

Wind force characteristics of scaffoldings with sheets

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ABSTRACT: Wind loads have a very severe effect on the stability of scaffolding, especially when is covered with sheets of 0% porosity, which significantly changes the wind forces acting on it. Wind tunnel experiments were carried out based on a prototype of scaffolding attached to a medium-height building, and covered with sheets of 0% porosity. Wind force characteristics of scaffoldings with sheets for different building opening ratios and scaffolding arrangements were studied. For most scaffolding arrangements, both maximum positive and minimum negative wind force coefficients tended to be smaller when the building opening ratio was increased. When scaffolding was arranged on one side or encompasses half the building, local wind force coefficients of the scaffolding sheets were more sensitive to changes of building openings.

Keywords: Scaffolding sheet; Wind force coefficient; Wind tunnel experiment; Building opening ratio; Scaffolding arrangement.

1 INTRODUCTION

Scaffolding is a temporary structure used to support people and material in the construction or repair of buildings and other large structures. It is usually a modular system of metal pipes or tubes. For safety, environmental and noise considerations, it is commonly net clad or sheet clad. On construction sites, scaffolding collapses sometimes occur due to strong wind when the scaffolding is covered with sheets of 0% porosity, which significantly increases the wind forces acting on it (Katsutoshi Ohdo, 2005). Furthermore, buildings of different structural types have different kinds of wall openings during construction stages, which also significantly affect wind forces (F. Yue, 2005; Yasumichi Hino, et al, 2005). Thus, the influence of building opening ratios should be considered in the design stage when estimating wind forces acting on scaffolding. For different construction sequences and engineering needs, for a common rectangular section building, scaffolding arrangements vary from one side to all four sides, which affect the wind flow between building and scaffolding (Yasumichi Hino, et al, 2005).

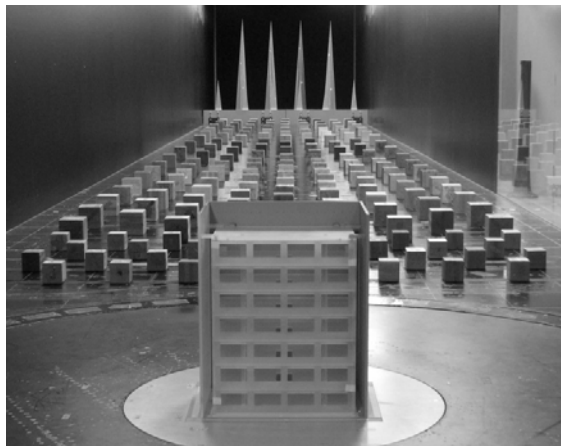
In this study, wind tunnel experiments were carried out based on a prototype of scaffolding attached to a medium-height building, and covered with sheets of 0% porosity. A systemic study of the influence of different building openings on wind forces acting on scaffolding covered with sheets was conducted, and scaffolding arrangements were also taken into account.

2 EXPERIMENT SETUP

The experiments were carried out in the Boundary Layer Wind Tunnel of the Tokyo Polytechnic University, Japan. Two scaffolding sheet models 5mm thick and 0.363m high were selected to

simulate 0% porosity sheets covering scaffolding, attached to a medium-height building with 1/75 geometric scale.

304 pressure taps were arranged on both outer and inner sides of the two sheet models (Sheet A and Sheet B). 4 building opening ratios and 6 scaffolding arrangements were considered. Building opening ratios ϕ_B for Models B0, B20, B40, B80 were 0%, 20%, 40%, 80%, respectively, and two dummy models (no pressure taps) of sheets were used in some scaffolding arrangements. Fig. 1 shows experiment pictures. Fig. 2 shows building models and scaffolding arrangements.

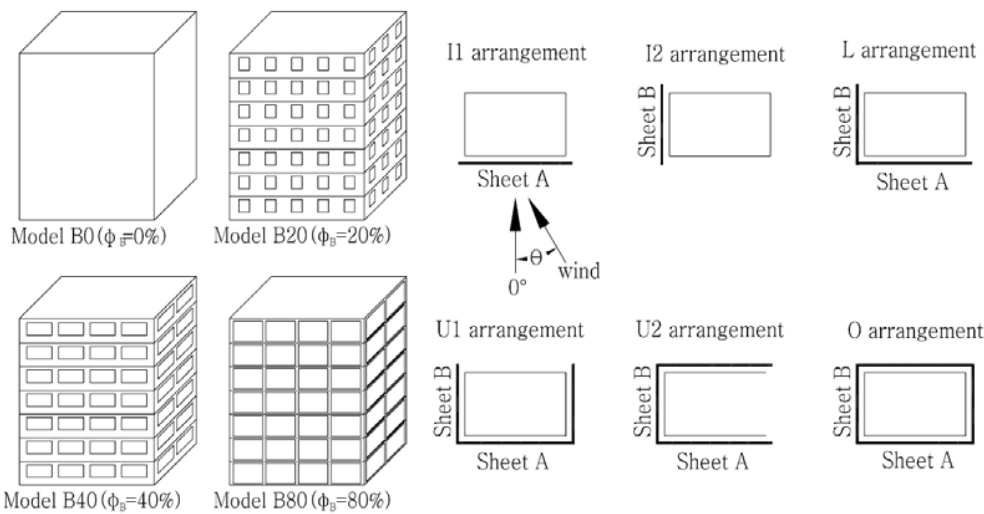


(a) U1 arrangement, $\phi_B=40\%$



(b) I1 arrangement, $\phi_B=80\%$

Fig.1 Experiment pictures



(a) Building models

(b) Scaffolding arrangements

Fig. 2 Building models and scaffolding arrangements

Reference wind pressures recorded by a pitot tube and pressure data were simultaneously collected at 781.25Hz for a sampling period of 20 seconds for each sample, corresponding to 26Hz and 10 minutes in full scale. Wind direction was changed at intervals of 5 degrees for each test case. The top wind speed, U_H , was used to obtain the wind pressure coefficients. A turbulent boundary layer with a power-law exponent, α , of 0.2 ($U_H \approx 8.8\text{m/s}$, $I_w H \approx 21\%$) was simulated (Fig. 3). Experimental cases are shown in Table 1.

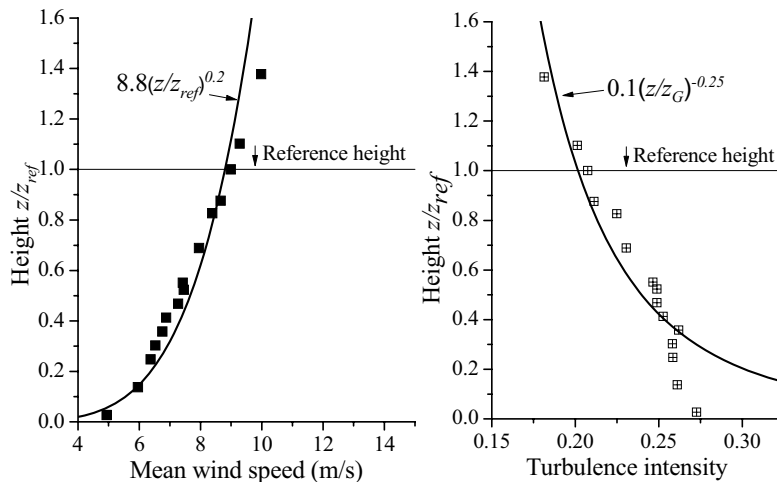


Fig. 3 Mean wind speed and turbulence intensity profile

Table 1 Experimental cases

Scaffolding arrange- ments	Building models	Wind directions
I1	Model B0, B20, B40, B80	0°~180°
I2	Model B0, B80	90°~270°
L	Model B0, B20, B40, B80	0°~360°
U1	Model B0, B20, B40, B80	0°~360°
U2	Model B0, B80	0°~360°
O	Model B0, B20, B40, B80	0°~360°

3 RESULT

Wind pressures measured on the models were expressed in the form of a non-dimensional pressure coefficient, defined as:

$$C_{p, outer} = \frac{P_{outer} - P_0}{0.5\rho U_H^2} \quad C_{p, inner} = \frac{P_{inner} - P_0}{0.5\rho U_H^2} \quad (1)$$

where $C_{p,outer}$ and $C_{p,inner}$ are the wind pressure coefficients of the model's outer and inner surfaces, respectively, P_0 is the static reference pressure, U_H is the mean longitudinal wind speed at the reference height(model top) and ρ is air density. Wind force coefficient $C_f = C_{p,outer} - C_{p,inner}$, namely, net pressure coefficient. Thus, the positive wind force coefficient direction is from outside to inside. The maximum and minimum peak wind force coefficients are expressed as $C_{f,max}(i, \theta, \phi_B)$ and $C_{f,min}(i, \theta, \phi_B)$, respectively, where i and θ indicate the i -th pressure tap and the approaching wind direction, and ϕ_B is building opening ratio.

3.1 Local mean wind force coefficient

3.1.1 Local mean wind force coefficient distribution

The maximum local mean C_f usually occurs near wind direction 45 degrees for scaffolding arrangement I1. Fig. 4 shows the local mean C_f distribution of model Sheet A for scaffolding arrangement I1 and wind direction 45 degrees. The maximum local mean C_f occurs at the top corner of the model when ϕ_B (building opening ratio) increases, and the value of the maximum local mean C_f becomes smaller, from 2.6 decreasing to 1.8 at the corner of the model.

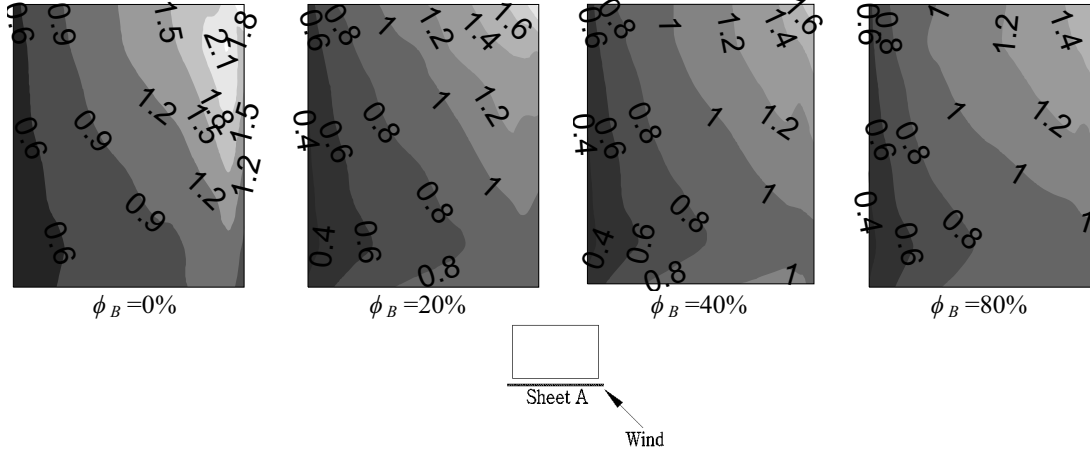


Fig.4 Local mean wind force coefficient distribution, arrangement I1, 45 degrees (Sheet A)

The minimum local mean C_f was found near wind direction 90 degrees, with wind flow almost parallel to the scaffolding sheet. When ϕ_B increased from 0% to 80%, local mean C_f became smaller, and was from -1.2 to -1.3 at the top corner. Thus, when ϕ_B increases, the changing tendencies of both the maximum and minimum local mean C_f are decrease.

Fig. 5 shows the distribution of mean $C_{p,outer}$ and $C_{p,inner}$ of Sheet A for different ϕ_B (0% and 80%). It shows almost the same distributions of $C_{p,outer}$, but for $C_{p,inner}$, they are quite different in both values and distribution. When ϕ_B increases from 0% to 80%, the mean $C_{p,inner}$ at the corner changes from -1.8 to around -0.8. When ϕ_B increases, the mean $C_{p,inner}$ increases and the mean $C_{p,outer}$ remains almost the same. Thus, the mean net pressure coefficients become smaller, namely, local mean C_f tend to be smaller.

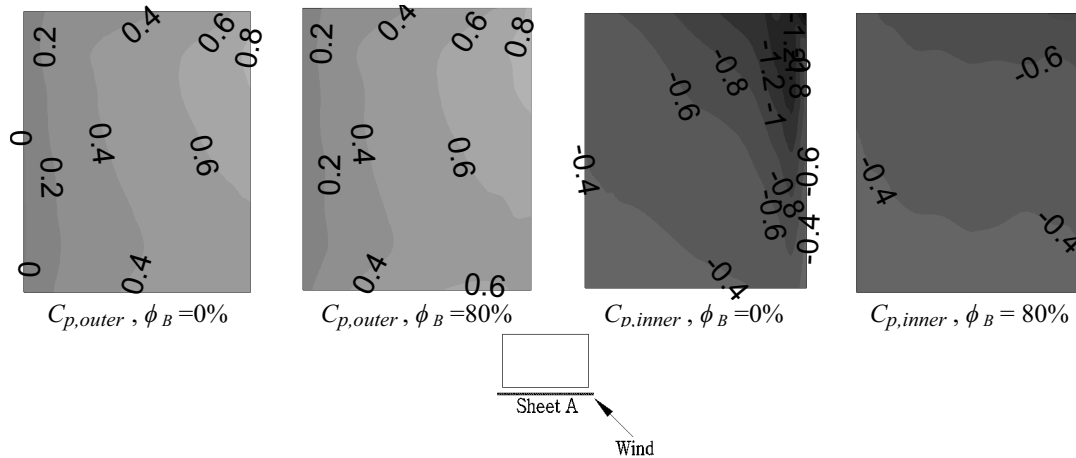


Fig.5 Mean wind pressure coefficient distribution of outer and inner surface, arrangement I1, 45 degrees (Sheet A)

For other scaffolding arrangements, both the maximum and minimum local mean C_f positions are usually located on the top layer or side edge. From the experimental results, the distribution and tendency of local mean C_f on model Sheet B is similar to that on model Sheet A, except that the maximum value is smaller.

Unfavourable wind direction is the direction that causes a maximum or minimum local mean C_f on the models. When the scaffolding arrangement was I1, I2, L, or U1, the unfavourable wind directions changed within the range of $\pm 25^\circ$ for different ϕ_B . This means that the opening ratio of the building didn't greatly change the unfavorable wind direction for these arrangements. When the scaffolding arrangement was U2 or O, the unfavourable wind directions changed a lot within the range of $\pm 80^\circ$ for different ϕ_B .

3.1.2 Local fluctuating wind force coefficients

The standard deviation values show the fluctuating characteristic of C_f . Fig. 6 shows the local fluctuating C_f distribution of arrangement I1 of Sheet A. 45 and 90 degrees are unfavourable wind directions for the maximum positive and minimum negative local mean C_f , respectively. When ϕ_B changes from 0% to 80%, the maximum local fluctuating C_f becomes smaller (from 1.0 to 0.5) at wind direction 45 degrees but becomes larger (from 0.7 to 0.8) at wind direction 90 degrees. When $\phi_B=0\%$, maximum local fluctuating C_f occurs at wind direction 45 degrees, but when $\phi_B=80\%$, maximum local fluctuating C_f occurs at wind direction 90 degrees. Thus, building opening ratio significantly affects the fluctuating characteristic of C_f .

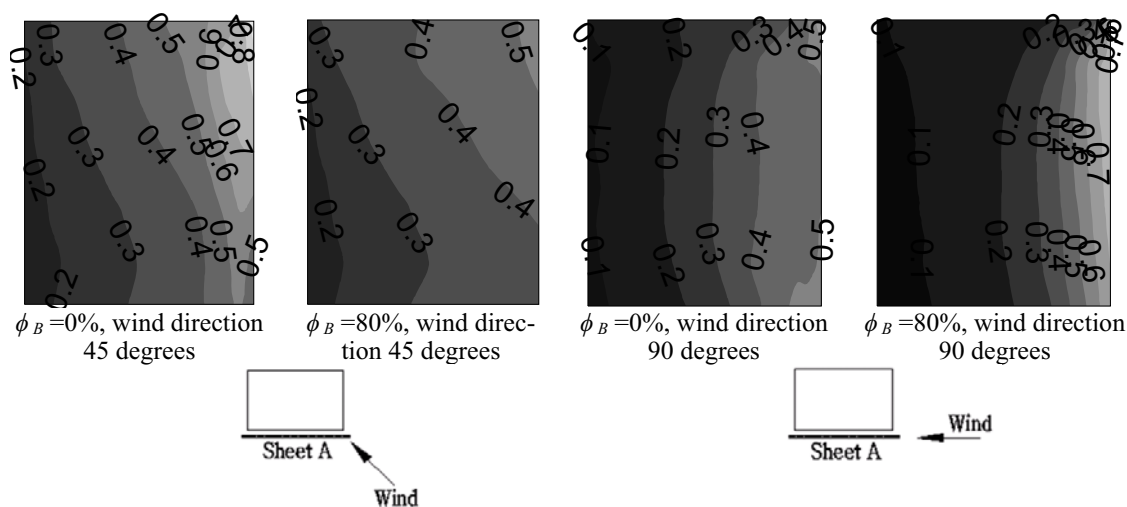


Fig.6 Local fluctuating wind force coefficient distribution, arrangement I1 (Sheet A)

The maximum local fluctuating C_f usually occurs on the top layer or side edge of the model. When scaffoldings is in O arrangement, which all four sides of the building encompassed, the value of local fluctuating C_f is almost unchanged by the effect of ϕ_B .

3.2 Local peak wind force coefficient

An "Equivalent time averaging" method was used to determine the wind load acting on a finite area from point pressure. 0.0038s corresponding to 0.11s in full scale was, used for time averaging. The peak force coefficients were calculated by the "Cook-Mayne method" using the maximum values (for positive wind force coefficient) and minimum ones (for negative wind force coefficient) of 10 samples.

3.2.1 Local peak wind force coefficient distribution

Local $C_{f,max}$ and $C_{f,min}$ distribution was similar to local mean C_f distribution. Both maximum and minimum peak values usually occurred on the top layer or side edge of the model in most scaffolding arrangements. Usually, the maximum local $C_{f,max}$ occurred when $\phi_B = 0\%$ and the minimum local $C_{f,min}$ occurred when $\phi_B = 80\%$. Fig. 7 shows the local $C_{f,max}$ distribution of Sheet A of all wind directions when $\phi_B = 0\%$. Fig. 8 shows the local $C_{f,min}$ distribution of Sheet A of all wind directions when $\phi_B = 80\%$. Scaffolding arrangements I1, L and O represent the conditions of a building single side clad, half clad and completely clad a building, respectively. The figures show that both maximum and minimum local peak values were smaller for arrangement O than for arrangements I1 and L. The maximum local $C_{f,max}$ of arrangement I1 is 7.6, larger than the value 6.2 for arrangement L, the minimum local $C_{f,min}$ for arrangements I1 and L are both -6.4.

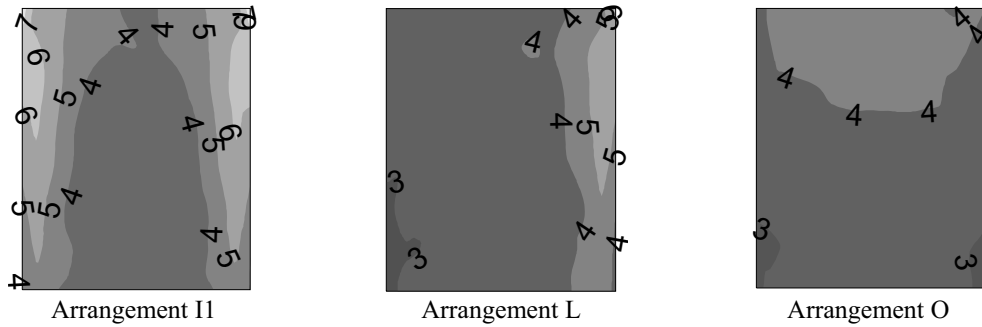


Fig.7 Local $C_{f,max}$ distribution, $\phi_B = 0\%$, all wind directions (Sheet A)

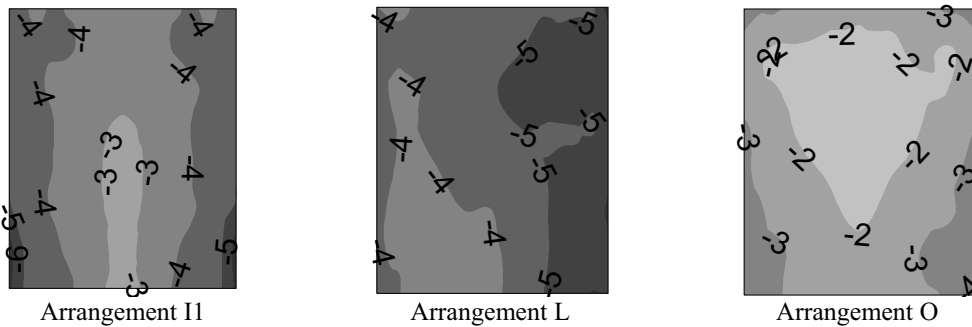


Fig.8 Local $C_{f,min}$ distribution, $\phi_B = 80\%$, all wind directions (Sheet A)

3.2.2 Effect of building opening ratio and scaffolding arrangement

Fig. 9 compares the maximum local $C_{f,max}(i, \theta)$ and minimum local $C_{f,min}(i, \theta)$ of model Sheet A for different building opening ratios. For arrangement I1, when ϕ_B increases from 0% to 80%, the maximum local $C_{f,max}(i, \theta)$ becomes smaller, changing from 7.6 to 5.3, and the minimum local $C_{f,min}(i, \theta)$ also becomes smaller, from -5.4 to -6.4. For arrangement L, when ϕ_B increases from 0% to 80%, the maximum local $C_{f,max}(i, \theta)$ becomes smaller, changing from 6.2 to 4.2, and the minimum local $C_{f,min}(i, \theta)$ also becomes smaller, from -5.6 to -6.4. For arrangements U1 and U2, both the maximum local $C_{f,max}(i, \theta)$ and minimum local $C_{f,min}(i, \theta)$ are almost unchanged, within the range of ± 0.3 for different ϕ_B . For arrangement O, when ϕ_B increases from 0% to 80%, the maximum local $C_{f,max}(i, \theta)$ becomes smaller, changing from 4.4 to 4.2, but the minimum local $C_{f,min}(i, \theta)$ becomes larger, changing from -4.6 to -4.

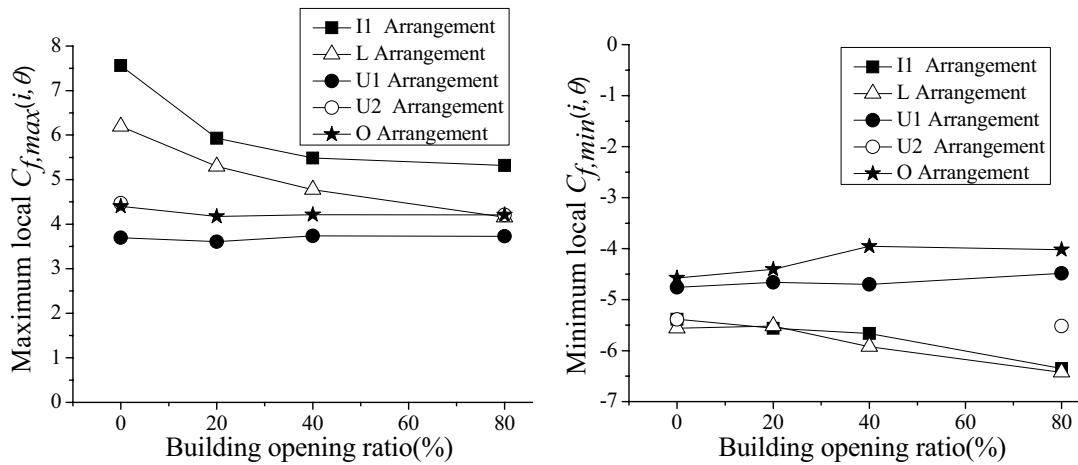


Fig. 9 Maximum local $C_{f,max}(i, \theta)$ and minimum local $C_{f,min}(i, \theta)$ for each building opening ratio (Sheet A)

From Fig. 10, it is clear that when ϕ_B increases from 0% to 80%, for arrangements I1 and L, the absolute values of both the maximum local $C_{f,max}(i, \theta, \phi_B)$ and minimum local $C_{f,min}(i, \theta, \phi_B)$ become significantly smaller, with a largest difference of 2.3. For arrangements U1, U2 and O, the maximum local $C_{f,max}(i, \theta, \phi_B)$ and minimum local $C_{f,min}(i, \theta, \phi_B)$ vary within the range of ± 0.6 for different ϕ_B . Thus, for scaffolding arrangement I1 or L, the local peak $C_f(i, \theta)$ is more sensitive to building openings than for arrangements U1, U2 and O.

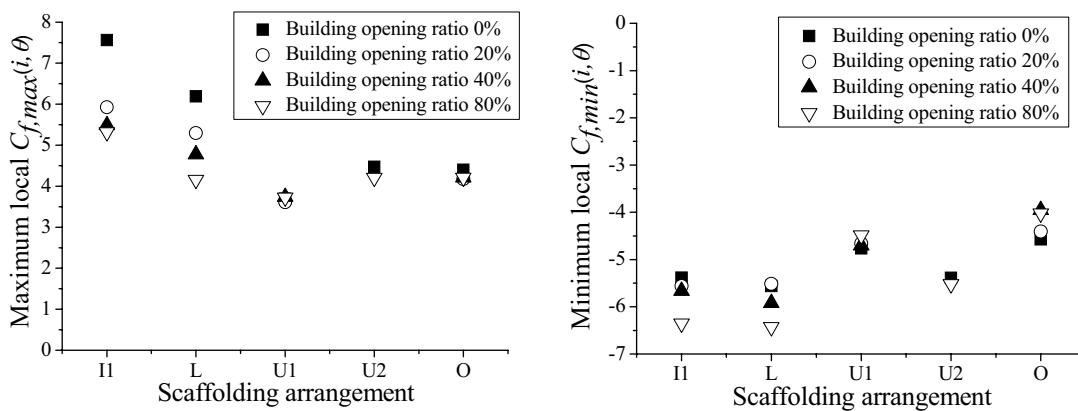


Fig. 10 Maximum local $C_{f,max}(i, \theta)$ and minimum local $C_{f,min}(i, \theta)$ for each scaffolding arrangement (Sheet A)

Fig. 11 shows local $C_{f,max}(i, \theta)$ for wind direction $\phi_B = 0^\circ$. For scaffolding arrangements I1 and L, the maximum local $C_{f,max}(i, \theta)$ are larger. For arrangement U1, the maximum local $C_{f,max}(i, \theta)$ is smaller than those for the other arrangements. The maximum local $C_{f,max}(i, \theta)$ of arrangements I1, L and U2 occur near wind direction 45 degrees. For scaffolding arrangements U1 and O, the maximum local $C_{f,max}(i, \theta)$ were found near wind direction 0 degrees.

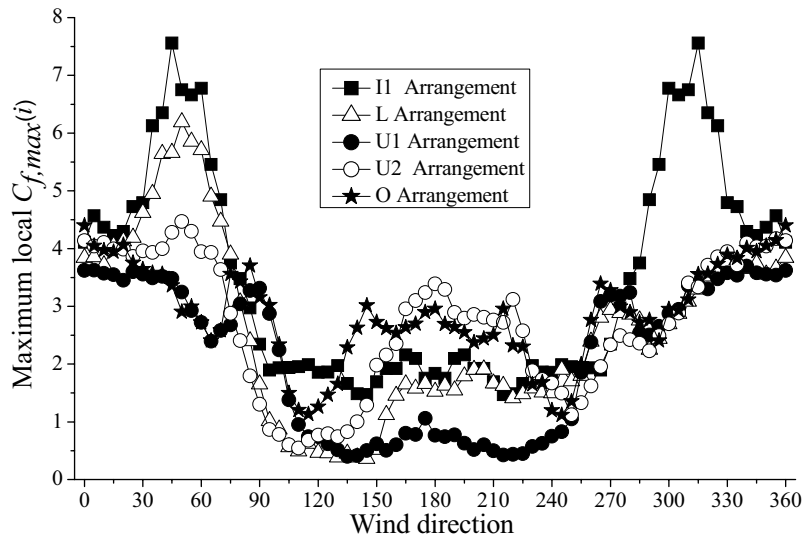


Fig. 11 Maximum local $C_{f,max}(i)$ for each wind direction, $\phi_B = 0^\circ$ (Sheet A)

3.2.3 Comparison of model Sheets A and B

The previous section discussed the characteristics of wind force acting on model Sheet A. This section compares model Sheets A and B. For scaffolding arrangements I (I1 or I2), L, and O, the distributions and changing tendencies of wind force on model Sheet B are similar to those on model Sheet A. Table 2 compares local $C_{f,max}(i, \theta, \phi_B)$ and $C_{f,min}(i, \theta, \phi_B)$ for model Sheets A and B. For arrangements I and L, the maximum local $C_{f,max}(i, \theta, \phi_B)$ value for Sheet A is larger than for Sheet B, but the minimum local $C_{f,min}(i, \theta, \phi_B)$ value is almost the same. For arrangement O, the absolute value of both maximum local $C_{f,max}(i, \theta, \phi_B)$ and minimum local $C_{f,min}(i, \theta, \phi_B)$ of Sheet B is smaller than of Sheet A, with a difference of around 0.5.

Table 2 Maximum local $C_{f,max}(i, \theta, \phi_B)$ and minimum local $C_{f,min}(i, \theta, \phi_B)$ of model Sheet A and Sheet B

Scaffolding arrangement	Maximum local $C_{f,max}(i, \theta, \phi_B)$		Minimum local $C_{f,min}(i, \theta, \phi_B)$	
	Sheet A	Sheet B	Sheet A	Sheet B
I1 or I2	7.6	6.6	-6.4	-6.5
L	6.2	4.6	-6.4	-6.4
U1	3.7	4.1	-4.8	-6.4
U2	4.5	4.1	-5.5	-4.2
O	4.4	4	-4.6	-4.1

For arrangements U1 and U2, the absolute values of both the maximum local $C_{f,max}(i, \theta, \phi_B)$ and the minimum local $C_{f,min}(i, \theta, \phi_B)$ of Sheet A is larger for arrangement U2 and that of Sheet B is larger for arrangement U1. For scaffolding arrangement U1, scaffolding sheets are located on both two adjacent sides of Sheet A, which diminish the absolute value of both the maximum local $C_{f,max}(i, \theta, \phi_B)$ and minimum local $C_{f,min}(i, \theta, \phi_B)$ of Sheet A. For Sheet B in arrangement U2, the absolute value of the minimum local $C_{f,min}(i, \theta, \phi_B)$ of Sheet B is also smaller due to the existence of the two adjacent side sheet models. Sheet A in arrangement U2 and Sheet B in arrangement U1 are the conditions with only one adjacent side scaffolding sheet model, which is similar to arrangement L.

3.3 Total panel force coefficient

For most wind load recommendations for scaffoldings, the resultant wind force F is calculated by a equation including three components: a velocity pressure, a reference area of scaffolding and a wind force coefficient C_f . C_f is usually used as a total panel C_f . In this study, the total panel C_f of each experimental case was calculated.

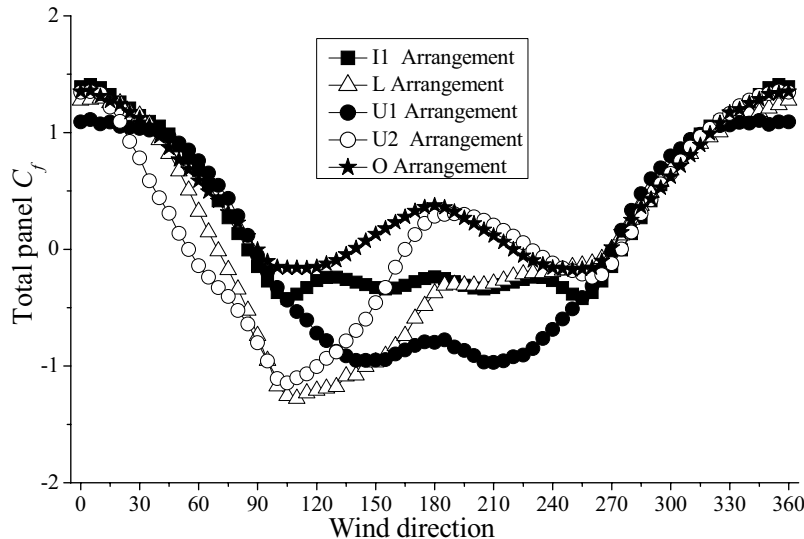


Fig. 12 Total panel C_f for each wind direction, $\phi_B = 0\%$ (Sheet A)

Fig. 12 shows the total panel C_f of model Sheet A for different scaffolding arrangements and each wind direction. Maximum positive total panel C_f occurs at wind direction near 0 degrees for each scaffolding arrangement, and its value is around 1.3 to 1.4, except for arrangement U1, which is 1.1. Minimum negative total panel C_f occurs at wind directions between 105 and 115 degrees for most scaffolding arrangements, except arrangement U1 at 150 degrees. The values are quite different. The minimum negative total panel C_f of arrangement L is the smallest, at around -1.3.

For other building opening ratios, the tendency of most scaffolding arrangements for both maximum positive and minimum negative total panel C_f become smaller when ϕ_B increases from 0% to 80%, but arrangement O has the inverse effect and becomes larger. Model Sheets B and A have the same tendencies as these results.

4 CONCLUDING REMARKS

Wind force characteristics of scaffoldings with sheets for different building opening ratios and scaffolding arrangements were studied from wind tunnel experiment results. The conclusions are:

(1) Local peak wind force coefficients usually occur on the top layer or side edge of a scaffolding sheet, and are significantly affected by building opening ratio. For most scaffolding arrangements, both maximum positive and minimum negative wind force coefficients tend to become smaller when building opening ratio increases.

(2) When scaffolding is arranged on one side or encompasses half a building, local wind force coefficients of scaffolding sheets are more sensitive to change of building openings. When scaf-

folding does not completely encompass a building, wind loads on the scaffolding sheet are larger.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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