Effect of low-rise building geometry on tornado-induced loads

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Challenges to quantify tornado-induced loads:

- Lack of research facilities capable of determining tornado-induced loads (pressures, forces, etc.)
- Absence of full-scale data
- Lack of interest in tornado-resistant design

How to overcome these challenges:

- Iowa State University (ISU) tornado simulator
- Full-scale data from several recent tornados
- Pressures obtained form the ISU simulator are verified

Maximum horizontal wind speed

Fact 1: Around 90% of all tornados are rated F2 or less

Fact 2: Maximum velocity of F2 tornado is 74 m/s

Fact 3: Design wind speed ranges from 63 m/s to 80 m/s (ASCE 7-10, 2010)

Fact 4: Maximum horizontal velocity of the tornado generated by ISU Simulator is 11.7 m/s

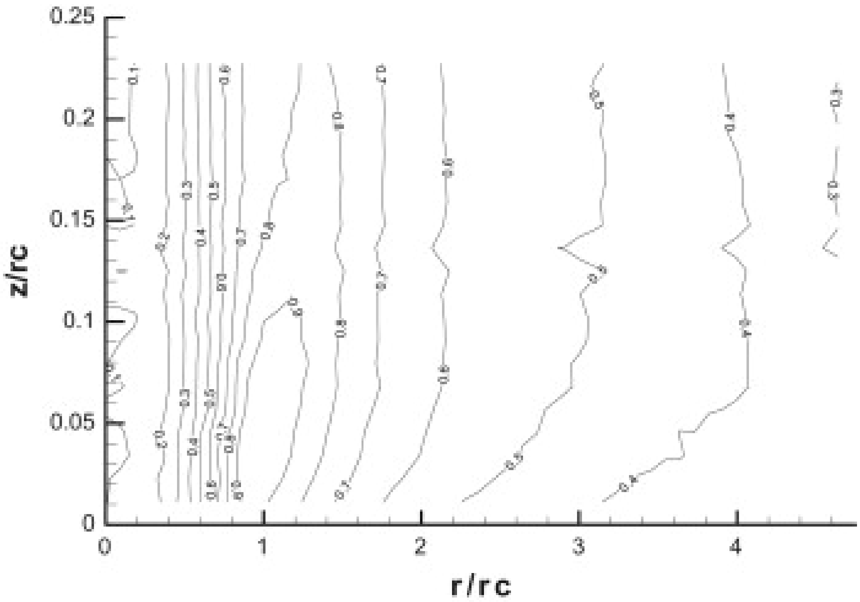
Choose target full-scale wind speed to be 74 m/s

Velocity scale $\lambda_v = 11.7/74 = 1/6.3$

Effect of low-rise building geometry on tornado-induced loads
└ Description of simulated tornado
└ Maximum horizonal wind speed

Contour plot of normalized tangential velocity

Figure: Contour plot of tangential velocity magnitudes normalized with respect to the maximum tangential velocity



Tornado vortex diameter

Definition

Radius of the core r_c: radius of the maximum wind near the ground

Fact 1: r_c of F2 tornado is between 45 to 225 m

Fact 2: r_c of simulated tornado is 0.56 m

Choose r_c of target full-scale tornado to be 56 m

Length scale is 1 : 100

Swirl ratio: definition

Definition

Swirl ratio S:

$$S = \frac{\pi V_{\theta \max} r_c^2}{Q}$$

r_c: core radius

$V_{\theta \max}$: maximum tangential wind speed

Q: inflow rate of the vortex measured at $r = r_c$

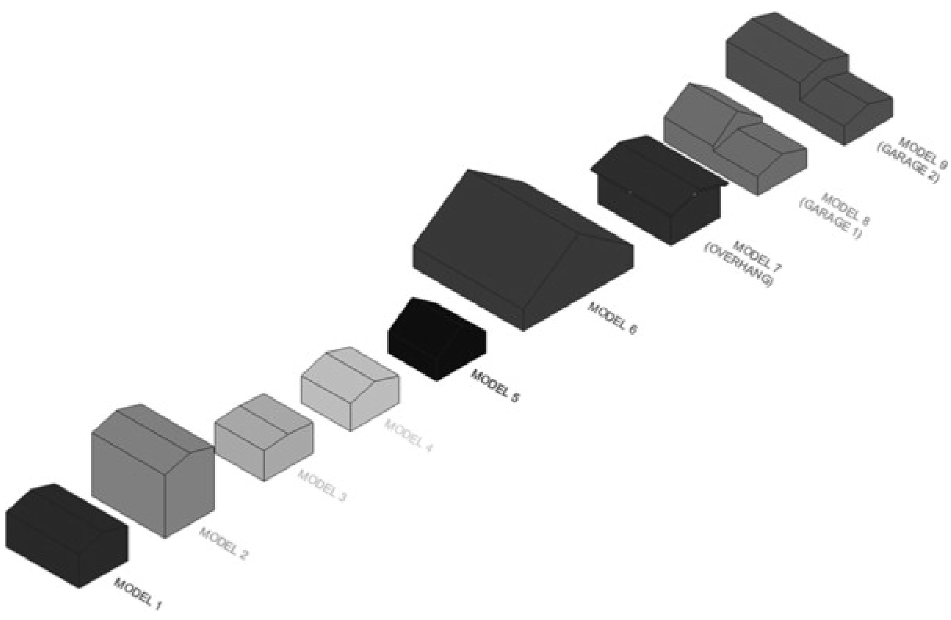
How to choose swirl ratio

Fact 1: Data from full-scale tornados indicates $S \geqslant 2.0$

Fact 2: Best fit of full-scale data with numerical simulation when $S \geqslant 2.0$

Choose the swirl ratio S to be 2.6

Building models

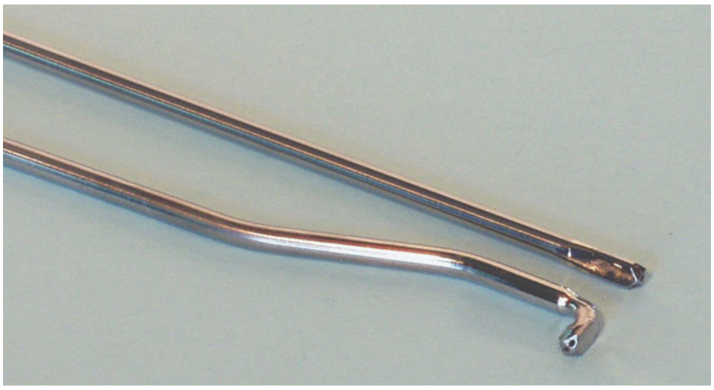


Model dimensions

Model	Roof pitch, θ (deg)	Width, B (mm)	Length, L (mm)	Eave height, h_e (mm)	Roof ridge height, h_t (mm)	Mean roof height, h (mm)	L/B	h/L
1	15.95	98	146	60	74	67	1.5	0.46
2	15.95	98	146	110	124	117	1.5	0.80
3	4.6	98	98	53	57	55	1.0	0.56
4	15.95	98	98	48	62	55	1.0	0.56
5	35.5	98	98	37	72	55	1.0	0.56
6	35.5	221	221	37	114	76	1.0	0.34
7 (Overhang)	15.95	98	146	60	74	67	1.5	0.46
8 (Garage 1)[a]	35.5[b]	98	187	37	72	55	1.9	0.29
9 (Garage 2)[a]	15.95[b]	98	235	60	74	67	2.4	0.29

[a] Dimensions of "garage" addition were B=98 mm, L=89 mm, h_e=33 mm, and h_t=47 mm.
[b] Roof pitch of "house" part of model. Roof pitch of "garage" addition was 15.95°.

Wind velocity measurement: Cobra probe



Measurement points

horizontally spaced at 50.8 mm
vertically spaced at 6.35 mm

Pressure measurement: ZOC33/64Px pressure transducer

Measurement frequency: 390 Hz

Procedure

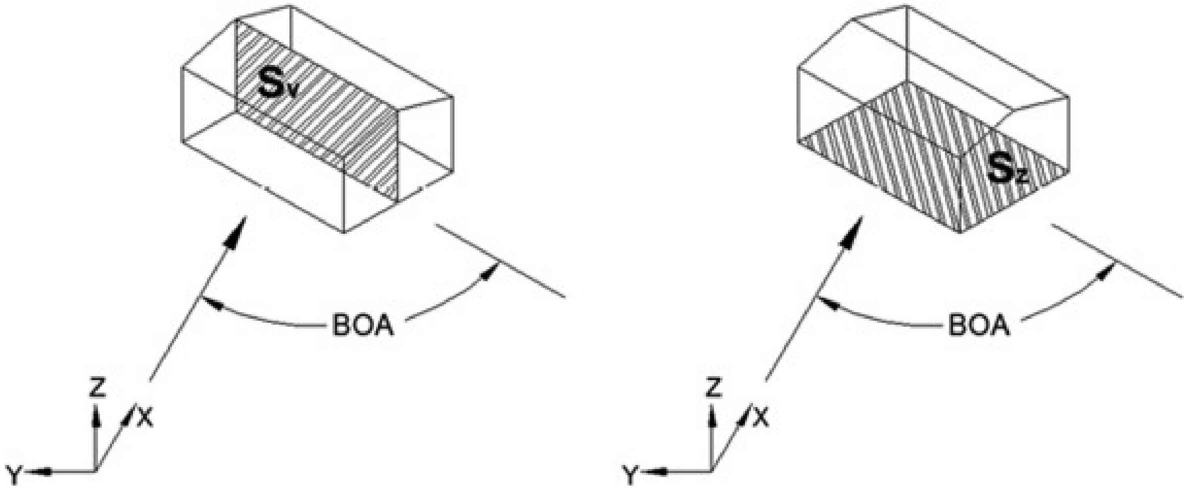
- For each test case the pressure were recorded 10 times
- Calculate the peak pressure as the average of the peak pressures from each of the 10 runs
- Change the BOA from 0° to 90° with a step size of 15°

Definition

BOA: the orientation of the building with respect to the direction of translation of the tornado

BOA & Areas used to compute force coefficients

Figure: Building orientation angle (BOA) with respect to the tornado translation axis (X) and areas (S_v, S_z) used to normalize force coefficients



Effect of low-rise building geometry on tornado-induced loads
└Model description, instruments, conventions
└Procedure and conventions

Calculation of force coefficients

$$C_{Fx} = \frac{F_x}{(1/2)\rho V_H^2 S_v} \tag{1}$$

$$C_{Fy} = \frac{F_y}{(1/2)\rho V_H^2 S_v} \tag{2}$$

$$C_{Fz} = \frac{F_z}{(1/2)\rho V_H^2 S_z} \tag{3}$$

$$C_{Fxy} = \sqrt{C_{Fx}^2 + C_{Fy}^2} \tag{4}$$

The effect of eave height: Models

Fact 1: Difference between Model 1 & 2 was eave heights h_e

Fact 2: Model 1: $h_e = 60\,\text{mm}$
Model 2: $h_e = 110\,\text{mm}$

Effect of low-rise building geometry on tornado-induced loads
└ Results
  └ The effect of eave height

The effect of eave height: Peak pressures

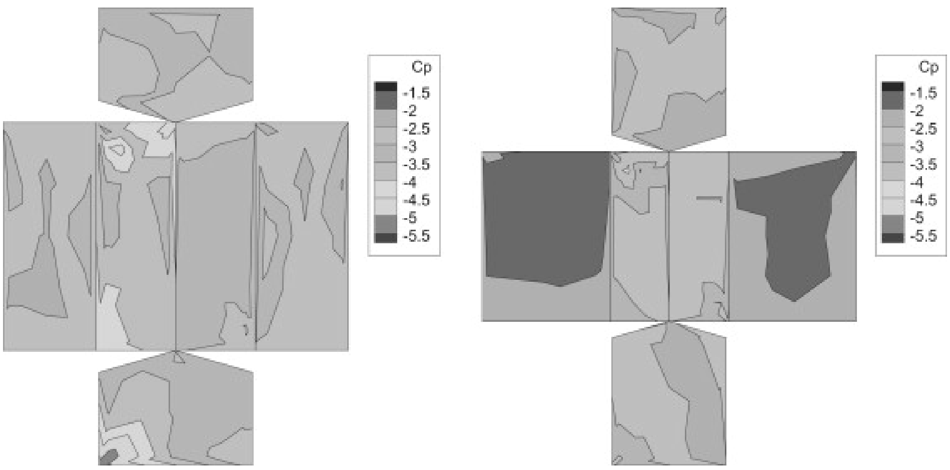


Figure: Peak pressure contours for Model 1 (left) & 2 (right), BOA=30°

- Peak pressure contours of Model 1 & 2 are similar
- Magnitudes of peak pressure: Model 1 > Model 2

The effect of eave height: Vertical force coefficient

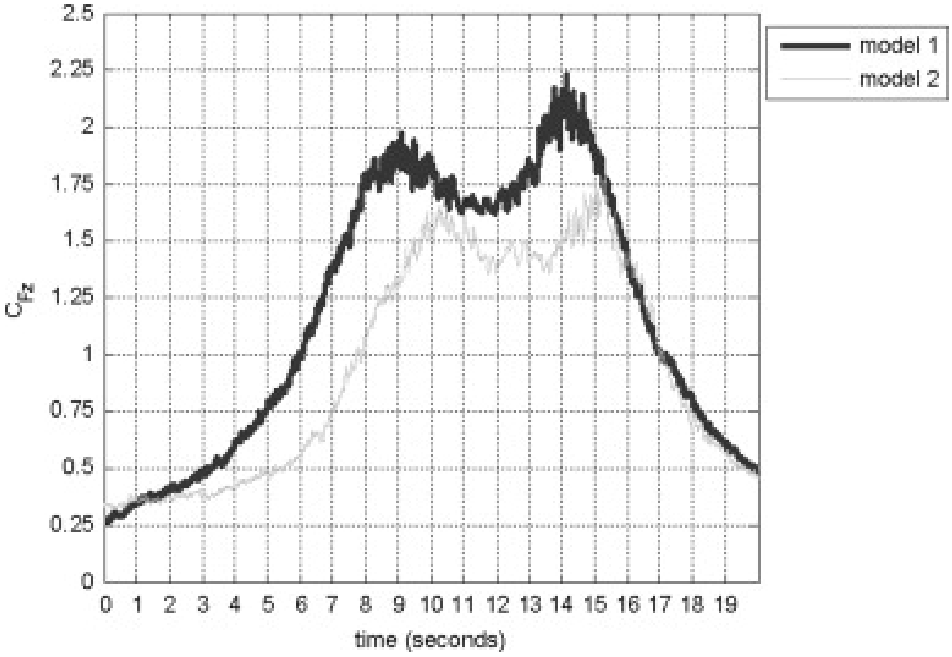


Figure: C_{Fz} time history for Model 1 & 2, BOA=30°

The effect of eave height: XY force coefficient

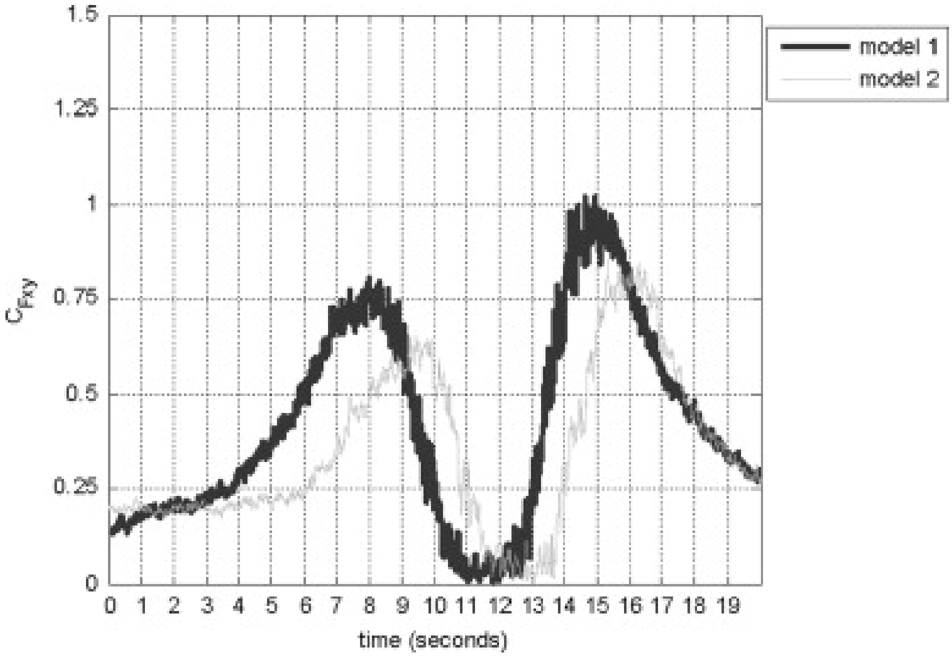


Figure: C_{Fxy} time history for Models 1 & 2, BOA=30°

The effect of roof pitch: Models

Fact 1: Difference between Model 3, 4 & 5 was roof pitch θ

Fact 2: Model 3: $\theta = 4.6°$
Model 4: $\theta = 15.95°$
Model 5: $\theta = 35.5°$

The effect of roof pitch: Peak pressures

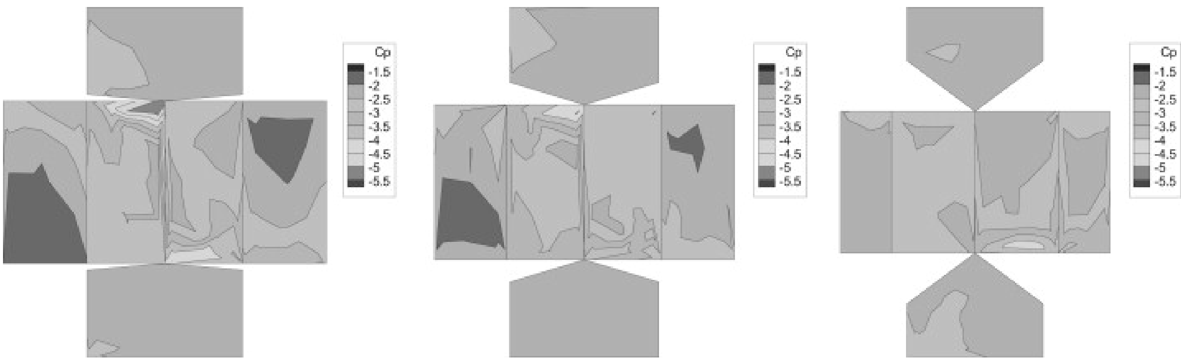


Figure: Peak pressure contours for Model 3 (left), 4 (center) & 5 (right), BOA=45°

- As $\theta \uparrow$, peak pressure magnitudes for the roof $\downarrow$
- As $\theta \uparrow$, peak pressure magnitudes for the wall $\uparrow$

The effect of roof pitch: Vertical force coefficient

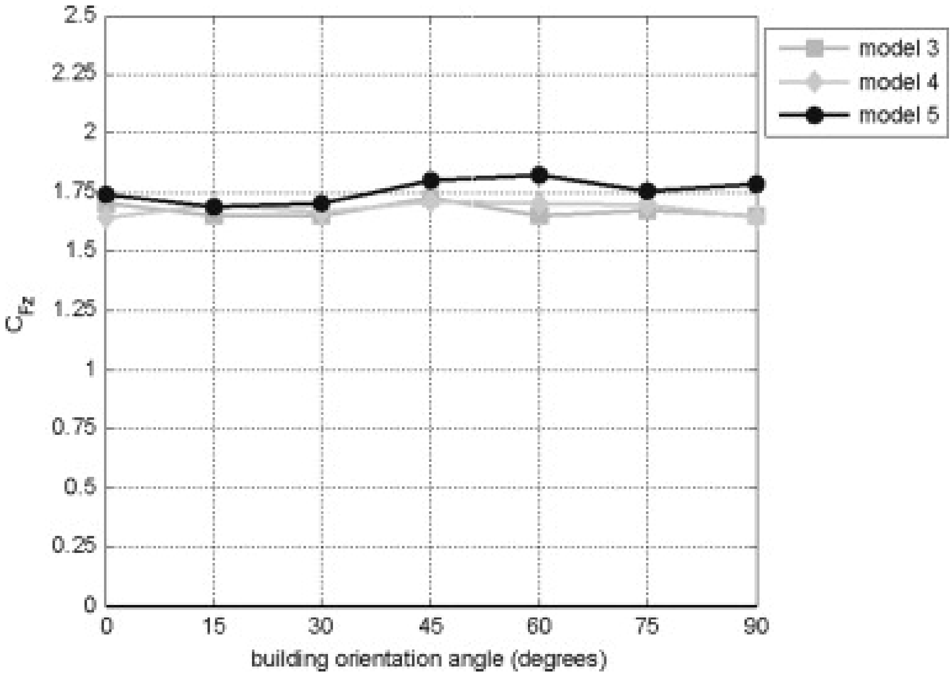


Figure: C_{Fz} time history for Models 3, 4 & 5, for each BOA

Effect of low-rise building geometry on tornado-induced loads
└Results
└The effect of roof pitch

The effect of roof pitch: Vertical force coefficient

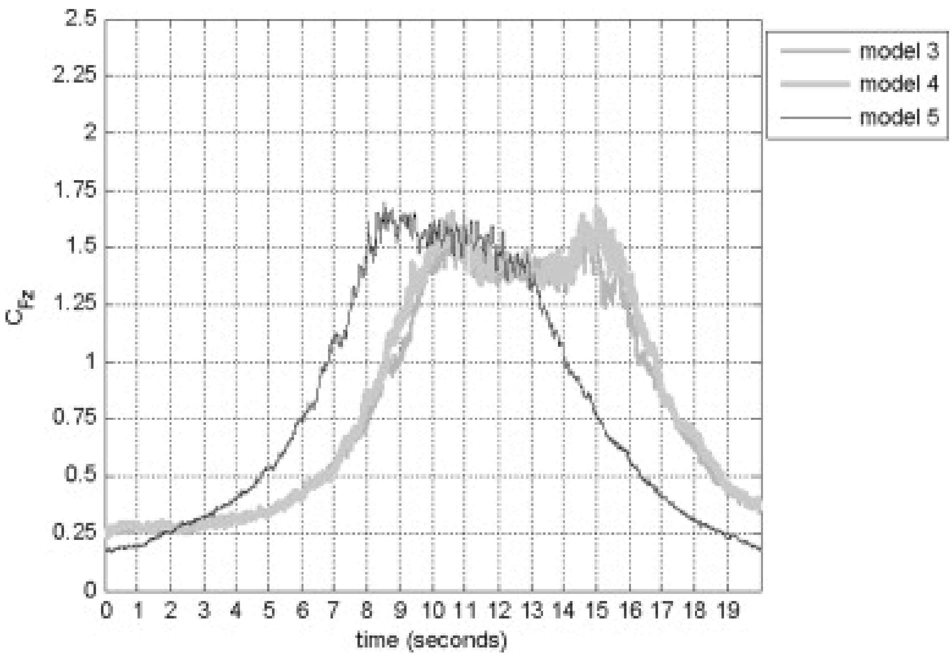


Figure: C_{Fz} time history for Models 3, 4 & 5, BOA=30°


Thank
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