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

CFD-assisted design of canopy in complex urban environment: case study

Shuyi Liu [1], Jie Wu [2], Zhengwei Zhang [3]

[1] *Arup International Consultants (Shanghai) Co., Ltd., Shanghai, China, shu-yi.liu@arup.com*
[2] *Arup International Consultants (Shanghai) Co., Ltd., Shanghai, China, jaycie.wu@arup.com*
[3] *Arup International Consultants (Shanghai) Co., Ltd., Shanghai, China, zheng-wei.zhang@arup.com*

SUMMARY:
Tradition canopy design process is one-way: from architects to structural engineers and then wind engineers. Based on a specific project which is a canopy surrounded by four towers in Shanghai, this paper aims to provide a generic CFD-assisted design process of canopy in complex urban environment. First, after deciding the location of canopy, through conducting CFD simulations, better architectural shape with smaller wind load and high pedestrian environment cannot be satisfied, which requires further aerodynamic solution. Furthermore, to reach a balance of structural performance and wind load, models with three different rise-span ratios have been analysed. Results indicate that wind load distribution of middle-rise canopy is more uniform due to smoother surface curvature and peak wind suction reduce 25%. Comparing wind load combination of aluminium canopy and steel canopy, steel is adopted in further design. Lastly, wind load distribution of canopy in two phases have been compared to ensure structure stability.

Keywords: canopy, CFD-assisted design, urban area

1. INTRODUCTION

Recently, free-standing canopies are widely used in public. Due to light weight and large span, canopies are usually vulnerable to wind load. As required in design code, wind tunnel test need conducting to obtain wind load of canopies. Nevertheless, shape of canopy may change frequently, which requires CFD simulation to conduct quicker assessment. Collies et al., 2020, and Poitevin et al., 2013, focus on canopy wind load distribution on specific shape with different shape parameters. Next to these studies, Llanera et al., 2018, focus on wind-induced responses of canopies like wind-induced rain. Besides, the impact of canopy to pedestrian comfort also has been studied, especially for downtown stadium project. (Blocken and Persoon, 2009；Shi and An, 2017)

Most studies only work on specific aspect but not relate to actual design process. Therefore, based on a specific project, this paper aims to provide a generic CFD-assisted design process about canopy design in complex urban environment.

1.1. Project information

The whole project is located at Shanghai near the Huangpu River, surrounded by several high-rise buildings. Canopy settled on the top of the podium. The canopy, as shown in Fig.1 is cloud-shape, with length of nearly 120 meters and width of 60 meters. The lowest point is 46 m high while the highest point will be further discussed in the following section.

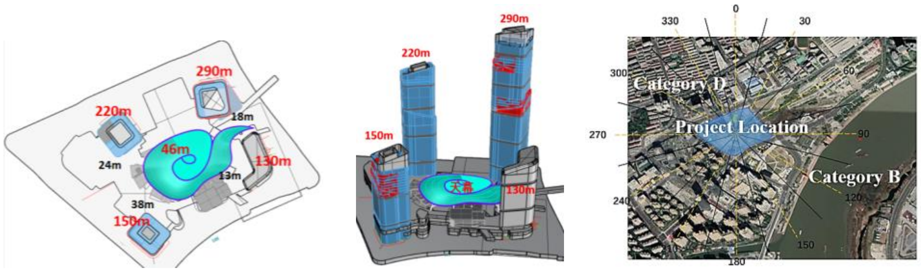
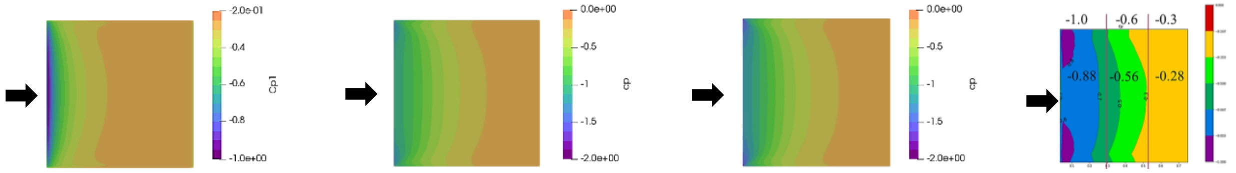


Figure 1. Project overview.

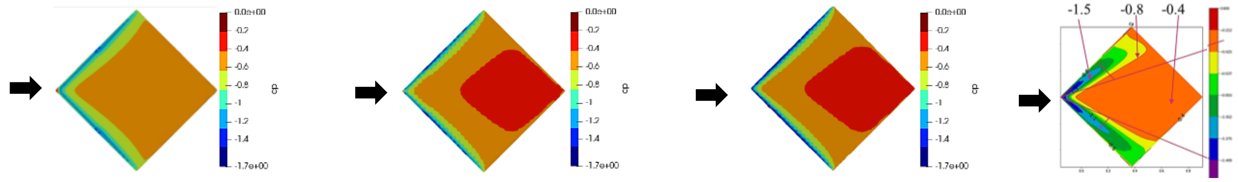
2. STATE OF ART

2.1. Validation study

In this paper, closure is provided by RNG k-ε turbulence model and snappyHexMesh is used to achieve computation grid. Since this paper focus on canopy, planar roof which is set as 120m x 120m x 46m is chosen to conduct benchmark. Three models with different smallest cell size have been analysed and compared with the results of wind tunnel test. Fig. 2 indicates that mostly mean pressure coefficient of CFD simulation results show overall good agreement with the results of WTT. Grid 2 is nearly grid independent and can satisfy accuracy requirement for conceptual design stage, which is further adopted in following sections.



0° (Grid 1) 0° (Grid 2) 0° (Grid 3) 0° (WTT)



45° (Grid 1) 45° (Grid 2) 45° (Grid 3) 45° (WTT)

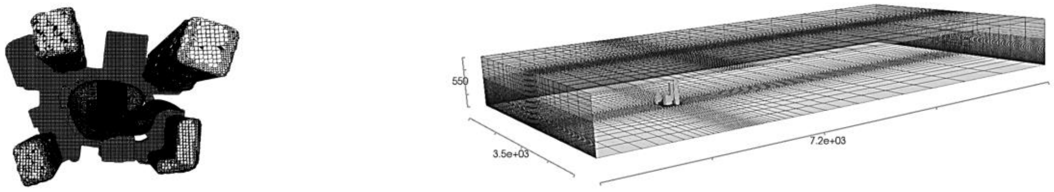
Figure 2. Comparison of Cp-distribution over planar roof in CFD and wind tunnels.

2.2. Model in OpenFOAM

The model and computation domain in OpenFOAM is shown in Fig. 3. Canopy itself is detailed modelling while surroundings are simplified. Others simulation parameters are listed in Table 1.

Table 1. Simulation parameters.

Catalogue	
Algorithm	SIMPLE algorithm
Pressure interpolation	Second order
Ground roughness height	0.1 (Category B) / 2.0 (Category D)
Wind direction	0° /30° /60° /90° /120° /150° /180° /225° /240° /270° /300° /330°



top view of the model

computation domain overview

Figure 3. Model in OpenFOAM.

3. PEDESTRIAN WIND ENVIRONMENT

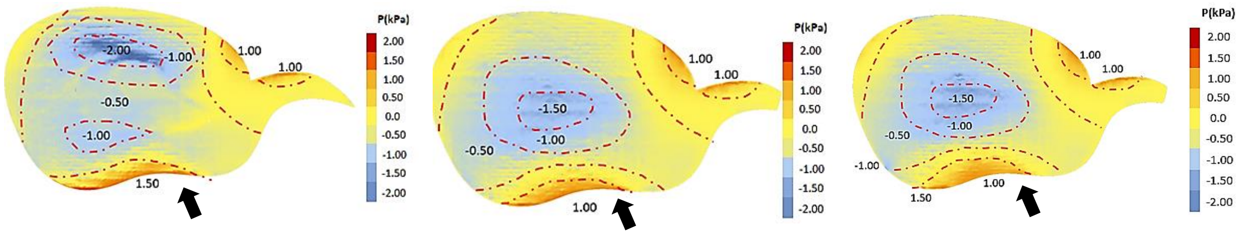
Based on design layout, canopy is at the top of podium which is designed as retail and restaurant. Simulation results imply that there is windless area in summer and windy area in winter for season return period wind speed. Therefore, building functional zoning need further considering.

Since canopy is in typhoon area, pedestrian safety should also be ensured. Results demonstrates that one-year return period peak wind speed reaches at 20 m/s, which shows pedestrian safety cannot be guaranteed. Further aerodynamic design solutions are required like setting small canopy.

4. STRUCTURAL DESIGN WITH CFD

Canopy form-finding and materials will influence both wind load and structural load, which requires a balance between them.

Inverse hanging method is often adopted in canopy form-finding, using shape after inverse hanging to reduce stress. Increasing rise-span ratio in it can modify structural efficiency but result in larger wind pressure. To reach a balance, simulation of shapes with different rise-span ratios after inverse hanging method has been conducted, further assessing wind load based on modal results. Fig. 4 indicates that wind-load distribution of canopy is more uniform due to smoother surface curvature after inverse hanging method and peak wind suction reduces 25%. However, for high-rise canopy, there is more wind pressure. Therefore, middle-rise canopy is chosen for next stage.



150° (prototype)

150° (middle-rise canopy)

150° (high-rise canopy)

Figure 4. Wind load distribution of different canopy shape.

Canopy with lighter materials will be more vulnerable to wind suction. Based on modal analysis and CFD simulations, aluminium canopy is vulnerable to both wind pressure (-1.7 kPa) and wind suction (1.6 kPa) while the control load case is only wind pressure (-2.8 kPa) for steel canopy. After overall consideration, steel canopy is adopted.

5. INFLUENCE OF SURROUNDING INTERFERING BUILDINGS

Generally, podium and canopy are often built up first and while towers are still on construction. Consequently, the construction phase of the project can be divided into two phases. Results indicate that there is larger wind pressure due to its own windward geometry in Phase 1 (without towers) while larger wind suction due to vortex shedding of towers in Phase 2 (all constructed). For structural design, both phases should be checked.

6. CONCLUSIONS

This paper provides a generic CFD-assisted design process for canopy in complex urban environment. CFD simulations are conducted for 1) pedestrian wind environment assessment; 2) wind load of canopy with different rise-span ratios; 3) wind load of canopy in different construction phases. Conclusions can be drawn as followed:

1) For season return period wind speed, there is windless area (wind speed ratio < 0.1) in summer while maximum wind speed is nearly 3 m/s in winter, which implies pedestrian comfort cannot be guaranteed and requires further function zoning. Besides, for one-year return period wind speed, peak wind speed reaches at 20 m/s which indicates pedestrian safety cannot be ensured. Further aerodynamic design solutions are required.

2)It is demonstrated that wind load distribution of canopy after form-finding is more uniform than prototype due to smoother surface curvature. The maximum wind suction of middle-rise canopy and high-rise canopy can reduce 25% than prototype while peak wind pressure increase 50% than middle-rise canopy. Considering dynamic characteristic and structural load combination, steel canopy is only controlled by wind pressure while aluminium canopy is controlled by both suction and pressure.

3)For Phase 1 (without towers), there is larger wind pressure due to canopy shape on windward side. For Phase 2 (all constructed), there is larger wind suction due to vortex shedding of adjacent towers. Wind load distributions in two construction phases are apparently different, which requires structural design to take both into consideration.

ACKNOWLEDGEMENTS

The work described in this paper is fully supported by Young Engineer Funding of Arup.

REFERENCES

Blocken, B., Persoon, J., 2009. Pedestrian wind comfort around a large football stadium in urban environment: CFD Simulation, validation and application of the new Dutch wind nuisance standard, Journal of Wind Engineering and Industrial Aerodynamics 97, 255-270.

Collies, J., Degroote, J., Mollaret, M., De Laet, L., 2020. Mean pressure coefficient distribution over hyperbolic paraboloid roof and canopy structures with different shape parameters in a uniform flow with very small turbulence, Engineering Structure 205, 1100343.

Llanera, J., Cabezuelo, L., Bilbao, A., 2018. Application of CFD Simulations of wind-driven rain (WDR) on the new roof extension of San Mames new football stadium, Journal of Wind Engineering and Industrial Aerodynamics 178, 105-111.

Poitevin, A., Natalini, B., Godoy, L.A., 2013. Pressures on open canopy structure with parapets under wind loading, Engineering Structure 56, 850-867.

Shi, L., An, R., 2017. An optimization design approach of football stadium canopy forms based on filed wind environment simulation, Energy Procedia 134, 757-767.