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COMPARISON OF WIND LOADS ON MEDIUM-RISE BUILDING ACCORDING TO ASIA-PACIFIC CODES/STANDARDS

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ABSTRACT

This paper compares wind load calculations on a medium-rise building using 15 different wind loading codes and standards from the Asia-Pacific Region. The main results of this comparison show various behaviors. The reasons for the differences are discussed.

KEYWORDS: MEDIUM-RISE BUILDING, WIND LOADS COMPARISON, CODE/STANDARD

1. Introduction

A practical outcome of the International Workshops on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-pacific Economies (APEC-WW) since 2004 has been a comparison of wind loads on three typical buildings, a low-rise building (Building 1), a medium-rise building (Building 2) and a high-rise building (Building 3), evaluated in accordance with various wind loading codes and standards across the Asia-Pacific region. The loading codes and standards of 15 Asia-Pacific economies were compared. This comparison will promote future harmonization of wind loading specifications across the diverse economies of the Asia-Pacific region.

This paper compares wind load calculations for a medium-rise building using these 15 different wind loading codes and standards. It also presents the main results of the comparison and discusses the reasons for the differences.

2. Benchmark analysis of a typical medium-rise building

Figure 1 shows a typical medium-rise building. It is an office building assumed to be in a tropical city in a typhoon/cyclone zone. The terrain is a suburban terrain for all directions.

The topography is flat (ground slope less than 1 in 20) for more than 5km in all directions. The building is 60m by 30m in plan (rectangular cross-section), and its average roof height is 48m. It is assumed to be of reinforced concrete frame construction. It is air-conditioned with non-opening windows, and can be considered effectively sealed. Mullions for glazing panels are spaced at 1.5m. The roof is flat with a 0.9m-high parapet.

The calculation conditions are originally set as:

- Design wind speeds at 10m (all-direction):
  3-second gust 52 m/s
  10-minute mean 35 m/s
  1-hour mean 31 m/s
- The sway frequencies were 1.2 Hz (about the 60m direction) and 1.4 Hz.

However, the obtained results were significantly dispersed, as shown in Fig. 3(a) in the following section. The maximum base bending moments and base shears were almost three times the minimum values. The main reason for this significant difference was assumed to be a significant difference in design wind speeds at the top of the building because of the different wind speed profiles. Thus, the calculation conditions were changed as follows:

- Design wind speeds at 48m (all-direction):
  3-second gust 56 m/s
  10-minute mean 36 m/s
  1-hour mean 33 m/s
- Sway frequencies is 1.2 Hz
- Damping ratio is 2%
- Turbulence intensity is 0.2 at 48m

Under these revised conditions, the design wind speeds and turbulence intensity at the top of the building, and the damping ratio, are set the same for all codes.

The along-wind base bending moment and shear force were required to be calculated for wind directions normal to the 60m wall. Cladding pressures on the window elements near the corners at the top level were also calculated.

The flow charts of wind load calculations for 15 different wind loading codes and standards were not the same, but the flow chart of wind load calculation by AIJ-RLB-2004 is shown in Fig. 2 as an example.

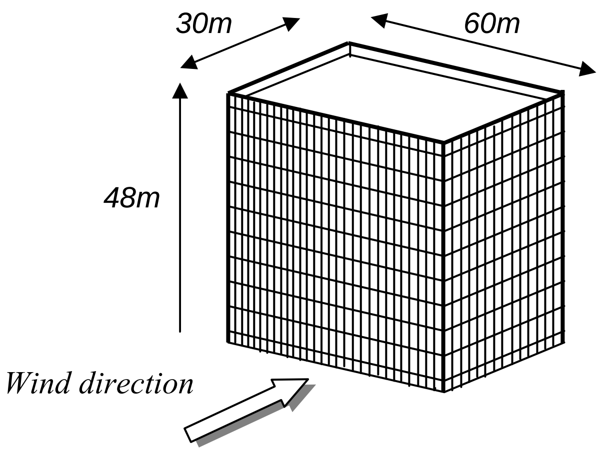


Fig. 1: Medium-rise building (Building 2)

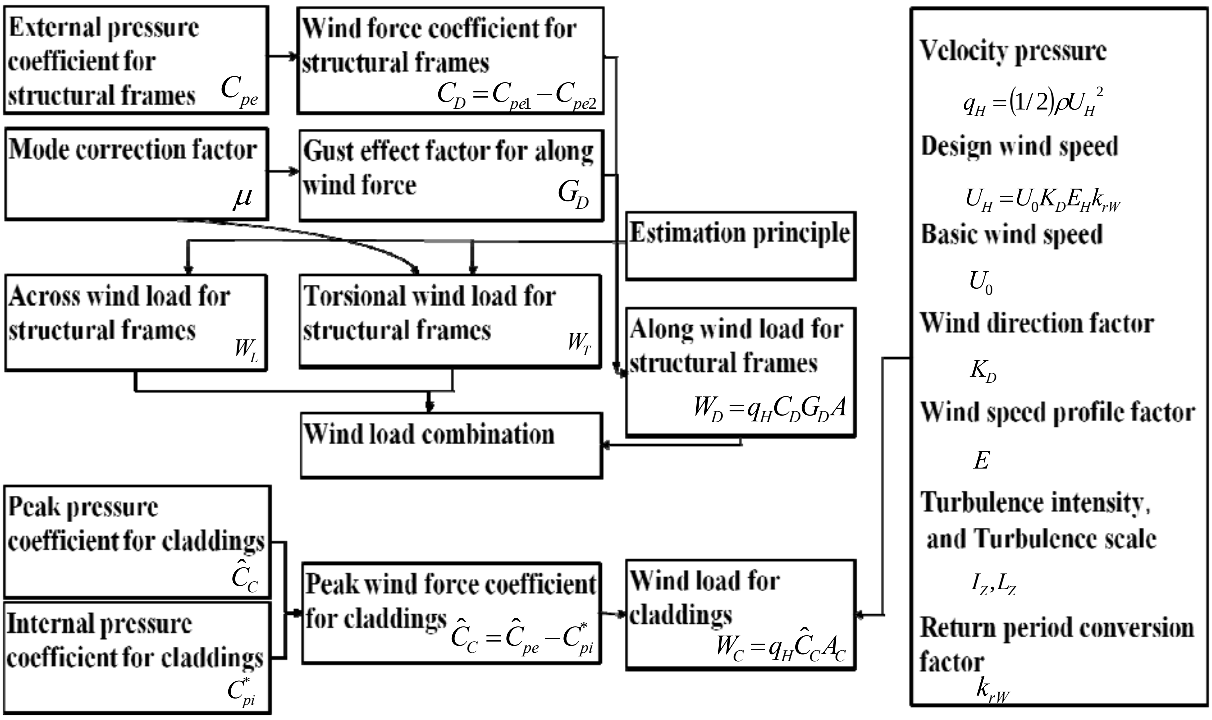


Fig. 2: Flow chart of wind load calculation by AIJ-RLB-2004

3. Results and discussions

The results of the calculations under the revised conditions are shown in Tables 1 and 2. These tables include the mean values of each response parameter and the corresponding coefficients of variation. In addition to the results for the 15 Asia-Pacific economies, Eurocode values are shown for reference.

The calculation results for along-wind base shears Q and base bending moments M are shown in Table 1 and compared in Fig. 3(b). Figure 3(b) shows smaller distributed ranges of Q and M under the revised calculation conditions than Fig. 3(a) for the original conditions. In Table 1, Indonesia shows the highest values (7,477kN and 210MNm) and China shows the lowest values (3,282 kN and 99MNm). The Indonesian values are more than double the Chinese values. The coefficient of variation (COV) is estimated at 22% for both the base shear and the base bending moment. Considering the given harmonized condition specifying the same design wind speed at the top, the coefficient of variation, 22%, is slightly larger than expected. Incidentally, the calculation details of China and Indonesia were rechecked by the authors. For China, the given along-wind dynamic response factor β_z seems to be too small. For Indonesia, the leeward $q_h C_{fig}$ seems have a calculation error, and the modified calculation results show that the base shear and the base bending moment are 5,957 kN and 169 MNm. The coefficients of variation are estimated at 19% and 17% for the base shears Q and the base bending moments M. The re-checked results are plotted in Fig. 3(b).

Singapore (draft standard), Vietnam, Australia/New Zealand, Malaysia, and Indonesia compose a higher magnitude group (see Circle A in Fig. 3(b)). Japan, Korea and Canada (Circle B), India and Hong Kong (Circle A') and the Philippines compose a medium magnitude group. Thailand and Taiwan (Circle C'), the US and China compose a lower magnitude group. The US and the Philippines are in Circle C. These groups closely correspond to several groups related to their origins.

The calculated values of base shear and base bending moment have no significant correlation with the values of dynamic response factor C_{dyn} or gust loading factor G_D as shown in Fig. 4, for example. A higher magnitude group including Australia/New Zealand, Malaysia, and Indonesia compose a clear cluster indicated by Circle A in Fig. 4 with a dynamic response factor of unity. The US and the Philippines (Circle C) have similar dynamic response factors of less than unity. Japan, Korea and Canada (Circle B), which belong to the medium magnitude group, compose a cluster having almost the same gust loading factor of around 2. Thailand and Taiwan (Circle C'), which belong to the lower magnitude group, also have a gust loading factor of around 2. Incidentally, almost the same tendency is observed for the base bending moment.

For reference, the effect of turbulence intensity I_H was examined by comparing the base shear and base bending moment obtained from the original conditions with the results obtained from the revised conditions where I_H is fixed to 0.2. Figure 5 shows that smaller results are obtained for larger I_H, except for China, which the reason is not clear.

Mean base shear coefficient C_Q and mean base bending moment coefficient C_M are derived as Eqs. (1) and (2), where $\hat{q}_H$ =0.61 $\times$ 56^2(m/s)^2 and $\bar{q}_H$ =0.61 $\times$ 36^2(m/s)^2. The relation between C_Q and power-law index α is shown in Fig. 6. It should be noted that the results for the 3-second-gust group, the 10-minute-mean group and the 1-hour-mean group cannot be compared, because the power-law index of the 3-second-gust profile, the 10-minute-mean wind speed profile and the 1-hour-mean wind speed profile are different even for the same terrain category. As shown in Fig. 6, the mean base shear coefficient C_Q has no significant correlation with the power-law index α. Almost the same tendency was observed for the mean base bending moment coefficient C_M.

$$C_Q = \frac{Q}{\bar{q}_H BHG_D}, \quad \frac{Q}{\hat{q}_H BHC_{dyn}} \tag{1}$$

$$C_M = \frac{M}{\bar{q}_H BH^2G_D}, \quad \frac{M}{\hat{q}_H BH^2C_{dyn}} \tag{2}$$

Table 2 shows the cladding pressures on window elements near the corners at the top level. The coefficients of variation for positive cladding pressures and negative cladding pressures are estimated at 22% and 23%. Figure 7 compares the positive cladding pressure $P+$ and the negative cladding pressure $P-$ on window elements near the corners at the top level of the building. There is no clear correlation between them. Vietnam shows the highest positive cladding pressure, 2.44kPa, but the highest negative (i.e. lowest magnitude) pressure, −1.83kPa. China shows the lowest positive cladding pressure, 1.22kPa, and a relatively high negative pressure, −2.44kPa, i.e. a lax provision. On the other hand, Australia/New Zealand, Malaysia, Indonesia and Singapore (Circle A) compose a very clear cluster showing the most unfavorable combination of positive and negative pressures, such as (2.3kPa and −3.8kPa).

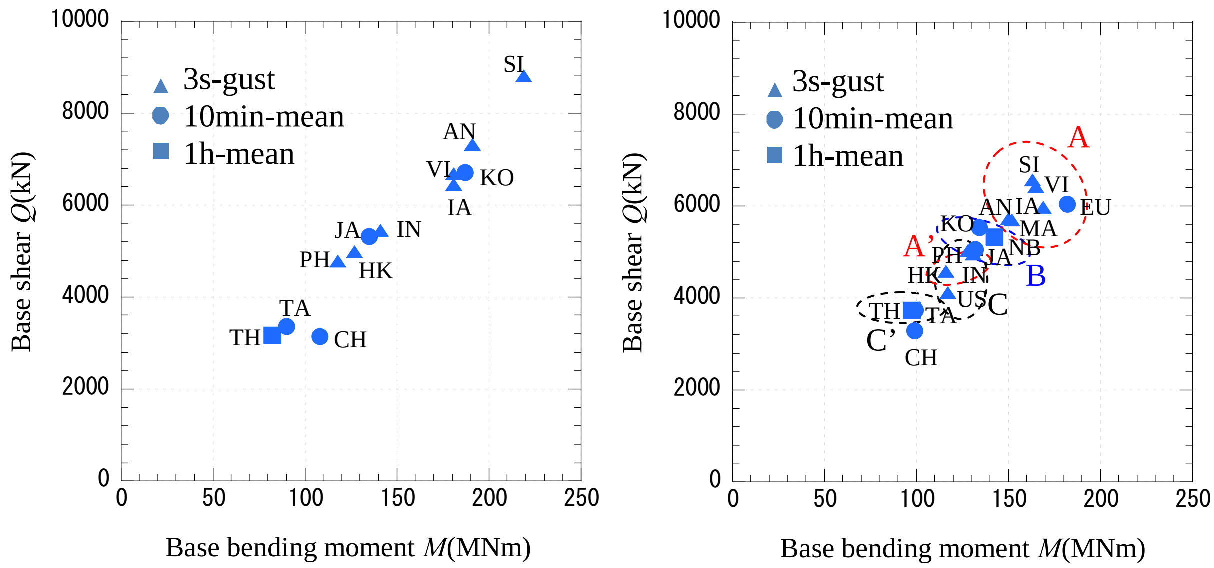
Figure 8(a) shows the correlation between the positive cladding pressure, $P+$, and the positive net peak force coefficient, $\hat{C}_c+$, which corresponds to the peak pressure difference between the external surface and the internal surface of a window element. Except for the Euro code, three groups indicated by Circles A, B and C are clearly identified, as shown in Fig. 8(a). The group indicated by Circle A consists of Australia/New Zealand, Malaysia., Singapore, Vietnam and Hong Kong, and all the calculations lie on a regression line. The group indicated by Circle B consists of Japan, Korea, Taiwan, Canada and Thailand, and all of these calculations also lie on a regression line. The group indicated by Circle C consists of the US, the Philippines and China. The positive cladding pressures $P+$ of the first two groups show a positive correlation with the positive net peak force coefficient, $\hat{C}_c+$. Figure 8(b) shows the correlation between the negative cladding pressure, $P-$, and the positive net peak force coefficient, $\hat{C}_c-$. In this figure for the negative cladding pressures, the three clusters are clearly observed as the same as in Fig. 8(a) for positive cladding pressures. In Figs. 7, 8(a) and 8(b), the Australia/New Zealand, Malaysia and Singapore plots are all closely located, and the Canada and Thailand plots also band together, suggesting the close relations of their origins. It is also recognized that the Korean values tend to show similarity with the Japanese ones for all cases.

Table 1: Along-wind base shears and base bending moments (*Re-calculated results)

Country/Region		Code/Standard	Base Shear Q (kN)	Base Bending Moment M (MNm)
Australia/New Zealand	AN	AS/NZS1170.2: 2002	5,727	150
Canada	NB	NBCC (2005)	5,332	142
China	CH	GB50009-2001	3,282	99
Hong Kong	HK	CP-2004	4,573	116
India	IN	IS875(Part 3)-1987	4,957	131
Indonesia	IA	SNI-03-1727	7,477(5,975)*	210(169)*
Japan	JA	AIJ-RLB-2004	5,061	132
Korea	KO	KBC (2005)	5,534	134
Malaysia	MA	MS1553-2002	5,698	152
Philippines	PH	NSCP-2001	5,026	128
Singapore	SI	(draft)	6,556	163
Taiwan	TA	TBC	3,738	100
Thailand	TH	EIT-1018-46	3,737	97
United States	US	ASCE 7-05	4,108	117
Vietnam	VI	TCVN2737-1995	6,423	165
Mean			5,149(5,047)*	136(133)*
Coefficient of Variation (%)			22(19)*	22(17)*
Eurocode	EU		6,042	182

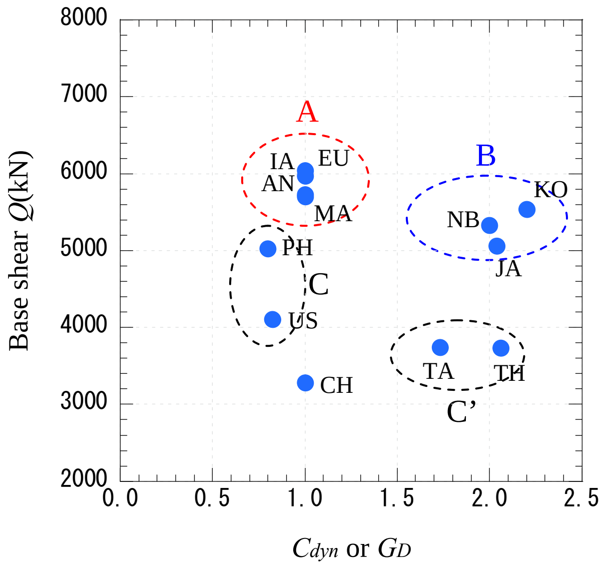
Table 2: Cladding pressures

Country/Region		Code/Standard	Positive Cladding Pressure $P+$ (kPa)	Negative Cladding Pressure $P-$ (kPa)
Australia/New Zealand	AN	AS/NZS1170.2:2002	2.25	–3.67
Canada	NB	NBCC (2005)	1.80	–2.11
China	CH	GB5009-2001	1.22	–2.44
Hong Kong	HK	CP-2004	1.87	–2.62
India	IN	IS875(Part 3)-1987	1.55	–2.26
Indonesia	IA	SNI-03-1727	2.24	–3.64
Japan	JA	AIJ-RLB-2004	2.14	–2.37
Korea	KO	KBC (2005)	1.53	–2.54
Malaysia	MA	MS1553-2002	2.26	–3.70
Philippines	PH	NSCP-2001	1.32	–2.85
Singapore	SI	(draft)	2.26	–3.67
Taiwan	TA	TBC	1.58	–2.95
Thailand	TH	EIT-1018-46	1.86	–2.23
United States	US	ASCE 7-05	1.41	–2.56
Vietnam	VI	TCVN2737-1995	2.44	–1.83
Mean			1.85	–2.76
Coefficient of Variation (%)			22	23
Eurocode	EU		1.69	–2.47



(a) Original calculation conditions (b) Revised calculation conditions

Fig. 3: Relation between base shear Q and base bending moment M



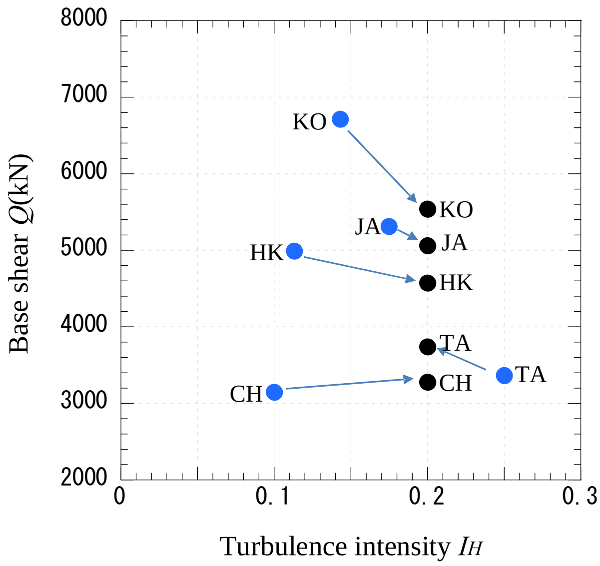


Fig. 4: Relation between Q and C_{dyn} or G_D

Fig. 5: Relation between Q and I_H

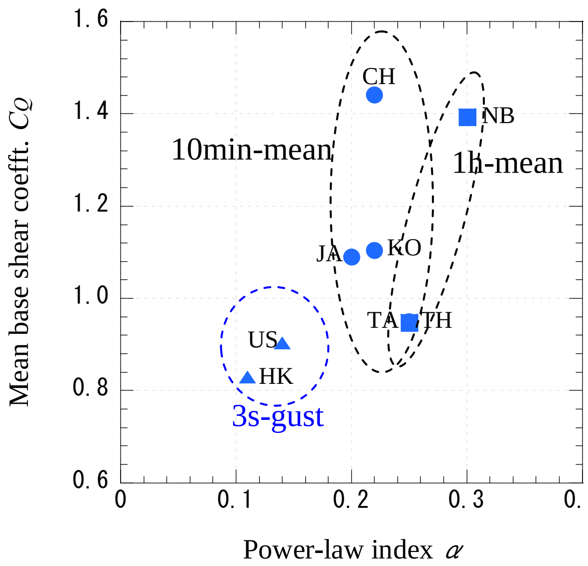


Fig. 6: Relation between and C_Q and α

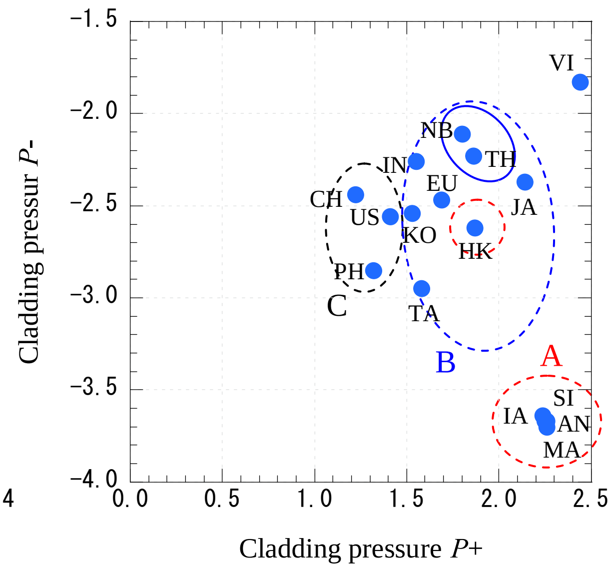
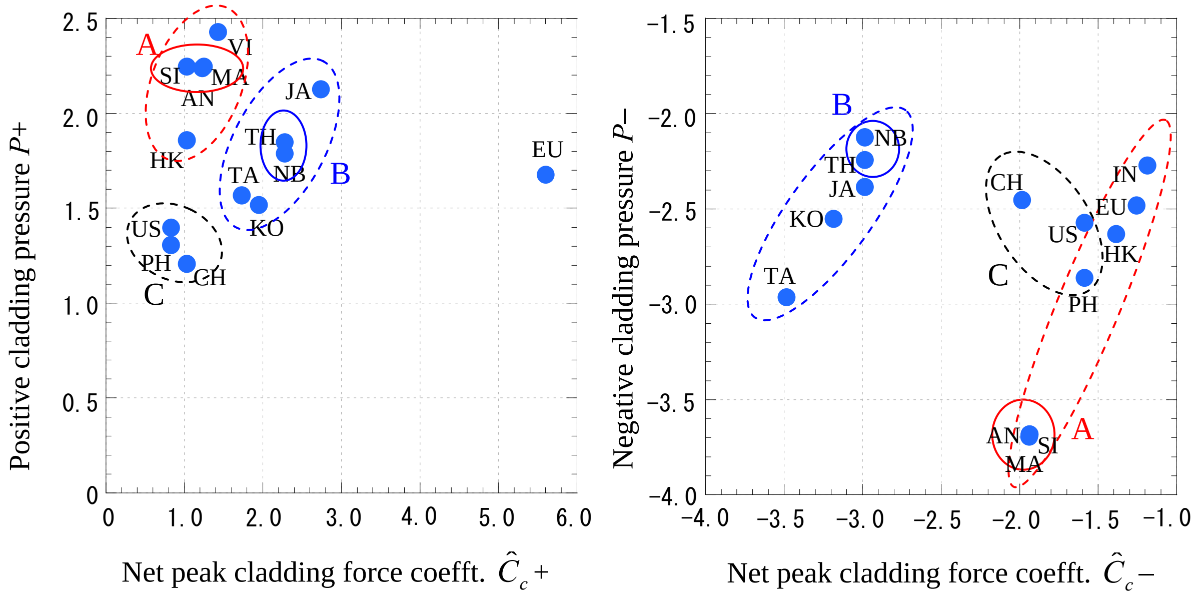


Fig. 7: Relation between P+ and P- cladding pressures



(a) Positive cladding pressure (b) Negative cladding pressure

Fig. 8: Relation between cladding pressure and net peak cladding force coefficient

4. Conclusions

From the comparison of wind load calculations, the following conclusions can be reached. For the medium-rise building, no significant correlation was observed between the along-wind load effects, i.e. base shears and base bending moments, and dynamic response factors or gust loading factors. However, some correlation was observed between cladding pressures and net peak cladding force coefficients. It was also clearly recognized that some clusters show almost the same or similar behaviors because of the existence of some common source codes/standards. The mean values and coefficients of variation of the fifteen codes/standards in the Asia-Pacific region were calculated, and the coefficients of variation were estimated at around 17% - 23% for both along-wind overall load effects and cladding pressures. Distributed ranges of base shears and base bending moments of the revised calculation conditions are smaller than those of the original conditions. Smaller base shear and base bending moment results are obtained for larger turbulence intensity at the top for most of the codes/standards. Mean base shear coefficient and mean base bending moment coefficient have no significant correlation with the power-law index.

Acknowledgments

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