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

Surrogate Model Updating-based Aerodynamic Shape Optimization of a Triangular Cylinder with Corner Recession Modification

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SUMMARY:
Corner modifications have been extensively applied as a control measure to reduce wind-induced loads and responses of tall buildings, especially the corner recession modification. This research combines the sampling strategy, a surrogate model (GA-GRNN), and a multi-objective optimization algorithm (NSGA-II) to build the surrogate model updating-based optimization framework. The framework is then adopted for the aerodynamic shape optimization of a triangle cylinder with corner recession modification. The optimal aerodynamic shape of each wind direction angle is then selected, and the complete wind direction angles investigation is conducted. The maximum mean drag coefficient and root mean square lift coefficient reduction is observed in the 15° wind direction angle, as the reduction can reach 38.68% and 87.16%, respectively. Lastly, a principle for selecting the global optimal aerodynamic shape is outlined by considering the optimization results and meteorological data.

Keywords: aerodynamic shape optimization, triangular cylinder, corner recession

1. INTRODUCTION

Wind resistance performance is becoming more prevalent during the design stage as the height of buildings is pushing towards the megatall buildings category. Traditional aerodynamic shape optimization of civil structures relies on trial and error of wind tunnel tests or CFD simulations of the limited number of sections. A more advanced approach is the surrogate model-based optimization approach, which enables a thorough search of optimal shapes within a broader design space and more efficient resource allocation (Bernardini et al., 2015).

A noticeable literature gap is observed in the triangular building shape, as only a handful of research includes the triangular-shaped building in the aerodynamic investigations and its optimization (Bandi et al., 2013). Another apparent limitation is that there is still no consensus for selecting the global optimal aerodynamic shape. Therefore, this research aims to address these two limitations: (1) presenting a thorough optimization of a triangular cylinder using the corner recession modification through the surrogate model updating-based optimization framework; (2) outlining the principle of global optimal aerodynamic shape selection by considering the full wind direction angles investigation and meteorological data.

2. SURROGATE MODEL UPDATING-BASED AERODYNAMIC SHAPE OPTIMIZATION FRAMEWORK

The surrogate model updating-based aerodynamic shape optimization framework (Wang et al., 2022) is shown in Figure 1. Initial sampling points are generated by the optimal Latin hypercube design (OPLHD). Moreover, the GA-GRNN surrogate model is then constructed and implemented into the non-dominated sorting genetic algorithm (NSGA-II) multi-objective optimization algorithm to find the potential Pareto optimal solutions. A CFD verification is conducted to validate the GA-GRNN's prediction accuracy, in which the optimization process will be repeated until the convergence criteria are satisfied.

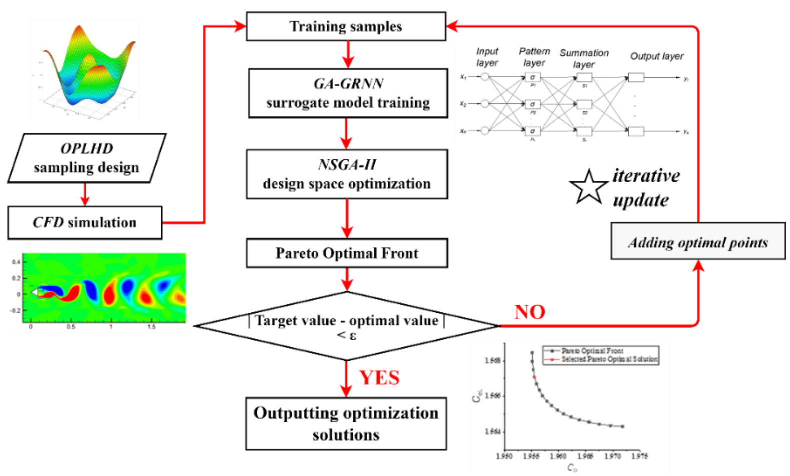

Figure 1. Overall surrogate model updating-based optimization framework.

3. AERODYNAMIC SHAPE OPTIMIZATION OF THE TRIANGULAR-SECTIONAL BUILDING

3.1. Geometric parameters and aerodynamic force coefficients

Figure 2 displays the design variables of the corner recession modifications, which are corner recession ratio (1%~20%, with the interval of 1%), corner recession angle (60°~120°, with the interval of 5°), number of corner recession (1~5, with the interval of 1), and the optimization is conducted for typical wind direction angles from 0° ~ 60° with an interval of 15°. The aerodynamic force coefficients considered for the optimization are the mean drag coefficient C_D and RMS lift coefficient $C_{\sigma L}$, evaluated through the CFD simulation of the sample points.

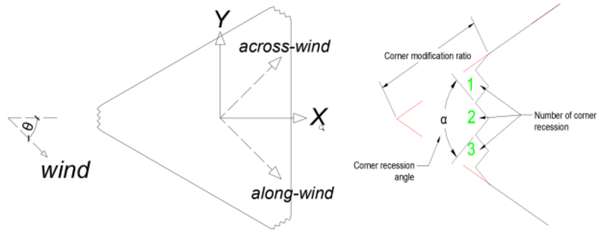

Figure 2. Design variables of the corner recession modifications of the triangular-sectional cylinder.

3.2. Optimization results of typical wind direction angle

Figure 3 displays the convergence history of the optimization and the corresponding Pareto optimal front in the 30° wind direction angle. Subsequently, each wind direction angle's optimal aerodynamic shapes are chosen and denoted as N1~N5. The reduction coefficients of the optimal aerodynamic shape under each wind direction angle i are calculated using Eqs. (1)~(2):

$$C_{\mathrm{DRi}} = \ (1 - C_{\mathrm{DC}}/C_{\mathrm{DB}}) \times 100\% \tag{1}$$

$$C_{\sigma \mathrm{LRi}} = \ (1 - C_{\sigma \mathrm{LC}}/C_{\sigma \mathrm{LB}}) \times 100\% \tag{2}$$

where C_{DB} and $C_{\sigma\mathrm{LB}}$ are the mean drag coefficient and RMS lift coefficient of the basic section respectively, i.e., the triangular section; meanwhile, C_{DC} and $C_{\sigma\mathrm{LC}}$ are the mean drag coefficient and RMS lift coefficient of the optimized sections. The reduction comparisons are shown in Table 1.

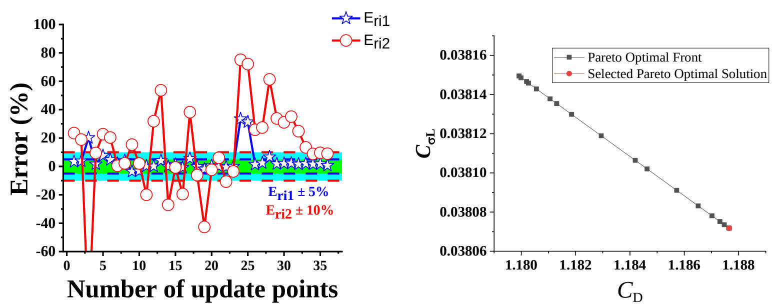

Figure 3. Convergence history of the optimization and the Pareto optimal front under the 30° wind direction angles.

Table 1. Aerodynamic force reduction coefficients of the optimized sections at different wind direction angles.

Model	θ	C_{DB}	$C_{\sigma\mathrm{LB}}$	Model	θ	C_{D}	$C_{\sigma\mathrm{L}}$	C_{DRi}	$C_{\sigma\mathrm{LRi}}$
	0°	1.502	0.181	N1	0°	1.082	0.034	27.96%	81.20%
	15°	1.693	0.295	N2	15°	1.038	0.038	38.68%	87.16%
Basic section	30°	1.798	0.900	N3	30°	1.195	0.042	33.54%	95.36%
	45°	2.613	1.674	N4	45°	1.806	1.356	30.87%	19.04%
	60°	2.381	1.163	N5	60°	1.503	1.329	36.91%	-14.33%

3.3. Selection of global optimal aerodynamic shape

This research proposes a selection method considering the full wind direction angles investigation and meteorological data. The aerodynamic shape's mean drag and RMS lift reduction coefficients are calculated using Eqs. (3)~(4):

$C_{DR} = \sum F_i \times C_{DRi}$ (3)

$C_{LR} = \sum F_i \times C_{\sigma LRi}$ (4)

where F_i is the probability of the incoming wind direction angle i. Afterward, the overall aerodynamic coefficient of the aerodynamic shape is calculated according to Eq. (5):

$OR = C_{DR} + C_{LR}$ (5)

which example of the global optimal aerodynamic assessment of model N1 is given in Table 2, based on the meteorological data in Jakarta from 2002~2022, obtained from the official BMKG online database (https://dataonline.bmkg.go.id).

Table 2. Global optimal aerodynamic shape assessment of N1 model based on meteorological data in Jakarta.

No.	Incoming wind direction	F_i	θ	$C_{DR,i}$	$C_{\sigma LR,i}$	$F_i \times C_{DR,i}$	$F_i \times C_{\sigma LR,i}$	C_{DR}	$C_{\sigma LR}$	OR
1	0 (North)	25.2%	0	27.96%	81.20%	7.05%	20.46%	20.93%	51.93%	72.86%
2	45	16.3%	45	12.39%	-23.93%	2.02%	-3.90%			
3	90	11.5%	30	16.11%	84.00%	1.86%	9.69%			
4	135	8.1%	15	38.22%	86.67%	3.10%	7.04%			
5	180	3.0%	60	-2.30%	-47.62%	-0.07%	-1.43%			
6	225	7.0%	15	38.22%	86.67%	2.67%	6.06%			
7	270	19.4%	30	16.11%	84.00%	3.12%	16.28%			
8	315	9.5%	45	12.39%	-23.93%	1.17%	-2.27%			

4. CONCLUSIONS

This research employs the surrogate model updating-based multi-objective optimization for the triangular cylinder optimization with corner recession modifications. The optimization is completed with 279 sampling points which accounts for 4.29% of the total design space, in which the reduction coefficients can reach 38.68% and 87.16% for C_D and $C_{\sigma L}$, respectively. This research also proposes the global optimal aerodynamic shape selection method considering the meteorological data and optimization results, which gives a basis for selecting an optimal aerodynamic shape.

ACKNOWLEDGEMENTS

The authors want to express their appreciation for the financial support provided by the National Key R&D Program of China (No. 2022YFC3801101) and the China State Construction Engineering Corporation (No. CSCEC-2020-Z-58-2).

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