1009 – Wind Loads on Duopitch Roof Building

Description

This verification example compares wind load calculations on a duopitch roof building with analytical equations per the ASCE/SEI 7-16, the automatically generated wind loads in RFEM [1] and CFD simulation in RWIND Simulation. The building is defined according to **Figure 1** and the inflow velocity profile is defined according the standard ASCE/SEI 7-16, in **Figure 2**. The problem is described by the following table:

Fluid Properties	Kinematic Viscosity	ν	0.000161	ft^2/s
	Density	ρ	0.078	lb/ft^3
Geometry	Width	b	33.000	ft
	Height	h_1	20.000	ft
	Total Height	h_2	27.000	ft
	Length	L	44.000	ft
ASCE/SEI 7-16 Settings	Exposure Category	D	-	-
	Wind Speed	V	100.000	mph
	Topographic factor	K_{zt}	1.000	-
	Ground Elevation factor	K_e	1.000	-
	Wind Directionality factor	K_d	0.850	-
	Gust-effect factor	G	0.850	-

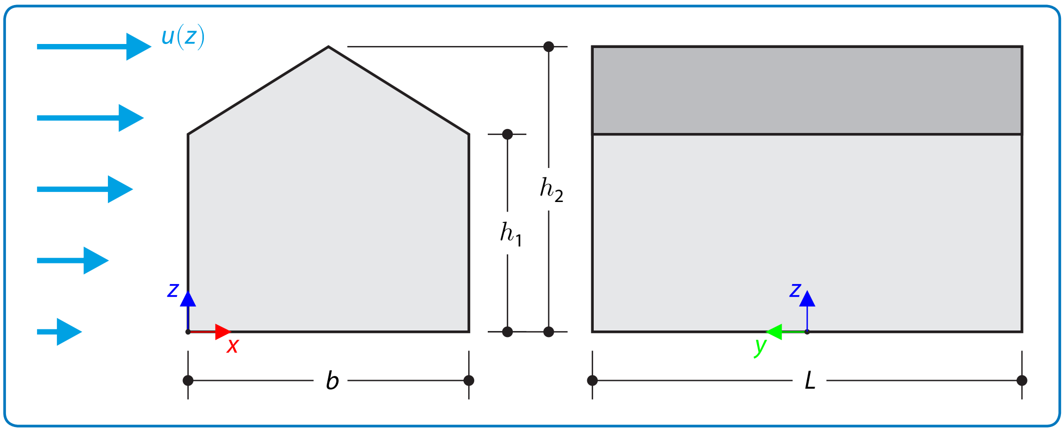

Figure 1: Problem sketch

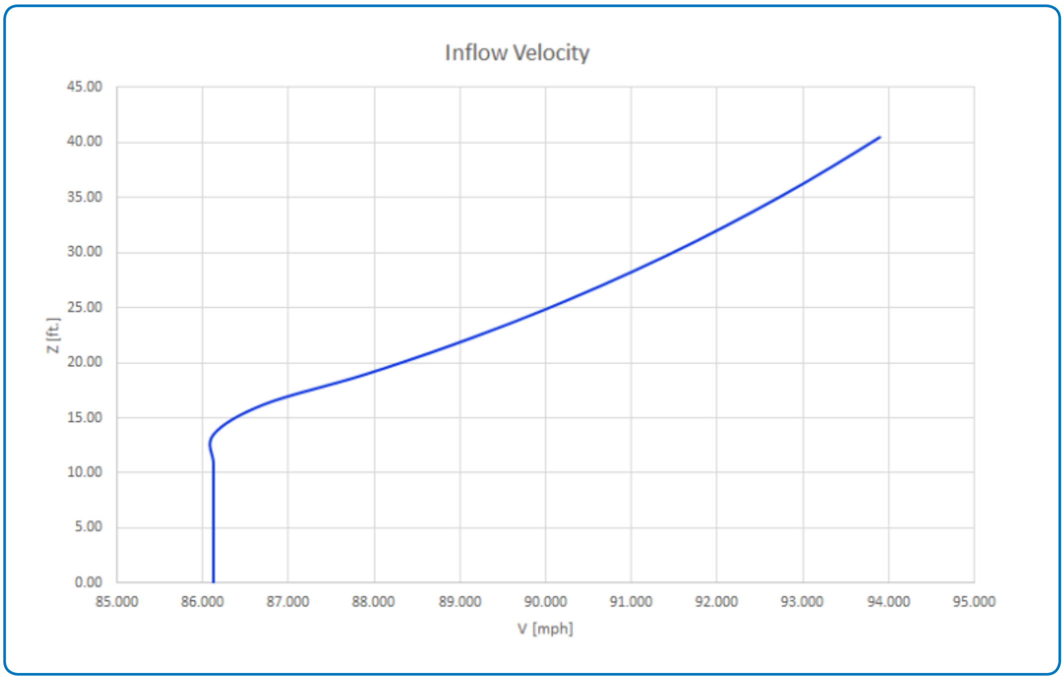

Figure 2: Inflow velocity according to ASCE/SEI 7-16 (exposure category D, basic wind speed 100 mph)

RFEM Wind Load Generator Settings

- Modeled in RFEM 5.22.03 utilizing the Wind Load Generator - vertical walls with roof tool
- Only Case 1 from Fig. 27.3-8 [1] is considered
- The windward roof pressure coefficient (C_p) is taken as the first value given in Figure 27.3-1 [1]

RWIND Simulation Settings

- Modeled in RFEM 5.22.03 and RWIND Simulation 1.21
- Turbulence model: k-ε

Remark: The calculation parameters according to the ASCE/SEI 7-16 are chosen for closely correlated CFD analysis results.

Analysis

This verification example will utilize the steps and analytical equations described in Table 27.2-1 [1] from the ASCE/SEI 7-16 for the MWFRS wind loads on an enclosed building. The steps for this calculation are listed below.

Step 1: Determine the risk category of the building by referencing Table 1.5-1 [1].

Assuming the building's failure could pose a substantial risk to human life; a Risk Category of III is selected.

Step 2: Determine the basic wind speed (V) for the applicable risk category by referencing Figure 26.5-1 and 26.5-2 [1].

$$V = 100.000\ mph.$$

Step 3: Determine the following wind load parameters:

- The wind Directionality Factor (K_d) is determined from Sect. 26.6 and Table 26.6-1 [1].

  $K_d = 0.850$

- The Exposure Category is determined using Sect. 26.7 [1].

  Exposure D is selected due to the smooth surrounding topography so wind is unobstructed.

- To calculate the Topographic variable (K_{zt}) see Section 26.8 and table in Fig. 26.8-1 [1].

  $K_{zt} = 1.000$, assuming the site conditions and locations of buildings and other structures do not meet all the conditions specified in Sect. 26.8.1 [1].

- The Ground Elevation factor (K_e) is determined from Sect. 26.9 [1].

  $K_e = 1.000$, assuming sea level = 0 ft

- Gust-effect factor (G or G_f) determined using Sect. 26.11 [1].

  G = 0.850

- Enclosure classification is determined using Sect. 26.12 [1].

  Enclosed building

- To determine the internal pressure coefficient (GC_{pi}) see Sect. 26.13 and Table 26.13-1 [1].

  $GC_{pi} = \pm 0.180$

Step 4: Determine the Velocity Pressure Exposure coefficient (K_z or K_h); see Table 26.10-1 [1]. A more accurate calculation is performed using the equation from Note 1.

Exposure D, ($a = 11.5$ and $Z_g = 700$)

$$K_z(windward) = 1.030\ (z = 0 - 15ft.),\ K_z(leeward) = 1.083\ (z = 20ft.),\ K_h = 1.110\ (Roof)$$

Step 5: Determine the Velocity Pressure (q_z and q_h) using Eqn. (26.10-1) [1].

$$q = 0.00256 \cdot K_z \cdot K_{zt} \cdot K_d \cdot K_e \cdot V^2 \qquad (1009-1)$$

$$q_z = 22.420\ psf\ (z = 0 - 15ft),\ q_z = 23.568\ psf\ (z = 20ft),\ q_h = 24.150\ psf\ (Roof)$$

Step 6: Determine external pressure coefficients (C_p or C_N) on the walls.

$$C_p = 0.8\,(windward),\; C_p = -0.5\,(leeward),\; C_p = -0.7\,(sidewall)$$

Using Figure 27.3-1 [1], C_p for the windward and leeward face of the roof are calculated using interpolation.

L/B = 0.71, a = 22.99

Windward:

$$C_p = -0.44$$

Leeward:

$$C_p = -0.6$$

Step 7: Calculate the Wind Pressure, (P), on each building surface using Eq. (27.3-1) [1].

$$P = q \cdot G \cdot C_p - q_i \cdot (GC_{pi}) \qquad (1009-2)$$

LC1 (-GC_{pi}):

Windward: P = $q_z \cdot$ G $\cdot$ C_p - $q_h \cdot (GC_{pi})$

$$P = 19.593\,psf\,(z = 0 - 15ft.),\; p = 20.373\,psf\,(z = 20ft.)$$

Leeward: P = $q_z \cdot$ G $\cdot$ C_p - $q_z \cdot (GC_{pi})$

$$P = -5.669\,psf\,(z = 20.00ft.)$$

Sidewall: P = $q_h \cdot$ G $\cdot$ C_p - $q_h \cdot (GC_{pi})$

$$P = -9.676\,psf\,(z = 20.00ft.)$$

Roof: P = $q_h \cdot G \cdot C_p - q_h \cdot (GC_{pi})$

$$p = -4.685\ psf\ (Windward),\ p = -7.970\ psf\ (Leeward)$$

LC2 (+GC_{pi}):

Windward: P = $q_z \cdot G \cdot C_p - q_h \cdot (GC_{pi})$

$$P = 10.899\ psf\ (z = 0 - 15ft.),\ p = 11.679\ psf\ (z = 20ft.)$$

Leeward: P = $q_z \cdot G \cdot C_p - q_z \cdot (GC_{pi})$

$$P = -14.259\ psf\ (z = 20.00ft.)$$

Sidewall: P = $q_h \cdot G \cdot C_p - q_h \cdot (GC_{pi})$

$$P = -18.716\ psf\ (z = 20.00ft.)$$

Roof: P = $q_h \cdot G \cdot C_p - q_h \cdot (GC_{pi})$

$$p = -13.379\ psf\ (Windward),\ p = -16.664\ psf\ (Leeward)$$

Results

Structure Files	Program
1009	ASCE/SEI 7-16 (Hand calculations)
1009	ASCE/SEI 7-16 (RFEM wind load generator)
1009	RWIND Simulation (inflow velocity according to ASCE/SEI 7-16)

Quantity	ASCE/SEI 7-16 Hand calculations (LC1)	ASCE/SEI 7-16 RFEM Wind load generator (LC1)	Ratio
F_x [kip]	23.514	23.641	0.995
F_y [kip]	0.000	0.000	-
F_z [kip]	9.226	9.248	0.998

Quantity	ASCE/SEI 7-16 Hand calculations (LC1)	RWIND Simulation	Ratio
F_x [kip]	23.514	22.154	0.942
F_y [kip]	0.000	-0.097	-
F_z [kip]	15.516*	17.092	0.908

*Note: RWIND Simulation does not consider internal pressure coefficients (GC_{pi}). Therefore, the value from the analytical equation LC1 and LC2 were averaged for a more accurate comparison to RWIND Simulation.

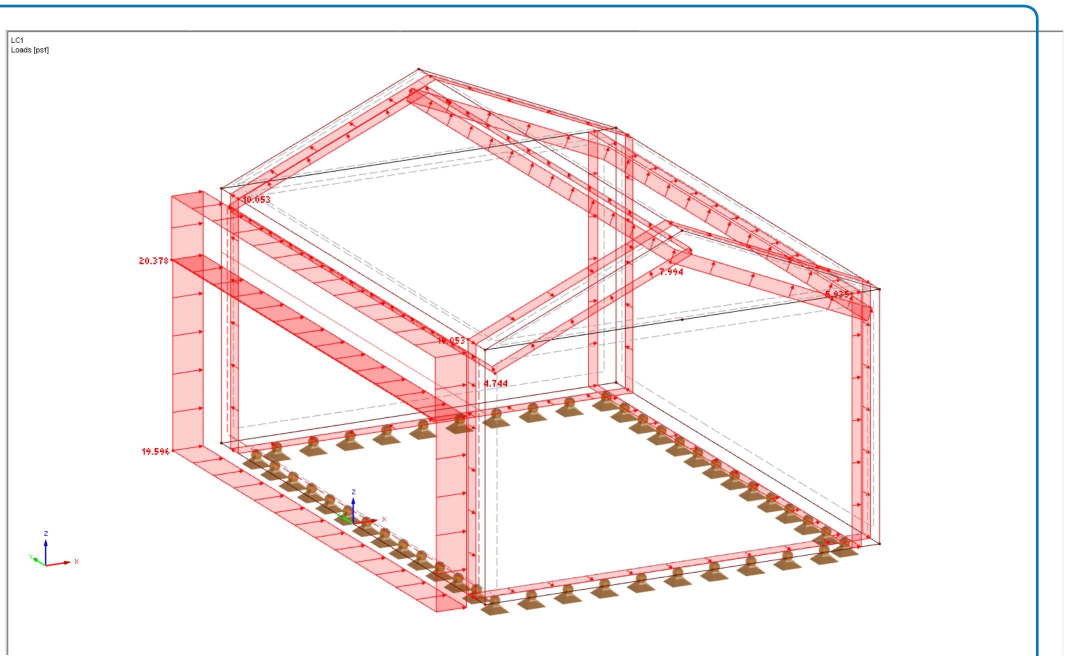

Figure 3: RWIND Wind Load Generator – LC1 Surface pressure

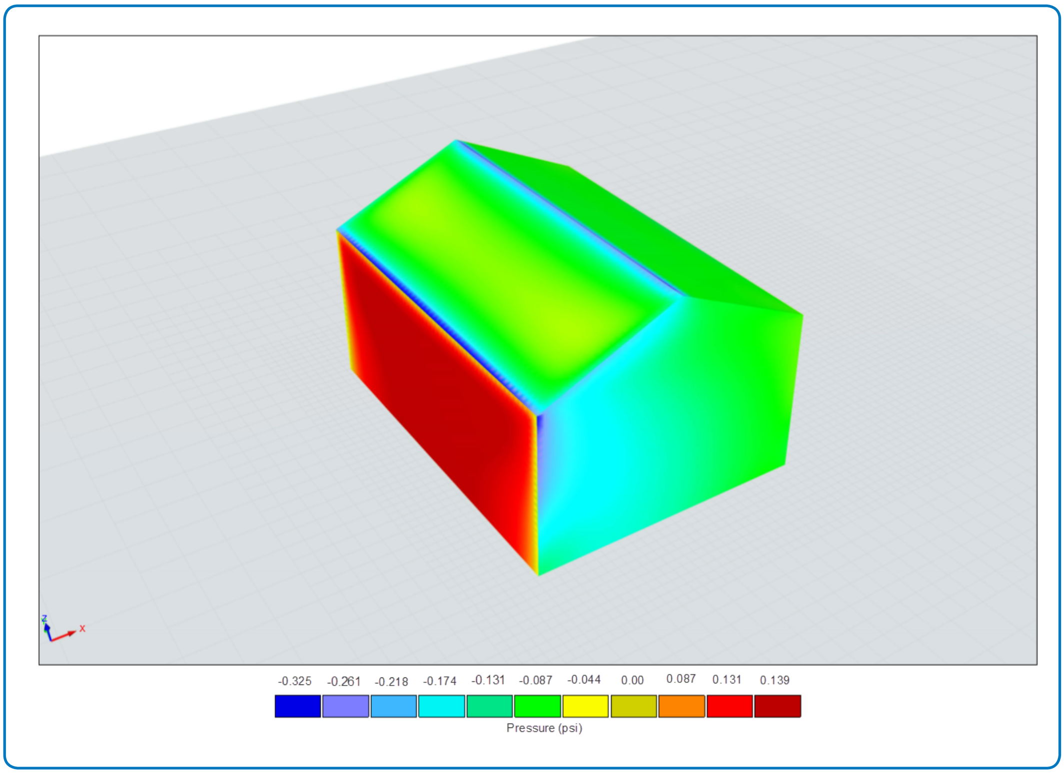

Figure 4: RWIND Simulation – Surface pressure

References

[1] Minimum Design Loads and Associated Criteria for Buildings and Other Structures. ASCE/SEI 7-16, American Society of Civil Engineers, 2017.