Analysis of Helmholtz resonance in double-layer flat roof systems using Computational Fluid Dynamics

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Abstract. In recent years, double-layer roof systems with porous panels have been widely used due to their excellent thermal insulation function, but the wind pressure distribution of each layer of double-layer roof is quite different from that of traditional bare roofs. To solve the problem of whether volume distortion is required for the double-layer roof test, this paper takes the double-layer roof structure with porous panels as the research object and studies the influence of volume distortion on the mean wind pressure coefficients of the double-layer roof system by Computational Fluid Dynamics, and the Helmholtz resonance in a double-roof system is further illustrated. The results show that there is Helmholtz resonance in the double-layer roof system, and the volume distortion influences the mean wind pressure coefficients on the upper surface of the roof. Volume distortion has an impact on the internal pressure of a double-layer roof system. If there is no volume distortion, the amplitude of the internal pressure of the double-layer roof system will be underestimated. Volume distortion should be taken for the double-layer roof system in Computational Fluid Dynamics.

Keywords: Double-layer flat roof; Helmholtz resonance; Volume distortion; Computational Fluid Dynamics.

1 Introduction

The double-layer roof system (Fig.1) attached to the porous panels is a new roof insulation system, which helps to prevent overheating or overcooling inside the building, reduces the requirements of heating and cooling systems, improves the comfort of indoor personnel, and can also eliminate the phenomenon of roof condensation in cold climates, and also has the advantages of low cost, rapid installation, and beautiful appearance.

Building roof failure is one of the most common forms of building wind damage. A large number of wind load studies have been carried out for building roofs at home and abroad, but the existing wind load studies are mainly focused on bare roof buildings, and the research on double-roof buildings is not in-depth enough, due to the problem of double-layer roof system scaling, most of the wind tunnel experiments are unconditionally studied. In the major international codes and standards, e.g. ASCE 7-05 (ASCE

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2006), AIJ-RFLB (Architectural Institute of Japan 2004), Eurocode (2005), and GB 50009-2012, there is no provision for these structures.

A distinctive feature of a double-roof system compared to a bare roof is that the airflow creates a Helmholtz resonance in the cavity of the double-roof. The occurrence of Helmholtz resonance will change the response of internal pressure, so that the wind load on the enclosure structure such as panels and roof will change, and the panels are very prone to failure under the combined action of internal pressure and external pressure.

At present, some scholars have conducted experimental studies on the internal pressure and Helmholtz resonance of building façade openings or building bare roof openings [1-5]. However, only Oh [6] showed the internal pressure power spectrum of the double-layer roof system, and the experimental results showed that there was a significant Helmholtz resonance in the internal pressure spectrum, but the Helmholtz resonance was not studied in the literature, and the corresponding volume distortion measures were not taken. In summary, most scholars at home and abroad have not studied the influence of Helmholtz resonance or volume distortion on the internal pressure response of double-layer roof structures.

According to the inadequacy of the available research, this paper studies the influence of volume distortion on the mean wind pressure coefficients of the double-layer roof system through Computational Fluid Dynamics (CFD), to judge whether the double-layer roof system has Helmholtz resonance phenomenon and whether the double-layer roof needs volume distortion in the scale test, which can be used as a reference for future numerical simulation and wind tunnel tests.

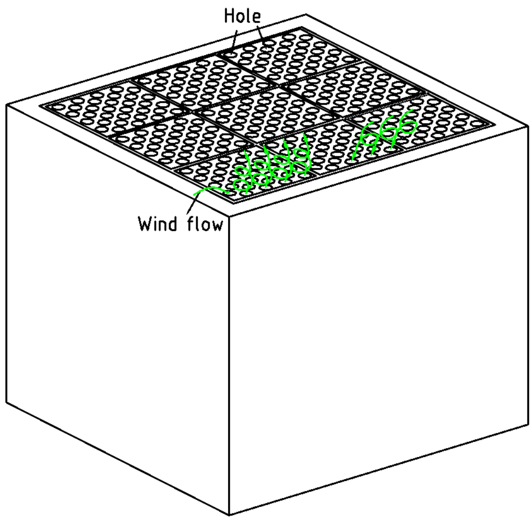


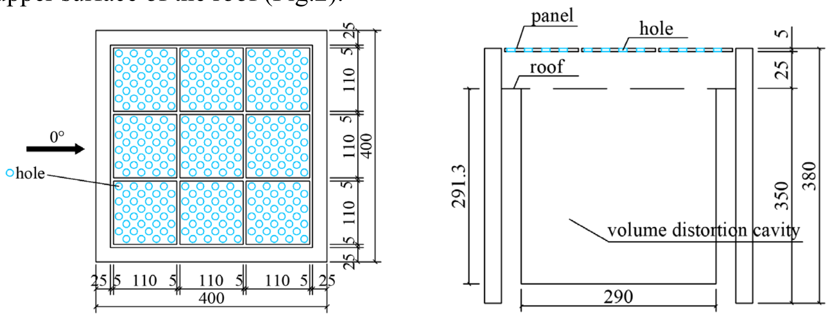
Fig. 1. Geometry of test model

2 Computational Fluid Dynamics

When carrying out the scale test, it is necessary to determine whether volume distortion is needed, to more accurately analyze the law of roof wind pressure distribution. The CFD is simple, fast, and economical, and the results meet the engineering accuracy requirements. In this paper, the CFD is used to simulate the numerical simulation of the double-roof building, and the wind pressure distribution without volume distortion and volume distortion is simulated, and the difference is analyzed. In this way, it is possible to determine whether the scale model needs volume distortion before testing the double roof, and to control the distribution of wind pressure on the roof, to reduce unsafe factors.

2.1 Test models

The experimental design has a double-layer roof model with a scale ratio of 1:20, a height of 380 mm, and a model roof plane size of 400×400 mm. In this paper, the 0-degree wind direction angle is selected to study the mean wind pressure coefficients on the upper surface of the roof (Fig.2).



(a) Top View of test model (b) Vertical section view of test model

Fig. 2. Geometric dimensions of test model

In this paper, two working conditions were selected for study: a double-layer roof without volume distortion and a double-layer roof with volume distortion. The design of the volume distortion cavity is based on the similarity rate of the internal pressure wind tunnel test and the volume distortion requirements, that is, the volume of the cavity is expanded according to the square of the ratio of the full ruler to the reduced scale wind speed, and the volume distortion cavity must follow the principle of "deep and narrow", but it should not be too deep and long. In the test, the velocity scale factor (the ratio of full scale velocity to model scale velocity) is 3, so the internal total volume after distortion should be 9 times that of the original structure. The cavity size of the original structure is 25mm×350mm×350mm (height × width× length), and the cavity volume is $V0=3062500mm^3$. The size of the volume distortion cavity is 291.3mm×290mm×290mm (height × width × length), and the internal total volume after distortion is $9V0=27562500\ mm^3$. There are 9 panels on the double-layer roof model roofing panel, 32 holes with a diameter of 14mm are evenly arranged on each panel, the size of the panels is 110mm×110mm, the cavity depth between the panels and the roof panel is 25mm, and the plane clearance between the panels is 5mm.

2.2 Computational mesh and boundary conditions

CFD software was used to numerically simulate the wind pressure distribution of a double-roof building. Figure 3 shows the computational mesh of the test model. The calculation area's length x width x height is taken as 6400mx4400mx3800m. The calculation area is meshed using an unstructured tetrahedral mesh with good topology. The computational efficiency needs to be considered when meshing the calculation area, so a relatively thin mesh division is needed near the wall to adapt to the large changes in the flow field and a coarser mesh is set on the periphery, and the thickness and thickness mesh are uniformly transitioned.

The inlet boundary adopts the velocity inlet boundary, and the exponential wind profile, turbulent energy, and turbulent dissipation rate are directly specified through the UDF method. The exit boundary adopts the free outflow boundary, the building surface and ground adopt the non-slip wall boundary, and the other boundaries adopt the symmetrical boundary, as shown in Table 1.

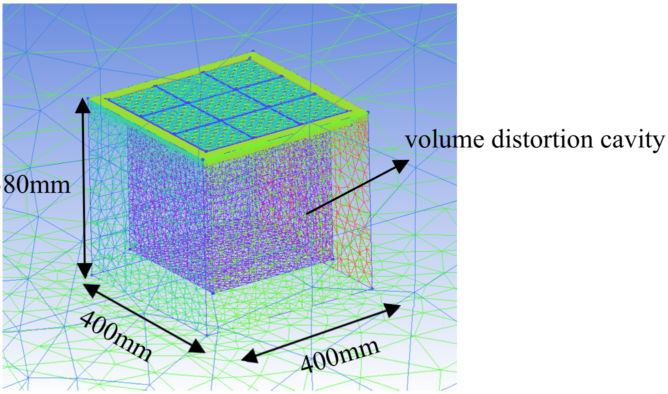


Fig. 3. Computational mesh of the numerical model with volume distortion

Table 1. Boundary conditions

Inlet	**Velocity inlet**
Outlet	**Pressure-outlet**
Ground	**Wall**
Sides, Top	**Symmetry**

2.3 Numerical solution

The various objects existing in the atmospheric boundary layer are obstacles in the wind flow, and various phenomena such as airflow impact, separation, reattachment, and circulation constitute the full flow. According to the blunt-body aerodynamics theory under the action of full flow, the airflow wind in the calculation area is a low-velocity incompressible turbulence process in the atmospheric boundary layer. The basic governing equations of the wind field are the continuity equation of the fluid, the equation of conservation of momentum (Navier-Stokes equation, NS equation), and the energy conservation equation. To simulate this irregular fluid, a flow model needs to be introduced. The k-e model is commonly used in low-velocity turbulence calculation, and the Standard k-e turbulence model is selected in this paper.

3 Results and discussion

3.1 Wind flows

Figure 4 and Figure 5 show the wind flows on the upper and lower surfaces of the panels of the double-layer roof system with and without volume distortion. It can be seen from Figure 4, that the wind mainly flows into the cavity from the second plane gap of the windward leading edge and out of the cavity from the last plane gap. In addition, there is also a small amount of wind flowing in and out of the pores. Under the condition of volume distortion, when the wind flows in from the gap in the second plane of the windward leading edge, it will not only flow out of the cavity from the gap in the last plane, but also flow into the volume distortion cavity from the opening of the volume distortion cavity at the windward trailing edge, and then flow out from the opening of the volume distortion cavity at the windward leading edge. This will significantly change the wind flows on the lower surface of the panel, leading to a change in the internal pressure of the double-layer roof system. Therefore, it is reasonable to speculate that there will be significant Helmholtz resonance in the double-layer roof system.

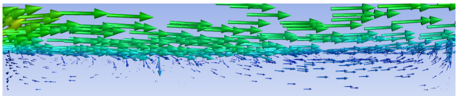


Fig. 4. Wind flows without volume distortion

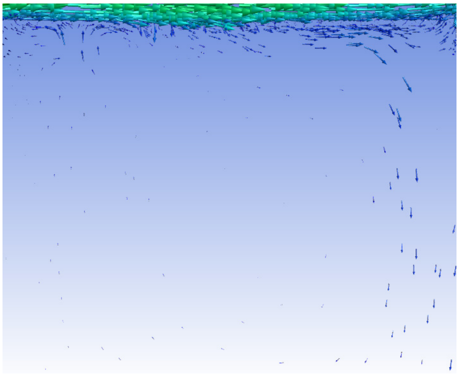
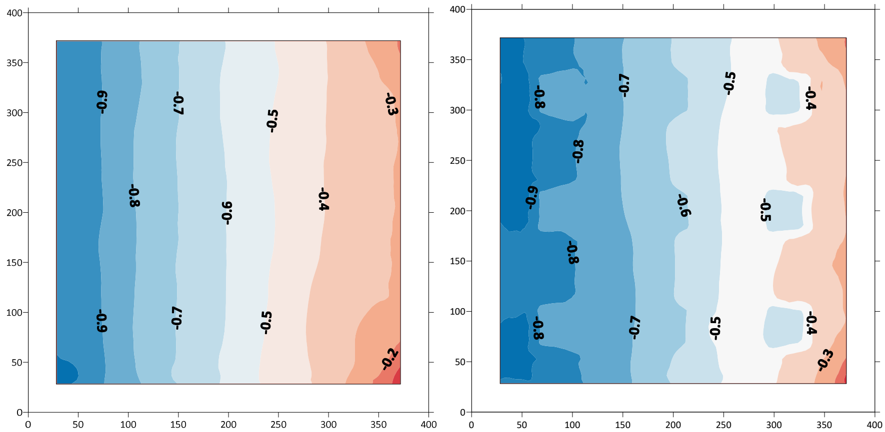


Fig. 5. Wind flows with volume distortion

3.2 Distributions of mean wind pressure coefficients

Figure 6 shows the distribution of mean wind pressure coefficients on the upper surface of the roof of the double-layer roof model without volume distortion and with volume distortion at a 0 ° wind direction angle. It can be seen from the figures that the distribution of the mean wind pressure coefficients is very similar, with a large mean negative pressure zone at the windward edge. The amplitude of the wind pressure coefficient gradually decreases along the incoming wind direction. The mean negative pressure amplitude with volume distortion is larger than that without the volume distortion model in most roof areas. Therefore, volume distortion has an impact on mean wind pressure coefficients on the surface of the double-layer roof.



(a) without volume distortion (b)with volume distortion

Fig. 6. Mean wind pressure coefficients

In the future, it is necessary to use Large Eddy Simulation or wind tunnel testing methods to study the double-layer roof system, and further investigate the influence of volume distortion on the RMS wind pressure coefficient, peak wind pressure coefficient, panel wind force coefficient of the double-layer roof system.

4 Conclusions

In this paper, the influence of volume distortion on the mean wind pressure coefficients of a double-layer roof system is studied by Computational Fluid Dynamics. Summarizing the work of this paper, the following conclusions can be obtained:

1. There is Helmholtz resonance in the double-layer roof system.

2. The volume distortion influences the mean wind pressure coefficients on the upper surface of the roof of the double-layer roof. The model without volume distortion will underestimate the amplitude of internal pressure in the double-layer roof system. Therefore, in CFD or wind tunnel tests, the double-layer roof system should be tested with volume distortion to obtain the correct wind load design value.

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