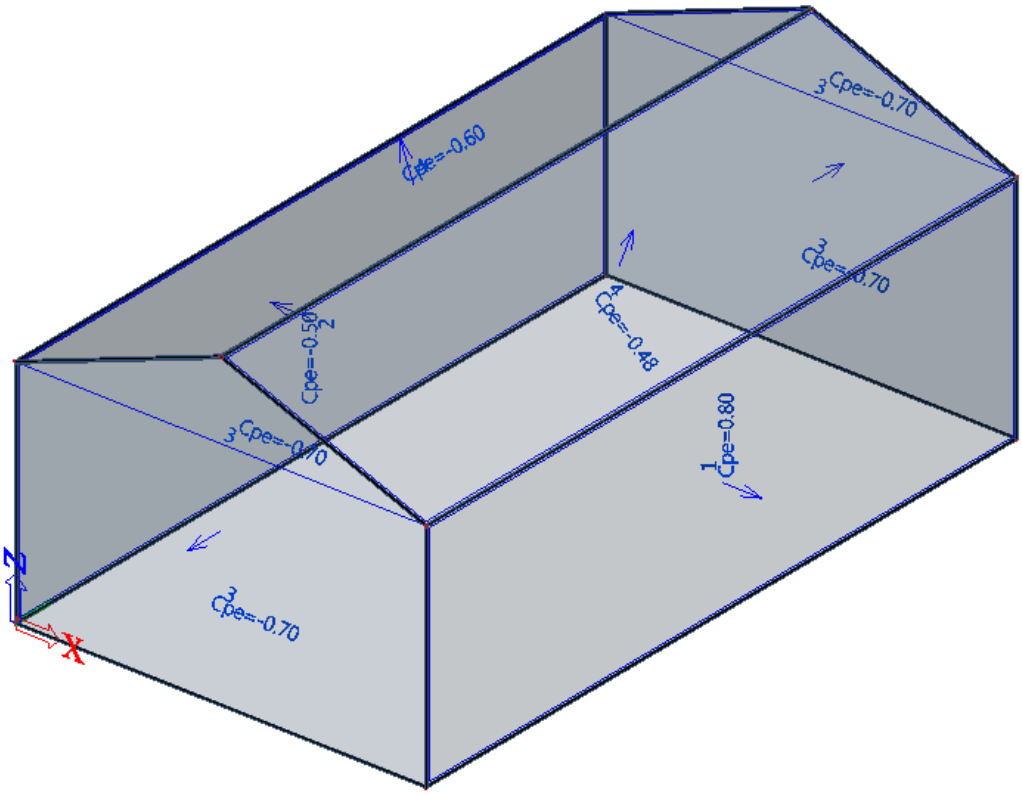
3DWind2 is similar to 3DWind1 with alternative windward roof pressure coefficient of -0.48
Note that a negative coefficient indicates load acting away from the surface (suction).



Load case: 3Dwind5, 180, +CPE, +CPI and 3Dwind6, 180, -CPE, +CPI

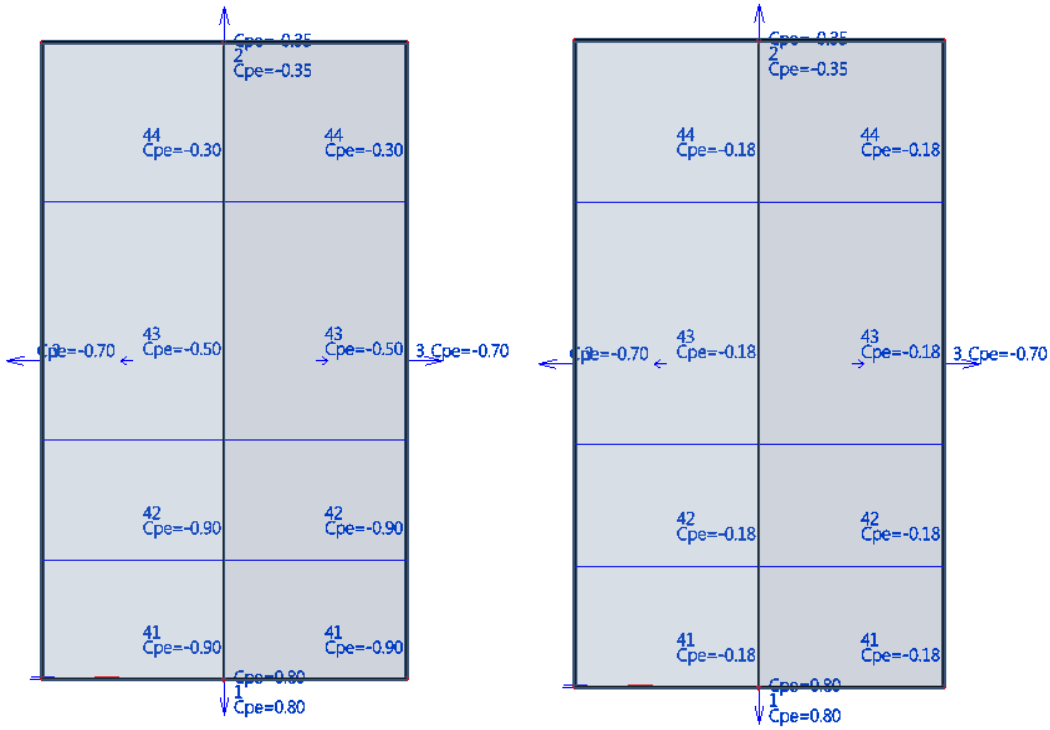
Wind direction 180 represents wind from –X direction. Hence the zones for load case 3DWind5 and 3DWind6 will be similar to 3DWind1 and 3DWind2 but with the windward and leeward faces swapped.





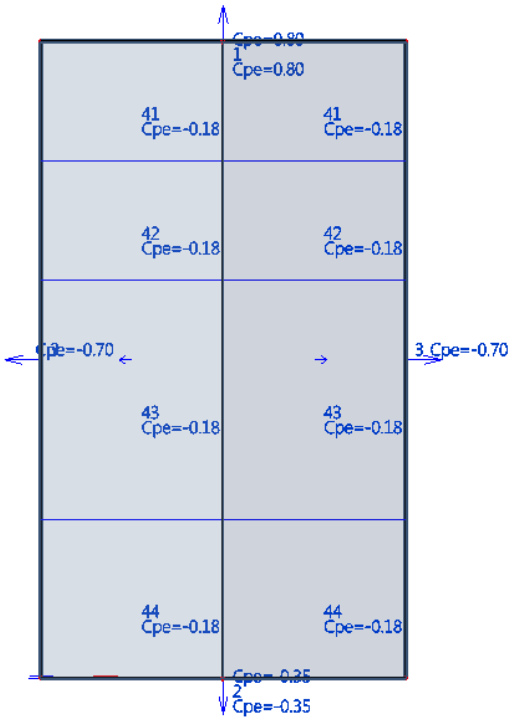
Load cases: 3Dwind3, 90, +CPE, +CPI & 3Dwind4, 90, -CPE, +CPI

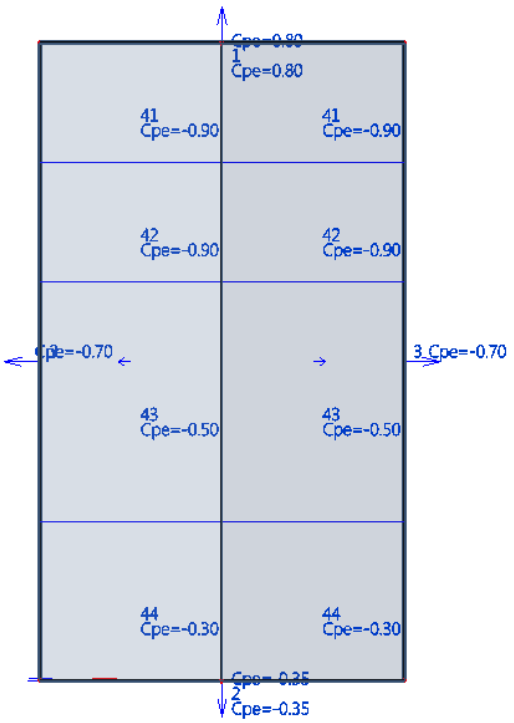
Load cases 3DWind3 and 3DWind4 represent wind along global Y direction i.e. wind parallel to the ridge hence has 4 zones (0 to h/2, h/2 to h, h to 2h and >2h) as shown below.



Load cases: 3Dwind7, 270, +CPE, +CPI & 3Dwind8, 270, -CPE, +CPI

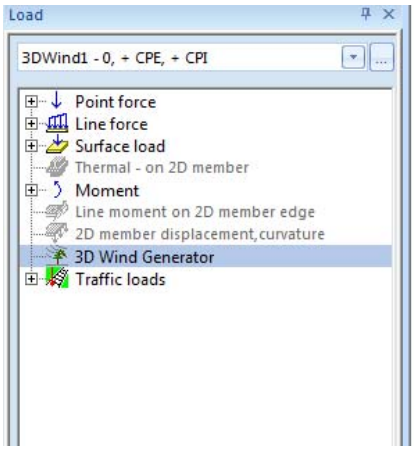
Load cases 3DWind7 and 3DWind8 are similar to 3DWind3 and 3DWind4 but with windward and leeward faces swapped.

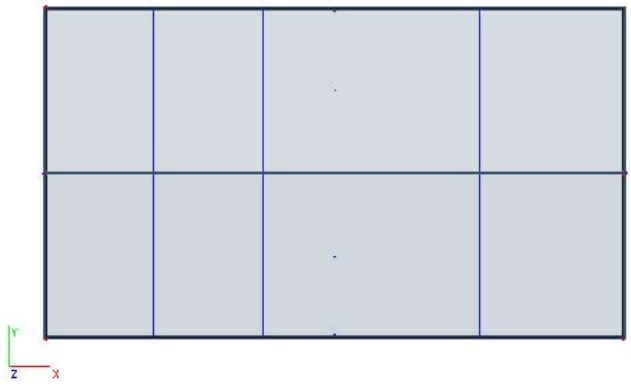




Note that the free loads created after invoking *Run generator* does not have a proper sign as it is not assigned to any particular member. The project has to be calculated OR the loads generated on to the members to verify the actual load direction.

When the building is rotated by 90^{o} the X wind (0^{o} wind) becomes wind parallel to the ridge hence the zoning will change accordingly for all the load cases.





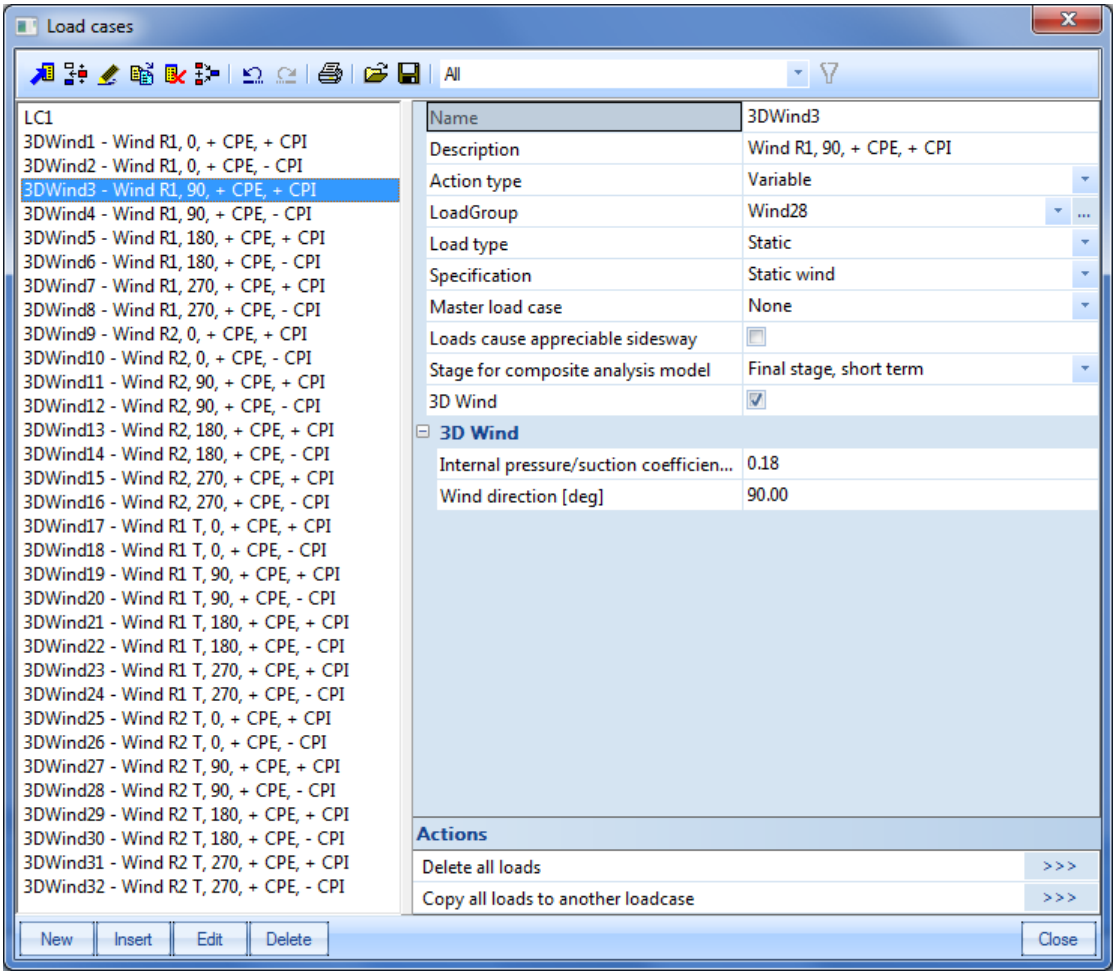
Similar working can be observed with other roof types such as flat, mono-pitch or hipped roof.

Envelope procedure – External pressure zones

The Envelope Procedure (ASCE 7-10 Chapter 28) is applicable for low rise buildings. Chapter 26 of ASCE 7-10 defines low-rise buildings as enclosed or partially enclosed buildings in which the mean roof height is less than or equal to 60 ft and the mean roof height does not exceed least horizontal dimension.

In this method the pseudo-external pressure coefficients are derived from past wind tunnel testing of prototypical building models successively rotated through 360°, such that the pseudo-pressure cases produce key structural actions (uplift, horizontal shear, bending moments, etc.) that envelop their maximum values among all possible wind directions.

With this method it is possible to include up to 32 wind load cases considering two reference corners for each wind direction with positive, negative internal pressure coefficients and torsional load cases.

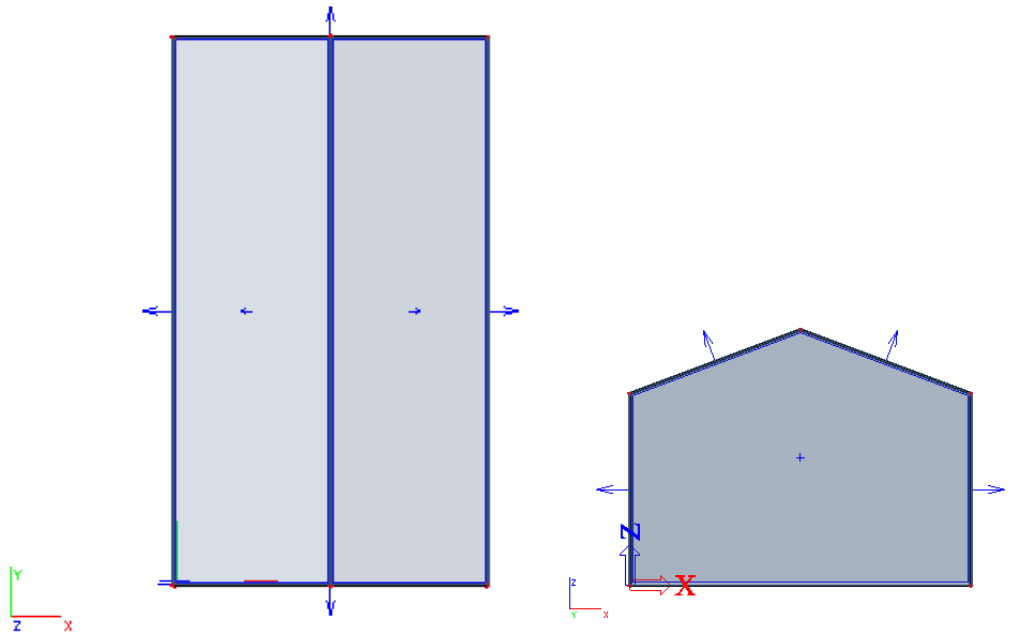


The above picture shows all the possible 32 load cases where 0°, 90°, 180°and 270° represent the wind direction, ‘T’ represents Torsional load cases and ‘R1’ and ‘R2’ represent the reference corners in detailed in Figure 28.4-1.

The external pressure zoning with the Envelope Procedure is explained through the same building with duo-pitch roof discussed within the Directional Procedure.

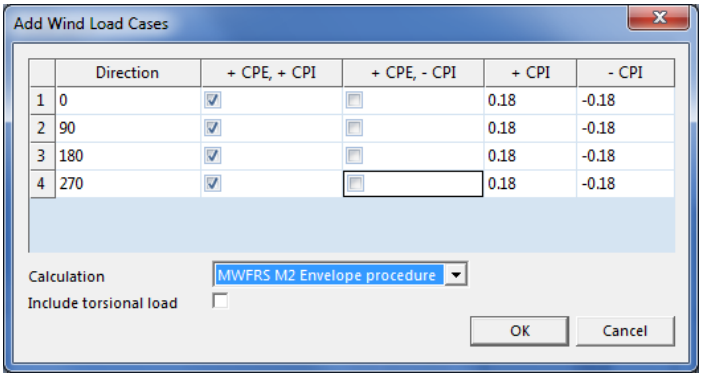
Note that the special zoning for hipped roofs presented in commentary Figure C28.4-1 is not supported in Scia Engineer 2014.1.

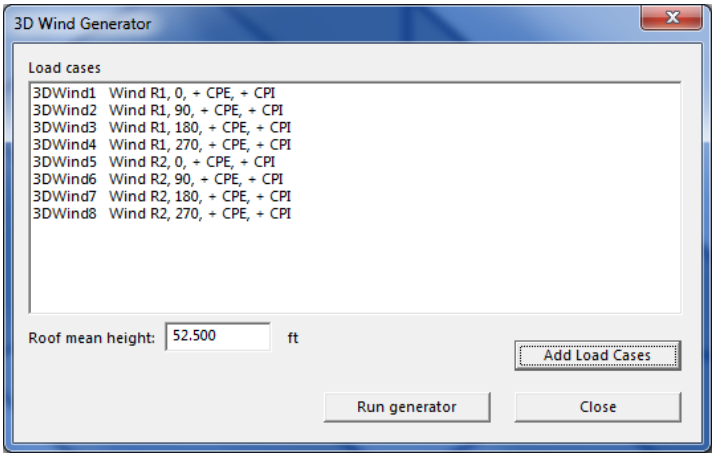
Envelope Procedure – Duo-pitch roof example:



Building length = 140 ft
Building width = 80 ft
Height to eaves = 45 ft
Height to ridge = 60 ft

As with Directional Procedure 8 load cases will be generated for this example (excluding the torsional load cases and –Cpi combinations)





External pressure coefficients from figure 28.4-1:

Roof angle = 20.56°

Zone coefficients for load case 'A' (wind normal to the ridge):

Roof angle	Zone 1E	Zone 1	Zone 4E	Zone 4
	Windward wall edge zone	Windward wall main zone	Leeward wall edge zone	Leeward wall main zone
20.56°	0.79	0.53	-0.63	-0.43

Note: No zones are created in the side walls with load case A

Roof angle	Zone 2E	Zone 2	Zone 3E	Zone 3
	Roof edge zone windward side	Roof main zone windward side	Roof edge zone leeward side	Roof main zone leeward side
20.56°	-1.0	-0.64	-0.68	-0.48

Zone coefficients for load case 'B' (wind parallel to the ridge):

Roof angle	Zone 5E	Zone 5	Zone 6E	Zone 6	Zone 1E	Zone 1	Zone 4E	Zone 4
	Windward wall edge zone	Windward wall main zone	Leeward wall edge zone	Leeward wall main zone	Sidewall edge zone	Sidewall main zone	Sidewall edge zone	Sidewall main zone
20.56°	0.61	0.40	-0.43	-0.29	-0.48	-0.45	-0.48	-0.45

Roof angle	Zone 2E	Zone 2	Zone 3E	Zone 3
	Roof edge zone windward side	Roof main zone windward side	Roof edge zone leeward side	Roof main zone leeward side
20.56°	-1.07	-0.69	-0.53	-0.37

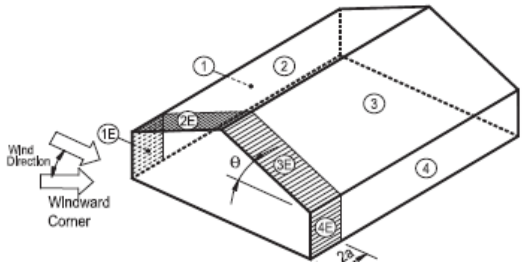
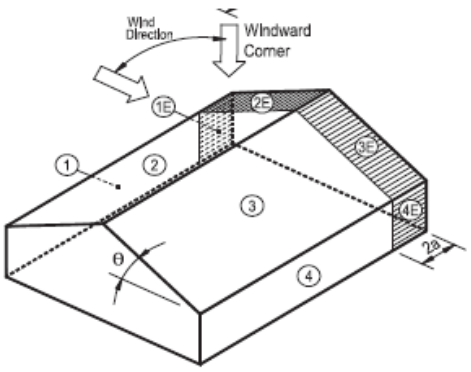
Half edge zone length, a = Minimum (0.1*80, 0.4*52.5) = 8 ft

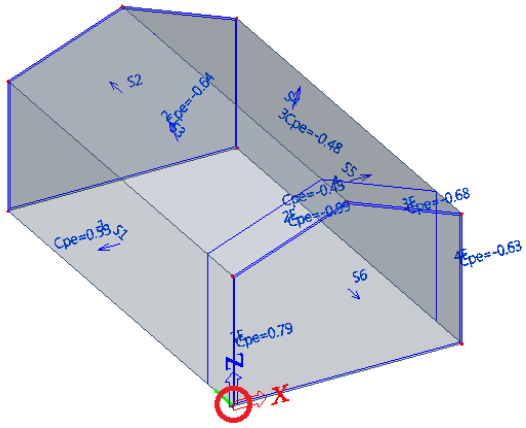
The external pressure zoning logic implemented in Scia Engineer for the Envelope Procedure is summarised below:

- A windward wall parallel to the ridge will have zones 1 and 1E from load case ‘A’
- A leeward wall parallel to the ridge will have zones 4 and 4E from load case ‘A’
- A sidewall perpendicular to the ridge will have no zones according to load case ‘A’
- A windward wall perpendicular to the ridge will have zones 5 and 5E from load case ‘B’
- A leeward wall perpendicular to the ridge will have zones 6 and 6E from load case ‘B’
- A sidewall parallel to the ridge will have zones 1 and 1E near the reference corner and 4 & 4E away from the reference corner.
- Roof will have zones 2 and 2E near the reference corner and 3 & 3E away from the reference corner.

External pressure zones created in Scia Engineer after invoking *Run generator* for the method is shown below. The reference corner in each case is marked with a red circle below.

With the current example 0^o and 180^o wind will create load case A zones and 90^o and 270^o wind will create load case B zones. If the building is rotated through 90^o you will observe that the load cases are swapped i.e. 0^o & 180^o wind will create load case B zones and 90^o wind and 270^o wind will create load case A zones.

Load case: 3DWind1 – Wind R1, 0, + CPE, +CPI	**Load case:** 3DWind5 – R2, 0, + CPE, +CPI
	

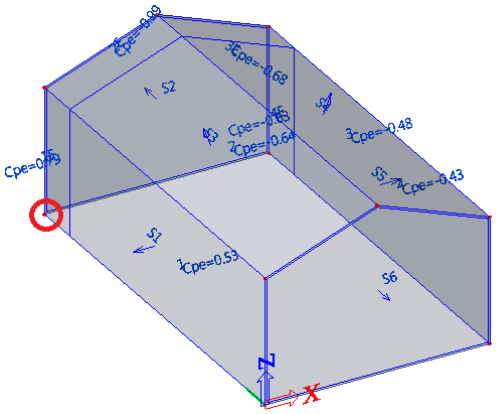


Wind direction: 0^{o} (Wind from +X direction)

Reference corner, R1: (0, 0, 0)

Load case A zones:

- Wall ‘S1’ is a windward wall with zones 1 and 1E (Cpe = 0.53 & 0.79)
- Wall ‘S5’ is a leeward wall with zones 4 and 4E (Cpe = -0.43 & -0.63)
- Wall ‘S6’ and ‘S2’ are side walls with no zones
- Roof ‘S3’ has zones 2 and 2E (Cpe = -0.64 and -1.0)
- Roof ‘S4’ has zones 3 and 3E (Cpe =-0.48 & -0.68)

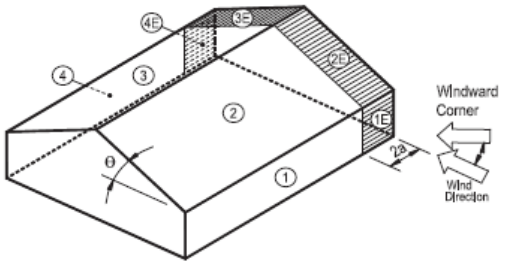
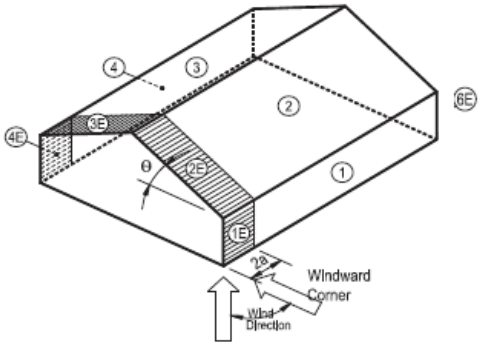
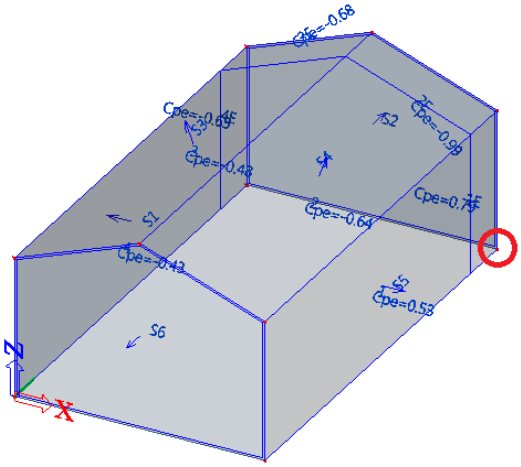
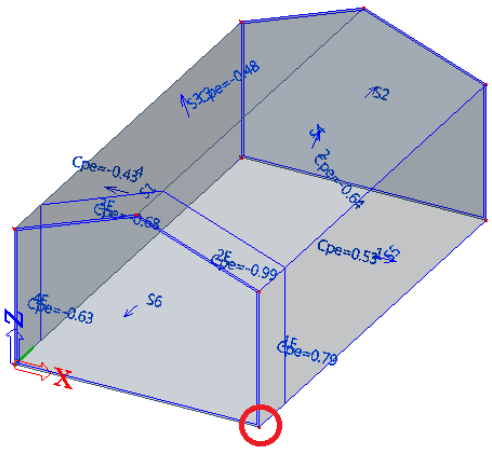


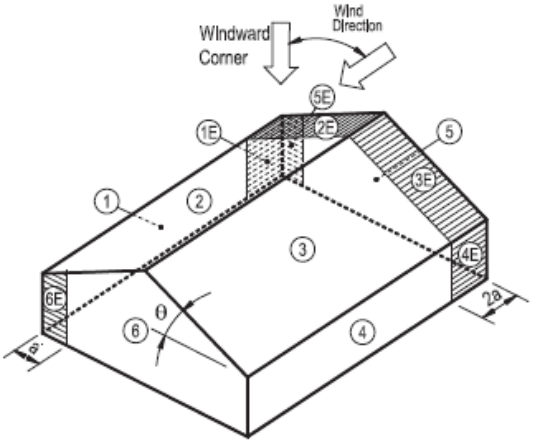
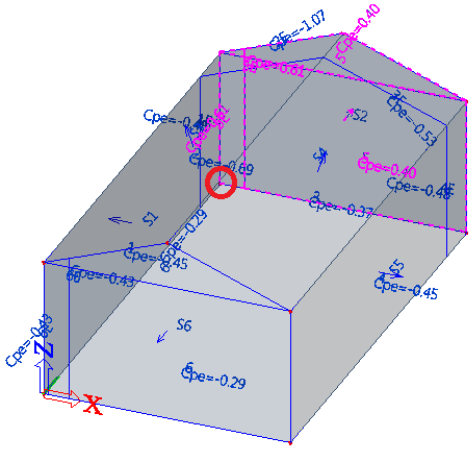
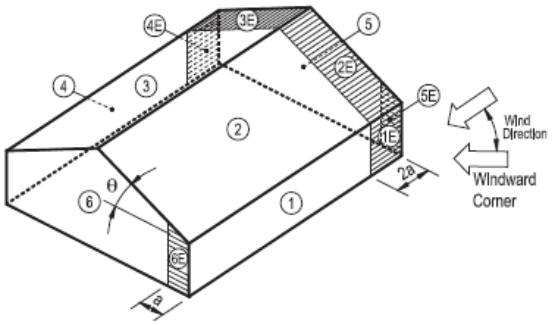
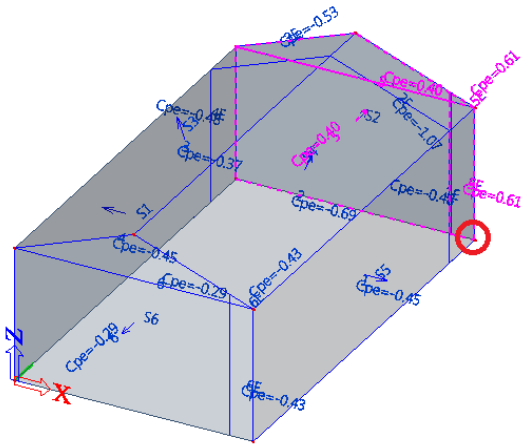
Wind direction: 0^{o} (Wind from +X direction)

Reference corner, R2: (0, 140, 0)

Load case A zones:

- Wall ‘S1’ is a windward wall with zones 1 and 1E (Cpe = 0.53 & 0.79)
- Wall ‘S5’ is a leeward wall with zones 4 and 4E (Cpe = -0.43 & -0.63)
- Wall ‘S6’ and ‘S2’ are side walls with no zones
- Roof ‘S3’ has zones 2 and 2E (Cpe = -0.64 and -1.0)
- Roof ‘S4’ has zones 3 and 3E (Cpe =-0.48 & -0.68)

Load case: 3DWind3 – Wind R1, 180, + CPE, +CPI	**Load case:** 3DWind7 – Wind R2, 180, + CPE, +CPI
	
	
Wind direction: 180° (Wind from -X direction) Reference corner, R1: (80, 140, 0) Load case A zones: • Wall ‘S1’ is a leeward wall with zones 4 and 4E (Cpe = -0.43 & -0.63) • Wall ‘S5’ is a windward wall with zones 1 and 1E (Cpe =0.53 & 0.79) • Wall ‘S6’ and ‘S2’ are sidewalls with no zones • Roof ‘S3’ has zones 3 and 3E (Cpe = -0.48 & -0.68)	Wind direction: 180° (Wind from -X direction) Reference corner, R2: (80, 0, 0) Load case A zones: • Wall ‘S1’ is a leeward wall with zones 4 and 4E (Cpe = -0.43 & -0.63) • Wall ‘S5’ is a windward wall with zones 1 and 1E (Cpe =0.53 & 0.79) • Wall ‘S6’ and ‘S2’ are sidewalls with no zones • Roof ‘S3’ has zones 3 and 3E (Cpe = -0.48 & -0.68)

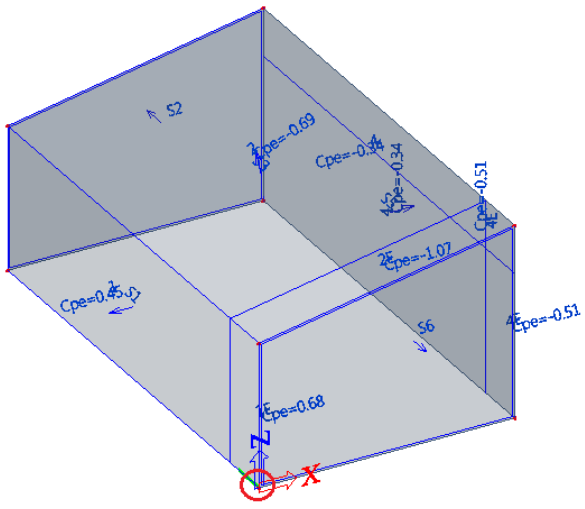
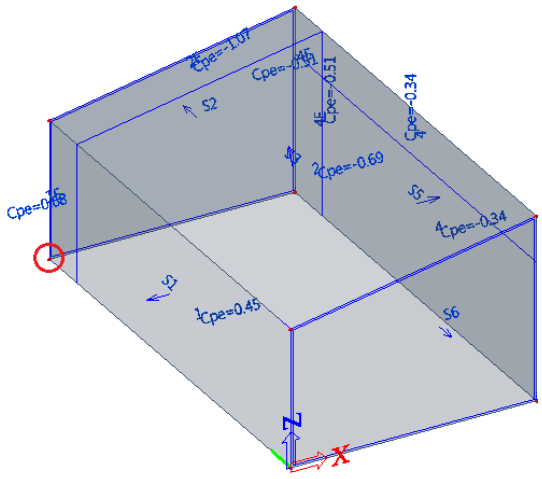
• Roof ‘S4’ has zones 2 and 2E (Cpe = -0.64 & -1.0)	• Roof ‘S4’ has zones 2 and 2E (Cpe = -0.64 & -1.0)
Load case: 3DWind4 – Wind R1, 270, + CPE, +CPI   Wind direction: 270° (Wind from -Y direction) Reference corner, R1: (0, 140, 0) Load case B zones: • Wall ‘S1’ is a sidewall with zones 1 and 1E (Cpe = -0.45 & -0.48) • Wall ‘S5’ is a sidewall with zones 4 and 4E (Cpe = -0.45 & -0.48) • Wall ‘S6’ is a leeward wall with zones 6 and 6E (Cpe = -0.29 & -0.43)	**Load case:** 3DWind8 – Wind R2, 270, + CPE, +CPI   Wind direction: 270° (Wind from -Y direction) Reference corner, R2: (80, 140, 0) Load case B zones: • Wall ‘S1’ is a sidewall with zones 1 and 1E (Cpe = -0.45 & -0.48) • Wall ‘S5’ is a sidewall with zones 4 and 4E (Cpe = -0.45 & -0.48) • Wall ‘S6’ is a leeward wall with zones 6 and 6E (Cpe = -0.29 & -0.43) • Wall ‘S2’ is a windward wall with zones 5

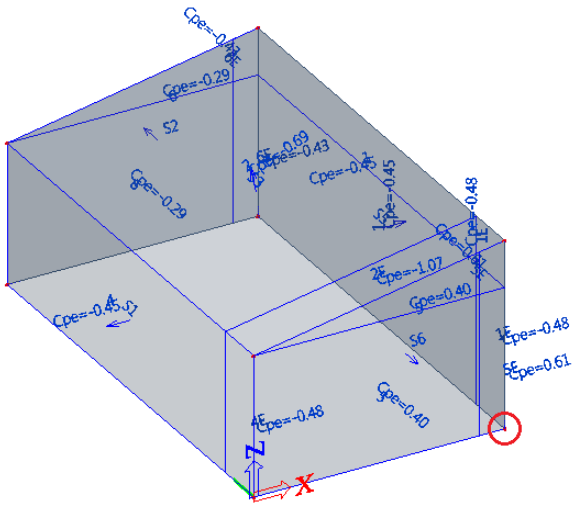
• Wall ‘S2’ is a windward wall with zones 5 and 5E (Cpe = 0.40 & 0.61) • Roof ‘S3’ has zones 2 and 2E (Cpe = -0.69 & -1.07) • Roof ‘S4’ has zones 3 and 3E (Cpe = -0.37 & -0.53)	and 5E (Cpe = 0.40 & 0.61) • Roof ‘S3’ has zones 2 and 2E (Cpe = -0.69 & -1.07) • Roof ‘S4’ has zones 3 and 3E (Cpe = -0.37 & -0.53)

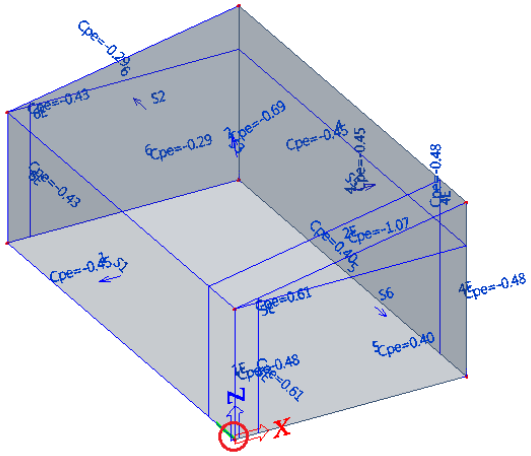
Mono-pitch roof example:

The pictures below show the zoning for the same building with mono-pitch roof. The principles are the same as explained in the previous example:

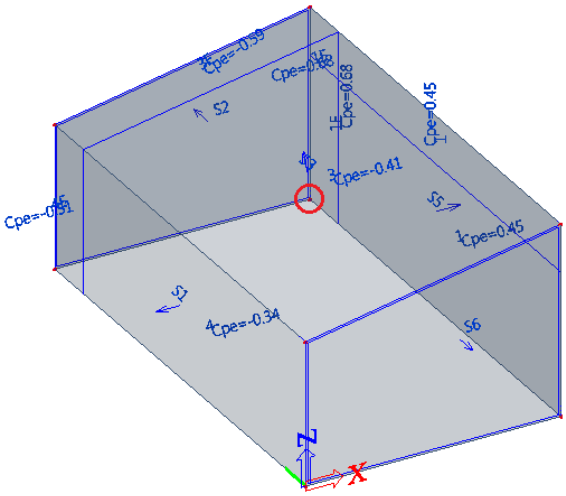
- A windward wall parallel to the ridge will have zones 1 and 1E from load case ‘A’
- A leeward wall parallel to the ridge will have zones 4 and 4E from load case ‘A’
- A sidewall perpendicular to the ridge will have no zones according to load case ‘A’
- A windward wall perpendicular to the ridge will have zones 5 and 5E from load case ‘B’
- A leeward wall perpendicular to the ridge will have zones 6 and 6E from load case ‘B’
- A sidewall parallel to the ridge will have zones 1 and 1E near the reference corner and 4 & 4E away from the reference corner.
- Roof will have zones 2 and 2E near the reference corner and 3 & 3E away from the reference corner.

Load case: 3DWind1 – Wind R1, 0, +CPE, +CPI	**Load case:** 3DWind5 – Wind R2, 0, +CPE, +CPI
	
Load case: 3DWind2 – Wind R1, 90, +CPE, +CPI	**Load case:** 3DWind6 – Wind R2, 90, +CPE, +CPI

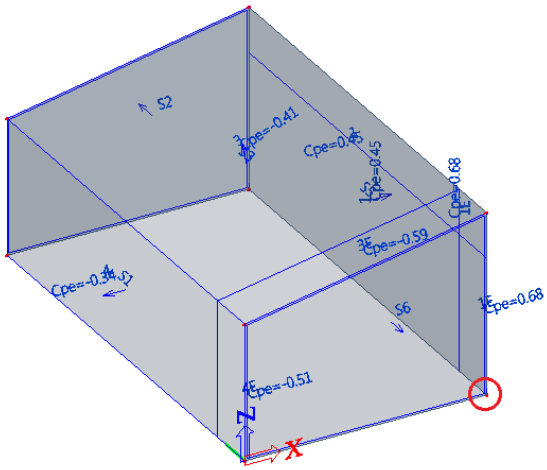




Load case: 3DWind3 – Wind R1, 180, +CPE, +CPI



Load case: 3DWind7 – Wind R2, 180, +CPE, +CPI



Internal pressure coefficient

The internal pressure coefficients are defaulted based on the *enclosure class* set in the wind setup following Table 26.11-1 of ASCE 7-10.

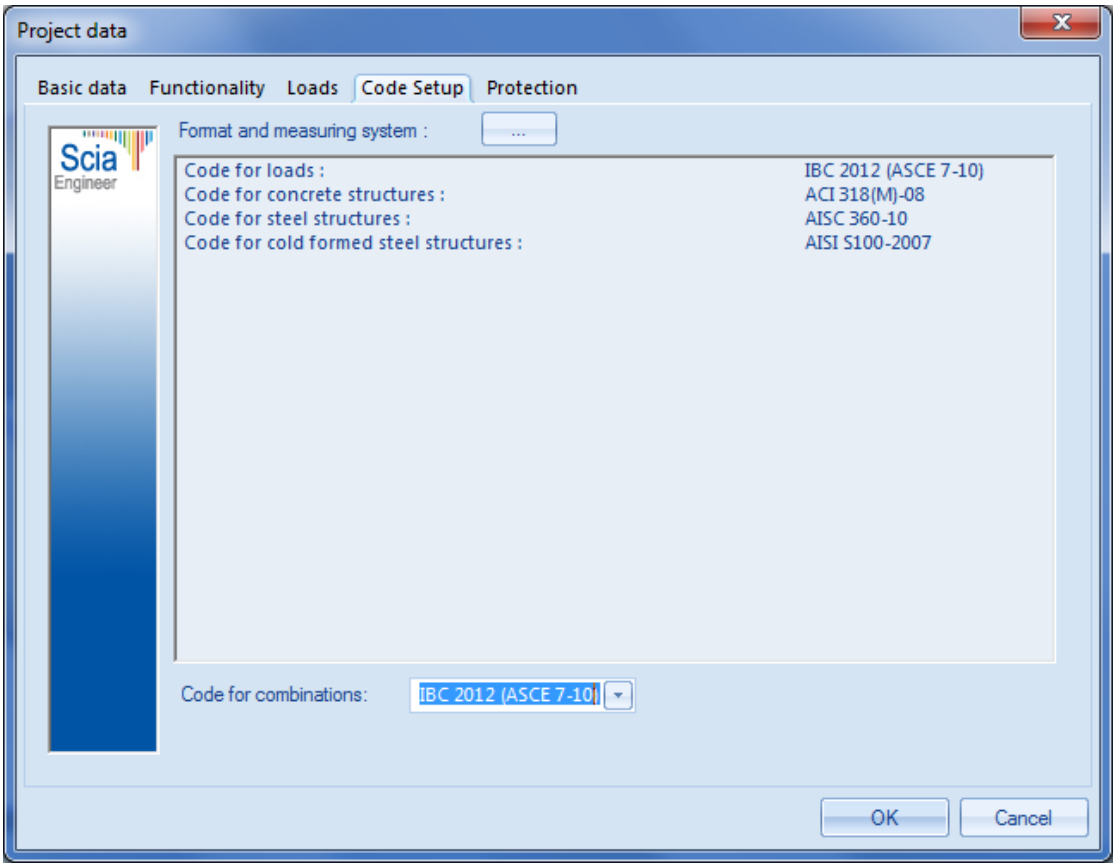
Enclosure classification	Default internal pressure coefficient
Partially enclosed buildings	+/- 0.55
Enclosed buildings	+/- 0.18

Wind load combination

The following changes can be observed comparing the load combinations (involving wind) between ASCE 7-05 with ASCE 7-10:

Load cases	Combination type	Combination	ASCE 7-05 load combination	ASCE 7-10 load combination
D = Dead load L = Live load Lr = Roof live load W = Wind load S = Snow load R = Rain load H = Lateral earth pressure F = Load due to fluids	LRFD combinations	1	1.2D + 1.6(Lr or S or R) + (L or 0.8W)	1.2(D + F) + 1.6(Lr or S or R) + (L or **0.5W**)
		2	1.2D + 1.6W + L + 0.5(Lr or S or R)	1.2(D + F) + **1.0W** + L + 0.5(Lr or S or R)
		3	0.9D + 1.6W + 1.6H	0.9D + **1.0W** + 1.6H
	ASD combinations	1	D + H + F + (W or 0.7E)	D + H + F + (**0.6W** or 0.7E)
		2	D + H + F + 0.75(W or 0.7E) + 0.75L + 0.75(Lr or S or R)	D + H + F + 0.75(**0.6W**) + 0.75L + 0.75(Lr or S or R)
		3	0.6D + W + H	0.6D + **0.6W** + H

Choosing ASCE 7-10 in the code setup will generate load combinations with appropriate factors with automatic load combination generation.



Design wind load

The external pressure coefficients are combined with the internal pressures to obtain the design wind loading according to expression 27.4-1 for Directional Procedure and 28.4-1 for Envelope Procedure.

Note that, with the Directional Procedure Figure 27.4-1 gives just the external pressure coefficient (Cp) whereas Figure 28.4-1 of the Envelope Procedure gives a combined gust effect factor and external pressure coefficient (GCp).