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Comparison of wind pressure on building from CFD analysis and wind tunnel test using dynamic mode decomposition

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ABSTRACT

Computational fluid dynamics (CFD) is currently being used in wind design fields, but previous studies show that CFD does not perfectly fit with wind tunnel test data. Even though CFD is considered to be good enough to be used for wind design, it is still important to understand the main difference between CFD analysis and wind tunnel measurement. In this study, dynamic mode decomposition (DMD) was used to compare the data from CFD analysis and wind tunnel test. DMD is a decomposition method to capture the spatial-temporal evolution characteristics. Wind pressure on a building is compared, and main pressure modes were extracted by the DMD to identify the difference.

1. INTRODUCTION

As computational fluid dynamics (CFD) techniques have been developed and computing power/speed has increased, the use of CFD for the wind design of buildings has also gradually increased. However, there are still some uncertainties with CFD because it does not fit perfectly with wind tunnel test (WTT) results, and the CFD result can vary depending on the computational setting done by researchers. To overcome this problem, it is needed to understand the possible difference that can occur between the CFD and WTT results.

To understand the flow pattern of fluid, Schmid (2010) developed the dynamic mode decomposition (DMD), which captures the spatial evolution characteristic of flow field. In this study, DMD was performed for the pressure field on the building, and the results from WTT and CFD were compared.

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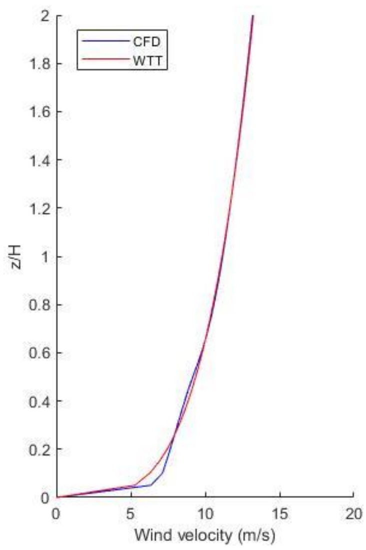
2. METHODOLOGY

2.1 Wind tunnel experiment and computational simulation

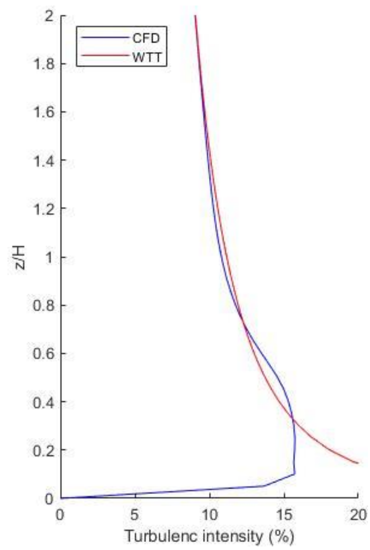
Wind pressure data of WTT provided by Tokyo Polytech University (TPU) was used for this study. A square section building with aspect ratio of 5:1 and wind direction of 0° was used. The model scale was 400:1 with the dimension of building of 0.1 m x 0.1 m x 0.5 m, and time scale was 80:1 for this experiment. Wind pressure data was collected every 0.001 seconds.

For CFD, large eddy simulation (LES) was performed for temporal simulation. Sub-Grid Scale (SGS) model was used for turbulence, and SIMPLE algorithm was used for implicit pressure solution. Time step was 0.0005 seconds, which is double the sampling frequency of WTT. For the simulation domain, the same model scale of 400:1 as WTT from TPU was used. Domain size and mesh size was decided based on the recommendation by COST 732 code. A total of 2,280,832 meshes were used for domain size of 10 m x 5 m x 2 m.

Wind flow profile in the inlet of CFD was determined by random flow generation method suggested by Guichard (2019). Fig. 1 shows the profile of wind arriving at the building, where *H* is the height of the building. It shows that the profiles of CFD and WTT fit well each other, except for turbulence intensity at the low height below 0.2*H*.



(a) Mean wind velocity



(b) Turbulence intensity

Fig. 1 Incoming wind profile on the building

2.2 Dynamic mode decomposition

The DMD divides the flow field into the spatial modes based on singular value decomposition. Each DMD mode has its own growth rate, and some modes show vibrating behavior. Then, the original flow field can be represented by the sum of DMD modes as in the following equation:

$$X(t) = \sum \phi_k \exp(\Omega_k t)\alpha_k \tag{1}$$

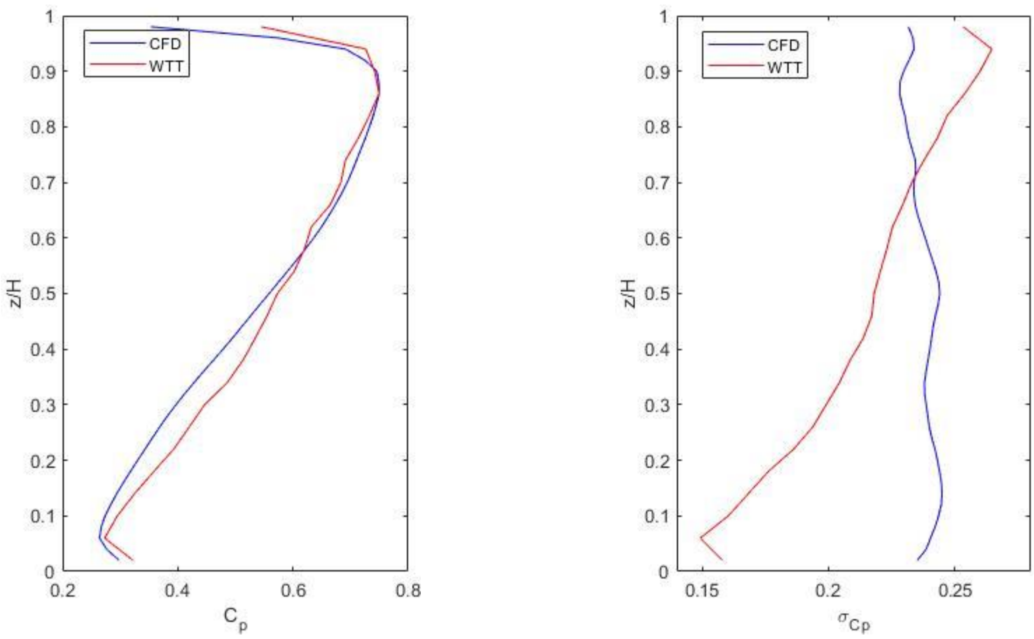
where the *X(t)* is original flow field, ϕ is DMD mode, and Ω and α are growth rate and amplitude of each DMD modes, respectively.

Specific theoretic description is provided by the previous research (Schmid 2010). To estimate the contribution of each mode, I-criterion suggested by Kou and Zhang (2017) was used. I-criterion of DMD mode is obtained by the summation of $\exp(\Omega_k t)\alpha_k$ in Eq. (1) at every time snapshot. In this study, I-criterion shows the contribution of DMD modes on the total time series of pressure flow field.

3. RESULTS AND DISCUSSION

3.1 Wind pressure coefficient and fluctuation

Fig. 2 shows the mean and standard deviation of wind pressure coefficient on the windward wall. The CFD was capable to represent the mean wind load on the building quite well, but not for the fluctuation tendency. In WTT, fluctuation increases with height due to increase of wind speed, but CFD did not show a significant difference on the fluctuation with height.



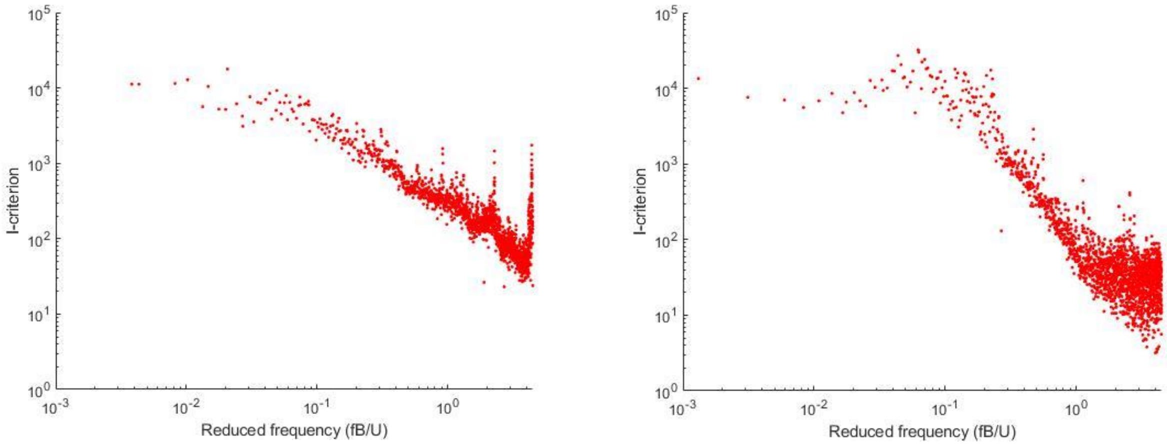
(a) Mean (b) Standard deviation

Fig. 2 Wind pressure coefficient on windward wall

3.2 DMD mode frequency distribution

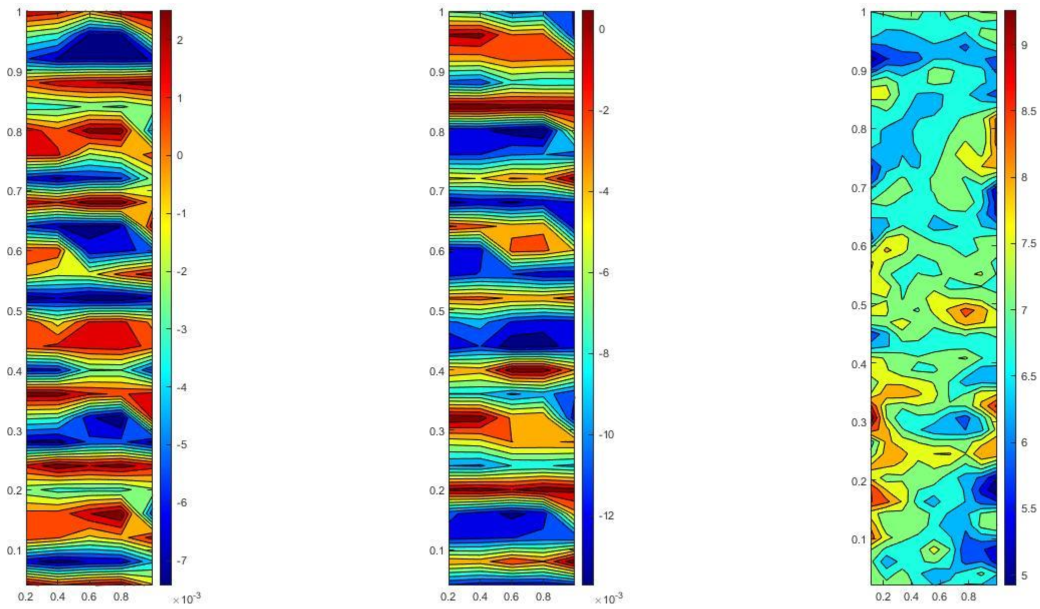
Total 4 seconds with 4,000 snapshots from WTT and LES are used for the DMD analysis. Fig. 3 shows the modal frequency and I-criterion of DMD modes. Both DMD modes of CFD and WTT show the decreasing tendency of I-criterion as the frequency gets higher. However, CFD modes have a peak around *fB/U*=0.1 and exhibit the steeper slope of I-criterion.

Local peaks of I-criterion in the high frequency region (*fB/U*>1) are observed, but the frequencies for local peaks of WTT and CFD are different. Fig. 4 shows the mode shape at the local peak of Fig. 3. For WTT, mode shape with local peak shows the stripe pattern while no certain pattern is observed in the DMD mode with local peak. Other DMD modes were also checked, but there were no DMD mode with stripe pattern in CFD. Stripe-patterned DMD mode of WTT had a total of 19 stripes for local peaks.



(a) WTT (b) CFD

Fig. 3 Distribution of frequency and I-criterion and DMD modes



(a) WTT, *fB/U*=2.28 (b) WTT, *fB/U*=4.41 (c) CFD, *fB/U*=2.56

Fig. 4 DMD mode shape at the local peak on high frequency

4. CONCLUSIONS

This study compared the DMD modes of experiment and computational data of wind pressure. The result shows that even the mean wind speed and turbulence intensity of incoming wind are similar, the fluctuation of wind pressure can be highly different. The DMD mode at high frequency with stripe pattern is only observed in the WTT data. It is expected that the mode with stripe pattern is related to vortex shedding phenomenon or building's aeroelastic behavior. This should be discussed further with the analysis of the wind flow pattern and wind pressure on side and leeward walls.

ACKNOWLEDGEMENTS

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