Wind Engineering Joint Usage/Research Center
FY2025 Research Result Report

Research Field: Wind Hazard Mitigation/Wind Resistant design
Research Year: FY2025
Research Number: 25252003
Research Theme: Impact of Tornado vortex induced aerodynamic loads on structural projections in low rise buildings

Representative Researcher: Prof. Rajesh Goyal

Budget [FY2025]: 2,36,000 Yen

1. Research Aim:

- To evaluate the damage of in low rise structure and attached canopies due to aerodynamic loads caused by tornadoes like flow due to varying roughness of surface.
- To enhance the wind pressure database of low-rise buildings with attached projections under varying roughness of the surface.

It was proposed to conduct extensive study on low rise buildings with attached canopies at 10-degree angles for different parameters under the influence of tornado induced vortexes. The building models can be tested for attached canopy at different roughness coefficients.

2. Research Method

The building models were prepared using Perspex sheets having attached canopies of different lengths. In the present phase of study, one canopy was prepared at 10 deg angle and the roughness of the surrounding surface of the building were changed. Canopy of 29.8 mm length attached to 3/4th height of the model building from the ground. The models were prepared for measuring the surface pressure on all the surfaces on tornado simulator. For measuring the surface pressure on the surfaces of building models, pressure tapings were provided. With the help of pressure tapings, the pressure on the surfaces of building models was measured using the pressure measuring instruments. View of the different roughness bend on the simulator are shown in Figure-1.

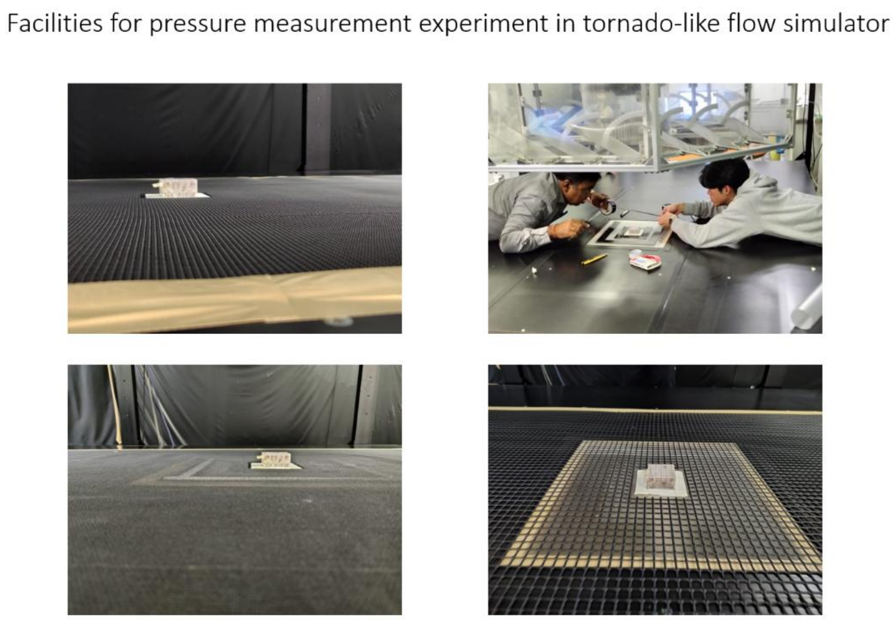


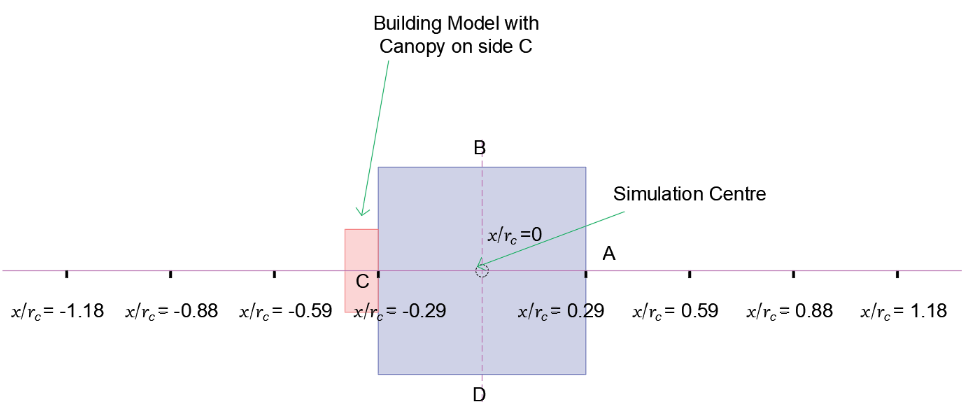
Fig-1: - Different roughness bed used during the experiment

3. Research Result

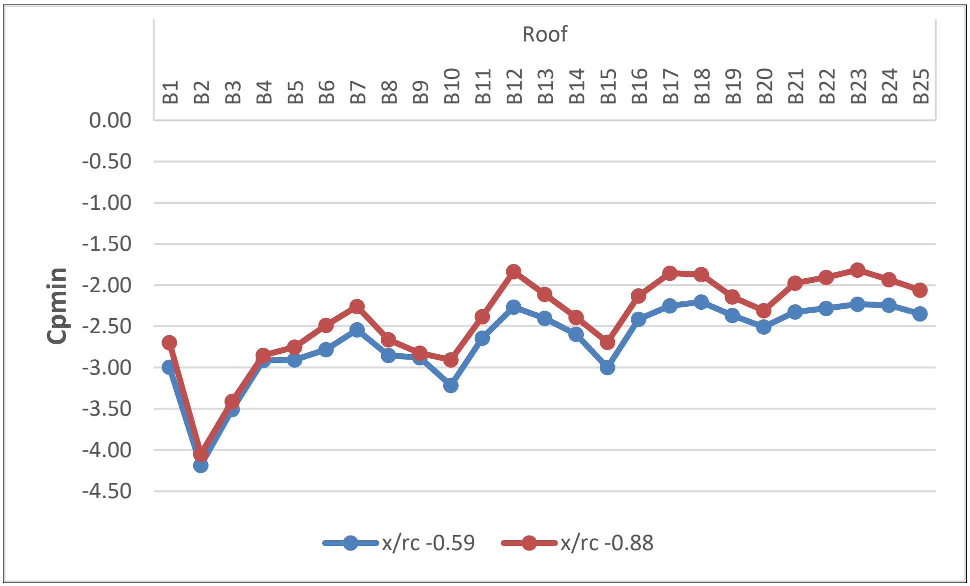
A series of experiments were conducted using a tornado-like flow simulator at Tokyo Polytechnic University to measure the temporal variations of wind pressure coefficients on low-rise building models with attached canopies of 29.8 mm length, fixed at 3/4th height of the building at a 10-degree angle. The experiments were carried out for different distances between the centers of tornado-like flows and the building, and different surface roughness beds surrounding the building models, with distances normalized by the radius of maximum wind of the swirling flows. Time series data were collected on the building model surface, canopy surface, and surroundings as the tornado approached and left the building in both x and y directions, and the mean components of the pressure coefficients are presented as follows:

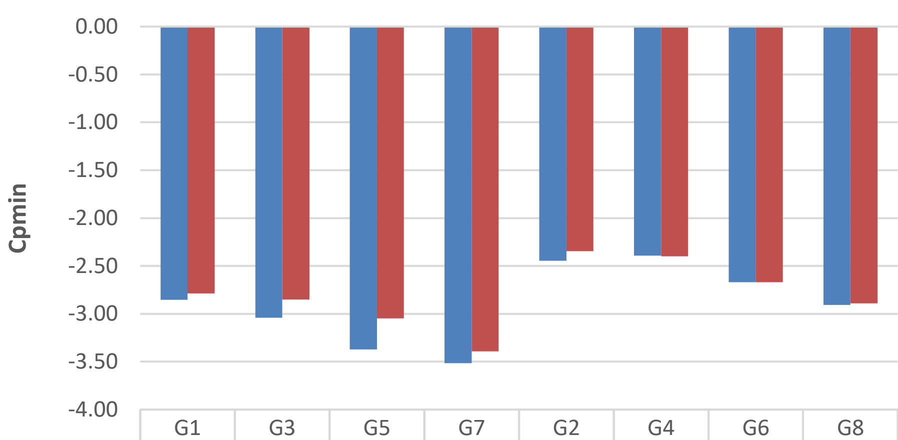
1. While edge taps are typically high-risk zones, results indicate that for high-roughness terrain (surface 1), the peak suction zone migrates inward. Tap B2 recorded the absolute maximum suction of -3.08, outperforming the corner tap B1 (-2.84).
2. The introduction of ground roughness significantly decreases the magnitude of the coefficient of pressure. This effect is particularly pronounced on the lower canopy surface, where roughness leads to a substantial drop in suction compared to smooth terrain.
3. The upper canopy surface consistently experiences higher pressure coefficients than the lower canopy surface. This pressure differential creates a strong net uplift force, identifying the upper surface as the primary vulnerability for structural projections.
4. Experimental data confirms a clear anti-symmetry in pressure distribution on opposite sides of the building. This is attributed to the rotational nature of the vortex flow, which subjects one side to windward-like conditions and the opposite to leeward-like conditions. Specifically, face ‘D’ (acting as windward) shows higher coefficients than face ‘F’ (acting as leeward).
5. In smooth terrain (plane surface), the maximum pressure coefficient on the roof occurs when the tornado is approximately 30m (75mm) away from the building center. In contrast, for rough terrain, the coefficient of pressure at this same location drops significantly, showing that roughness reduces the effective radius of maximum damage.
6. At the x/rc = -0.59 position, the building is situated near the outer core boundary of the vortex. The results indicate that this location experiences intense suction on the leading roof edges and the upper canopy corner (G7). Specifically, for smooth terrain (plane surface), the suction values are at their peak; however, the introduction of intermediate roughness (surface 3) creates a highly turbulent flow field that maintains extreme Cpmin levels on the roof surface
7. At the x/rc = -0.88 position, the building has moved further away from the vortex center, leading to a general reduction in sustained pressure. However, the data reveals that ground roughness has its most significant mitigation impact at this distance. For instance, the introduction of rough terrain reduced the Cpmin by approximately 35% on the upper surface of the canopy and 18% on the lower surface, proving that surface friction effectively "chokes" the vortex's reach at these outer-core distances.

Canopy Length 30mm, Height 18.75mm Slope 10-degree, X = 0mm

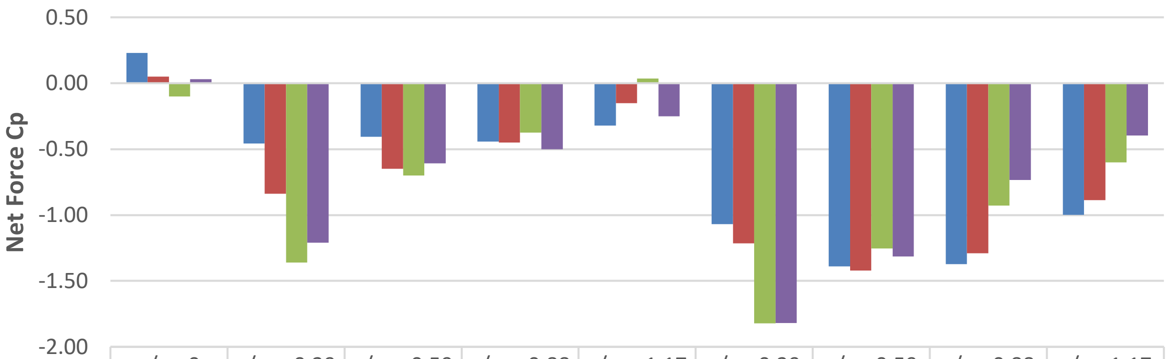


Building Model with rough terrain, surface-1

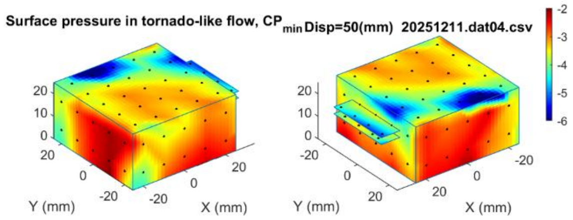


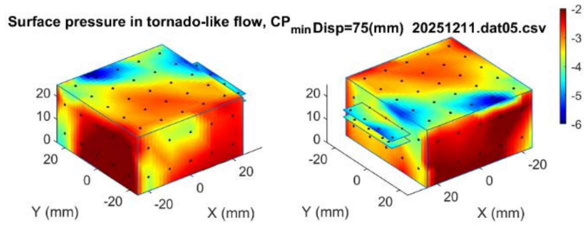


	Canopy Upper Surface				Canopy lower Surface			
	G1	G3	G5	G7	G2	G4	G6	G8
x/rc -0.59	-2.85	-3.04	-3.37	-3.51	-2.45	-2.39	-2.67	-2.91
x/rc -0.88	-2.79	-2.85	-3.05	-3.39	-2.35	-2.40	-2.67	-2.89

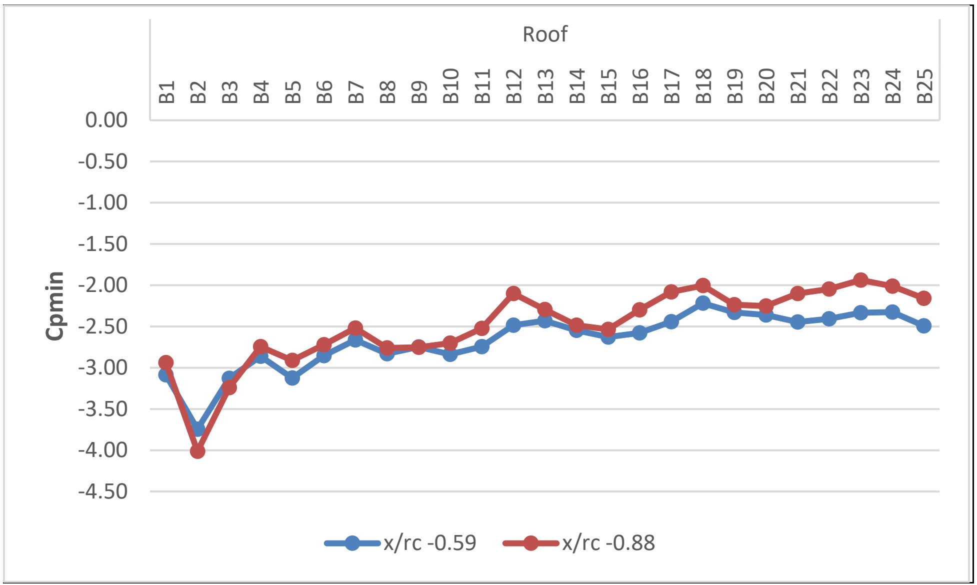


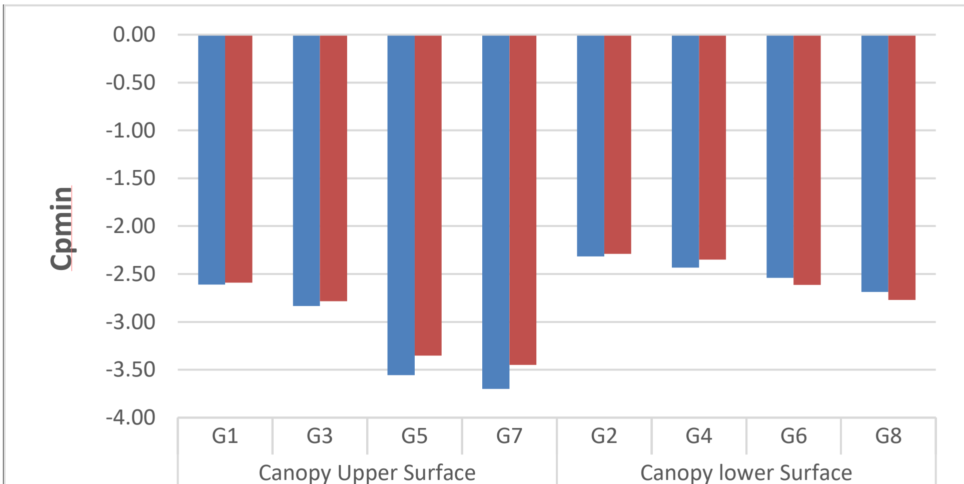
	x/rc=0	x/rc=-0.29	x/rc=-0.59	x/rc=-0.88	x/rc=-1.17	x/rc=0.29	x/rc=0.59	x/rc=0.88	x/rc=1.17
G1-G2	0.23	-0.46	-0.41	-0.44	-0.32	-1.07	-1.39	-1.37	-1.00
G3-G4	0.05	-0.84	-0.65	-0.45	-0.15	-1.21	-1.42	-1.29	-0.89
G5-G6	-0.10	-1.36	-0.70	-0.38	0.04	-1.82	-1.25	-0.93	-0.60
G7-G8	0.03	-1.21	-0.61	-0.50	-0.25	-1.82	-1.31	-0.73	-0.40



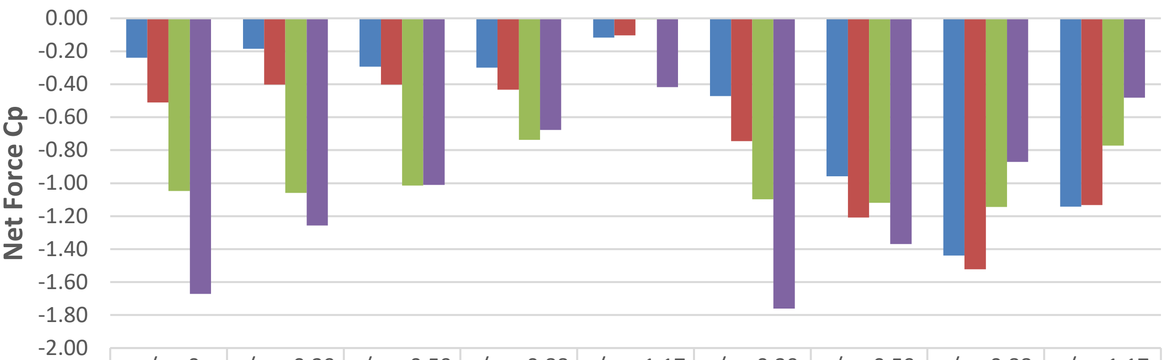


Building Model with rough terrain, surface-2

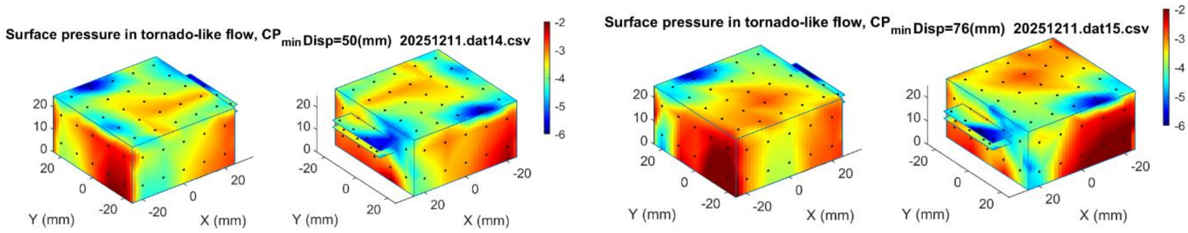




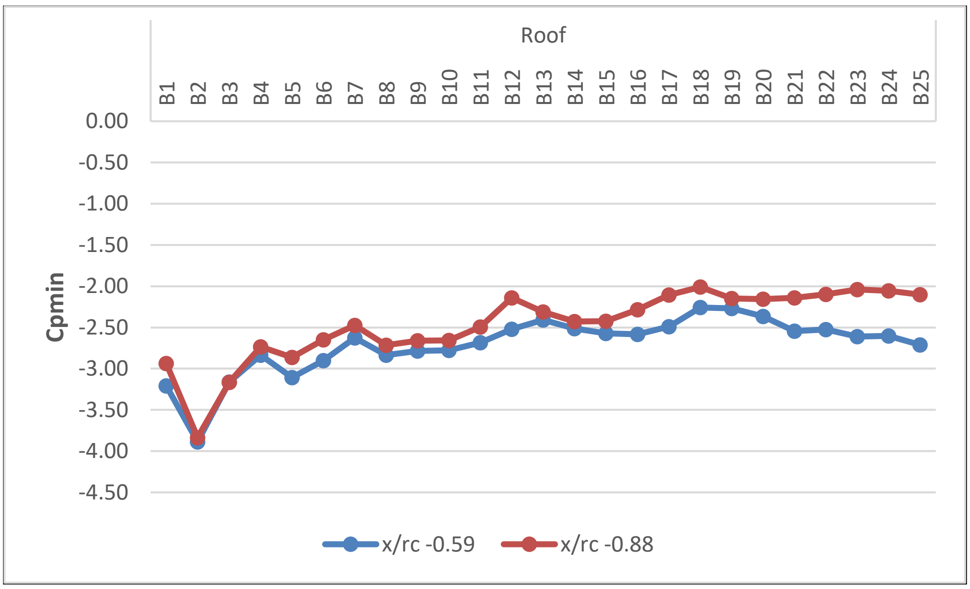
	Canopy Upper Surface				Canopy lower Surface			
	G1	G3	G5	G7	G2	G4	G6	G8
x/rc -0.59	-2.61	-2.84	-3.56	-3.70	-2.32	-2.43	-2.54	-2.69
x/rc -0.88	-2.59	-2.78	-3.35	-3.45	-2.29	-2.35	-2.61	-2.77

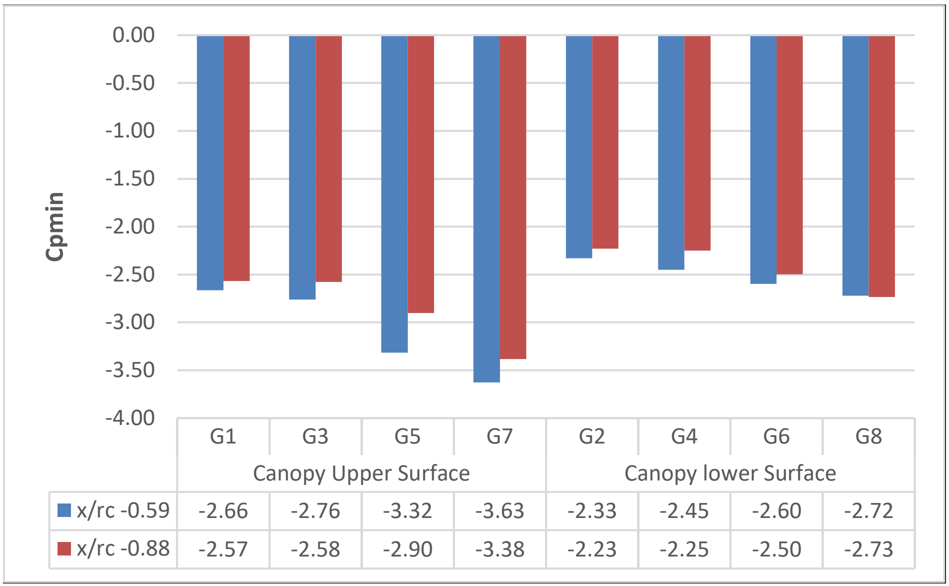


	x/rc=0	x/rc=-0.29	x/rc=-0.59	x/rc=-0.88	x/rc=-1.17	x/rc=0.29	x/rc=0.59	x/rc=0.88	x/rc=1.17
G1-G2	-0.24	-0.19	-0.29	-0.30	-0.12	-0.47	-0.96	-1.44	-1.14
G3-G4	-0.51	-0.40	-0.40	-0.43	-0.10	-0.75	-1.21	-1.52	-1.13
G5-G6	-1.05	-1.06	-1.01	-0.74	-0.01	-1.10	-1.12	-1.15	-0.77
G7-G8	-1.67	-1.26	-1.01	-0.68	-0.42	-1.76	-1.37	-0.87	-0.48

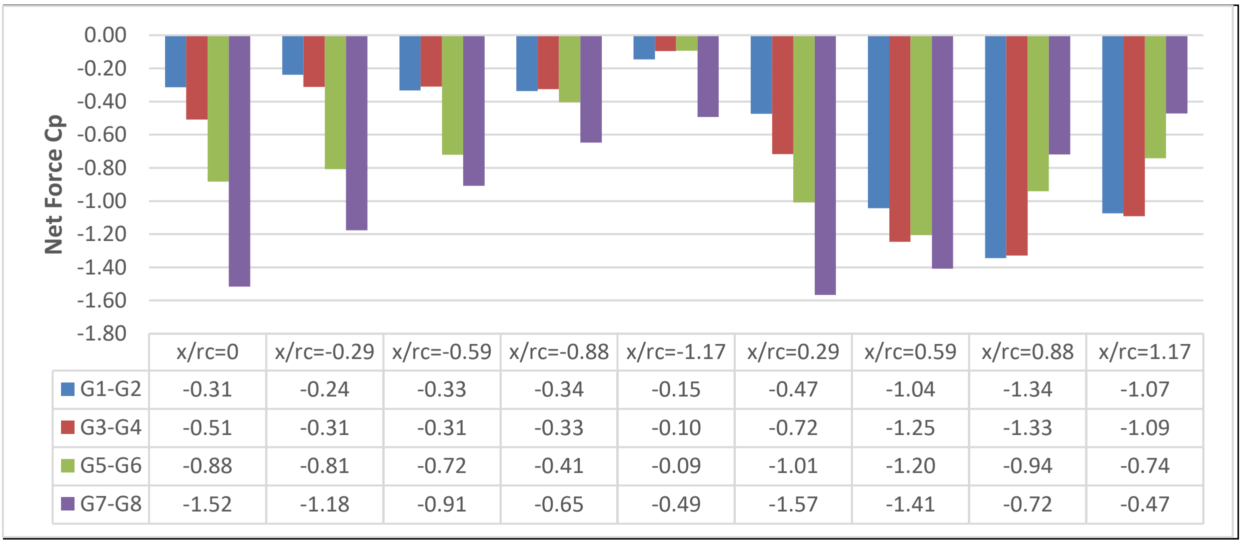


Building Model with rough terrain, surface-3

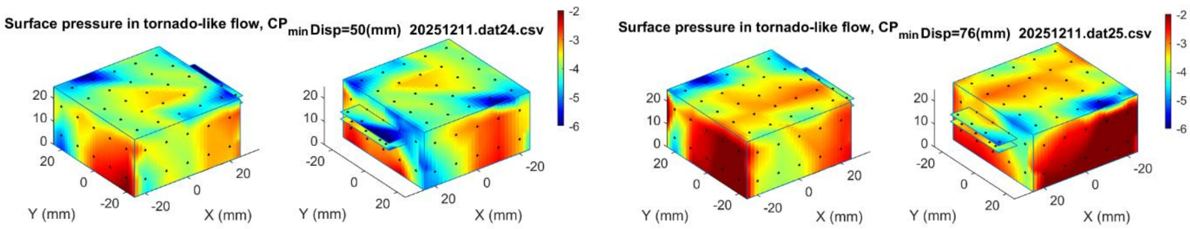




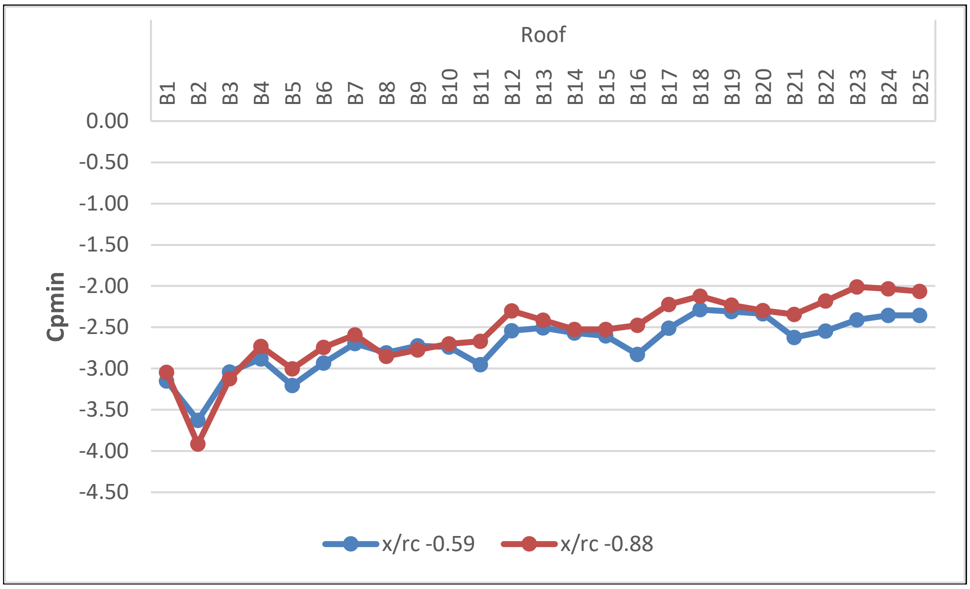
	G1	G3	G5	G7	G2	G4	G6	G8
	Canopy Upper Surface				Canopy lower Surface			
x/rc -0.59	-2.66	-2.76	-3.32	-3.63	-2.33	-2.45	-2.60	-2.72
x/rc -0.88	-2.57	-2.58	-2.90	-3.38	-2.23	-2.25	-2.50	-2.73

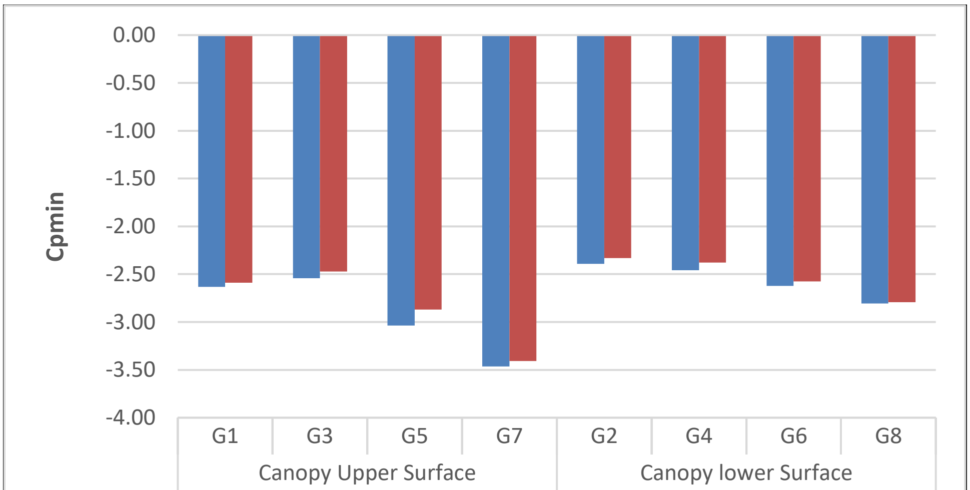


	x/rc=0	x/rc=-0.29	x/rc=-0.59	x/rc=-0.88	x/rc=-1.17	x/rc=0.29	x/rc=0.59	x/rc=0.88	x/rc=1.17
G1-G2	-0.31	-0.24	-0.33	-0.34	-0.15	-0.47	-1.04	-1.34	-1.07
G3-G4	-0.51	-0.31	-0.31	-0.33	-0.10	-0.72	-1.25	-1.33	-1.09
G5-G6	-0.88	-0.81	-0.72	-0.41	-0.09	-1.01	-1.20	-0.94	-0.74
G7-G8	-1.52	-1.18	-0.91	-0.65	-0.49	-1.57	-1.41	-0.72	-0.47

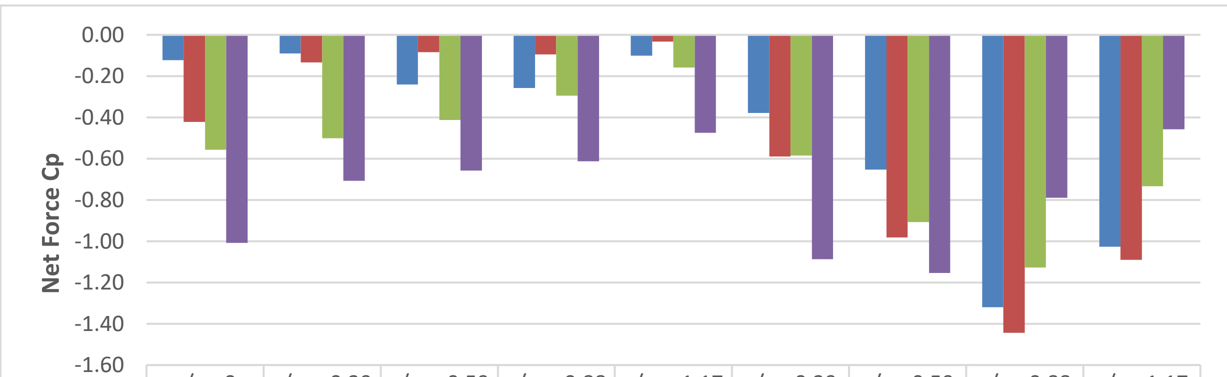


Building Model with rough terrain, plane surface

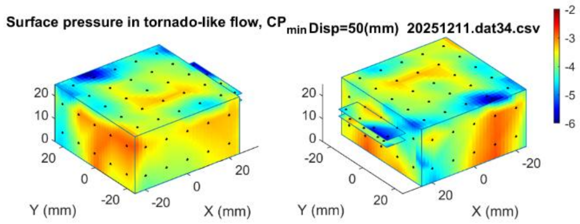


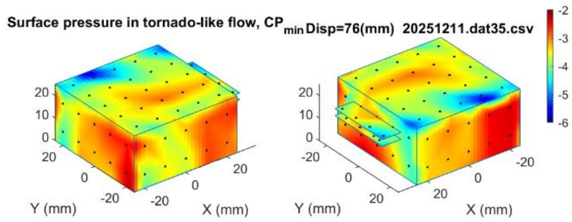


	Canopy Upper Surface				Canopy lower Surface			
	G1	G3	G5	G7	G2	G4	G6	G8
x/rc -0.59	-2.63	-2.54	-3.04	-3.46	-2.39	-2.46	-2.62	-2.81
x/rc -0.88	-2.59	-2.47	-2.87	-3.41	-2.33	-2.38	-2.58	-2.79



	x/rc=0	x/rc=-0.29	x/rc=-0.59	x/rc=-0.88	x/rc=-1.17	x/rc=0.29	x/rc=0.59	x/rc=0.88	x/rc=1.17
G1-G2	-0.12	-0.09	-0.24	-0.26	-0.10	-0.38	-0.65	-1.32	-1.03
G3-G4	-0.42	-0.13	-0.08	-0.09	-0.03	-0.59	-0.98	-1.44	-1.09
G5-G6	-0.56	-0.50	-0.41	-0.30	-0.16	-0.58	-0.91	-1.13	-0.73
G7-G8	-1.01	-0.71	-0.66	-0.61	-0.48	-1.09	-1.15	-0.79	-0.46





4. Published Paper etc.
[Underline the representative researcher and collaborate researchers]

[Presentations at academic societies]

1. One conference paper accepted in CIB World Building Congress WBC2025: Sustainable built environment – the role of the construction community in meeting The United Nation Sustainable Development Goals (UN SDGs), Purdue University. Titled "Evaluation of Wind Pressure on the Low-Rise Buildings and Surrounding Terrain under the Influence of Tornado Like Vortex Induced Aerodynamic Loads"

[Published books] 1.
1.
[Other]
Intellectual property rights, Homepage etc.

4. Research Group
1. Representative Researcher
Rajesh Goyal, Professor, NICMAR Institute of Construction Management and Research, Delhi-NCR, Bahadurgarh, India

1. Collaborate Researchers
1. Nakul Gupta, Associate Professor, NICMAR Institute of Construction Management and Research, Delhi-NCR, Bahadurgarh, India
2. Masahiro Matsui, Professor, WERC, Tokyo Polytechnic University, Japan

5. Abstract (half page)

Research Theme Impact of Tornado vortex induced aerodynamic loads on structural projections in low rise buildings
Representative Researcher (Affiliation): Prof. Rajesh Goyal, NICMAR Institute of Construction Management and Research, Delhi-NCR India Summary

This study investigates the aerodynamic impact of tornado vortex-induced loads on structural projections—specifically attached canopies—of low-rise buildings under varying surface roughness conditions. Experiments were conducted using a tornado-like flow simulator at Tokyo Polytechnic University, where building models fitted with canopies at a 10-degree angle were subjected to tornado-like vortex flows over four different roughness surfaces, including smooth (plane) terrain and three progressively rougher configurations. Surface pressure was measured through pressure tappings placed on all building surfaces, the canopy, and surrounding areas, with the tornado approaching and departing the model in both x and y directions. The findings demonstrate that increasing ground roughness substantially reduces wind pressure coefficients, especially on the canopy surfaces, and shifts the location of peak suction zones, thereby altering the damage risk profile of the structure. The results contribute to expanding the wind pressure database for low-rise buildings with structural projections under tornado-like flows and provide valuable insights for improved wind-resistant design of buildings in tornado-prone regions.