스카이브릿지로 연결된 쌍둥이 타워의 풍응답: 구조적 및 공기역학적 연계 효과

Wind-Induced Response of Twin Tall Buildings with a Skybridge: Effects of Structural and Aerodynamic Coupling

임 준 택*

* 삼성물산(주) 기술연구센터 선임연구원

1. Introduction

Two types of coupling may emerge in wind-resistant designs of twin buildings connected by a skybridge. One is aerodynamic coupling due to a high level of cross-correlation between the wind loading components exerted on the buildings. The other is structural coupling, introduced by the skybridge, synchronizing the motions of vibration of the buildings. Recently, these types of coupling have been of primary interest to engineers interested in accurately estimating the aerodynamic response of structurally connected tall buildings.

The above coupling issues have stimulated wind tunnel studies utilizing an expanded high-frequency force balance (HFFB) technique, originally developed and utilized in laboratory investigations of single tall buildings. To date, only a limited number of studies employing an enhanced HFFB approach have been published in the open literature. RWDI (Rowan Williams Davies and Irwin Inc.) developed a multi-HFFB system and proposed a generalized loading model formulated in the time domain through combined the base wind loading, the non-linear mode shapes, building eccentricity and an assumed wind pressure scheme. The proposed framework was applied in the estimation of the dynamic wind response of a twin-tower. CPP (Cermak, Peterka and Petersen Inc.) studied a two-tower structure with coupled motions and employed six (coupled) modes in the modal superposition analysis of the vibration of the buildings. WEFL (Wind Engineering and Fluids Laboratory) at Colorado State University developed a dual high-frequency force balance (DHFFB) system to measure the correlated wind loading which was subsequently use to predict the coupled building response. Of main interest in the study were the wind-induced rooftop accelerations of twin tall buildings with various aspect ratios.

The above efforts have shown useful applications of an enhanced HFFB system in experiments and analyses of building complexes with coupled motions. However, it has been recognized that in-depth studies are needed to better understand the aerodynamic response of twin building configurations. The issues of primary interest include the effects of structural linkages between tall buildings and the role of correlated wind loading exerted on the two buildings.

This article is concerned with issues associated with structural and aerodynamic couplings. Although a refined HFFB to account for such couplings formulated based on a traditional HFFB treatment is not addressed here, several levels of structural coupling and wind loading correlations are together considered and their effects on the building aerodynamic accelerations are investigated for wind speeds associated with three representative return periods.

2. Application and discussion

2.1 Twin building configuration

A twin building configuration comprising of two identical buildings was assumed. Each prototype building had a square plan of 38m x 38m (*D* x *D*), a height of 305m (*H*) and a gross mass density of 200kg/m^3 (ρ_m). A skybridge connecting the buildings was located at mid-height of the buildings. In the study, the distance (*l*) between the building centers, the depth (*d*) and the rigid beam portion (*b*) of the sky bridge were respectively set to: 25m, 6m and 19m. The structural damping ratio of the buildings was assumed to be 1.5%. The mode shapes of the two buildings were approximated, for all principal structural directions, using a power law with the exponent (β) set to 1.3.

A model of the above twin building was tested in a boundary layer wind tunnel at the Wind Engineering and Fluids Laboratory at Colorado State University, see Fig. 1.

The rooftop building accelerations for 5-year mean return periods were computed and compared with the results for 1- and 10-year mean return periods. The corresponding design (mean) wind speeds at the rooftop of the building were 20.6m/s (1year), 25.1m/s (5years) and 27.1m/s (10years), respectively. These speeds were obtained using the Type I extreme value distribution fitted for mean wind speeds recorded in Seoul.

2.2 Aerodynamic coupling cases

The aerodynamic coupling between tall buildings in close proximity may appear in full or in part, which can be classified into the following three cases:

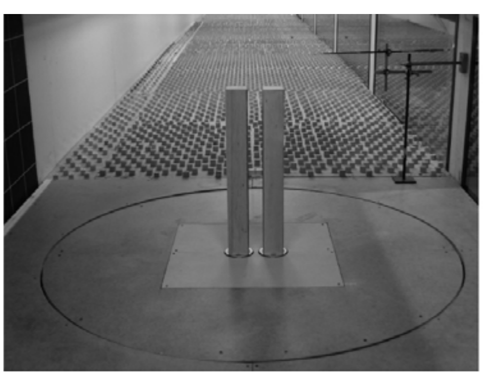
- Case I (fully coupled) - all loading correlations are accounted for;
- Case II (not coupled) - all loading cross-correlations are ignored; and
- Case III (partially coupled) - cross-correlations involving the loading components of two buildings are ignored.

In an intuitive manner, these cases are described in a matrix form, as shown in Fig. 2.

To identify the effects of aerodynamic coupling on the wind-induced building accelerations, the responses of the twin buildings were calculated for the above three cases. It should be noted that the cross-correlations of Case I require the use of DHFFB in measurement of the base wind loading, while the correlations of Cases II and III do not require the use of DHFFB, as they can be determined from wind loading measurements resulting from the use of a (single) HFFB.

2.3 Effects of aerodynamic coupling

As shown in Fig. 3, the resultant accelerations obtained for Cases II and III were similar, however smaller than those obtained for Case I. Inclusion of the full aerodynamic coupling resulted in an increase of up to 3% in the resultant acceleration for the building B1 and a decrease of up to 6% for the building B2. For both the buildings, the largest



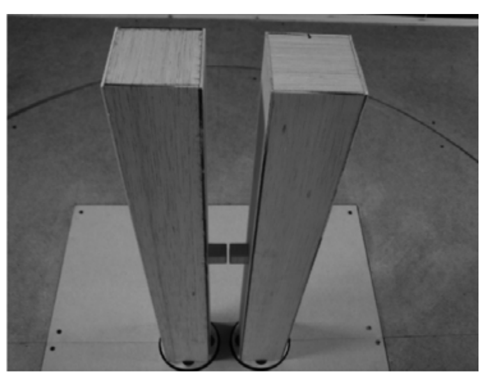


Fig. 1 Wind tunnel model (left) and close-up view of skybridge (right)

discrepancy between the coupled and uncoupled cases occurred for an intermediate level of structural coupling.

The above findings indicate that the inter-building coupling of the aerodynamic loading significantly affects the building rooftop accelerations and it should be included in predictions of the building responses. Capturing of the coupling of the aerodynamic loading on the two buildings (of the twin-building configuration) requires the use of DHFFB.

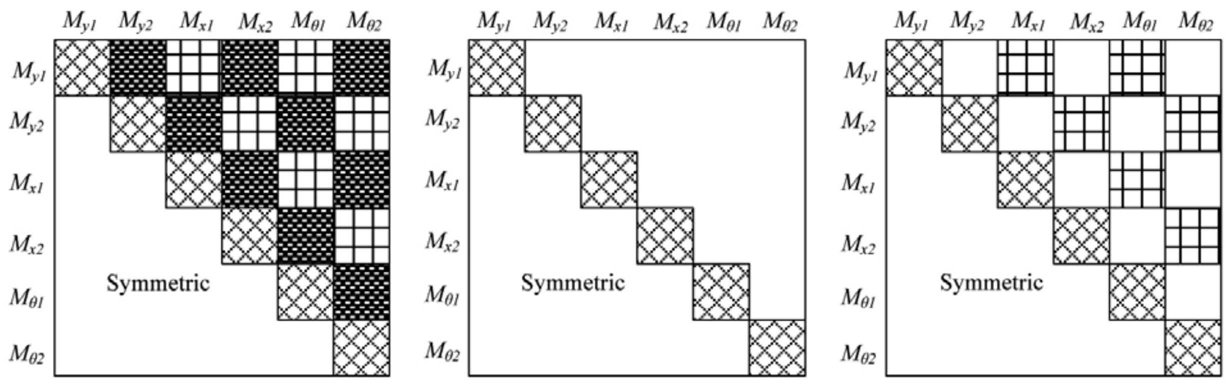
In view of the importance of the full aerodynamic coupling, the parametric study presented in the remainder of this article is limited to Case I.

2.4 Effects of structural coupling

The obtained acceleration ratios are shown in Fig. 4. This format captures the overall impact of the structural coupling on the response of buildings in the twin-building configuration considered in this study. Hence, the uncoupled analysis may lead to significant over- and underestimations of the roof-corner acceleration of structurally coupled twin buildings.

3. Concluding Remarks

Neglecting the aerodynamic coupling due to the cross-correlations of the loading components may lead to biased predictions of the building acceleration. The discrepancies were significant by up to 11% for the directional accelerations and up to 6% for the resultant acceleration. For the twin building configuration considered, most of the contributions



(a) Case Ⅰ (b) Case Ⅱ (c) Case Ⅲ

Fig. 2 Aerodynamic coupling cases for twin building configuration
(⊠: diagonalcomponent, ⊞ : building correlation and ▩ : inter-building correlation)

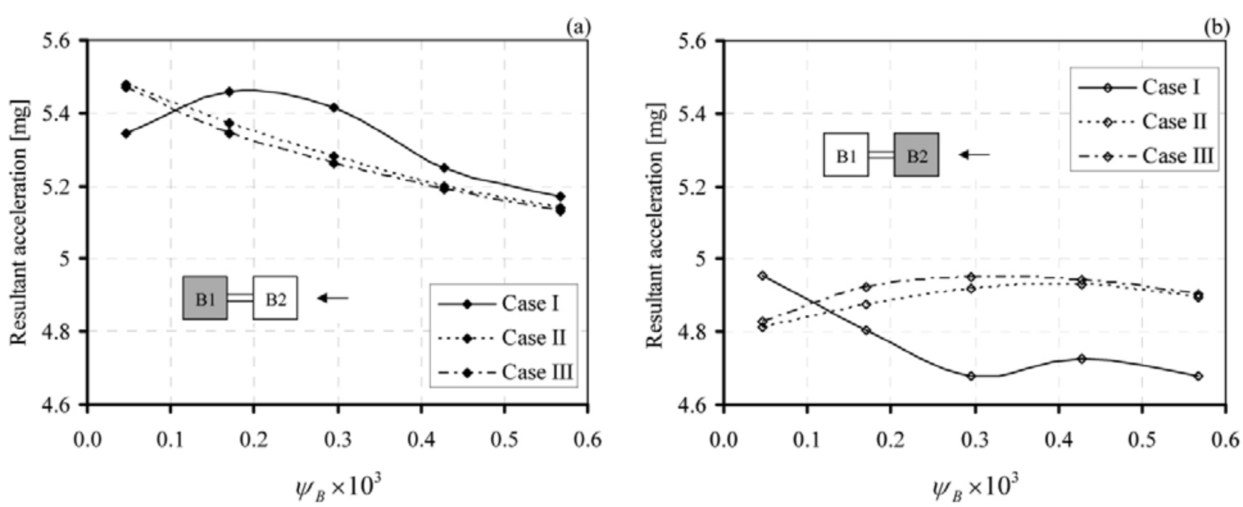


Fig. 3 Effects of aerodynamic coupling on resultant acceleration: (a) B1 and (b) B2

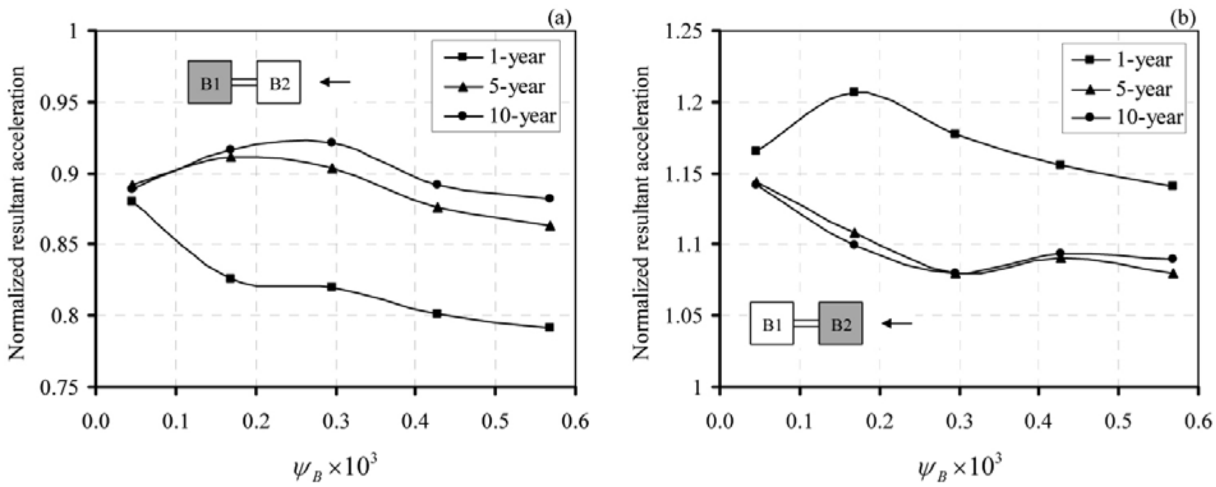


Fig. 4 Effects of wind mean return period on resultant acceleration for buildings B1 and B2

of the aerodynamic coupling resulted from the inter-building correlations.

The presence of structural coupling led to a significant reduction (up to 22%) in the maximum acceleration obtained for the structurally uncoupled buildings, while an increase occurred in the lower acceleration. Overall, the impacts of the structural coupling were greater with an increase in the coupling level. Therefore, since the structural coupling may yield substantial impacts on estimations of the building acceleration, its inclusion in wind-resistant designs of structurally coupled twin buildings or other slender structures is desirable.