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Improved Wind Response Assessment Using Both HFPI and Numerical Simulation

Hansol Lee [1], Thomas Kang [2]

[1]*Seoul National University, Seoul, Korea, hansol817@snu.ac.kr*
[2]*Seoul National University, Seoul, Korea, tkang@snu.ac.kr*

SUMMARY
While high-frequency pressure integration (HFPI) test is one of the most common methods for evaluating wind load on the building structure, a lack of pressure taps can cause the error of integrated wind load and analyzed structural response. To overcome such a problem, study on the combined application of Computational Fluid Dynamics (CFD) with HFPI test is conducted. Peak wind response errors by pressure tap resolution of HFPI test and CFD were compared, for the applicable range of CFD.

Keywords: High-frequency pressure integration test, Large eddy simulation, Structural response

1. INTRODUCTION

For evaluating design wind load on the building structure, wind tunnel tests and computational fluid dynamics (CFD) are widely used. For wind tunnel testing, high-frequency force balance (HFFB) test and high-frequency pressure integration (HFPI) test are two of the most common methods for building structure having insignificant aeroelastic effect. While HFFB directly measures the base overturning moment of aerodynamic wind load, HFPI measures synchronous wind pressure from pressure taps. HFPI has an advantage for evaluating wind loads along the height, but its accuracy depends on the number and distribution of pressure taps. While integrated wind load by HFPI test with sufficient resolution of pressure tap makes a good agreement with the base overturning moment measured by HFFB test (Kim *et al*., 2010; Cluni *et al*., 2011), a lack of pressure taps can cause the error of integrated load and analyzed structural response (Park and Yeo, 2021).

Meanwhile, computational fluid dynamics (CFD) is a numerical tool for evaluating wind load on the building. Large eddy simulation (LES) is currently the most common model to obtain the time series of wind load, and several studies showed that LES can be an efficient tool for assessing the wind load on building (Ricci *et al*., 2018; Thordal *et al*., 2020). CFD has an advantage on the unlimited number of measuring points, but still it is hard to obtain the long-time data for ensemble averaging analysis due to high computational cost.

In this study, use of CFD as the revising tool when HFPI test is done with insufficient number of pressures taps is discussed. From the HFPI test and CFD simulation, effects of pressure tap resolution on the analyzed wind response were compared to examine if two methods show the same or similar tendency.

2. WIND LOAD SIMULATION

2.1. Open-accessed HFPI test

The open-accessed HFPI test data provided by Tokyo Polytechnic University(TPU) aerodynamic database was used (Tamura, 2012). Among the test cases done by TPU database, square section building with an aspect ratio of 5 was selected for the case study. For each face, 125 pressure taps were located at uniform spacing with 25 levels and 5 pressure taps per level. While TPU database provides 32.7 second data of HFPI test for each case, total data was divided into 4 divisions for ensemble averaging.

2.2. Numerical simulation

LES was conducted on the building with wind incident angles of 0°, 15°, 30°, and 45°. For incident wind profile, building's geometric profile, and location of predefined point for pressure measurement, the same condition with TPU database was used. For each case, total 12.5 seconds of LES data were collected with 0.0005 second interval. The first 5 seconds were used for flow stabilization and the later 7.5 seconds were used for further analysis of wind load and response assessment, corresponding to the 10-minute data in full-scale with time scale of 1/80.

3. PRESSURE TAP SELECTION

Table 1 shows the three cases of horizontal pressure tap distribution and five cases of vertical pressure tap distribution for comparison. The first case for each horizontal and vertical tap arrangement belongs to the original case with every location selected. For vertical taps, case (b) and (d) have uniform tap distribution, while the other two cases have tap distribution concentrated on the top of building. With the combination of horizontal and vertical cases, total 15 cases were analyzed.

Table 1. Cases of pressure tap selection

Horizontal	(1)	0.1B, 0.3B, 0.5B, 0.7B, 0.9B
	(2)	0.1B, 0.5B, 0.9B
	(3)	0.3B, 0.7B
Vertical	(a)	Every 25 heights (0.02H ~ 0.98H)
	(b)	h = 0.02, 0.14, 0.26, 0.38, 0.50, 0.62, 0.74, 0.86, 0.98 H (9 locations)
	(c)	h = 0.18, 0.34, 0.50, 0.62, 0.70, 0.78, 0.86, 0.94, 0.98 H (9 locations)
	(d)	h = 0.02, 0.18, 0.34, 0.50, 0.66, 0.82, 0.98 H (7 locations)
	(e)	h = 0.18, 0.38, 0.58, 0.70, 0.82, 0.94, 0.98 H (7 locations)

4. WIND RESPONSE COMPARISON

4.1 Peak response assessment

Table 2 summarizes the structural property of 50-story high-rise building for a case study on structural response. For each case, time history analysis on the building was conducted to obtain the peak response.

For assessment of peak response, non-Gaussian distribution of response was considered. Based on the comparative study on the peak estimation methods for non-Gaussian distribution done by Peng (2014), translation method with Hermite polynomial model which showed the best performance and stability was used for peak factor estimation.

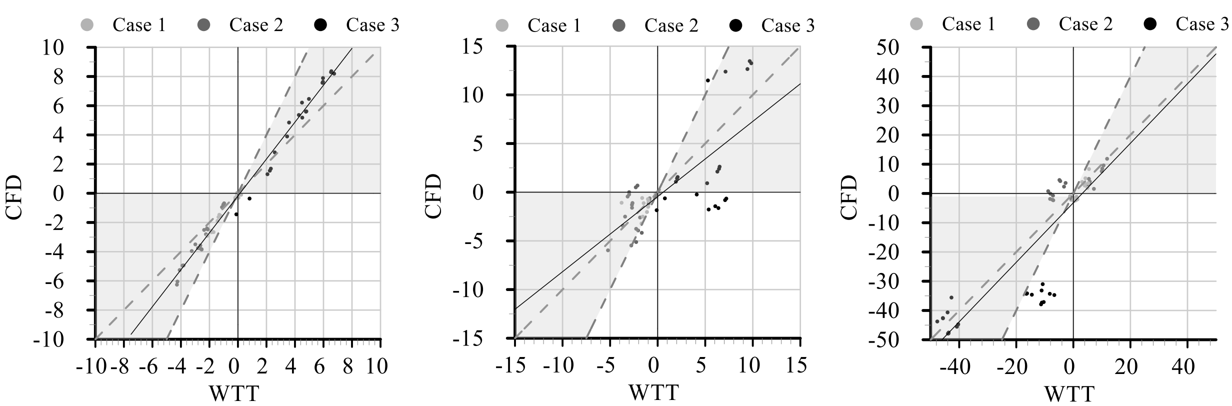
Table 2. Property of building model for structural analysis

Building size	Structural system	Concrete property	Natural frequency
50 m (*B*) 50 m (*D*) 200 m (*H*)	Building frame system with core wall	Strength f_c' : 40 MPa Modulus of elasticity E_c : 30 GPa	x-dir. : 0.199 Hz y-dir. : 0.201 Hz z-dir. : 0.321 Hz

4.2 Error of peak response by pressure tap resolution

Assuming that the original case 1-a with every pressure tap selected represents the proper wind load, the errors of peak wind response were obtained for other cases.

Fig. 1 shows the scatter plot of the error percentage (%) of peak displacement responses at top floor when the wind tunnel test or CFD simulation was used. While the dashed line represents the error percentage of CFD showing double or equal to that of wind tunnel test, the colored region shows the applicable range of CFD for supplementing HFPI test results. Most of the cases were in the applicable range for along-wind response, but some cases such as the case 3 of horizontal tap were out of the range for across-wind and torsional responses. The solid line shows the linear regression curve of the scattered errors. For along-wind, CFD averagely shows 33% larger error than HFPI test.



(a) Along-wind (b) Across-wind (c) Torsional

Figure 1. Peak response error percentage (%) by HFPI and CFD

Fig. 2 shows the maximum error percentage of peak displacement response obtained by HFPI test result and reduced error percentage by the supplementation of CFD to HFPI test result. For along-wind response, application of CFD reduced the error percentage to below 2%. For across-wind and torsional response, application of CFD usually increased accuracy but its effect was less significant than along-wind.

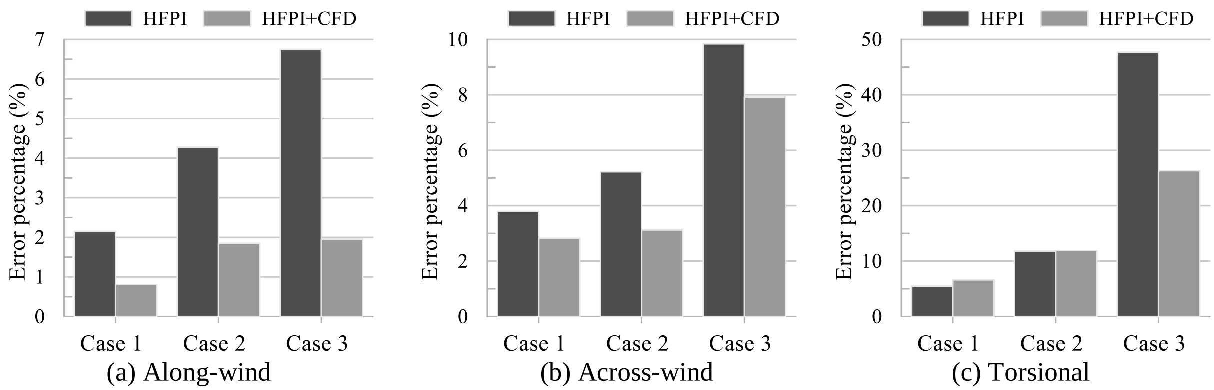


Figure 2. Reduction of peak response error percentage (%)

5. CONCLUSION

In this study, correction of the wind response based on insufficient HFPI test using CFD simulation was discussed. Based on this study, the combined use of experimental and numerical simulation is suggested for more reliable wind design. For HFPI test with limited pressure tap resolution, combined use of CFD was efficient for increasing the accuracy of along-wind response. For across-wind and torsional responses, application of CFD was not as effective as the along-wind response. Improvement of accuracy of CFD simulation on across-wind direction pressure field would be needed. Not only the correction of wind responses will be discussed in further study, but also the reconstruction of wind pressure fields using CFD.

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