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An evaluation theory of area-averaged mean wind pressure with consideration of uneven distribution in tributary area

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SUMMARY: Reasonable evaluation of design wind load is an important link to ensure the wind resistance safety of the building structure. Usually, the wind load, based on the assumption of the uniform wind pressure distribution among a certain area, is calculated by the area-averaged wind pressure of each tributary area expressed by the tap pressure, which may differ from the actual uneven distribution. This study proposes a new evaluation theory of mean wind load on building structure by an optimized interpolation technology. The case study was carried out with a saddle-type roof according to the presented evaluation theory. The results indicate that wind load may be incorrectly estimated regardless of uneven distribution in the tributary area.

Keywords: tributary area, wind pressure interpolation method, area-averaged mean wind load

1. INSTRUCTIONS

Wind-induced disasters often occur in large-span building structure widely used in modern society (Yang et al. 2018). Wind load, as a main control load of wind sensitive structure, is often considered as a key link in structural design (AIJ-RLB-2015; Stathopoulos and Alrawashdeh 2020). The design wind load should be the integral value of wind pressure at each point, which won't work limited to experimental cost and condition, such as the number of piezometer tube. The wind load is usually considered as the sum of the product of Cp and tributary area of each tap. The triangulation method is generally used to get applicable tributary area assignments (Gierson et al., 2017).

The rationality of the above method lies in the assumption that Cp is uniformly distributed in the tributary area. The distribution may be uneven for the corners and windward leading edges of saddle type roofs (Liu et al., 2016). There is no specific criterion for determining whether the Cp in the tributary area is evenly distributed. The interpolation technique is considered as a means to improve the resolution of wind pressure field to calculate the wind load as accurately as possible (Alvares et al. 2013; Weng & Paal 2022). The previous studies may neglect the interpolated locations and number, which will lead to lower efficiency and higher computational cost.

In this paper, a criterion for judging the uniform distribution of Cp in the tributary area is proposed firstly based on the Cp of adjacent points. Secondly, a new idea for determining the interpolated number and location is obtained based on the above criterion. Then k-fold cross validation is used to verify the accuracy of an improved interpolation method. The higher resolution wind pressure distribution results are used to determine the mean wind load of saddle roof at different wind angles.

2. METHOD FOR EVALUATING AREA-AVERAGED MEAN WIND PRESSURE COEFFICIENT

2.1 Method of Area-Average Wind Pressure for Uninform Wind Pressure Distribution

Uniformity can be judged by whether the mean Cp of any two adjacent taps, i.e. $\bar{C}_{pi}$ and $\bar{C}_{pj}$, is close to the mean value of averaged-area Cp history $C_p^{i,j}(t)$:

$$C_p^{i,j}(t) = A_i C_{pi}(t) \big/ \left(A_i + A_j\right) + A_j C_{pj}(t) \big/ \left(A_i + A_j\right) \tag{1}$$

Where A_i and A_j are the size of the tributary area of the tap *i* and *j* respectively, i.e. $A_i = kA_j$.

$$\bar{C}_p^{i,j} = \mathbf{E}\left[C_p^{i,j}(t)\right] = \left(k\bar{C}_{pi} + \bar{C}_{pj}\right) \big/ (k+1) = \bar{C}_{pj}\left(k\Delta_{\bar{C}_{pij}} + 1\right) \Big/ (k+1) \tag{2}$$

Where $\Delta_{\bar{C}_{pij}} = \bar{C}_{pj} / \bar{C}_{pj}$ Assume $\left|\bar{C}_{pi}\right| < \left|\bar{C}_{pj}\right|$, when $\bar{C}_p^{i,j}$ is close to $\bar{C}_{pj}$ at tap *j*, then $\bar{C}_p^{i,j} / \bar{C}_{pj} = \left(k\Delta_{\bar{C}_{pij}} + 1\right) \Big/ (k+1) > 1 - \varepsilon$ .As $\Delta_{\bar{C}_{pij}} > 1 - \varepsilon - \varepsilon/k$, the mean Cp is uniformly distributed along the *i*-*j* direction. When Cp of each tap and its adjacent taps all meet the above requirement, the mean Cp of building surface, whose area is *A*, is: $\bar{C}_{ps} = \frac{1}{A}\sum_{i=1}^{N} \bar{C}_{pi} A_i$.

2.2 Method of Area-Average Wind Pressure for Uneven Wind Pressure Distribution

2.2.1 The number and locations of interpolation points

Assuming that the Cp varies linearly along the distance, $\delta\bar{C}_{pij} = (\bar{C}_{pj} - \bar{C}_{pi}) \big/ dist(i,j) = \boldsymbol{Constant}$,Cp of adjacent points after interpolation need to meet the uniform requirement:

$$\bar{C}_{p,n} \big/ \bar{C}_{pj} = \bar{C}_{pi} \big/ \bar{C}_{pj} + (1 - \bar{C}_{pi} \big/ \bar{C}_{pj}) \bullet n/(n+1) > 1 - \varepsilon - \varepsilon/k \tag{3}$$

From Eq.(3), the total number of interpolation points between two taps is:

$$n = \left\lceil \left(k\left(\bar{C}_{pj} - \bar{C}_{pi}\right)\right) \big/ \left(\varepsilon(k+1)\bar{C}_{pj}\right) \right\rceil - 1 = \left\lfloor \left(k\left(\bar{C}_{pj} - \bar{C}_{pi}\right)\right) \big/ \left(\varepsilon(k+1)\bar{C}_{pj}\right) \right\rfloor \tag{4}$$

Where $\lceil \bullet \rceil$ and $\lfloor \bullet \rfloor$ represent integers up and down, respectively. The value of ε can be determined by the refinement requirements, i.e. ε=0.1. The location of each interpolation point is:

$$(x_{ij}^{'}, y_{ij}^{'}) = \left(x_i + \left(n_{ij}^{th}\left(x_j - x_i\right)\right) \big/ (n+1), y_i + \left(n_{ij}^{th}\left(y_j - y_i\right)\right) \big/ (n+1)\right)\left(n_{ij}^{th} = 1, 2, \ldots, n\right) \tag{5}$$

2.2.2 The wind pressure interpolation method

The $\hat{\bar{\mathbf{C}}}_{pj}$ at point *j* can be linearly estimated by the Cp within a certain radius, i.e. $\hat{\bar{\mathbf{C}}}_{pj} = \sum_{i=1}^{n_j} w_i \bar{\mathbf{C}}_{pi}$.

The radius proposed in this paper should be determined by the relationship between the correlation and the distance between any two taps. Each Cp of interpolation can be obtained by kriging method (Alvares et al. 2013). The method interpolates multiple times until uniform distribution. Cps of test and interpolation are compared based on cross validation to ensure rationality. The accuracy, i.e. $\bar{\eta}$, should meet $\bar{\eta} = 1 - \frac{1}{N}\sum_{j=1}^{N}\left|\bar{C}_{pj} - \hat{\bar{C}}_{pj}\right| \Big/ \left|\bar{C}_{pj}\right| \geq 0.8$.

3. AREA MEAN WIND PRESSURE RESULTS AFTER INTERPOLATION FOR A SADDLE TYPE ROOF AT DIFFERENT WIND DIRECTIONS

The rise-span ratio of the saddle type roof is 1:12, the scale of model is 1:100, and the scale of wind speed is 1:2, the time ratio is 1:50. The mean Cp results from Liu et al., 2016.According to Section 2.2.1, the number and locations of interpolation points are shown in Fig. 1.

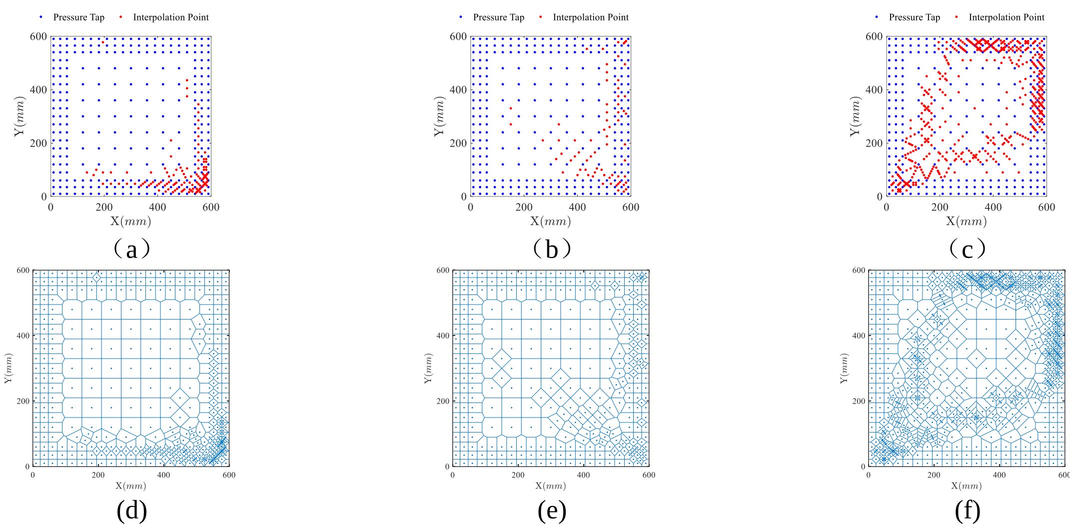


Fig.1 Locations and tributary area of points at (a)(d) 0° wind angle; (b)(e) 45° wind angle; (c)(f) 90° wind angle

From the above figure, the number of interpolation points varies greatly in different wind angles. The accuracy of proposed method is validated by Section 2.2.2 as shown in Fig.2.

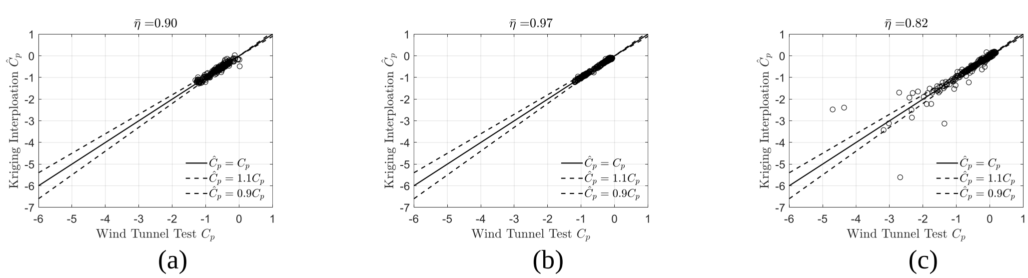
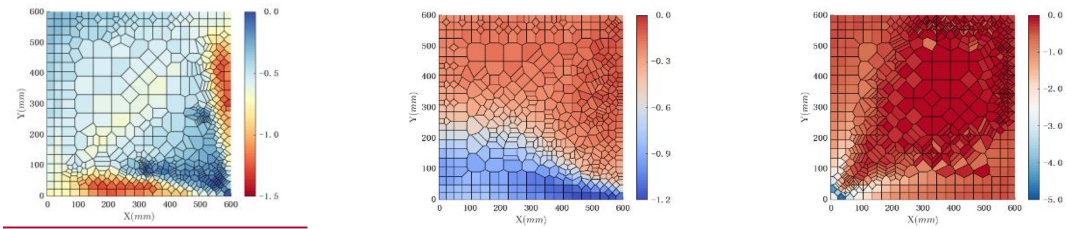


Fig.2 Validation on interpolation results at (a)0° wind angle; （b） 45° wind angle;(c) 90° wind angle

Based on the proposed method, the area pressure contours can be obtained as shown in Fig.3.



(a) (b) (c)

Fig.3 Contours of area Cp after interpolation at (a)0° wind angle; （b） 45° wind angle;(c) 90° wind angle

Results show that the interpolation point arrangement is consistent with the uneven distribution of wind pressure. The results of each step of the proposed method are shown in Tab. 1.

Tab. 1. Results of each step at different wind angle.

Wind angle	Interpolation number	Radius(mm) $(\rho = 0.2)$	Area-averaged mean wind load w/o interpolation	Area-averaged wind load with interpolation	Error rate
0°	326	450	-0.65	-0.63	3.2%
45°	961	200	-0.43	-0.44	2.3%
90°	786	170	-0.63	-0.51	21.2%

When comparing the results of area-averaged mean wind load obtained by interpolation or not, it can be seen in Tab.1 that there are certain errors at all angles, especially at 90° wind angle.

4. CONCLUSIONS

In this present paper, an evaluation theory of mean wind load at different angles is proposed by an optimized interpolation methodology, specifically referring to uneven pressure distribution in the tributary area. Applying the proposed method to a saddle roof, results show that whether the uneven distribution is considered or not, the results may vary greatly, resulting in inaccurate value.

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REFERENCES

AIJ-RLB-2015. (2015). Recommendations for loads on buildings. Architectural Institute of Japan.

Gierson, M. L., Phillips, B. M., Duthinh, D., & Ayyub, B. M. (2017). Wind-pressure coefficients on low-rise building enclosures using modern wind-tunnel data and Voronoi diagrams. Journal of structural engineering (New York, NY), 3.

Liu, M., Chen, X., & Yang, Q. (2016). Characteristics of dynamic pressures on a saddle type roof in various boundary layer flows. Journal of Wind Engineering and Industrial Aerodynamics, 150, 1-14.

Stathopoulos, T., & Alrawashdeh, H. (2020). Wind loads on buildings: A code of practice perspective. Journal of Wind Engineering and Industrial Aerodynamics, 206, 104338.

Weng, Y., & Paal, S. G. (2022). Machine learning-based wind pressure prediction of low-rise non-isolated buildings. Engineering Structures, 258, 114148.

Yang, Q., Gao, R., Bai, F., Li, T., & Tamura, Y. (2018). Damage to buildings and structures due to recent devastating wind hazards in East Asia. Natural hazards, 92(3), 1321-1353.

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. D. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, 22(6), 711-728.