Experimental investigation of aerodynamic characteristics of tall building with various aspect ratios

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SUMMARY:
In the present study, using a square and a rectangular section tall building models with various aspect ratios, characteristics of peak pressure coefficients, mean and fluctuating force coefficients and power spectra were systematically investigated through a series of wind tunnel tests. From the wind tunnel tests, the following were found. Mean force coefficients in *X*- and *Y*-axis increased with increasing aspect ratios, while fluctuating force coefficient C_{FX} showed decreasing tendency and fluctuating force coefficient C_{FY} showed increasing tendency with aspect ratio. Mean and fluctuating torsional moments were quite small and showed less variation when compared with force coefficients in translational directions. And, from the Den Hartog Criterion, it was found that aerodynamically unstable vibration could occur for square tall buildings with aspect ratio larger than 3 for the current experimental conditions. Lastly, the shapes of power spectra of *X*-axis force coefficient $S_{CFX}(f)$ showed similar shapes regardless of aspect ratios, but for the power spectra of *Y*-axis force coefficient $S_{CFY}(f)$, peaks corresponding to the reduced frequency of 0.1 increased and became narrow band with increasing aspect ratios.

Keywords: Aspect ratio, Pressure measurement, peak pressure coefficient, generalized force coefficient, Power spectrum

1. GENERAL INSTRUCTIONS

In current Recommendations for Loads on Buildings (Architectural Institute of Japan, 2015) (abbreviated as AIJ-RLB (2015)), wind loads are determined based on the concept of an equivalent static wind load, and structural frames are assumed to behave elastically in strong wind. The along-wind load is generally composed of a mean component caused by the mean wind speed, a quasi-static component caused by relatively low frequency fluctuation and the 1st mode resonant component caused by fluctuation in the vicinity of the natural frequency. For along-wind load, various force coefficients (in AIJ-RLB (2015), wind force coefficient at the top of the building, a factor relevant to overturning moment in the along-wind direction and a factor relevant to rms overturning moment in the along-wind direction), which were used to calculate the mean load and gust effect factor, were modelled as a functions of building shapes and approaching flow characteristics. The across-wind load can be obtained by multiplying fluctuating overturning moment coefficients by the peak factor and the fluctuating overturning moment coefficients were modelled as a function of side ratio only.

So far, there are lots of studies on the tall buildings with the specific height, there are few studies to investigate the effect of building heights on aerodynamic and response characteristics systematically. In the present study, fluctuating pressures on the square and rectangular section tall buildings with various heights, whose aspect ratio changed from 2 to 9.5 were measured, and effect of aspect ratio on aerodynamic characteristics were investigated.

2. WIND TUNNEL TESTS

Wind tunnel tests were conducted at Tokyo Polytechnic University in Japan. In the present study, a square section model with 0.08m (SR10) and a rectangular section model with width of 0.098m and depth of 0.0653m were used (side ratio of 1:1.5, SR15), whose heights can be changeable from 0.16m to 0.76m. As the cross-sectional areas were the same, these heights correspond to the aspect ratio of 2 to 9.5. Pressure taps were installed on four surfaces, equally spaced horizontally and vertically. The total number of pressure taps was 304 for H/B = 9.5. All pressures were measured simultaneously using a multi-channel pressure measurement system, and a low-pass filter of 300Hz cutoff frequency was installed in each data acquisition channel to eliminate aliasing effects. After pressure measurements, tubing effects were numerically compensated using the gain and phase characteristics of the pressure measurement system. Fig. 1 shows the definition of wind direction and coordinate system. Characteristics of approaching flow are shown in Fig. 2. The approaching flow was simulated using spires, barriers and various-sized roughness elements. The power-law index of the simulated flow was 0.2, which represents a suburban area. Note that mean wind speeds are different depending on building heights and pressure coefficients were defined using the mean wind speed at the building height.

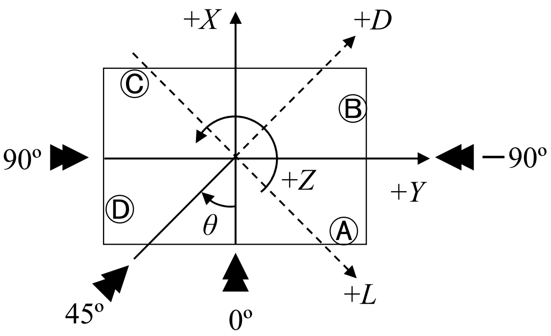


Figure 1. Definition of wind direction and coordinate system.

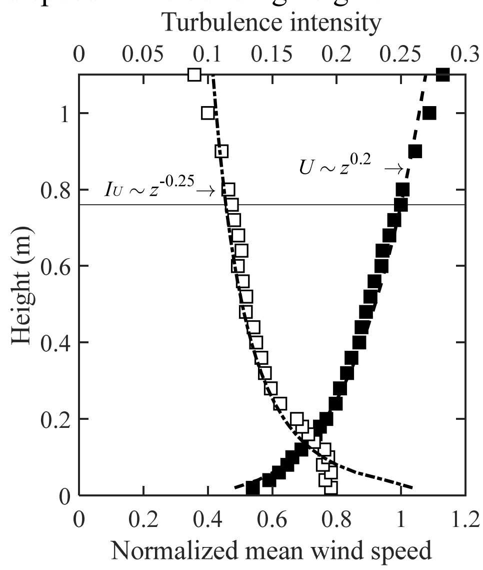


Figure 2. Profiles of approaching flow.

5. RESULTS AND DISCUSSION

Fig. 3 shows a variation of the largest maxC_p and minC_p on aspect ratio. The averaging time for peak pressure coefficients is 0.1 second, and the largest values among all wind directions were chosen at the specific height. The largest maxC_p shows decreases with increasing aspect ratio, while minC_p changes little on aspect ratio. Fig. 4 shows a variation of the largest meanC_{F1X} (left) meanC_{F1Y} (right) on wind direction. In the present study, the 1st linear mode were considered. As can be seen, the coefficients on the square section model are larger than those of the rectangular section model. The variation of meanC_{F1Y} near the wind direction of 0° was sometimes used to examine if the instability vibration could be occurred. Fig. 5 shows the results of Den Hartog criteria. As can be seen, the instability vibration can better be occurred for the shallow cross section model. Power spectral densities were calculated as shown in Fig. 6 and the spectral values for the wind speeds corresponding to the return periods of 500-year and 1-year wind speed ($(f_{500}S_{CF}(f_{500}))^{0.5}$ and $(f_1S_{CF}(f_1))^{0.5}$)were shown in Fig. 7.

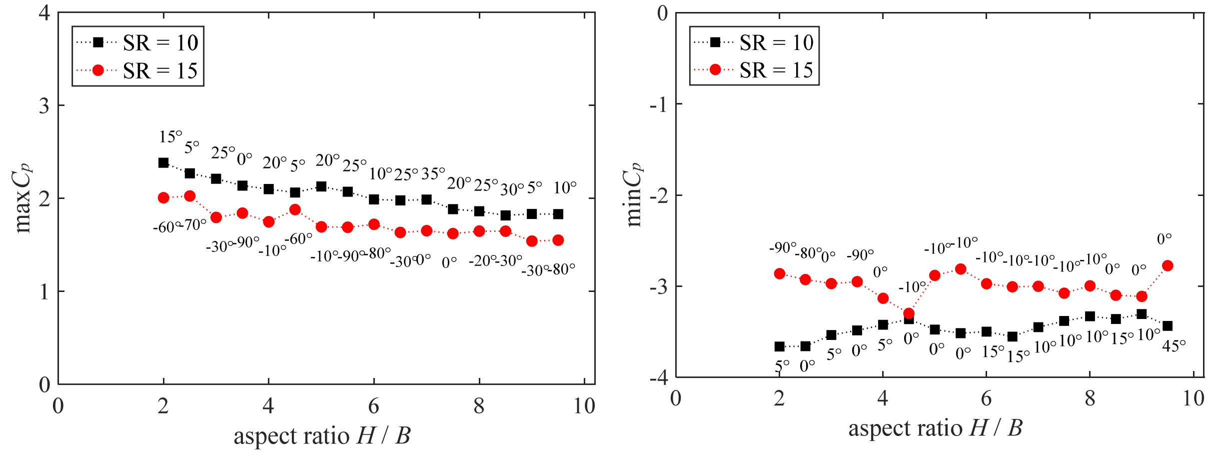


Figure 3. Variation of the largest maxC_p (left) and minC_p (right) on aspect ratio.

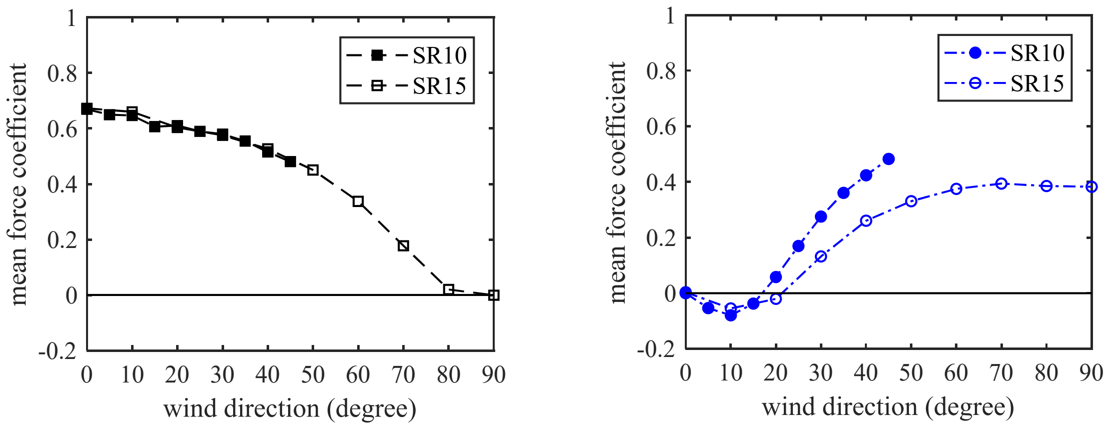


Figure 4. Variation of the largest meanC_{F1X} (left) and meanC_{F1Y} (right) on wind direction.

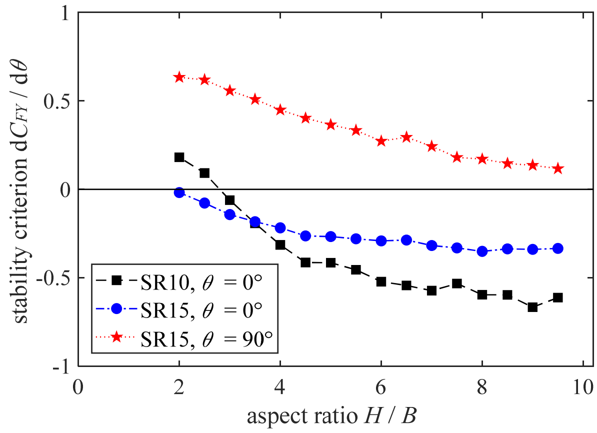
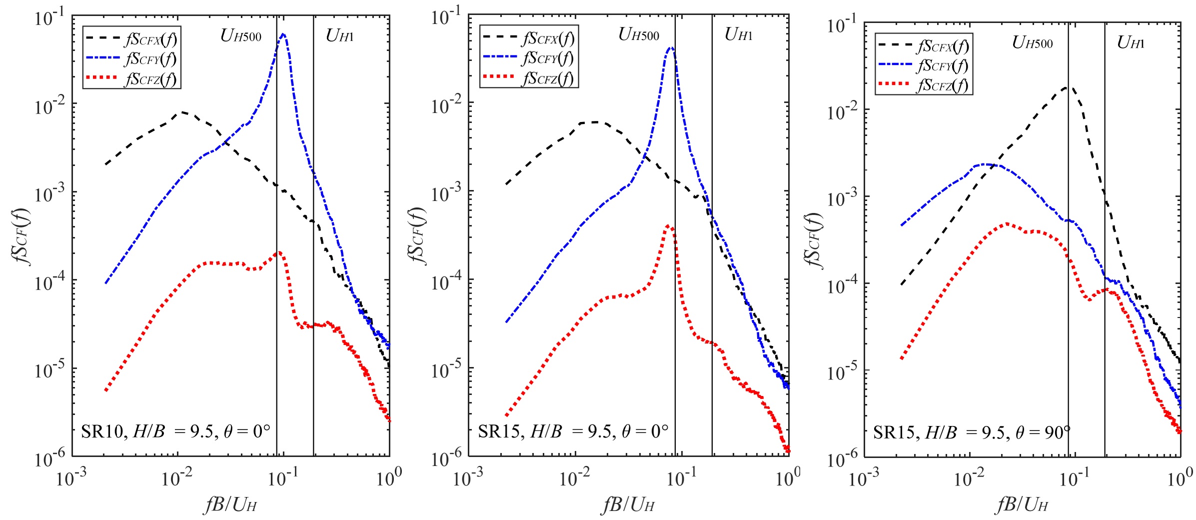


Figure 5. Variation of stability criterion with aspect ratio.



(a) SR10, $\theta = 0^{\circ}$ (b) SR15, $\theta = 0^{\circ}$ (c) SR15, $\theta = 90^{\circ}$

Figure 6. Shape of power spectral density.

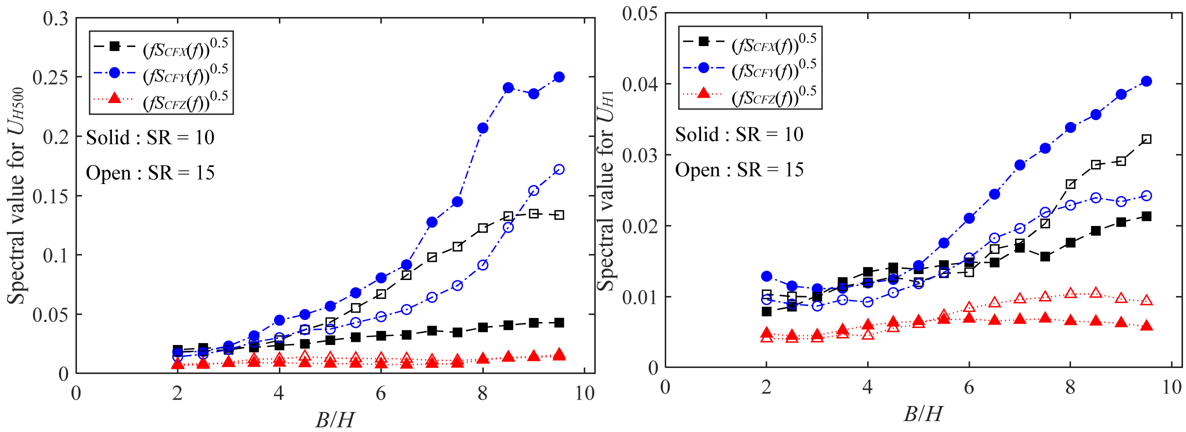


Figure 7. Variation of spectral values for U_{H500} (left) and U_{H1} (right) with aspect ratio.

4. CONCLUDING REMARKS

In the present study, the effect of side ratio and aspect ratio on peak pressure coefficient, generalized force coefficient and power spectral density were investigated through wind tunnel tests.

ACKNOWLEDGEMENTS

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REFERENCES

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