Experimental Study on Wind Load Characteristics Caused by Wind Damage in Vulnerable Areas of Low-rise Building Roofs
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Abstract. Through the wind tunnel test on the opening of different locations and local areas in vulnerable areas of low-rise building roofs, the distribution characteristics of wind pressure inside and outside the roof caused by roof damage. The results show that the influence of the wind direction angle on the internal pressure caused by the wind is obvious, and the internal pressure caused by the opening on the leeward surface is small and the change law is obviously different from that on the windward surface. The correlation coefficient on the inner side of the roof opening is higher than that on the side of the unopened roof, and the correlation between wind pressure on the measurement points near the opening is larger than other regions.

Introduction
Low-rise buildings are highly vulnerable to severe damage under strong storms. The main forms of damage incorporate doors, windows and roofing areas failure. After the failure of vulnerable areas, the interior of the building will suffer from the impact of accelerated flows through the opening, causing secondary damage to low-rise buildings. The investigation scope of domestic and foreign researchers mainly focuses on the internal pressure caused by wall opening. Guha et al.[1] studied the variation of internal pressure in multi-opening and single-opening of wall, and analyzed the gain function of internal pressure. Ginger et al.[2] compared the measured internal pressure with the theoretically calculated internal pressure through the experiment of openings in different areas of the wall. Guha and Sharma[3] studied the influence factors of wind-induced internal pressure in low-rise buildings with dominate openings, including the internal volume of the building, the opening size, and the wind speed. Sharma et al.[4] investigated the TTU building model with openings on the wall and studied the application of Helmholtz resonance response and quasi-stationary method in internal pressure under various wind directions. In this paper, the spatial distribution characteristics of the wind pressure inside and outside the roof are studied for the local openings of different locations of the low-rise building roof with the slope angle of 18.4°.

Wind Tunnel Test Experiments
Test Model Details
The prototype building of the experimental model is a 18.4° double-slope low-rise building with a geometric size of 12m×8m×9.33m. The model is made of double plexiglass with a scale of 1:40. The test opening positions, shapes and opening ratios are shown in Table 1. The layout of measuring taps on roofs and wind direction angles definition were illustrated in Figure 1. According to the geometrical characteristics of the experimental model, the volume distortion is carried out by connecting the cavity at the bottom of the model to achieve the correct simulation of internal pressure fluctuation characteristics in terms of the Holmes’ similarity ratio formula.
Table 1. Roof opening test cases.

| Cases | Opening location          | opening shape | opening ratio |
|-------|---------------------------|---------------|---------------|
| Case1 | Windward corner square    | 3.1%          |
| Case2 | Leeward roof L-shaped     | 3.1%          |
| Case3 | Upwind corner L-shaped    | Same condition 2 | 3.1%        |
| Case4 | Windward corner gable     | 1.5%          |
| Case5 | Windward corner eaves     | 2.3%          |

Boundary Layer Simulation

The wind tunnel pressure test is carried out at the Wind Engineering Experimental Research Center of Hunan University of Science and Technology. The section size of the wind tunnel test section is 4m×3m×21m. The pulsating anemometer and the pressure scanning valve are used for the pressure test. The sampling frequency in the test is 333 Hz, and the number of samples that can simultaneously collect the measuring points is 10,000. The test wind direction angle is 0°~360° with interval of 10°, and the wind directions such as 45°, 135°, 225°, and 315° are added. The test reference height was set at the average height of the roof, and the layout of the test model is shown in Fig. 2. According to the Code for Building Loads (GB 50009-2012), the category B terrain wind field with a scale ratio of 1:40 was simulated using wedge and rough elements. The controlled wind speed was 11m/s (corresponding to the actual wind speed of 11m/s), the wind field simulation results are shown in Figure 3.

Figure 1. Schematic diagram of model measurement points.

Figure 2. Model layout.

Figure 3. Wind field simulation results.
Wind Pressure Characteristics

Net Pressure Distribution Characteristics

The overall wind pressure distribution characteristics were studied using average net wind pressure coefficient. Taking 0° and 45° wind direction as an example, the results are as follow.

As shown in Fig. 6, under the action of the 0° wind direction, the windward surface of the five kinds of opening configuration roofs is obviously affected by the wind suction, and the windward surface is significantly affected by the wind pressure. The working condition of the windward opening of Fig. 6 is analyzed. It is found that the negative pressure gradually decreases with the increase of the distance from the front edge of the windward, and the positive pressure gradually increases, and the positive and negative pressure transition starts in the roof of the windward roof. The working conditions of the orifice with a small windward length are 1~4, and the net pressure distribution is -0.4~0.22, -0.47~0.2, and the case 3 and 5 have a net pressure of -0.3~0.28, -0.33~0.26 due to the large windward length. Different from the opening of the windward side, the net pressure of the roof when the leeward side is opened is mainly negative pressure, and the positive and negative pressure transition occurs in the leeward ridge area, and the negative pressure of the net pressure reaches a maximum of -0.6, and the distribution of the positive pressure lower, indicating that wind suction has a greater impact on the leeward opening. After the wind-induced destroyed orifice is formed at a wind angle of 0°, the roof will be cracked or even reversed under the action of the front suction, causing secondary damage.

As shown in Fig. 7, under the action of 45° oblique wind direction, although the windward face opening case is positive pressure distributed in the windward ridge and the leeward tail area, but the value is low, the net pressure of the roof is mainly affected by negative pressure. The larger value of negative pressure is also distributed in the area where the roof is affected by the oblique wind direction and the two conical vortex generated at the corner of the roof and the vortex roof vortex shedding. The values are mainly distributed at -0.4~0.1, only case 4 distributed at -0.54~0. When the leeward roof is opened, the net pressure value varies between -0.51~0.23, the roof suffer positive and negative net pressure, the negative pressure action area is consistent with the windward surface opening, and the positive pressure is distributed in the two cone vortex range. Under the action of oblique wind direction, the roof will be damaged by the overall lifting after the opening formation, which will cause serious damage to the low-rise building.

Figure 4. Distribution of average net wind pressure coefficient of roof under 0° wind direction.

Figure 5. Distribution of average net wind pressure coefficient of roof under 45° wind direction.
Fluctuating Pressure Distribution of Full Wind Angle

The fluctuating characteristics of the steady-state internal pressure of the structure with opening are much more complicated than the average counterpart. In order to study the fluctuating characteristics of the roof vulnerable area, the fluctuating values inside and outside the roof is weighted to obtain the distribution law of the fluctuating wind pressure under the influence of the wind direction. The results were shown in Figure 8.

![Fluctuating pressure distribution](image)

Figure 6. Mean pressure coefficient under full wind angles.

As shown in Fig. 8(a) and (b), there is no significant difference in the fluctuating pressure of the outer roof when the openings located in different positions, and the variation trend is basically the same, and the distribution of the fluctuating pressure coefficient of the inner roof is obviously different. The fluctuating pressure coefficient of the outer roof also peaks at the four oblique wind direction angles and is the maximum near the 210° wind direction. The inner roof has the opposite regularity when the leeward opening and the windward opening opened; when the windward opening is opened, the fluctuating pressure coefficient decreases first and then gradually increases in terms of the wind direction angle, while the leeward surface opens. The 180° wind direction is as the limit, showing a completely opposite trend.

Fluctuating Internal Pressure Amplification Factor

To study the characteristics of steady internal pressure fluctuation, the ratio of $\sigma_{pwC}$ (external pressure standard deviation near orifice) to $\sigma_{piC}$ (internal pressure standard deviation) was defined. The orifice measurement points are numbered 1~8 from the gable side to the eaves side, and the fluctuating internal pressure amplification factors of the typical wind angles of 0°, 45°, 90° and 120°are analyzed. The results were shown in Fig. 9.

As shown in Fig. 9(a), the fluctuating internal pressure amplification factor increases gradually along the orifice at the 0° wind direction, and is the largest except for the case 1 at number 3 point, and the other four cases are at the number 2 point. The amplification factor gradually decreases as the number increases, and increases at the number 8 point of the windward corner. Under the 45° oblique wind direction, the number 3~6 points at the corner of the orifice are the most fluctuating amplification factor. At the 90° wind direction, it is the largest at the number 6~7 point in the windward corner. At the 120° oblique wind direction, except for the case 2, the fluctuating internal pressure amplification coefficient of other cases is basically unchanged, while the case 2 is significantly larger than the other cases at the number 6-8 point, and is larger than the numbering points of other positions. Comprehensive comparison of the distribution of the four wind direction angles, the fluctuating internal pressure amplification factor at the orifice is more significant.
Figure 7. Fluctuating internal pressure amplification factor at typical wind direction angle.

Conclusions

1. The wind-induced internal pressure distribution of the low-rise building is relatively uniform, and the internal pressure of the windward surface opening and the leeward opening is significantly different in terms of the wind direction, while the leeward surface opening wind-induced internal pressure is smaller than the windward surface opening.

2. The difference in the fluctuating pressure of the outer roof when the openings located in different positions, and the variation trend is basically the same, and the distribution of the fluctuating pressure coefficient of the inner roof is obviously different.

3. From the eaves to the gable, the magnification factor is gradually reduced. The four wind direction angles and the different position openings are comprehensively compared. The maximum magnification factor is 1.53 at the leeward ridge hole of the 120° wind direction angle.

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References

[1] Guha T K, Sharma R N, Richards P J. Internal pressure in a building with multiple dominant openings in a single wall: Comparison with the single opening situation[J]. Journal of Wind Engineering & Industrial Aerodynamics, 2012, (107–108): 244-255.

[2] Ginger J D, Holmes J D, Kim P Y. Variation of Internal Pressure with Varying Sizes of Dominant Openings and Volumes[J]. Journal of Structural Engineering, 2010, 136(10):1319-1326.

[3] Guha T K, Sharma R N, Richards P J. Influence factors for wind induced internal pressure in a low rise building with a dominant opening[J]. Journal of Wind & Engineering, 2011, 8(2): 1-17.

[4] Sharma R N, Richards P J. The influence of Helmholtz resonance on internal pressures in a low-rise building[J]. Journal of Wind Engineering & Industrial Aerodynamics, 2003, 91(6):807-828.