Estimation of Peak pressure by LES for Tall Building on Complex Terrain

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Abstract— **In order to investigate the effects of real complex terrain on peak pressures of tall buildings, this study conducted numerical simulations based on LES model consisting of three cases using actual high-rise building only, high-rise building on complex terrain and high-rise building with surroundings on complex terrain. To study the statistical characteristics of peak pressures, different estimation methods of peak pressures were examined and validated by comparison with the LES results. Then the effects of complex terrain and the surroundings on the accuracy of the estimation method were studied.**

I. INTRODUCTION

The peak negative pressures on the side surfaces of tall buildings under the shear layers have long been recognized as a major cause of damage to the claddings of tall buildings. Furthermore, the peak suctions on the target building are significantly influenced by the nearby complex terrain and the surrounding buildings. As a result, the evaluation of peak pressures on actual complex terrain is urgently needed.

In order to reduce the consumption of time and cost of wind tunnel experiments and CFD simulations in engineering applications, estimation of extreme surface pressures have to be made based on limited number of short-term time history samples. Many researches have been conducted in the past to propose methods to estimate peak pressures (Davenport 1964; Sadek and Simiu 2002; Kwon and Kareem 2011). Nevertheless, the accuracy of the methods currently applied has not been determined because it depends highly on the form of the peak probability model applied and the quantity of data obtained.

This study will discuss the statistical characteristics of peak pressures. Three of the most promising peak pressure estimation methods will be tested for three cases and the results will be compared with the numerical results to check the accuracy of the estimation methods.

II. NUMERICAL SET UP

A. Calculation method

The governing equations of turbulent field are the incompressible Navier-Stokes equations and the continuity equations. Also, for subgrid scale term, Smagorinsky model with Van-Driest type of damping function near the wall is applied.

B. Calculation model

Numerical model around the target building is reproduced by the CAD data with the same geometry as experimental model. Mesh systems are generated using unstructured grid system. Inflow conditions of wind velocity profile and spectrum of velocity fluctuation are generated by the Synthetic Eddy Method (SEM) method proposed by Jarrin (2009). The direction of inflow and the configuration of numerical models for J2 building is presented in Fig. 1. The dimensions of the target J2 building is 84m×48m×22m (height×length×width). The size of calculation domain is 1000 m×1000m×1500m (height×length×width). The scale ratio is 1/400. No-slip condition is used at the building surfaces and the ground.

III. EVALUATION OF PEAK PRESSURE

A. Peak estimation methods

Amerio (2014) classified the methods for peak pressure estimation into three main categories in his PhD thesis: (1) determining C_{p_max} from observed peaks (observed peak methods); (2) mapping the peak distribution of a Gaussian process to a non-Gaussian peak cumulative distribution function (CDF) via the translation process (translation methods) and (3) compute a peak factor by calculating the probability that one maxima from a sample of N maxima is higher than a threshold value (peak factor method). One of the most promising methods of each category will be presented in the peak pressure estimation and compared with the CFD results: improved Gumbel method by Quan et al (2014), improved Hermite polynomial model (HPM) by Yang et al (2014), and improved peak factor method by Pillai and Tamura (2009). Due to the length of this paper, these methods will not be elaborated. The details of these methods can be found in the references [1-3].

B. Comparison results

The pressure coefficient data obtained by CFD results at each point of the building surface (192 points in total) are divided into 3 ten minute (full scale) segments. The maximum values are extracted from each segment. The standard extreme values C_{pk_CFD} are defined as the mean values of the 3 peak values extracted from 3 samples of the CFD results. The estimation methods mentioned above are each applied to the 3 ten minute segments to generate peak CDF (F_{pk}) and peak pressure coefficient estimates, C_{pk_est},, defined as the 22% probability of exceedance from F_{pk} for negative extreme values and 78% for the positive. Each of the three methods uses a 10 min (full scale) record to produce a single peak pressure coefficient estimate C_{pk_est}.. For each method, the mean of these 3 C_{pk_est}. determines the accuracy relative to C_{pk_CFD}.

From Fig. 2, the pressure time histories on the windward surface in Case 1 are almost slightly non-Gaussian processes (|skewness|⩽0.5, kurtosis⩽3.5). These points are plotted either near or along the monotonic curve. On the other hand, the points with pressure processes that show strongly non-Gaussian properties are distributed on the side and leeward surfaces. As the height of the building increases, the non-Gaussian properties of the pressure processes decrease. When the terrain is added in Case 2, the pressure processes on the windward still present slightly non-Gaussianity. While the strongly non-Gaussianity of the processes on the side and leeward surfaces is greatly reduced, especially on the middle and top heights of the building where the pressure processes are almost slightly non-Gaussian. In Case 3 with surrounding buildings added, the distribution of the slightly non-Gaussian and strongly non-Gaussian processes on the building surfaces are quite different from the two cases discussed above. The pressure processes on the lower height of the windward also show strongly non-Gaussian characteristics. This phenomenon disappears as the height increases.

The comparison of peak values between CFD results and the methods presented above is shown in Fig. 3. It appears that each of the methods returns peak positive values equivalent to the CFD results in each case. When comes to the peak negative values, the improved Gumbel method gives better estimation than other two methods with 8.72% and 7.49% larger on average than the CFD peaks in Case 1 and Case 3 respectively. While it shows low performance in Case 2 with an error equal to 29.73% on average, in which the strongly non-Gaussianity of the processes on the side and leeward surfaces is greatly reduced. The translation method proposed by Peng and Yang shows better estimation with an error of 7.78% smaller on average in Case 2. The peak factor method by Tamura overestimate the peak suctions in all three cases with 24.12%, 33.4% and 28.2% respectively higher than CFD peaks.

The mean error ratios for all 192 points are calculated as follows:

$$e = \frac{1}{n}\sum_{i=1}^{n} \frac{C_{p_{est}} - C_{p_{CFD}}}{C_{p_{CFD}}}$$

where C_{p_CFD} and C_{p_est} represent estimated extreme values and extreme value from CFD results of the wind pressure coefficients on each point, n is the number of points (equals to 192), and e is the mean error ratios.

IV. Conclusions

In this paper, LES model with polyhedral mesh is applied to estimate the peak pressures on the target J2 building and the accuracy of three peak value estimation methods are discussed.

The three methods applied in this paper are robust in the prediction of peak positive pressures on the windward surface. The large difference appears in the estimation of peak negative pressure. The Gumbel method improved by Quan still performs better in Case 1 and Case 3 with strongly non-Gaussian processes. The estimation results from the translation method improved by Peng and Yang is more accurate in Case 2 with slightly non-Gaussian processes. The Tamura method tends to overestimate the peak suctions with a highest error on average than the CFD peaks.

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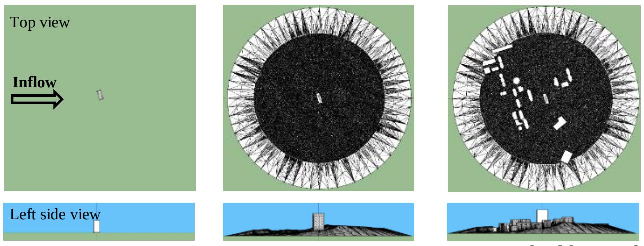

Case 1: J2 building on flat floor | Case 2: J2 building on actual terrain | Case 3: J2 building with surrounding buildings

Fig.1 Inflow direction and configuration of numerical models

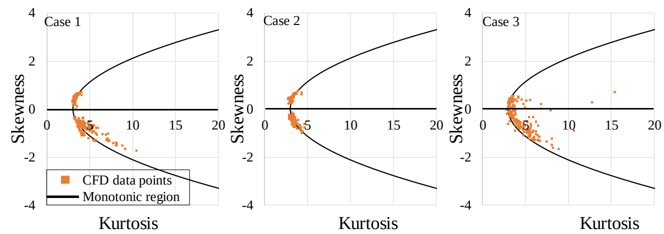

Fig.2 Skewness and kurtosis from all poins for the 3 cases, and the monotonic region forHPM

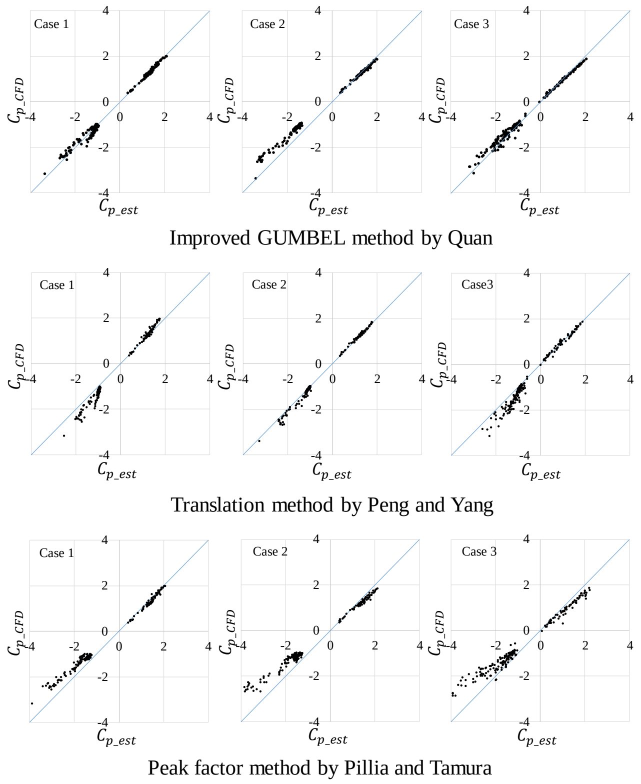

Fig.3 Comparison of extreme values in cases between estimated probability methods and CFD