August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering
ICWE 16

Comparison of tornado-induced wind pressures on Multi-span Gable-roof and Sawtooth-roof industrial buildings

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SUMMARY:
This study presents the comparison of external wind pressures on a multi-span sawtooth-roof industrial building with that on a multi-span gable-roof industrial building through wind pressure measurements conducted in a tornado simulator. Given that the characteristics of tornado-induced wind pressures on the gable-roof industrial buildings were previously analyzed by the authors, this study focuses on the wind pressure characteristics of the multi-span sawtooth-roof industrial building under the tornado attack. The test model is designed as a three-span low-rise building with a sawtooth roof based on the practical measured sizes of the light steel industrial buildings destroyed in the Suzhou tornado, China (2021). Considering the roof angle and the distance from the tornado-like vortex center to the building as the parameters, the most unfavorable peak pressure coefficients are calculated for all building surfaces. The results of the most unfavorable peak pressure coefficient illustrate that the wind-ward roof and back surfaces on the side span experienced the most unfavorable external pressures under the tornado attack, and the sawtooth roof shape and a larger roof angle facilitate the generation of higher external pressure coefficients.

Keywords: tornado-induced pressure, multi-span sawtooth-roof industrial building, physical simulation

1. INTRODUCTION

Tornadoes have been widely recorded in China over the past few decades, causing severe destruction of the low-rise buildings. It is necessary to analyze the effect of the tornado wind load on structures precisely, and the physical simulation conducted through the tornado simulator has been a reasonable and reliable tool for the analysis. Dynamic wind pressures on structures under tornado-like vortices can be quantified through the physical simulation. There have been various types of research about aerodynamic pressures and loads on low-rise buildings, most of them compared the experimental result with the specification. For instance, the wind pressures on components and cladding of low-rise buildings were analyzed, and the changes of wind pressure zones specified in ASCE 7-10 were recommended (Duthinh et al., 2017). The characteristics of the wind loads acting on multi-span roofs of low-rise buildings were analyzed by conducting wind tunnel tests with models whose parameters are roof shape, roof slope and the number of spans, and the comparisons with ASCE 7-16 design values were performed (Gavanski and Nishimura, 2022).

Among the previous analysis, typical low-rise buildings with a single-span gable roof were widely tested under the simulated tornado winds, while various low-rise buildings were only tested in the boundary layer wind tunnel. It is inevitable to consider the effect of multiple spans, different roof shapes and roof angles on the tornado-induced dynamic pressures on the external surfaces of the low-rise building. The design of the model utilized in this study is based on the destroyed light-steel industrial buildings in the Suzhou tornado (2021), so that the result of the study can be valuable for the improvement of the wind-resistant design.

2. RESEARCH METHOD

2.1. Tornado simulator and test model

The dynamic external pressures on a three-span sawtooth-roof low-rise building model were collected using the tornado simulator at Tongji University. The simulated tornado is rotated anticlockwise, and the position of the tornado goes from -240 mm to 240 mm. The roof angle of the building model is set as 20 and 30 degrees, respectively. Fig. 1 illustrates the general arrangement of the tornado simulator and the test model. The pressure taps layout and dimensions of the building model are presented in Fig. 2. To simulate Suzhou tornado, which is an EF2 to EF3 tornado, the geometric scale ratio is set as 1:400.

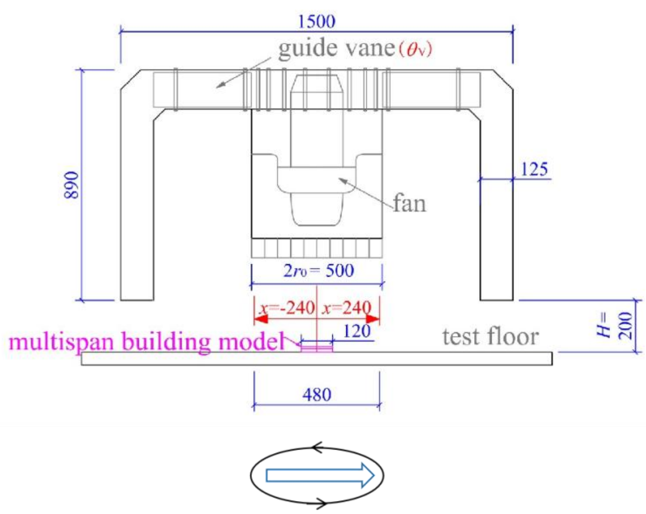


Figure 1. General arrangement of the tornado simulator and the test model (Unit: mm).

2.2. Most unfavorable peak pressure coefficients

The test condition setup in this study follows the previous setup for the three-span gable-roof building presented in 8EACWE. For the three-span industrial building model, the main parameters that may affect the external pressure coefficients are the roof shape and angle of the building, the position of the tornado center, the building orientation, and the swirl ratio of the tornado-like vortices. In the previous study, the effect of building orientation and swirl ratio was analyzed in detail. Therefore, in this study, only the most unfavorable cases of them are considered for the analysis of the three-span sawtooth-roof building. The building orientation is set to be 0 degrees, which indicates that the left surfaces of the model are the wind-ward surfaces. The swirl ratio is set to be 0.23, which simulates a single-vortex core tornado. The most unfavorable peak pressure coefficient on each surface of the building model is mainly investigated in this study, which is selected where the smallest negative (largest absolute) peak value occurs among all pressure taps on that surface.

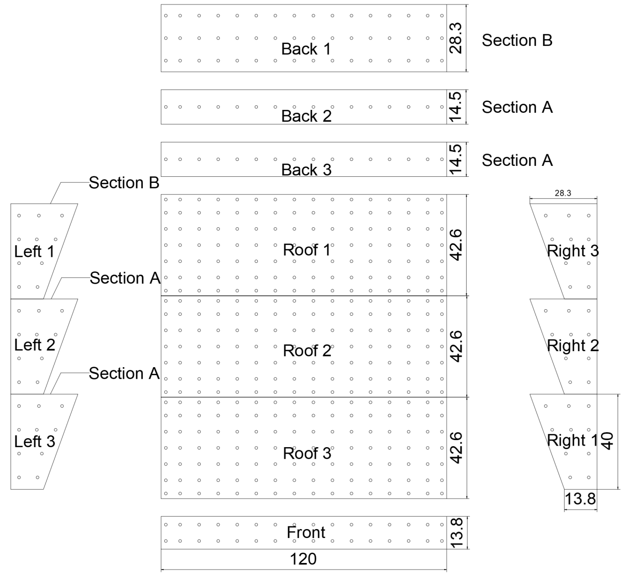
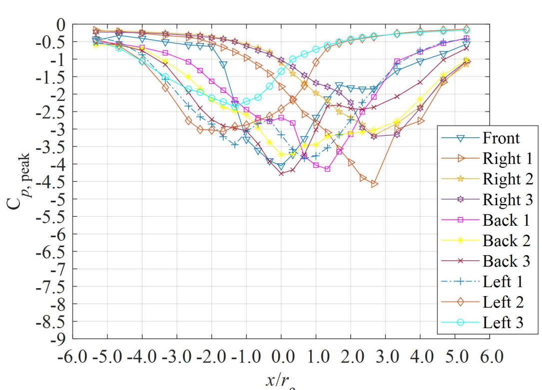


Figure 2. Pressure taps layout and dimensions of the building model (Units: mm).

3. RESULT AND DISCUSSION

The variation of $C_{p,\text{peak}}$ over x/r_c for the case of a) sawtooth-roof building with a 20-degree roof angle, b) sawtooth-roof building with a 30-degree roof angle, and c) gable-roof building with a 20-degree roof angle are illustrated in Fig. 3. For the three-span sawtooth-roof building, the most unfavorable peak pressure coefficient occurs at roof 1 and roof 3 in both cases, which indicates that the side-span roof surfaces suffer the peak pressures. This phenomenon also appears on the gable-roof building. However, back surface 3 of the sawtooth-roof building, which is in between the roof surface 2 and 3, shows high pressure coefficient in both two cases, while this phenomenon is not apparent for the gable-roof building. The reason for this peak is that back 3 is the wind-ward surface when $x/r_c = 0$ for the sawtooth-roof building. With the increase of the roof angle for the sawtooth-roof building, the most unfavorable peak pressure coefficient rises in magnitude sharply, and is always greater than that for the gable-roof building.



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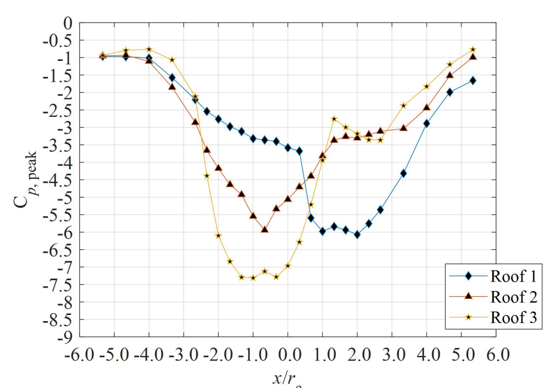

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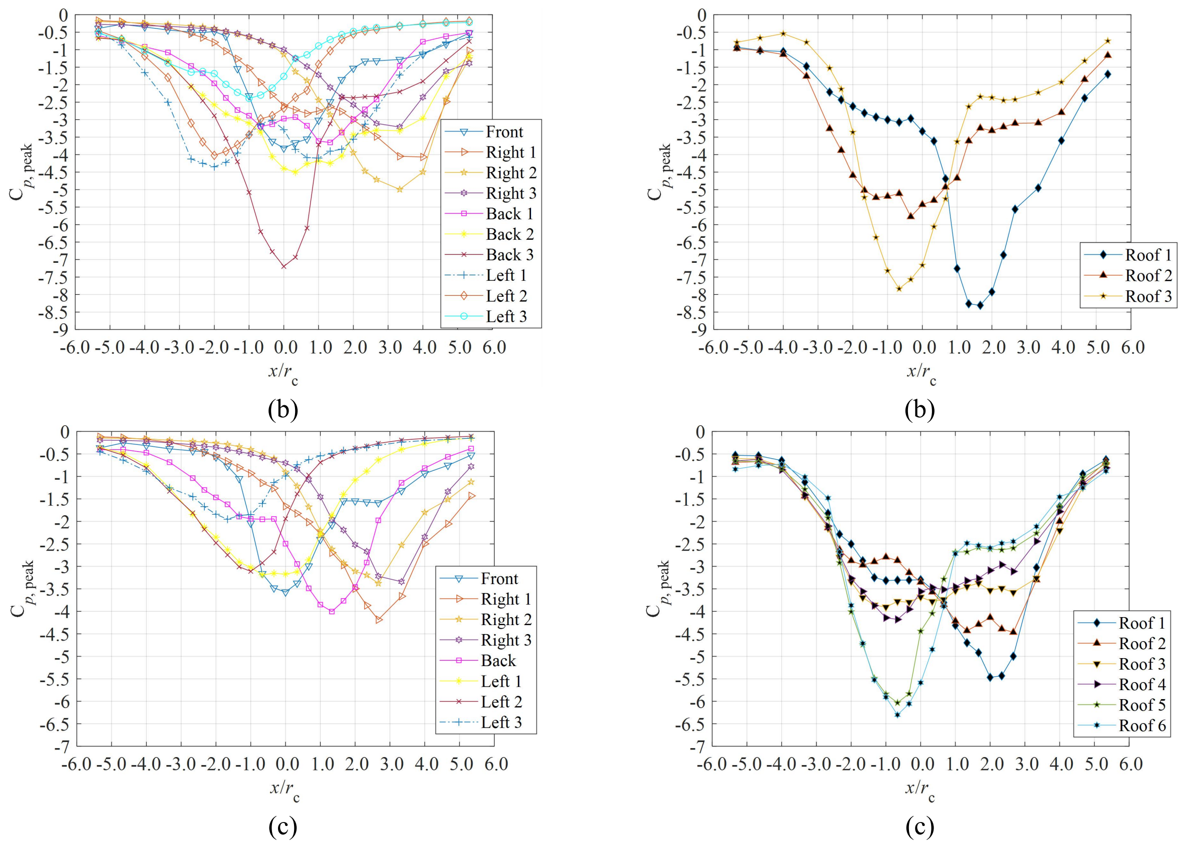

Figure 3. Variation of most unfavorable peak pressure coefficient over distance.

4. CONCLUSIONS

The dynamic external pressures on three-span sawtooth-roof low-rise buildings under a tornado-like vortex were analyzed through physical simulation. The most unfavorable peak pressure coefficients are strongly affected by the roof shape and roof angle of the building. For the building with a sawtooth roof and a larger roof angle, the wind-ward roof and back surfaces on the side span experienced the most severe external pressures.

ACKNOWLEDGEMENTS

This study is funded by the Natural Science Foundation of China (NSFC) (Grant No. 51878504 and 52178502), and the Research Foundation of State Key Laboratory of Disaster Reduction in Civil Engineering (Grant No. SLDRCE19-B-01), which is gratefully acknowledged.

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