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# Aerodynamic admittance functions of windward walls with different aspect ratios

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**SUMMARY:**
Aerodynamic admittance function (AAF) relates the wind pressure fluctuation to oncoming wind turbulence in the frequency domain. The AAF has been used in many international building codes, which is explicitly included in the term of background response factor within the gust effect factor model. This paper elaborately examines the AAF of area-averaged windward wall pressures on rigid buildings with various aspect ratios of H/B from 0.25 to 12, where H denotes the building height and B is plan dimension across wind direction. The comparisons between measured data from wind tunnels and widely used AAF models are made. Separated flow and horseshoe vortices in front of buildings are observed to influence the characteristics of AAF, which are not involved in the widely used AAF models. These body-generated turbulences result in the increase of AAF and background response factor. A new AAF model is proposed to account for the body-generated turbulence effects on windward wall pressures. This new model is developed based on strip theory and considers the coherence of wind pressures on windward walls. The non-dimensional geometric parameter, H/B, and the ratio of integral scale to building breadth, are found to be key parameters controlling the AAF.

*Keywords: Aerodynamic admittance function, gust effect factor, background response factor*

## 1. INTRODUCTION

Quasi-steady theory is widely used as the fundamental concept for wind load provisions in building codes since it allows for the combination of background and resonant wind loads through the development of closed-form solutions of the gust effect factor, $G$, such as that of Solari (1993a and b). Within Solari's gust effect factor model, the background response factor, $Q$, which only considers the upstream turbulence effects on wind pressure fluctuations, is determined by the aerodynamic admittance function (AAF) in the frequency domain. In the past decades, many theoretical or empirical AAF models for buildings have been studied. Hunt (1976) observed attenuation of point pressure fluctuations at high frequencies, which is attributed to the distortion and blockage of turbulent eddies caused by the presence of the body. Vickery (1965) developed an empirical function, which collapsed measured values of aerodynamic admittance of varying shapes in isotropic turbulence for overall loads, implying that the effects of incomplete coherence of the pressures over the wall area together with the distortion of the pressures at high frequencies are taken into account. Kawai (1983) proposed an admittance function for fluctuating pressures at the stagnation point of buildings with $H/B > 1$ by considering the flow distortion effects. Solari (1993a and b) suggested that the product of coherence functions in along wind and cross-wind directions is the AAF by implicitly assuming that wind loads are completely coherent with upstream turbulence. Sharma and Richards (2004) developed models of the aerodynamic admittance for both points and the entire windward wall on a low-rise building with a wall aspect ratio of *H/B* = 0.43. Their model for the area-averaged windward wall pressures is derived by a two-stage process of windward wall pressure admittance: (i) attenuation of point pressures at high frequency due to the flow distortion in front of the windward wall, as discussed in Hunt (1976), and (ii) attenuation of area-averaged windward wall pressures due to the filtering effects of the integration process over the averaging area.

The wind field in front of the windward walls is complex due to the downward flow directions below the stagnation streamline near the wall, along with resulting horseshoe vortices (i.e., Baker, 1979). However, the previously mentioned AAF models do not include the body-generated turbulence effects. Wang and Kopp (2021b) observed that the aspect ratio of windward walls, *H/B*, would influence the background response factor *Q* and gust effect factor *G*, due to the effects of separated flow and horseshoe vortices, indicating the [probable] dependence of AAF on *H/B*. Solari's model, which neglects the body-generated turbulence, was observed to underestimate the background response factor and gust effect factor. Hence, there is a need to develop a new model which can account for the body-generated turbulence effects on wind load fluctuations.

The objective of this paper is to address the limitation of Solari's model by proposing a new model of AAF for windward walls. The strip theory is the basis of the newly developed model. The dependences of the parameters in the proposed model on non-dimensional geometrical parameter H/B and the ratio of integral scale to building breadth are examined.

## 2. METHODOLOGY FOR DETERMINING AAF

### 2.1. Building configurations and wind field measurement

The dataset used in this paper was from Wang and Kopp (2021a) for mid- to high-rise buildings with height-to-breadth ratio (*H/B*) ranging from 0.25 to 12. Note that breadth *B* is the building plan dimension cross-wind direction. Specifically, 30 building configurations from Wang and Kopp (2021a) were used in this paper. The wind field was measured in the empty wind tunnel without building models, with aerodynamic roughness length of 0.034m in full scale using the length scale of 1/200. More details can be referred to Wang and Kopp (2021a).

### 2.2 New model for AAF

In Solari's model (1993a and b), the AAF is implicitly the product of coherence functions in the along wind and cross-wind directions, by assuming the wind load fluctuation is completely coherent and correlated with stream-wise turbulence. However, this assumption is not necessarily the case in reality probably due to: 1) area-averaging technique would increase the decay rate of coherence of wind pressures at high frequencies due to the nonsynchronous effects of high-frequency turbulence on surfaces; 2) complex body-generated vortices, such as the separated flow and horseshoe vortices in front of the buildings, might change the AAF, which are not involved in the commonly used models; and 3) the ratio of turbulence integral length scale relative to the characteristic size of buildings might be a key parameter in AAF based on QST, in which large-scale freestream turbulence is responsible for the wind load fluctuations while smaller scale turbulence is assumed to affect the local flow field around the building (Bearman and Morel, 1983). Therefore, the proposed new model aims to account for the above hypothesis. Eq. 1 is the expression of proposed AAF for windward walls based on strip theory.

$$\chi_r^2(f) = \chi_p^2(f) Coh\_r(f) \quad (1)$$

$$Coh\_r(f) = \frac{\sum_i \sum_j A_i A_j \sqrt{\bar{P_i}^2 \bar{P_j}^2 Co\ \ (P_i, P_j, f)}}{\sum_i \sum_j A_i A_j \bar{P}_i \bar{P}_j} \tag{2}$$

where $\chi_r^2(f)$ is the AAF of area-averaged windward wall pressures, $\chi_p^2(f)$ indicates the AAF of strip pressures and named as equivalent AAF of strip pressures in this paper, $A_i$ and $A_j$ are tributary areas of pressure tap $i$ and $j$, $P_i$ and $P_j$ are wind pressures at tap $i$ and $j$, $Coh(P_i, P_j, f)$ is the coherence function of pressures at tap $i$ and $j$, and $Coh\_r(f)$ is joint acceptance function, which is represented by the coherence function of wind pressures as shown in Eq. 2. Given the expression of AAF for windward walls in Eqs. 1 and 2, we further obtain the expression for background response factor, $Q$, as shown in Eq. 3, which follows the same format in Solari's model.

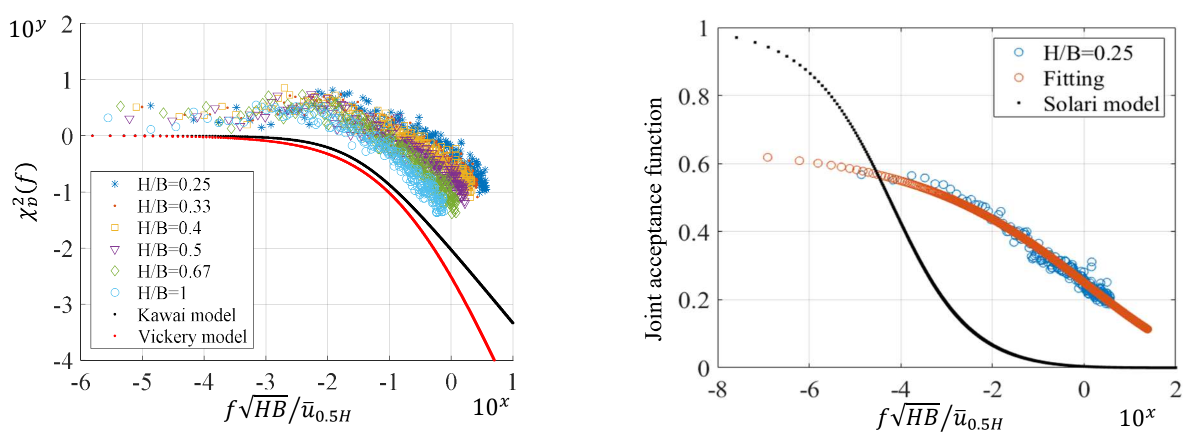
$$Q = \sqrt{\int_0^\infty \chi_p^2(f) \frac{S_u(f)}{\sigma_u^2} Coh\_r(f) df} = \sqrt{\int_0^\infty \frac{S_u(f)}{\sigma_u^2} \chi_r^2(f)\ df} \tag{3}$$

where $S_u(f)$ is the spectrum of longitudinal wind velocity and $\sigma_u^2$ is the variance of longitudinal wind velocity.

In this paper, we will specifically develop the models for equivalent AAF of strip pressures, $\chi_p^2(f)$, and joint acceptance function, $Coh\_r(f)$.

## 3. RESULTS AND DISCUSSIONS

Fig. 1a presents the equivalent AAF of strip pressures and Fig. 1b indicates the joint acceptance function for the building with H/B=0.25. The commonly used AAF models developed by Vickery (1965) and Kawai (1983) are presented as well. It is notable to find that equivalent AAF for strip pressures is beyond unity at reduced frequencies of $f\sqrt{HB}/\bar{u}_{0.5H} \approx 0.01$, due to the effects of separated flow and horseshoe vortices in front of buildings. While the AAF gradually reduces to unity at low frequencies approaching to zero. The previous models, such as Kawai's and Vickery's models, are not appropriate to represent the actual equivalent AAF of strip pressures, which is attributed to the negligible of body-generated turbulence. It is interesting to find that the joint acceptance function is lower than unity at low reduced frequencies, which is considered to be caused by the small integral scale relative to building geometry. Fig. 1b indicates that the integral scale relative to the building size would be a key parameter in joint acceptance function.




(a) (b)

**Figure 1.** (a) Equivalent AAF of strip pressures and (b) joint acceptance function for low-rise building.

To validate the proposed model, we compare the background response factors using Eq. 3 with measured data, as presented in Fig. 2. Solari's model, which has been widely used in many building code provisions, is also presented. Due to the negligible of body-generated turbulence, such as the horseshoe vortices and separated flow in front of buildings, Solari's model would underestimate the actual background response factor, particularly for the buildings with *H/B*<4, as shown in Fig. 2a. The currently proposed model addresses this limitation by introducing flexible parameters to account for the body-generated turbulence, as shown in Fig. 2b.

The proposed models consists of several parameters, which are observed to be highly dependent on building shapes, *H/B*, and the ratio of integral scale to building breadth. This finding is consistent with our previous study (Wang and Kopp, 2021b), that the aerodynamics of windward walls are function of non-dimensional geometric parameter *H/B*. Due to the length of this abstract, the detailed description of these parameters will not be presented.

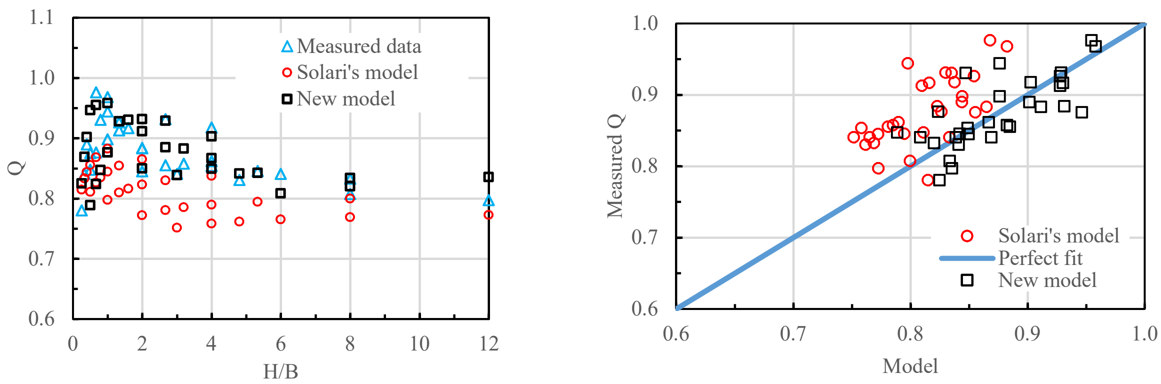



**Figure 2.** Proposed model versus measured background response factor: (a) background response factor vs H/B; (b) measured background response factor vs models.

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