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Database-enabled surrogate-assisted investigation on the interference effects of two adjacent buildings

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SUMMARY:
Urban cities are vulnerable to the impact of dynamic wind effects including the interference effects resulting from the cluster of tall buildings undergoing complex interactions with their surrounding wind environment. Wind-induced interference effects have been studied through a series of wind tunnel experiments. To comprehensively understand the influence of the interfering factors on the pressure variations on the building surfaces, a high-dimensional surrogate modeling technique is employed in this study, which is capable of predicting the mean and peak pressure coefficients with high dimensionality under random building arrangements. This surrogate model is trained through the wind tunnel dataset developed by Tokyo Polytechnic University (TPU). Furthermore, the classification approach is incorporated into the sensitivity analysis to identify critical regions where the local peak pressures are significantly affected by the building arrangements, incident wind directions and height ratio. Additionally, adaptive Design of Experiments (DoEs) for building arrangements is applied to the wind tunnel experiments to efficiently guide the sequential design of wind tunnel tests, aiming at identifying the aerodynamically favorable and unfavorable wind scenarios due to the interference effects while largely reducing the number of wind tunnel tests.

Keywords: interference effects, high-dimensional surrogate modeling, adaptive DoEs

1. INTRODUCTION

The worldwide trend in urbanization is resulting in moving more people to densely populated urban centers. Those urban cities are extremely vulnerable to the impacts of dynamic wind, as the wind-induced interference effects result in the cluster of tall buildings undergoing complex interactions with their surrounding wind environment, which may pose undesirable load effects or even wind hazards on those buildings. Past studies have shown that the interference effects on two adjacent tall buildings could induce either shielding or amplification effects on the mean and peak pressure (Bailey and Kwok, 1985; Hu et al., 2020; Hui et al., 2013; Kim et al., 2015; Yu et al., 2015). The aerodynamically unfavorable building arrangements could lead to significant increase in the local peak pressure that could cause extensive damage to cladding and glass failure.

This study focuses on investigating the influence of the adjacent building arrangement and spacing as well as height ratio on the surface pressure distributions of a tall buildings. In particular, the aerodynamic database developed by TPU (http://www.wind.arch.t-kougei.ac.jp) is utilized to study the wind-induced interference effects. In view that the limited dataset provided by the wind tunnel experiments may not fully represent the various interfering wind environments, a high-dimensional surrogate model that is capable of predicting the mean and peak pressure coefficients in high-dimensional output space at random building arrangements is proposed, which is trained through the TPU database. To advance the understanding of the interference effects, sensitivity analysis coupled with the classification approach is applied to identifying the critical regions where the local peak pressures are significantly affected by the interfering factors. Furthermore, the proposed surrogate model can also aid in the adaptive DoEs that can effectively reduce the number of wind tunnel experiments while maintaining the same precision level to reveal the aerodynamically favorable and unfavorable arrangements of two adjacent buildings.

2. WIND PRESSURE DATABASE

The TPU wind pressure database for high-rise building with adjacent building is obtained through the synchronous pressure measurement technique that is able to obtain the time series of local pressure coefficients on a structure. The building where the pressure taps were installed is referred to as the principal building. Multiple locations of the interfering building in two-dimensional design space are set to examine its interference effects on the pressure distribution of the principal building. As for the database, 37 arrangements of the interfering building were considered. At each building arrangement, wind tunnel tests for 72 incident wind directions were tested ranging from 0 degree to 355 degree in 5 degree steps. Moreover, five height ratios of the interfering building height over the principal building height were taken into account. In total, the database contains 8640 experimental results with respect to the interfering factors of the interfering building location, height ratio and incident wind directions.

3. METHODOLOGY

This section discusses about the development of the high-dimensional surrogate model into systematic investigation of the interference effects of the interfering building on the pressure distributions of the principal building.

3.1. High-dimensional Surrogate Modeling to Predict the Interference Effects on the Principal Building

Although past studies have revealed the interference effects of the building arrangements and shapes on tall buildings using experimental data, wind tunnel experiments provide the limited database, resulting in a vast portion of the design space remains unexplored. To comprehensively investigate the variations of the surface pressure distribution of the principal building at random locations of the interfering building, it is crucial to develop a predictive model that is capable of delivering the high-dimensional pressure predictions on the building surfaces.

In this study, an advanced high-dimensional surrogate model is introduced to predict the mean pressure coefficients and peak pressure coefficients based on extreme value analysis (Cook and Mayne, 1980). The TPU aerodynamic database is employed to train the surrogate model. Moreover, the experimental data is split into 70% for the training data that is used to calibrate the surrogate model and 30% for the test data that validates the predictive accuracy of the surrogate model. The fundamental hypothesis of the surrogate model is that the true underlying function can be modeled as a realization of a Gaussian stochastic process. To reduce the high dimensionality of the output space representing the pressure fields, the dimension reduction method, e.g. principal component analyses (PCA) is incorporated into the surrogate predictions. Similar high-dimensional surrogate modeling framework has been applied to predicting the regional storm surge (Jia et al., 2016), which significantly reduced the computational complexity and enhanced the predictive accuracy. The major advantage of using high-dimensional Gaussian processes over other interpolation schemes including machine learning is that it additionally provides confidence level of predictions. The proposed surrogate model is able to predict the optimal locations of the interfering building considering the most aerodynamically favorable conditions on the principal building. For predicting temporal behaviors, the applicability of the dynamic mode decomposition (DMD) will also be investigated as a dimension reduction strategy.

3.2. Sensitivity Analysis and Classification on the Distribution of Pressure Coefficients on Building Surfaces

To systematically examine the influence of the interfering factors on the pressure variations on the principal building, sensitivity analysis is conducted using Sobol's sensitivity index (Borgonovo and Plischke, 2016). Results from sensitivity analysis are incorporated into classifiers to identify the local regions on each building surface, where the mean and peak pressure coefficients are significantly affected by the locations and height of the interfering building as well as the incident wind direction. This strategy has the promise to predict and eventually mitigate wind hazards resulting in the local cladding damages under specific wind conditions as well as optimizing the locations of pressure taps in wind tunnel experiments.

3.3. Optimal DoEs for Wind Tunnel Tests on Two Adjacent Buildings

The study of the interference effects often requires a number of wind tunnel experiments to evaluate the aerodynamic performances at multiple building configurations and arrangements, which is costly and time-consuming. The application of the adaptive DoEs that consist of sequentially selecting new samples assisted by the surrogate model can reduce the number of experiments while yielding the high-quality results. The information gained from the previously conducted wind tunnel experiments can guide the sequential experimental configurations through adaptive DoEs in order to identify the most aerodynamically favorable and unfavorable arrangements of the interfering building. In this study, initial DoEs are uniformly selected from the design space for the interfering building. The optimality criterion for adaptive DoEs aims at minimizing the uncertainty in surrogate predictions and searching for the experimental configurations that generate the optimal and worst wind scenarios. The optimization process is conducted with respect to the coordinates of the interfering building as shown in Fig 1. This tool will be beneficial in reducing the wind tunnel costs and accelerating the process in determining the most critical wind scenarios.

4. CONCLUSIONS

This study focuses on investigating the wind-induced interference effects using TPU wind pressure database and high-dimensional surrogate modeling scheme. Mean and peak pressure coefficients on the principal building surfaces at random interfering building configuration can be predicted, while the sensitivity analysis with the classification approach provides a powerful tool to reveal the local pressure variations. Additionally, the adaptive DoEs are introduced to design the sequential wind tunnel tests in order to accelerate the process to identify critical wind scenarios, thus effectively reducing the number of wind tunnel tests.

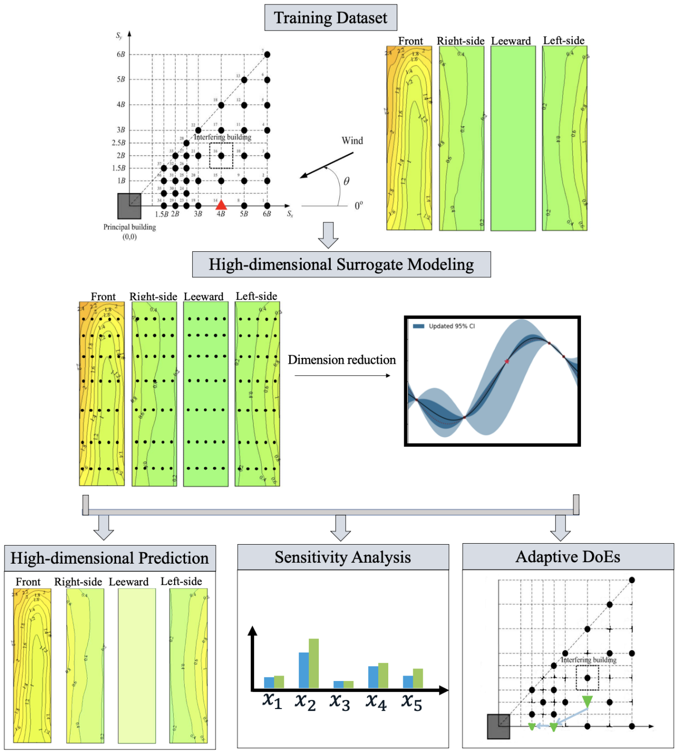

Figure 1. Schematic of the implementation using high-dimensional surrogate modeling.

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