

Experimental simulation of downburst-generated wind loading on building structure

Honghai Li ^a, Jinping Ou ^{a, b}

^a *School of Civil Engineering, Harbin Institute of Technology, Harbin
Heilongjiang Province, China*

^b *Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian
Liaoning Province, China*

ABSTRACT: This paper figures the resulting wind loading on a building structure, as observed in the wind tunnel. In the laboratory, the natural downburst downdraft phenomenon and spreading out is replicated using a round jet impinging onto a flat plate. An extensive experimental simulation was conducted to study the effects of the static downburst at various distances from the prismatic building structure to the jet. The outcome is better understanding of wind loading on buildings produced by downburst generated outflows and this paper evaluates the reliability of experimental simulation to simulate downburst type wind loads on buildings.

KEYWORDS: wind loading; downburst; building aerodynamics; impinging wall jet model

1 INTRODUCTION

Downburst is a weathering phenomenon occurred within a thunderstorm. When the severe convection of atmosphere developed into the vigorous stage, the weight of the precipitation acts to accelerate the air downwards. In the regions where the thunderstorm happens frequently, the strong downward air current could get together in a very short time and suddenly hit the ground surface, the diffusion of the reflected air is expanding in all directions with high wind velocity. So, the downburst is characterized by an intense localized downwards and an outburst of strong winds near the ground.

Fujita described downburst as a small downdraft having an outburst of damaging winds with the horizontal extent of the damaging winds being less than 4 km [1]. A strong downburst can result in damaging winds near 75 m/s. Vickery & Twisdale found that up to 75% of the peak gust wind speeds occurred during thunderstorms [2]. This kind of disaster can destroy the main body of the structures and their exterior-protected construction both. The annual insured property loss from thunderstorm winds in the U.S.A. is \$1.4 billion on an average. Almost all of the damages due to thunderstorms can be assumed to be caused by intense downdraft winds, downbursts.

2 DOWNBURST MODEL

Two methods have been used in general to simulate and study downburst outflow characteristics. These are the impinging wall jet model and the “ring vortex” model (Fig. 1).

There is a steady flow against a flat plate in the impinging wall jet model. This impingement gives rise to a wall jet. As air touches the ground, the vertical component of the wind decelerates downwards and the horizontal component of the wind accelerates outward from the impact center. So, the impact pressure field is generated. However, there are no hydrostatic pressure changes in this model.

In the second type of model, the downwards flow shapes into a vortex ring before approaching the ground. After touchdown, it is the radial outflow, which influences the surface structures. In conclusion the first model seems to replicate the effects of downburst better. The schematic of a wall jet for JAWS is shown in Figure 2 [3].

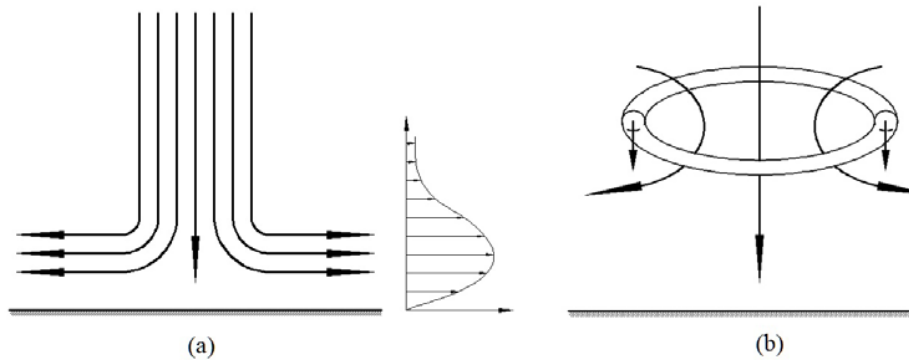


Figure 1 downburst model (a) impinging wall jet model (b) ring vortex model

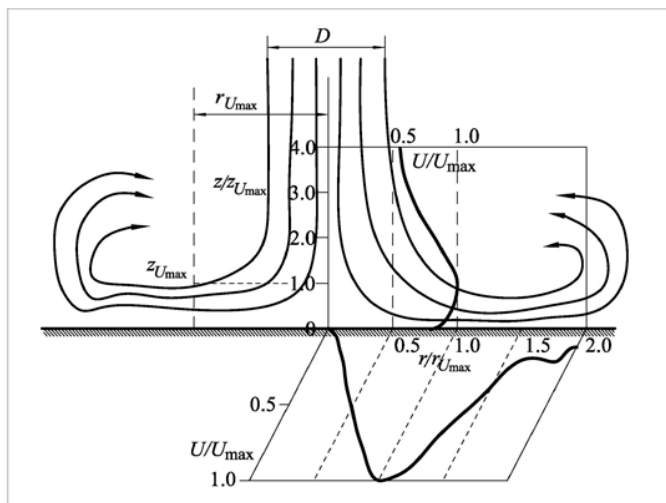


Figure 2 JAWS downburst Schematic [3]

3 EXPERIMENTAL SIMULATION

The current research focuses on the simulation of a stationary downburst using experimental methods.

Compared with the natural boundary layer type wind flow, the extent of work done to study the effects of downburst wind on civil engineering structures is very limited. Only a few case studies on downburst-generated wind loading on building structures have been found in the literature.

The first to use an impinging jet model to simulate downburst were Selvam and Holmes [4]. And then, Holmes [5] and Letchford and Illidge [6] undertook physical model studies of a jet impinging on a wall to study topography effects in downburst. Savory et al. [7] also studied the effects of failure of lattice transmission towers due to tornado and downburst induced wind loading. Sengupta et al. [8] studied the pressure distribution on a cubic building. Chay and Letchford

[9] also studied the effects of stationary jet on cubic building models and used a translating jet (which was moved manually) to see the effects to jet translation speeds [10]. Sengupta and Sarkar [11-13] have reported their findings on laboratory and numerical simulation of both static and translating downbursts and compared them to wind loads on cubic as well as tall buildings due to a translating tornado using the Tornado/Downburst Simulator in the WiST laboratory at Iowa State University. Lin and Savory [14], Kim and Hangan [15] have studied the outflow velocity characteristics and the effects of these wind fields over buildings.

Because the downburst is sudden and random occurrence in nature, there is currently no field data available for study. So, the only possible mechanism to study the effects of downburst type of wind loads on buildings is through laboratory simulation. The primary objective of the present work was to perform a systematic parametric study of laboratory simulation of stationary downburst using an impinging jet to determine the pressure distribution on cube-shaped buildings. The effects of the building's location with respect to the center of the downburst were the main focus of the parametric study.



Figure 3 (a) the equipment of the experimental simulation (b) model building dimensions and pressure tap locations

The experimental setup is shown in Figure 3(a). Here the downburst is modeled as an impinging jet coming out of a pipe and hitting against on a flat wooden board placed below. Roughness elements situated on the plate uniformly could establish the essential coincidence between the experimental simulation and the downburst wind practical condition. The diameter (D) of injection nozzle used to generate the impinging jet was 500 mm. The height (H) of the injection nozzle from the ground board was 1000 mm. So, $H/D = 2$ was resulted. And the impinging jet velocity was used, $V = 10$ m/s. This resulted in a Reynolds number of 3.45×10^5 based on the diameter of injection nozzle (D). The building model was made of rigid plastics. The structure is designed as a high-rise building and the size is set as 100 mm ($W, 0.1D$) $\times$ 100 mm ($L, 0.1D$) $\times$ 200 mm ($H, 0.2D$). The main focus of the parametric study was the location with respect to the center of the downburst of the building model. For the current work, $L_1 = 0$ mm ($0D$), $L_2 = 250$ mm ($0.5D$), $L_3 = 300$ mm ($0.6D$), $L_4 = 400$ mm ($0.8D$), $L_5 = 450$ mm ($0.9D$), $L_6 = 500$ mm ($1.0D$), $L_7 = 550$ mm ($1.1D$), $L_8 = 600$ mm ($1.2D$), $L_9 = 750$ mm ($1.5D$) were used as a series of the various distances from the model to the injection nozzle.

Digital pressure transducers were used to measure the pressures on the surface of the building model. Pressure taps were uniform distributed on the building model that were tested on the front, back, left, right and top surfaces. A total of 225 pressure taps were used with 25 taps on the top surface and 50 taps on the each surface of the others. The arrangement of pressure taps for the building model is shown in Figure 3(b). Four 64-channels scanning valve pressure trans-

ducers were used to measure both the static and fluctuating pressures on the building model. And the sampling rate to acquire the data was 312.5Hz.

4 RESULTS AND DISCUSSION

The pressure coefficient C_p was normalized with the impinging jet velocity V , where C_p is defined as:

$$C_p = \frac{P - P_s}{0.5\rho V^2} \quad (1)$$

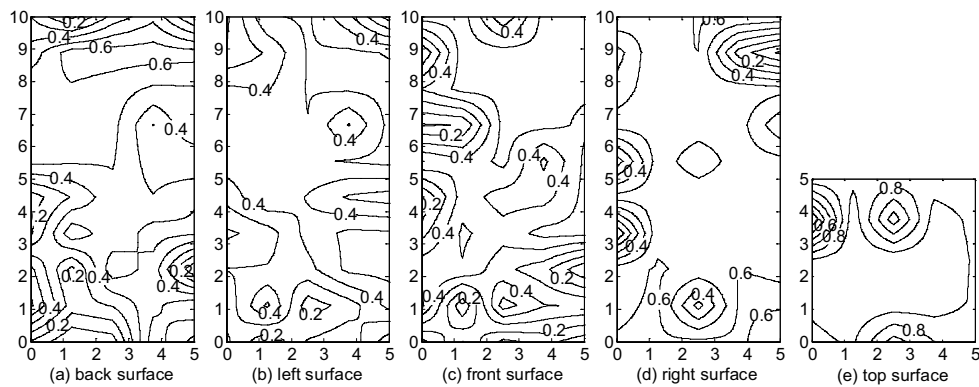


Figure 4 pressure coefficient for building model at 0D

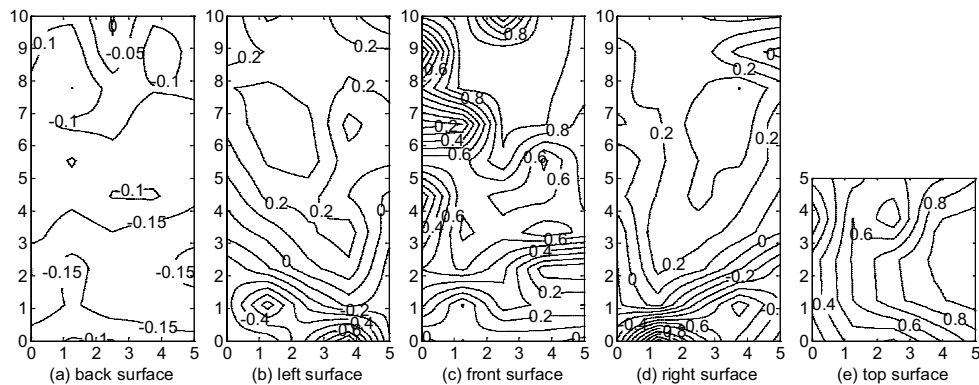


Figure 5 pressure coefficient for building model at 0.5D

The building model is placed directly under the direct impact of the jet downdraft in Figure 4. The impinging jet downwards reaches the top of the building model before attacking on the plate. Not only is the top surface subjected to a significant amount of negative lift, but also the other surfaces are suffering the pressure of the downdraft wind.

At location 0.5D (Fig. 5), same as the building location 0D, there is no flow separation on the top of the building model. The top surface is still partly under the injection nozzle and the pressure distribution is still positive. But the pressure on the back surface is reduced obviously and the wind loadings on the left and right surfaces are decreased slightly. Meanwhile, the front surface is endured stronger wind and the pressure is raised perpendicularly.

As mentioned above, the building model is subjected to a downward force on the top surface and a positive pressure on the front surface. This wind loading generated by downburst is different from those produced by natural wind with a regular straight line type flow, and is not considered in the current design practice.

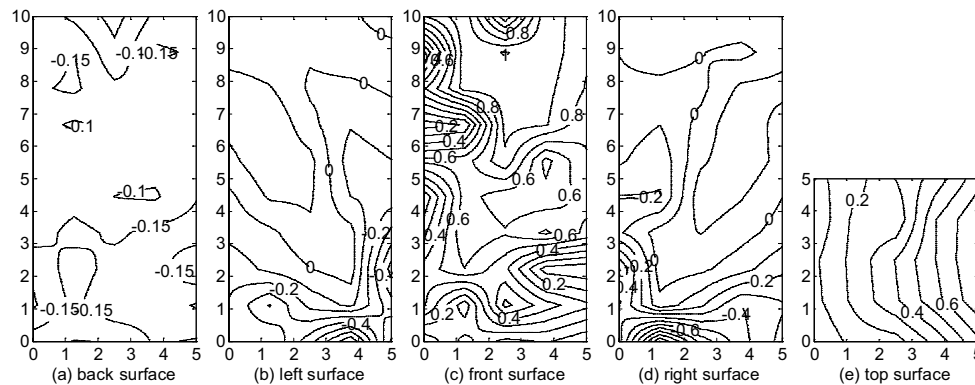


Figure 6 pressure coefficient for building model at 0.6D

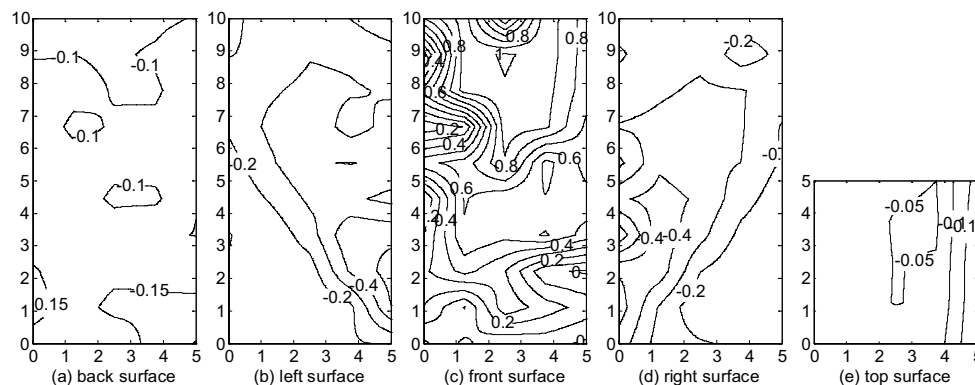


Figure 7 pressure coefficient for building model at 0.8D

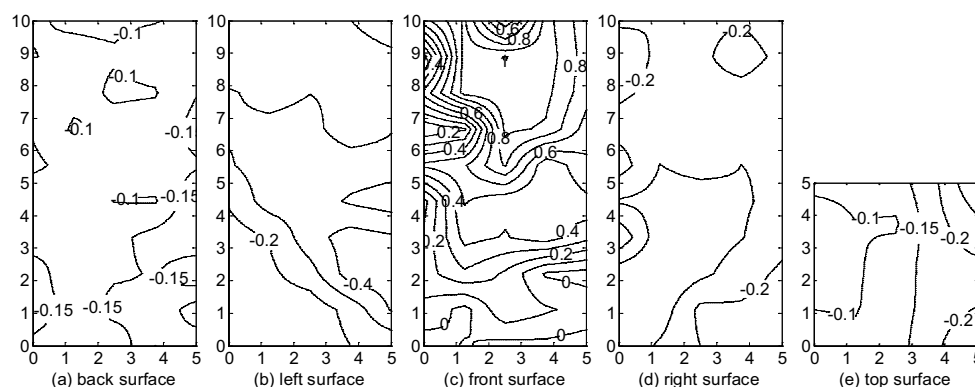


Figure 8 pressure coefficient for building model at 0.9D

When the building model is at a distance of 1.0D from the center location of the injection nozzle, the front surface is subjected to higher positive pressures. Though the pressure distribution on the back surface of the building model is identical almost, there is some difference on the

top surface and the left and right side faces. It can be seen that the pressure distributions are observed to change: the suction or negative pressure is generated (Figs 6-11).

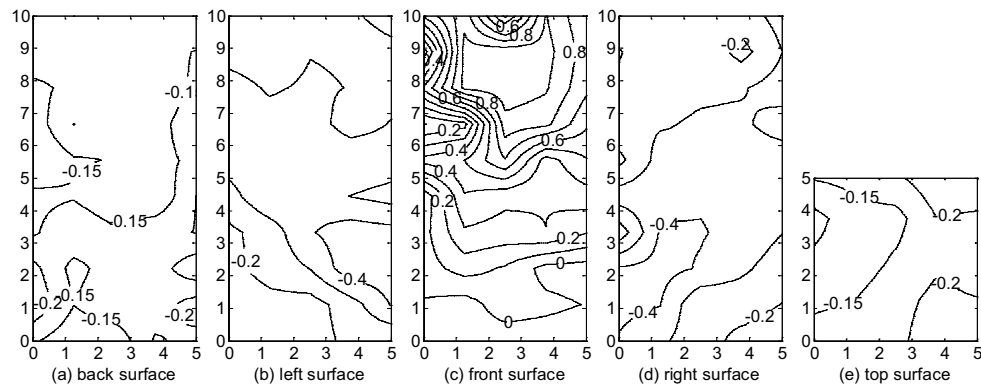


Figure 9 pressure coefficient for building model at 1.0D

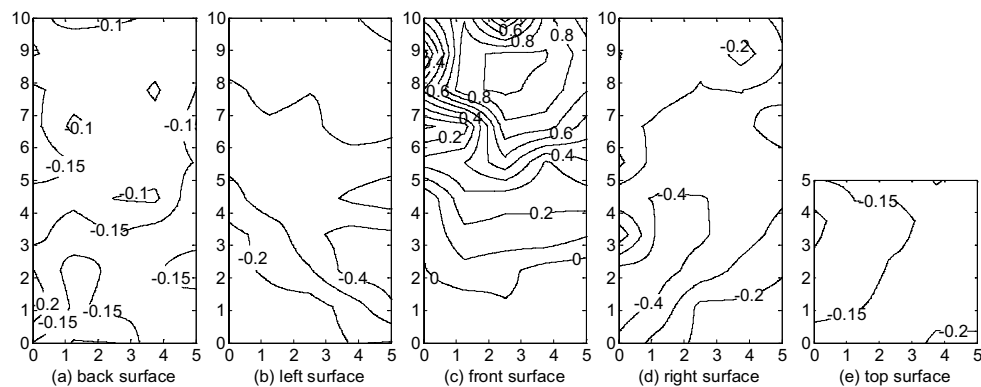


Figure 10 pressure coefficient for building model at 1.1D

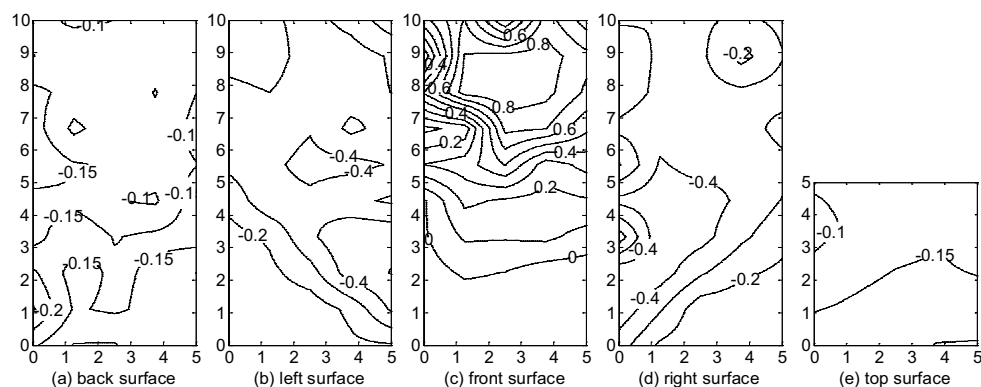


Figure 11 pressure coefficient for building model at 1.2D

When the building is placed at 1.5D (Fig. 12), the positive pressure on the front surface is reduced clearly and the negative pressure on the left and right side face and the top surface is decrease appreciably. So the effect of downburst on the building model is turn to be weakened.

Based on the experimental simulation results, four conclusions can be made with respect to the wind loading generated by downburst on the surface of the prismatic building structure.

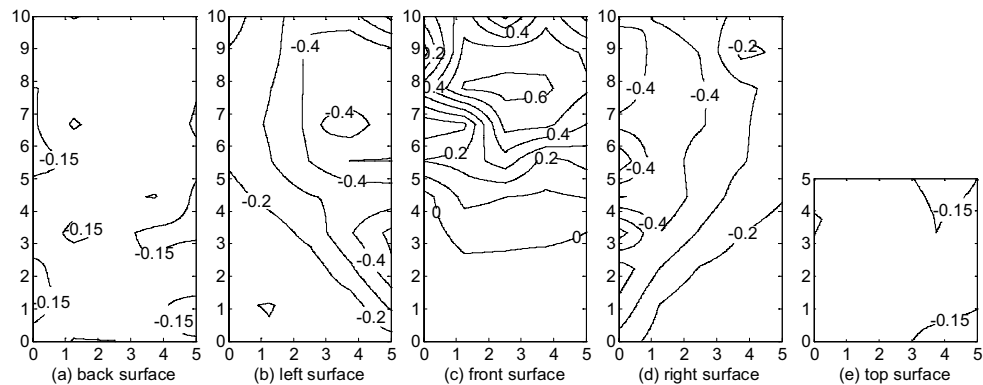


Figure 12 pressure coefficient for building model at 1.5D

The first is that the building is subjected to the maximum wind pressure when it is exactly under the injection nozzle (0D). (Fig. 13)

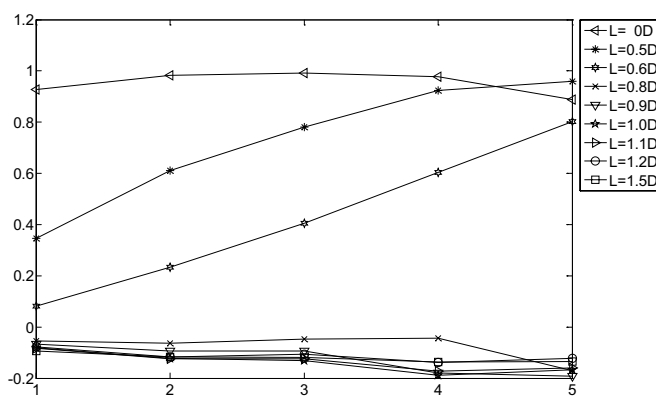


Figure 13 pressure coefficient on top surface

Secondly, the maximum positive pressure on the building is generated when the building is located at 1D from the center of the impinging jet. (Fig. 14)

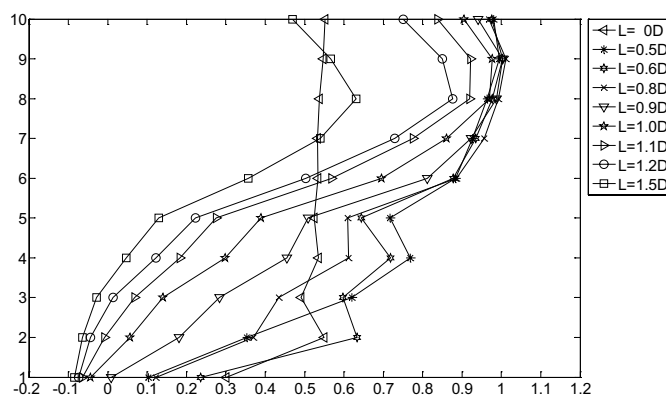


Figure 14 pressure coefficient on the front surface

Thirdly, the pressure distributions on the left and right surfaces are converted from positive pressure to negative pressure for building location $0.8D$ and beyond from the center of the injection nozzle. (Fig. 15-16)

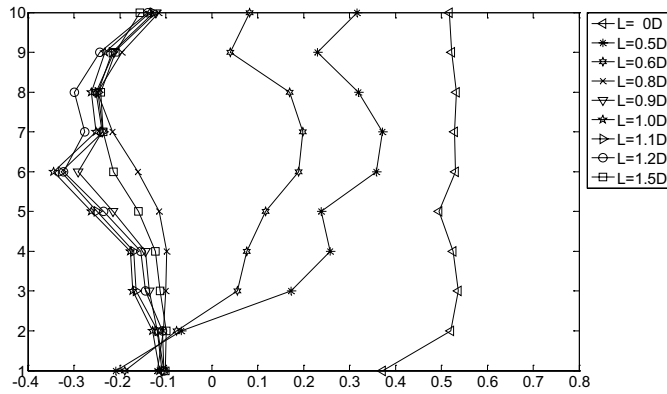


Figure 15 pressure coefficient on the left surface

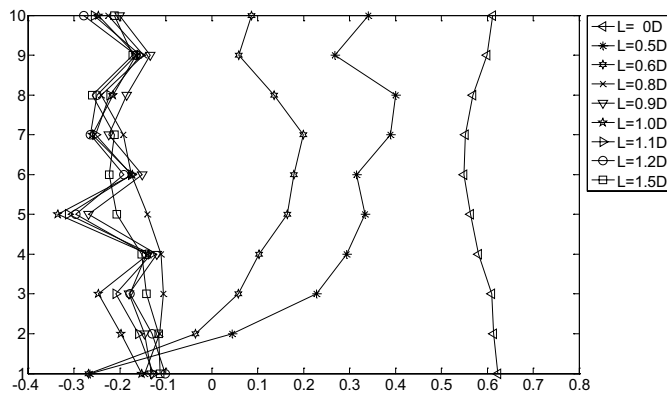


Figure 16 pressure coefficient on the right surface

Fourthly, the wind loading on the back surface is smaller than the other surfaces all but the placed $0D$. (Fig. 17)

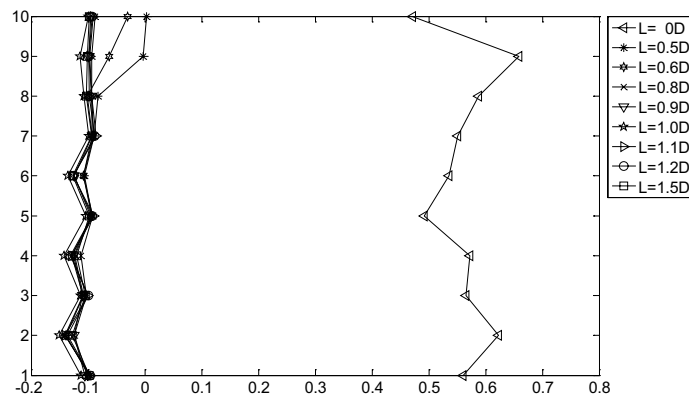


Figure 17 pressure coefficient on the back surface

The maximum and the mean values of pressure coefficients on the surfaces of the building model are given in table 1.

Table 1. the maximum and the mean values of pressure coefficients on the building surfaces

Loca- tions	Back surface		Left surface		Right surface		Front surface		Top surface	
	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean
L=0	0.6589	0.5617	0.5371	0.5083	0.6233	0.5874	0.5517	0.5105	0.9910	0.9532
L=250	-0.1405	-0.0844	0.3717	0.1992	0.4005	0.2351	0.9950	0.7311	0.9593	0.7242
L=300	-0.1392	-0.0958	0.1982	0.0664	-0.2678	0.0683	1.0037	0.7600	0.8015	0.4250
L=400	-0.1242	-0.1005	-0.2483	-0.1473	-0.2404	-0.1594	1.0114	0.6964	-0.1698	-0.0756
L=450	-0.1256	-0.1067	-0.2911	-0.1837	-0.2683	-0.1740	1.0026	0.6104	-0.1912	-0.1253
L=500	-0.1511	-0.1178	-0.3439	-0.2076	-0.3352	-0.2128	0.9773	0.5250	-0.1892	-0.1381
L=550	-0.1404	-0.1050	-0.3280	-0.1962	-0.3124	-0.2000	0.9221	0.4479	-0.1716	-0.1326
L=600	-0.1361	-0.1059	-0.3231	-0.2026	-0.2954	-0.1994	0.8762	0.3953	-0.1377	-0.1117
L=750	-0.1287	-0.1070	-0.2416	-0.1653	-0.2598	-0.1808	0.6308	0.2562	-0.1361	-0.1201

5 SUMMARY AND CONCLUSIONS

The primary mission of this work presented here was to subject an impinging jet to simulated downburst winds and to test a prismatic building model to study the aerodynamic loading.

Wind loadings on the building model at various distances from the center of the injection nozzle were studied. It was found that the top surface experienced a significant amount of pressure when it is straight under the center of the impinging jet. A symbol change in the loads on the building was generated by varying the distance. When the model placed at 1.0D, the wind loadings are somewhat greater than the other locations. This should be paid more attention in the practical engineering of the downburst-prone areas.

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