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ACCELERATION RESPONSES FOR TALL REINFORCED CONCRETE OFFICE BUILDINGS UNDER WIND LOADING

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Abstract. The serviceability limit state design of tall reinforced concrete buildings under wind induced vibrations requires accurate estimations of the dynamic properties, e.g. fundamental vibration period, damping ratio and wind field characteristics. Dynamic responses of tall buildings in terms of maximum lateral displacements and accelerations are of utmost interest. In this study, the acceleration responses of tall RC office buildings are comprehensively investigated by considering various parameters, i.e. number of storeys, side ratio of buildings, damping ratio and wind characteristics including basic wind velocity, peak factors, etc., and evaluated based on various international design codes and standards, namely ASCE 7, AS/NZS 1170.2, AIJ recommendations and BS EN 1991-1-4, and the database-enabled design module for high-rise buildings (DEDM-HR) in two principal alongwind and acrosswind directions. The height and plan aspect ratio of buildings have a significant impact on the peak accelerations due to their direct correlations to the stiffness and mass of the buildings. For alongwind direction with fixed damping ratio, AIJ recommendations give the largest estimated alongwind peak accelerations compared with other codes and standards for 10- and 20-storey buildings. With the increase of building height, BS EN 1991-1-4 gives the highest accelerations. For the acrosswind direction, AIJ recommendations give the highest acrosswind peak accelerations compared with AS/NZS 1170.2 and DEDM-HR. Variations in the damping ratio between 0.009 and 0.01592 with the building height for a fixed basic wind velocity increase the accelerations by 3% for 10-storey buildings, by 19% for 20-storey buildings and 33% for 30- and 40-storey buildings. The variations in the wind characteristics and damping ratio between the design codes and standards are the main sources for the high discrepancies in the corresponding acceleration responses.

1 INTRODUCTION

Design of RC tall buildings for serviceability limit states under wind-induced vibrations requires the accurate estimation of their dynamic properties, i.e. fundamental vibration period, damping ratio and wind field characteristics. These criteria include the checks on the overall lateral drift of buildings and occupants' comfort [1]. In the past, verifying the overall lateral drift was only done to satisfy the serviceability limit state requirements for tall buildings under wind load. For slender tall buildings, some studies have indicated that satisfying the criterion on the overall lateral drift of tall buildings do not necessarily satisfy the occupants' comfort in terms of accelerations because the overall lateral drifts are statically related to the stiffness of buildings only, whereas the acceleration responses are dynamically related to the stiffness, mass and damping ratio of buildings [2]. These serviceability issues under wind load should be verified separately for tall buildings to ensure their functional purposes. The main reason for adopting the acceleration response for evaluating human comfort is related to the sensitivity of people to the dynamic forces acting on them because they are not directly sensitive to other dynamic responses such as displacement and velocity. Hence, the building design codes and standards have adopted the acceleration as the acceptance assessor for evaluating the motion perception [3].

Dynamic responses are very important for tall buildings compared to low-rise buildings because the background response is more dominant in low-rise buildings due to their geometrics and results in lower resonant responses and smaller accelerations. However, the resonant response is more dominant for tall buildings and causes high acceleration responses, in particular for slender tall buildings corresponding to the studied dynamic properties and wind characteristics of buildings [4]. Since 1970s, the human comfort in tall buildings has been of utmost interest and been investigated using various methods, e.g. full-scale tests, wind-tunnel tests, motion room simulators, statistical models, answering questionnaires by occupants affected under wind-induced vibrations in tall buildings, etc. However, there is still no general consensus about the criteria for verifying human comfort due to the complexity of human response to different motion intensities including physiological and psychological factors and different reactions from person to person. This restricts the establishments of unique accepted limits for the perceived motions [5].

The assessment of acceleration responses has been based on either the RMS value or the peak value. The latter was used in the early assessment of human responses to wind-induced vibrations for different return periods. Currently, most adopted criteria are based on the peak value of one-year return period as recommended in ISO 10137 [6] and AIJ guidelines [7]. The ISO standard specifies the motion perceptions in terms of the peak acceleration whereas AIJ guidelines specify the percentage of occupants who perceive that motion in terms of the peak acceleration. The recommended limits for residential buildings in ISO 10137 correspond to 90% of the motion perception thresholds of AIJ guidelines [8]. The Concrete Centre [9] indicates that the current criteria used in the North America for assessing human comfort in tall buildings are based on the peak acceleration response of 10-year return period ranging 10-15 milli-g for residential buildings and 20-30 milli-g for office buildings. However, these values are not related to the changes in the natural frequencies of buildings which affect the perception thresholds of human response. In this study, the focus is on the serviceability design limit state criteria of acceleration responses of tall RC office buildings which were investigated in the previous study [10] with considering the effects of various parameters on the assessment of the acceleration responses using different design codes and standards and the up-to-date online design module, including ASCE 7 [11], AS/NZS 1170.2 [12], AIJ recommendations [13], BS EN 1991-1-4 [14], and the online database-enabled design module for high-rise buildings (DEDM-HR) [15].

2 DESIGN CODES AND STANDARDS FOR BUILDINGS

Four international design codes/standards are utilised here on the alongwind and acrosswind acceleration responses. For the alongwind response quantities or factors, most international design codes/standards provide simplified and detailed procedures for evaluating the quantities. These codes/standards adopt and develop the most popular approach “Gust loading factor” which was first proposed by Davenport [16] for evaluating the alongwind effects. However, complex mechanisms of the acrosswind response make barriers for adopting a popular approach for this direction. For the acceleration response of the top storey of a building, the resonant factor is very important, depending on the reduced frequency, size reduction factor, energy factor and damping ratio. These parameters also depend on other intermediate ones such as wind characteristics including basic and design wind velocities, wind turbulence intensity profile, wind turbulence length scale, and building configurations and are treated differently in each design code/standard. For example, the averaging time varies from 3 seconds to 10 minutes for the basic wind velocity but from 10 minutes to 1 hour for wind-induced responses. The reference height for evaluating wind characteristics is the total height building *h* or 0.6*h*, see Table 1.

Table 1 Averaging times and reference heights in the design codes and standards

Codes/Standards	ASCE 7	AS/NZS 1170.2	AIJ recommendations	BS EN 1991-1-4
Basic wind velocity	3 seconds	3 seconds	10 minutes	10 minutes
Wind-induced response	1 hour	10 minutes	10 minutes	10 minutes
Reference height	0.6*h*	*h*	*h*	0.6*h*

The mean design wind velocity profiles are evaluated using power and logarithmic laws. The power law is adopted by ASCE 7 and AIJ recommendations while the logarithmic law is used by others. The same laws are adopted for evaluating the wind turbulence intensity profiles. The wind turbulence length scales are different in these design codes/standards because they are based on different exposure categories. Thus, these parameters are different due to different laws and exposure categories adopted [17]. For resonant components, the energy factor varies among the design codes/standards. For example ASCE 7 and BS EN 1991-1-4 use the Kaimal wind spectrum, while AS/NZS 1170.2 and AIJ recommendations adopt the von Karman spectrum [18]. The use of these different wind spectra with varied averaging times for basic wind velocity results in varied energy factors so as to affect the resonant response factor and acceleration responses. Also, the size reduction factor varies between the design codes/standards by combining with energy factor and damping ratio in various resonant responses.

For acrosswind responses, not all design codes/standards provide expressions for evaluating acrosswind acceleration responses due to complexity for this direction which involves many sources, e.g. longitudinal turbulence and wake excitation that induce vibrations in the acrosswind direction. This direction is more vulnerable for tall buildings with aspect ratios over 3 than the alongwind direction due to its high sensitivity to the aspect and side ratios of buildings and the turbulence intensity of the wind flow [19]. Based on AS/NZS 1170.2, AIJ recommendations and DEDM-HR, the acrosswind acceleration responses are evaluated. AS/NZS 1170.2 provides the empirical expressions for the limited aspect and side ratios in the acrosswind direction with the possibility of linear interpolations for other values. In addition, AIJ recommendations require some conditions to be satisfied for evaluating the responses in the acrosswind direction, i.e. (i) buildings have a uniform plan, (ii) $H/\sqrt{BD} \le 6$, (iii) $0.2 \le D/B \le 5$, and (iv) $V_{\mathrm{href}} / n_{\mathrm{L}}\sqrt{BD} \le 10$, where *H*, *B*, *D* and n_{L} are the height, width, depth of the building, and the first acrosswind natural frequency, and V_{href} is the design wind velocity at the reference height of the building.

3 SIMULATED MODELS FOR EACH DESIGN CODE AND STANDARD

The numerical models adopted in the previous study [10] are used for comparing the alongwind and acrosswind accelerations based on the design codes/standards quoted for this study. The investigated parameters are the height, width and depth of modelled buildings, the wind characteristics, and damping ratio. The height of buildings varies from 10 to 40 storeys, and the side ratio D/B for the alongwind direction varies from 0.5 to 1. Hence, the short side of a building is assumed to be the alongwind direction. For the acrosswind direction, the side ratios are selected in two stages for rectangular models as either long side or short side of a building can be taken as the depth of the building. The side ratio for the acrosswind direction varies from 0.5 to 2. For the simulated models, the basic wind velocity V_b of 30 m/s for a 50-year return period is used for the ultimate limit state design. For the serviceability limit state design, the basic wind velocity of 1-year return period is used as common practice. BS EN 1991-1-4 provides the probability conversion factor to convert the basic wind velocity of 50-year return period for 10-min averaging time to the one of annual return period as:

$$C_{prob} = \left(\frac{1 - 0.2\ln(-\ln(1-p))}{1 - 0.2\ln(-\ln(0.98))} \right)^{0.5} \tag{1}$$

A probability conversion factor of 0.75 is used for 1-year return period with the corresponding basic wind velocity of 22.5 m/s. For comparison, this basic wind velocity varies from 20 m/s to 24 m/s. The basic wind velocity values are 28.4 m/s and 34.08 m/s for ASCE 7 and AS/NZS 1170.2 due to a smaller averaging time of 3 seconds. The conversion factor varies from 3 seconds to 10 minutes as given by ASCE 7. Also, the simulated building models are assumed to be in open terrain for evaluating the wind characteristics at the reference height, i.e. mean wind velocity, wind turbulence intensity, and wind turbulence length scale. For assessing the damping ratio, two stages are used for comparison. Firstly, the structural damping ratio for reinforced concrete buildings recommended in BS EN 1994-1-1 is used for all models to analyse the effect of changes in the basic wind velocity. Secondly, structural damping ratios for concrete buildings are adopted from the recommendation of the International Organisation for Standardisations ISO 4354 [20] as stated in Table 2 with a reduction factor of 0.75 for assessing the effect of vibration of structures on human comfort.

Table 2 Damping ratios in ISO 4354

Building height, h	Damping ratio, ζ
40-50 m	0.0200
60-70 m	0.0150
> 80 m	0.0120

Only BS EN 1991-1-4 and ISO 4354 provide the total damping ratio based on three sources of damping, i.e. structural damping, aerodynamic damping and auxiliary damping. Also, they provide the values for the structural damping ratio and the expressions for evaluating the aerodynamic damping ratio while the auxiliary damping ratio is left for further experimental and analytical investigations due to different sources for this damping ratio. In other design codes/standards, the total damping ratio for a building is based only on the structural damping ratio for design under ultimate and serviceability limit states though the aerodynamic damping ratio can affect dynamic responses of tall buildings by up to 20% [4].

The motion perception in terms of acceleration limits for checking human comfort is based on the criteria recommended in ISO 10137. However, this standard does not specify whether to consider the combined acceleration responses in translational and torsional directions or use them in each direction separately. Not all the current design codes/standards provide the expressions for assessing other responses in the acrosswind and torsional directions, so they can apply the standard criteria for separated directions. Flay et al. [21] recommended that these directions should be considered separately. The torsional response is not evaluated here as this study focuses on the translational directions only.

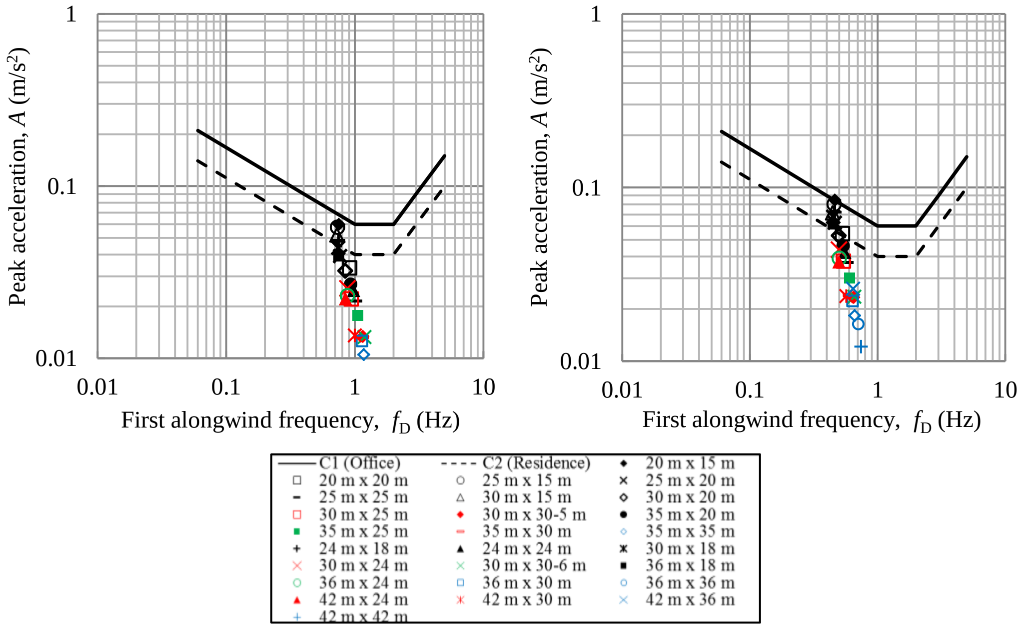
4 RESULTS AND EFFECTIVE PARAMETERS

In this section, the obtained alongwind and acrosswind accelerations for each design code/ standard and DEDM-HR are discussed along with the influential parameters on the acceleration responses, including the height and plan dimensions of buildings, wind characteristics and damping ratio.

4.1 Effects of heights and plan dimensions of buildings

In general, the increase in the height of a building decreases the stiffness of the building and leads to a higher fundamental vibration period (or a lower frequency). This affects the dynamic responses of the building in terms of the accelerations at the top of the building in three principal directions, i.e. longitudinal, translational and rotational directions. When the natural frequency of a building increases, the acceleration at the top of the building decreases. Also, the human perception thresholds corresponding to the period of oscillation increase and the frequency decreases. For low-rise buildings, the acceleration response can be ignored due to high stiffnesses of these buildings and high natural frequencies. Mid-rise to high-rise buildings have low stiffnesses in comparison with low-rise buildings, resulting in low natural frequencies and high acceleration responses. In serviceability limit state design for mid-rise to high-rise buildings the maximum lateral drifts and accelerations at the top of buildings should be checked to ensure the safety and stability of claddings and occupants' comfort against the recommended limits. Also, satisfying the criteria for the lateral drifts of buildings does not necessarily mean the occupants' comfort will be satisfactory in terms of acceleration as stated by Griffis [2]. With variations in basic wind velocities, this issue has currently been addressed in some slender models which specify that the lateral drifts and top accelerations should be treated separately to verify the serviceability limit state criteria. Fig. 1 illustrates the evaluated alongwind peak acceleration responses for various building models of 20 and 30 storeys at a basic wind velocity of 20 m/s (10 min), an air density ρ_{air} = 1.25 kg/m^3, and a damping ratio of 0.01592 corresponding to a structural logarithmic decrement of 0.1 for damping according to BS EN 1991-1-4. The aerodynamic and auxiliary damping ratios are ignored. Hence, the residential curve for the human comfort with the motion thresholds is used to indicate the differences between the office and residential buildings.

Fig. 1 indicates the dominant effect of the building height on the alongwind peak acceleration responses, which increase with the increased building height due to the decrease in the stiffness and decrease the natural frequency. For the same building height with different plan aspect ratios or side ratios, however, the acceleration responses decrease with the increases in the stiffness and mass of the buildings as shown in Figs. 1(a) and (b). Fig. 1 also indicates that these models lay within the recommended limits for the alongwind peak acceleration responses under the assumed wind characteristics. With the increased basic wind velocity and decreased damping ratio, the results for some models lie above the recommended limits for office buildings.



(a) For 20-storey buildings **(b)** For 30-storey buildings

Fig. 1 Evaluated alongwind peak acceleration responses to BS EN 1991-1-4

Similar trends can be observed for the acrosswind peak acceleration responses with some differences directly related to the side ratio of the considered buildings where the RMS or force lift coefficients are dependent on the side ratios of the buildings [19]. With the increase in the side ratio of buildings, the acrosswind wind loading increases. Thus, for low side ratios of buildings, i.e. the building depth is shorter than the building width, the alongwind wind loading becomes dominant if the wind flow is assumed to act on the long surface of the building. When the side ratio is high, i.e. the building depth is larger than the building width, the acrosswind wind loading becomes dominant due to the effect of the side ratio of the building if the wind flow is perpendicular to the short surface of the building.

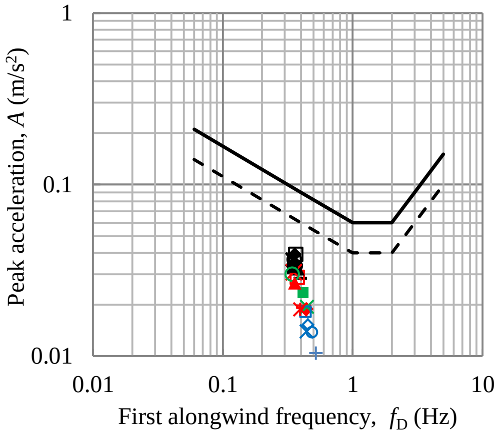
4.2 Effects of wind characteristics

In some of the quoted design codes/standards, the alongwind peak acceleration response is adopted together with the standard deviation. The peak acceleration index is evaluated by multiplying the standard deviation to the acceleration by a defined resonant peak factor based on the averaging time of the wind-induced vibration response and the alongwind natural frequency. Although the expressions for the peak factor are approximately similar for ASCE 7 and BS EN 1991-1-4 or for AS/NZS 1170.2 and AIJ recommendations, the adopted averaging times for the wind-induced vibration responses are different and result in various resonant peak factors. For instance, the resonant peak factor in BS EN 1991-1-4 is always lower than that in ASCE 7 due to the different averaging times, 10 minutes for BS EN 1991-1-4 and 1 hour for ASCE 7. The alongwind standard deviations for the acceleration response estimated form BS EN 1991-1-4 are higher than those from ASCE 7 due to other intermediate parameters such as mean wind velocity, turbulence intensity, turbulence length scale and wind spectrum which all affect the resonant response factor and result in various acceleration responses. Similar trends are observed for AIJ recommendations and AS/NZS 1170.2 while the expressions for the resonant peak factor are fairly the same in the two code/standards with the same averaging time of 10 minutes for wind-induced vibration responses.

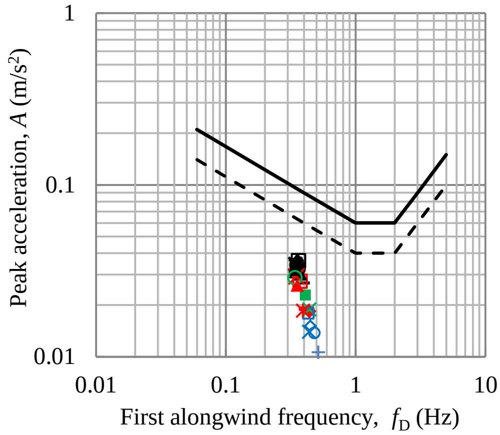
A total of 104 RC building models have been simulated and evaluated in terms of the alongwind acceleration response based on individual design code/standards. Fig. 2 illustrates the alongwind peak accelerations of the evaluated models of 40 storeys for a basic wind velocity of 20 m/s (10-min) or 28.4 m/s (1-hr) and a fixed damping ratio ζ of 0.01592 based on the four design codes/standards and the online design module DEDM-HR. The input parameters include basic wind velocity, damping ratio, air density, and force coefficients used in DEDM-HR based on BS EN 1991-1-4. DEDM-HR has limitations for the alongwind acceleration responses as shown in Fig. 2 due to the limited available aspect and side ratios for the employed models. Fig. 2 clearly indicates that BS EN 1991-1-4 gives higher alongwind peak acceleration responses than the other codes/standards for tall buildings. For 10-storey buildings, compared with AIJ recommendations, other three design codes/standards, ASCE 7, AS/NZS 1170.2 and BS EN 1991-1-4, give lower estimates for the alongwind peak acceleration by 53.6%, 37.1% and 18.8%, respectively. Similar trends were observed for 20-storey buildings for the same three design codes/standards, lower by 46%, 36.3% and 3%. For 30- and 40-storey buildings, compared with AIJ recommendations, ASCE 7, AS/NZS 1170.2 and DEDM-HR (for 30-storey buildings) still give lowered estimates for the alongwind peak acceleration by 39.7%, 36.4% and 7.6%, respectively.

Meanwhile, BS EN 1991-1-4 gives larger estimates for the alongwind peak acceleration for 30- and 40-storey buildings in comparison with AIJ recommendations by 10.2% and 18.9%. Also, DEDM-HR gives larger estimates for the alongwind peak acceleration for 40-storey buildings in comparison with AIJ recommendations by 26.6%. These differences in the alongwind peak acceleration responses are related to the wind characteristics such as basic wind velocity averaging time, mean wind velocity, wind turbulence intensity, wind turbulence length scale, wind spectrum, force coefficients, and the applied reduction factors in some design codes/standards. Here, AIJ recommendations can be used as the basis for comparison because this standard can estimate the acceleration responses for buildings in three principal directions, i.e. two translational and one rotational.

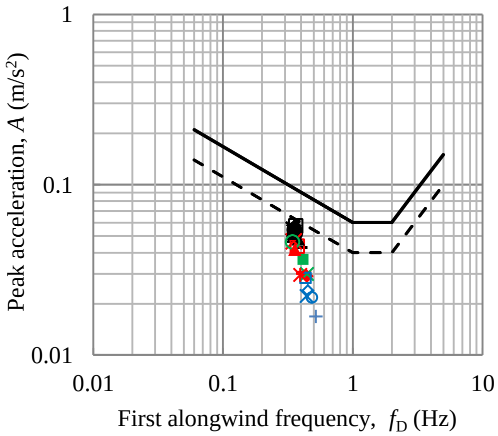
It is worthwhile to mention that only an increase in the basic wind velocity by 1 m/s will lead to an increase of 15-17% in the alongwind peak acceleration response based on the design codes/standards and the online design module adopted for this study. This basic velocity is used for determining the mean or design wind velocity which is highly needed for other intermediate parameters, e.g. size reduction and energy factors. These intermediate parameters will significantly affect the resonant response factor for determining the acceleration responses. Other parameters include such as the drag force coefficients and the mode shape factor of predicting linear and nonlinear mode shapes.



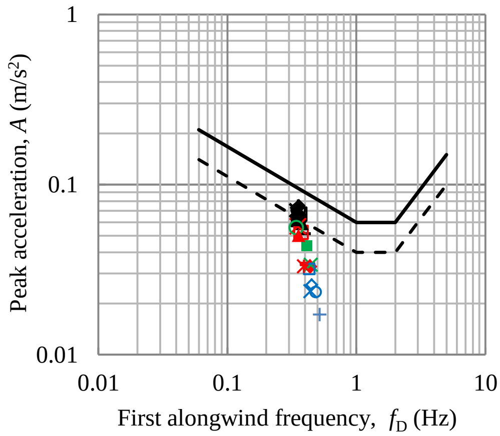
(a) Based on ASCE 7



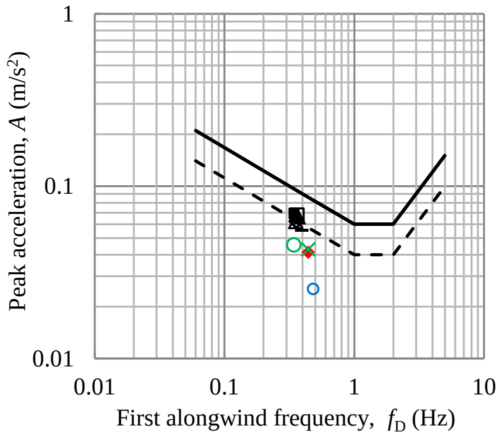
(b) Based on AS/NZS 1170.2



(c) Based on AIJ recommendations



(d) Based on BS EN 1991-1-4



(e) Based on DEDM-HR

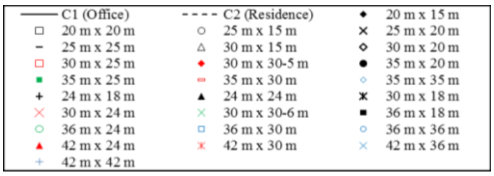
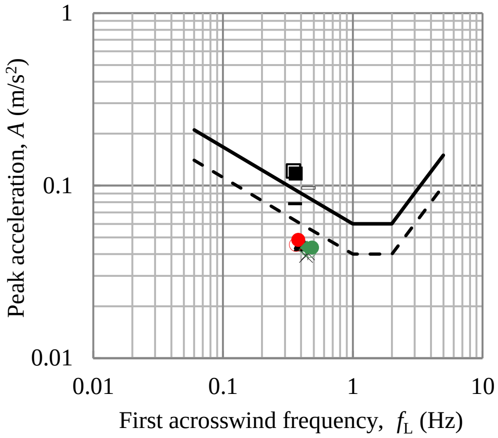


Fig. 2 Evaluated alongwind peak acceleration responses to various design codes/standards and online design module for 40-storey buildings with $\zeta = 0.01592$

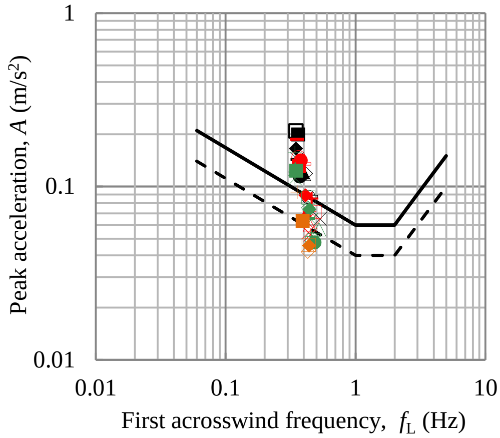
Here, the mode shapes are assumed to be linear for all models. The drag force coefficient is usually defined as the windward external pressure coefficient minus the leeward external pressure coefficient in the design codes/standards which are dependent on the side ratio *D*/*B*. For rectangular buildings with heights no larger than 45 m, only AIJ recommendations provide the external pressure coefficients based on the building width and depth-to-height ratio. Only BS EN 1991-1-4 provides the external pressure coefficients based on the height-to-depth ratio, *H*/*D*, of the designed building in the direction parallel to wind, and also recommends the use of force coefficients for $H/D > 5$ based on the side ratio and other reduction factors. AIJ recommendations apply a reduction factor for the windward external pressure coefficient and result in the lowest drag force coefficients amongst the quoted design codes/standards, while AS/NZS 1170.2 and BS EN 1991-1-4 apply a reduction factor when there is lack of correlations between the windward and leeward pressures for the evaluated wind forces and result in reduced wind effects such as base shears, moments and accelerations. BS EN 1991-1-4 also provides higher drag force coefficients amongst the quoted codes/standards in particular for tall slender buildings and result in higher estimated alongwind peak acceleration responses.

For the acrosswind acceleration responses and the conditions for evaluating the response in this direction as stated in Section 2, the models of 20 storeys and above can all satisfy these conditions set by AIJ recommendations. However, even for these models there are still some unsatisfied conditions due to limited aspect and side ratios of buildings in comparison with those in literature. For example, not all the aspect and side ratios are available in AS/NZS 1170.2 and DEDM-HR. Also, the interpolations between the available aspect and side ratios may possibly result in high errors on the estimated acrosswind responses because small alterations in the building shape can result in significant aerodynamic effects, e.g. acrosswind responses. Thus, only the models with available aspect and side ratios in the mentioned sources are evaluated. In particular, linear interpolations are employed for some models based on for AS/NZS 1170.2. For DEDM-HR, the models with overestimated results and error outputs are excluded from comparisons and are not put in the figures for the alongwind and acrosswind directions. Fig. 3 illustrates the acrosswind peak acceleration responses by considering these three sources for 40-storey buildings.

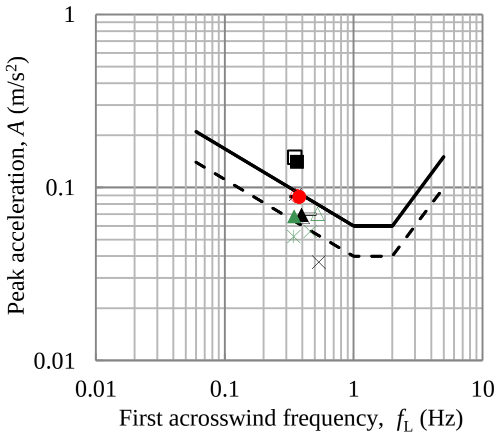
For 30- and 40-storey buildings, AIJ recommendations give higher acrosswind peak accelerations compared with AS/NZS 1170.2 and DEDM-HR by 6.1%, 53.2%, 37.9% and 31.7%, respectively. However, high discrepancies exist in the obtained results between AIJ recommendations and AS/NZS 1170.2 due to use of linear interpolations on the aspect and side ratios for some models based on AS/NZS 1170.2. Fig. 3 indicates that the estimated acrosswind acceleration responses are higher than those in the alongwind direction due to the severe wind excitations in this direction which usually exceed the motion thresholds. This reveals that for slender tall buildings with aspect ratios over 3, the serviceability limit state design should consider the acceleration in the acrosswind direction. Unfortunately, the evaluation of the acceleration for the acrosswind direction is not available in most design codes/standards. Thus, these design codes/standards recommend use of wind-tunnel tests for slender tall buildings with aspect ratios larger than 3 or even 4 as stated in BS EN 1991-1-4. AIJ recommendations give very high estimates for the acrosswind acceleration response in comparison with AS/NZS 1170.2 and DEDM-HR. Hence, the number of models evaluated by using AIJ recommendations can also be higher, while other two sources only provide limited aspect and side ratios of buildings. In particular, the limitations for AS/NZS 1170.2 and DEDM-HR can be seen in Fig. 3 on the acrosswind peak acceleration responses.

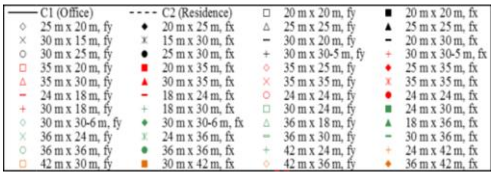


(a) Based on AS/NZS 1170.2



(b) Based on AIJ recommendations





(c) Based on DEDM-HR

Fig. 3 Evaluated acrosswind peak acceleration responses to various design codes/standards and online design module for 40-storey buildings with $\zeta = 0.01592$

4.3 The effects of damping ratios

For the same models studied, the damping ratio varies with a fixed basic wind velocity to show its effect on the acceleration responses of tall buildings. The adoption of various damping ratios in the design codes/standards may cause high discrepancies in the acceleration response which is directly related to the assumed damping ratio through the resonant factor. For example, the structural damping ratio in BS EN 1991-1-4 is assumed to be 0.01592 for all RC buildings. However, this ratio varies with the height of buildings as stated in ISO 4354. For 10-storey buildings with a storey height of 3 m, when the damping ratio varies from 0.0150 to 0.01592, the alongwind peak acceleration response increases by 3%. For 20-storey buildings, the alongwind peak acceleration response increases by 19% when the assumed damping ratio varies from 0.01125 to 0.01592. For 30- and 40-storey buildings, when the damping ratio varies from 0.0090 to 0.01592, the alongwind peak acceleration response increases by 33%. The basis for comparison is dependent on the damping ratio given in BS EN 1991-1-4. Also, the relationship between the acceleration with fixed parameters and the damping ratio indicates that the acceleration varies linearly with $1/\zeta^{0.5}$ as stated in literature [1,2]. Similar trends can be observed for the acrosswind peak acceleration response. The acrosswind direction is predominant for tall building design and the corresponding accelerations are very high in comparison with those in the alongwind direction. Thus, evaluating only the alongwind response quantities for tall buildings as common practice in most design codes/standards is insufficient due to severe acrosswind effects.

5 CONCLUSIONS

- The alongwind and acrosswind acceleration responses are directly influenced by the dynamic characteristics of buildings in terms of mass, stiffness and damping ratio.
- Wind characteristics include basic/mean wind velocity, averaging time, turbulence intensity, turbulence length scale, wind spectrum and peak factors and act as the main sources of high discrepancies in the acceleration responses amongst the studied design codes/standards. The force coefficients in these codes/standards also are different, resulting in various acceleration responses.
- The uncertainty in the basic wind velocity can cause high differences in the peak acceleration responses. Also, the uncertainties in the natural frequency and damping ratio may significantly affect the peak accelerations of the building so as to influence human comfort.
- The acrosswind accelerations are usually higher than the alongwind accelerations. However, there is lack of full expressions provided for different aspect and side ratios between the design codes/standards.
- AIJ recommendations are encouraged to use for preliminary wind design of tall RC buildings because they cover full envelops of buildings for all wind directions.
- The online design module DEDM-HR provides a good basis for evaluating the alongwind, acrosswind, and torsional acceleration responses with possible combinations for the acceleration components. However, these modules are based on the limited aspect and side ratios of tall buildings. Hence, more wind tunnel tests are needed to extend the current database for tall buildings.
- The motion perception thresholds for tall buildings are higher than those for low-rise and mid-rise buildings with respect to their natural frequencies.

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