Chinese Country Report 2012 - Revision of wind loading code and wind tunnel test guidelines

Xinyang Jin [a], Yaojun Ge [b], Shuyang Cao [b]

[a]*China Academy of Building Research, 30 Beisanhuan Donglu, Beijing, China*
[b]*SLDRCE of Tongji University, 1239 Siping Road, Shanghai, China*

ABSTRACT: This country report summaries three recent achievements in China related to wind loading code. A new version of Chinese National Standard “Load Code For The Design of Building Structures (GB50009-2012)” has been issued and put into practice in China since 1st Oct. 2012. This version was updated from the 2006 version of GB50009-2001, with important revisions on basic wind pressures, exposure factor, gust factor, local aerodynamic coefficient and dynamic along-wind response factor. Provisions for cross-wind and torsional dynamic response were introduced into the wind load code for the first time. Meanwhile, the guidelines for wind tunnel testing of bridges as well as structures were individually being prepared to provide specific criteria in the Chinese wind engineering community.

KEYWORDS: Wind load code, wind tunnel test, large span bridges, high-rise buildings.

1 INTRODUCTION

Chinese National Standard “Load Code For The Design of Building Structures (GB50009-2012)” was released recently, in which wind load on structures was one of the major concerns. This version was updated from the 2006 version of GB50009-2001, and put into practice in China since 1st Oct. 2012. Important revisions on basic wind pressures, exposure factor, gust factor, local aerodynamic coefficient and dynamic along-wind response factor were made. Provisions for cross-wind and torsional dynamic response were introduced into the wind load code for the first time. Meanwhile, the guidelines for wind tunnel testing of bridges as well as structures were individually being prepared to provide specific criteria and guidelines in the Chinese wind engineering community. This report has three sections to summarize the contents of these achievements. After introducing the new version of wind load code in Section 2, the activities of the wind tunnel test guidelines will be briefly reported in Section 3 and Section 4, respectively for bridge and building tests.

2 A NEW VERSION OF WIND LOAD CODE OF CHINA

2.1 *Background of load code revision*

A new version of Chinese National Standard “Load Code For The Design of Building Structures (GB50009-2012) ” has been issued and practised in China on 1st Oct. 2012, which is revised from the 2006 version of GB50009-2001. In the new version of the code, thermal actions and accidental loads have been firstly added, and sme important provisions of live loads on floors, snow loads and wind loads have been amended[1,2]. Wind load is a main aspect in this revision and most of contents, such as basic wind pressures, exposure factor, gust factor, local aerodynamic coefficient, dynamic response factor of along-wind have been revised. Some provisions for cross-wind and torsinal dynamic response have been newly added.

2.2 *Expressions of wind load for main structures and claddings*

The expressions of wind load for design of main structures and claddings are kept in the same. The wind pressure (wind force per unit area) normally acted on surface of buildings and structures for design of main structures should be calculated as:

$$W_k = \beta_z \mu_S \mu_z W_0 \qquad (2.1)$$

Where W_k =characteristic value of wind pressure (kN/m^2); β_Z =dynamic response factor at the height of z; μ_S = aerodynamic pressure coefficient; μ_Z = pressure exposure factor; W_0 = basic wind pressure(kN/m^2).

The wind pressure normally acted on surface of structural parts for design of windows, doors and clddings should be calculated as:

$$W_k = \beta_{zg} \mu_{Sl} \mu_z W_0 \qquad (2.2)$$

Where β_{zg} = gust factor at the height of z; μ_{sl} = local aerodynamic coefficient.
Basic wind pressure is determined as:

$$W_0 = \frac{1}{2}\rho v_0^2 \qquad (2.3)$$

where v_0 = reference wind speed (m/s), which is defined as the 10-minute mean wind speed over a flat and open terrain at an elevation of 10m with a mean return period of 50 years; ρ = air density (t/m^3).

The climate data from the year of 1995 to 2008 have been added in the statistical samples, and the referece wind speed for more than 600 stations have been renewed together with the country wind map in the new version of the code.

2.3 *Exposure factor*

4 categories of ground roughness (A sea and lake, B open countryside, C towns and cities, D center of large cities) are kept in the same and the power low velocity profile is yet used. The value of α for B category and the gradient heights of C and D categories have been changed as shown in Table 2.1.

Table 2.1 Ground roughness

Categories of ground roughness		A	B	C	D
GB50009-2001	Gradient height(m)	300	350	400	450
	α	0.12	0.16	0.22	0.30
GB50009-2012	Gradient height(m)	300	350	**450**	**550**
	α	0.12	**0.15**	0.22	0.30

The expressions of exposure factor for wind pressure are then given as follows:

$$\mu_z^A = 1.284\left(\frac{z}{10}\right)^{0.24};\quad \mu_z^B = 1.000\left(\frac{z}{10}\right)^{0.30};\quad \mu_z^C = 0.544\left(\frac{z}{10}\right)^{0.44};\quad \mu_z^D = 0.262\left(\frac{z}{10}\right)^{0.60} \qquad (2\text{-}3)$$

The variation of wind velocity profile is shown in Figure 2.1. It can be found clearly that the values of exposure factors are decreased.

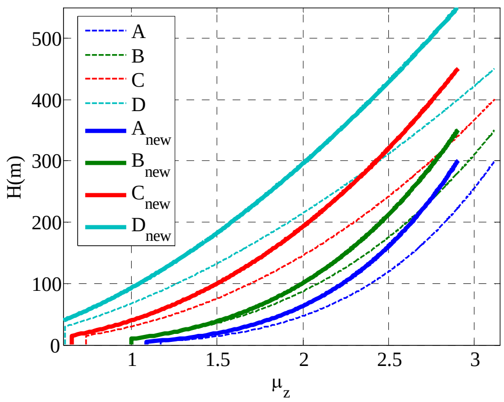

Figure 2.1 Difference of wind velocity profile

2.4 *Gust factor*

The new expression of gust factor is as follows:

$$\beta_{zg} = 1 + 2gI_{10}\left(\frac{z}{10}\right)^{-\alpha} \qquad (2.4)$$

Where g = peak factor; I_{10} = coefficient for turbulent. The value of g has been changed from 2.2 to 2.5, and the values of I_{10} are increased as shown in Table 2.2.

Figure 2.2 shows the variation of the peak wind pressure profile. It can be found that the peak wind loads used for design of claddings are increased.

Table 2.2 Values of coefficients I_{10}

Categories of ground roughness	A	B	C	D
GB50009-2001	0.088	0.114	0.167	0.278
GB50009-2012	0.120	0.140	0.230	0.390

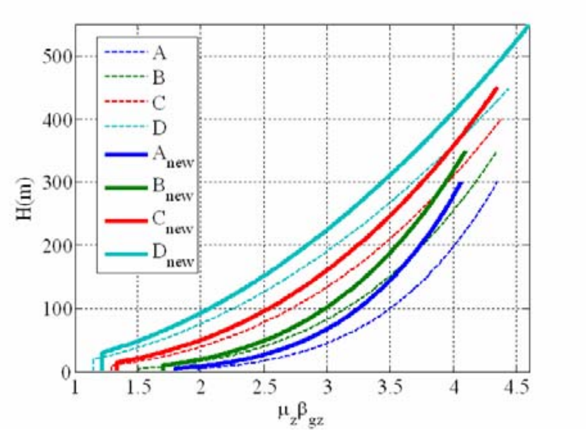

Figure 2.2 Peak wind pressure profile

2.5 *Along-wind dynamic response factor*

The expression of along-wind dynamic response factor has been changed to as follows:

$$\beta_z(z) = 1 + 2gI_{10}B_z\sqrt{1+R^2} \tag{2.5}$$

$$B_z = kH^{a_1}\rho_x\rho_z\frac{\phi_1(z)}{\mu_z(z)} \tag{2.6}$$

$$R = \sqrt{\frac{\pi}{6\zeta_1}\frac{x_1^2}{(1+x_1^2)^{4/3}}} \tag{2.7}$$

$$x_1 = \frac{30f_1}{\sqrt{k_w w_0}}, x_1 > 5 \tag{2.8}$$

Where B_z = background response factor; R = resonant response factor; f_1 = structural natural frequency; ζ_1 =structural damping ratio; k_w = modification factor of ground roughness (1.28, 1.0, 0.54 and 0.26 for A, B, C and D); $\phi_1(z)$ = modal shape; ρ_x, ρ_z = correlation coefficient; k, a_1= coefficient given in Table 2.3.

Table 2.3 Values of coefficients k and a_1

Ground roughness		A	B	C	D
building	k	0.944	0.670	0.295	0.112
	a_1	0.155	0.187	0.261	0.346
tower	k	1.276	0.910	0.404	0.155
	a_1	0.186	0.218	0.292	0.376

The values of β_z will be increased because of the increase of g and I_{10} though the theory and methodology used kept in the same (Figure 2.3). The base shear and moment of wind load is increased for high-rise buildings with total height below 350m (Figure 2.4).

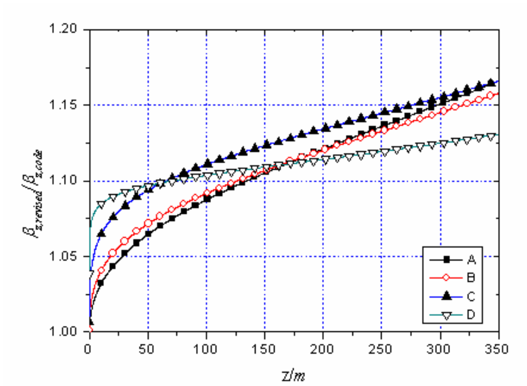

Figure 2.3 Difference of dynamic response factors

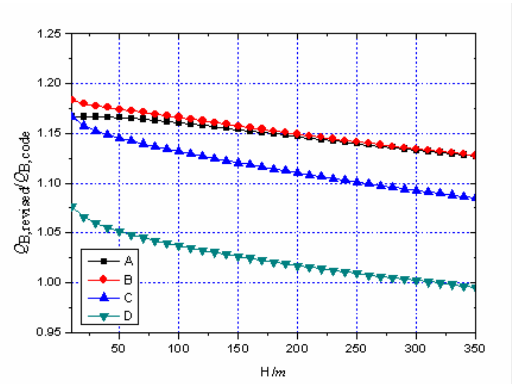

Figure 2.4 Difference of shear force

2.6 *Cross-wind and torsional dynamic response*

2.6.1 cross-wind equivalent wind load

For rectangular plan high-rise buildings with 4⩽H/B⩽8, 0.5⩽D/B⩽2 and $v_H T_{L1}/\sqrt{BD}$ ⩽10, the equivalent wind load induced by cross-wind dynamic repose of structure is expressed as follows[3-5]:

$$w_{Lk} = g w_0 \mu_z C'_L \sqrt{1+R_L^2} \quad (2.9)$$

$$C'_L = (2+2\alpha) C_m \gamma_{CM} \quad (2.10)$$

$$\gamma_{CM} = C_R - 0.019\left(\frac{D}{B}\right)^{-2.54} \quad (2.11)$$

$$C_m = \begin{cases} 1.00 - 81.6\left(\frac{b}{B}\right)^{1.5} + 301\left(\frac{b}{B}\right)^{2} - 290\left(\frac{b}{B}\right)^{2.5} & 0.05 \le b/B \le 0.2 \quad \text{case 1} \\ 1.00 - 2.05\left(\frac{b}{B}\right)^{0.5} + 24\left(\frac{b}{B}\right)^{1.5} - 36.8\left(\frac{b}{B}\right)^{2} & 0.05 \le b/B \le 0.2 \quad \text{case 2} \end{cases} \quad (2.12)$$

$$R_L = K_L \sqrt{\frac{\pi S_{F_L} C_{sm} / \gamma_{CM}^2}{4(\zeta_1 + \zeta_{a1})}} \quad (2.13)$$

$$K_L = \frac{1.4}{(\alpha + 0.95) C_m} \cdot \left(\frac{z}{H}\right)^{-2\alpha+0.9} \quad (2.14)$$

$$\zeta_{a1} = \frac{0.0025\left(1 - T_{L1}^{*2}\right) T_{L1}^{*} + 0.000125 T_{L1}^{*2}}{\left(1 - T_{L1}^{*2}\right)^2 + 0.0291 T_{L1}^{*2}} \quad (2.15)$$

$$T_{L1}^{*} = \frac{v_H T_{L1}}{9.8B} \quad (2.16)$$

Where C'_L =lateral force coefficient; R_L =resonant factor of cross-wind vibration; S_{F_L} =power spectral density function of lateral force, given in Figure 2.5 ($f_{L1}^{*} = f_{L1} B / v_H$); C_m, C_{sm} = modification factor of force and spectrum for corner shape (Figure 2.6, Table2.4); C_R =factor of ground roughness (0.236, 0.211, 0.202 and 0.197 for A to D); ζ_{a1} =aerodynamic damping ratio; T_{L1}^{*} = reduced period.

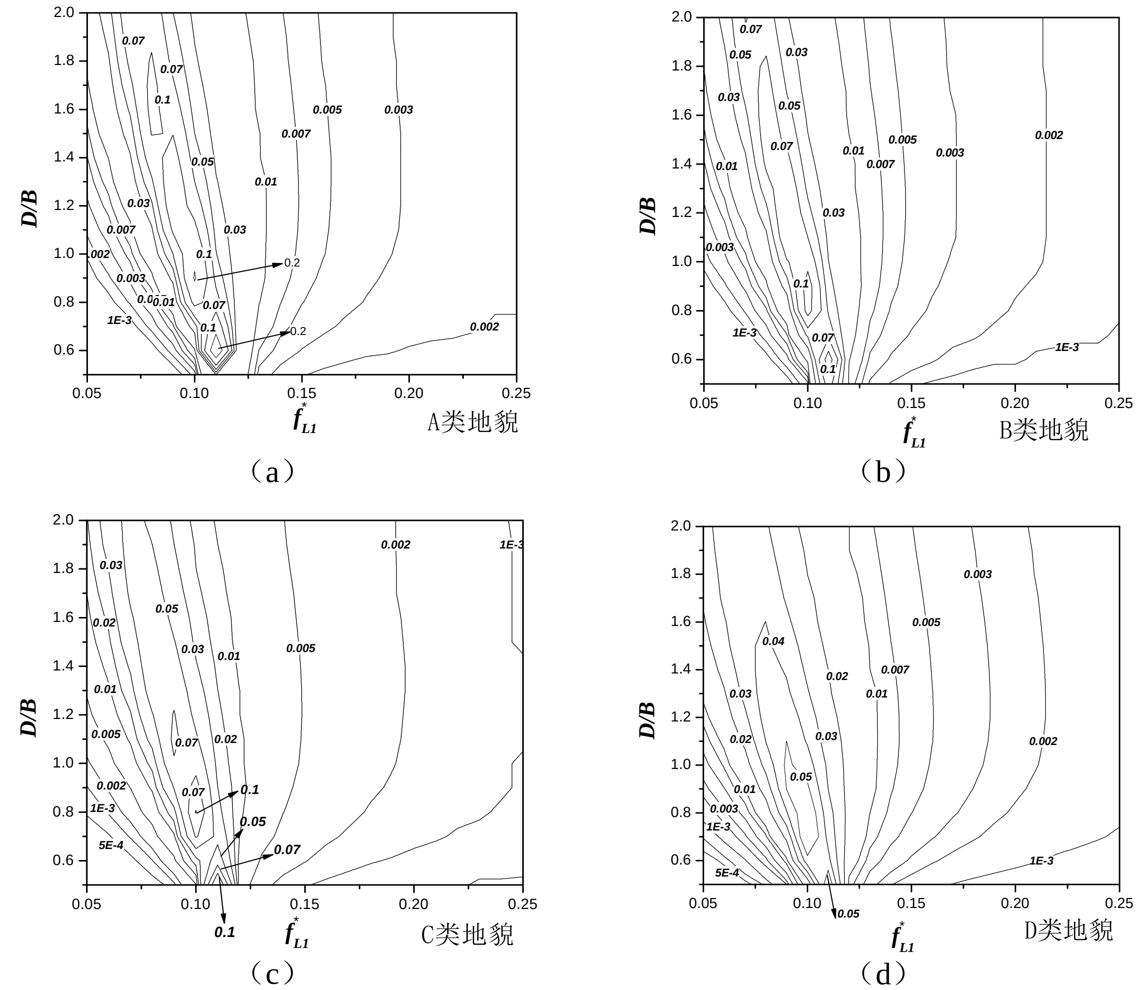

Figure 2.5 power spectral density function of lateral force

(a) case 1 (b) case 2

Figure 2.6 Corner shape

2.6.2 Torsional equivalent wind load

For rectangular plan high-rise buildings with $\frac{H}{\sqrt{BD}}$≤6, 1.5≤D/B≤5 and $\frac{T_{T1}v_H}{\sqrt{BD}}$≤10, the equivalent wind load induced by torsional dynamic repose of structure is expressed as follows:

$$w_{\mathrm{Tk}} = 1.8 g w_0 \mu_H C'_{\mathrm{T}} \left(\frac{z}{H}\right)^{0.9} \sqrt{1+R_{\mathrm{T}}^2} \tag{2.17}$$

Table 2.4 Values of coefficient C_{sm}

case	Ground roughness	*b/B*	Reduced frequency （f^*_{L1}）						
			0.100	0.125	0.150	0.175	0.200	0.225	0.250
1	B	5%	0.183	0.905	1.2	1.2	1.2	1.2	1.1
		10%	0.070	0.349	0.568	0.653	0.684	0.670	0.653
		20%	0.106	0.902	0.953	0.819	0.743	0.667	0.626
	D	5%	0.368	0.749	0.922	0.955	0.943	0.917	0.897
		10%	0.256	0.504	0.659	0.706	0.713	0.697	0.686
		20%	0.339	0.974	0.977	0.894	0.841	0.805	0.790
2	B	5%	0.106	0.595	0.980	1.0	1.0	1.0	1.0
		10%	0.033	0.228	0.450	0.565	0.610	0.604	0.594
		20%	0.042	0.842	0.563	0.451	0.421	0.400	0.400
	D	5%	0.267	0.586	0.839	0.955	0.987	0.991	0.984
		10%	0.091	0.261	0.452	0.567	0.613	0.633	0.628
		20%	0.169	0.954	0.659	0.527	0.475	0.447	0.453

$$C'_{\mathrm{T}} = \left\{0.0066 + 0.015(D/B)^2\right\}^{0.78} \qquad (2.18)$$

$$R_{\mathrm{T}} = K_{\mathrm{T}}\sqrt{\frac{\pi F_{\mathrm{T}}}{4\zeta_1}} \qquad (2.19)$$

$$K_{\mathrm{T}} = \frac{(B^2 + D^2)}{20r^2}\left(\frac{z}{H}\right)^{-0.1} \qquad (2.20)$$

Where C'_{T} =torsional force coefficient; R_{T} =resonant factor of torsional vibration; S_{F_L} = power spectral density function of torsion; F_{T} = energy factor of torsional spectrum, given in Figure 2.7 ($f^*_{\mathrm{T1}} = \frac{f_{\mathrm{T1}}\sqrt{BD}}{v_H}$).

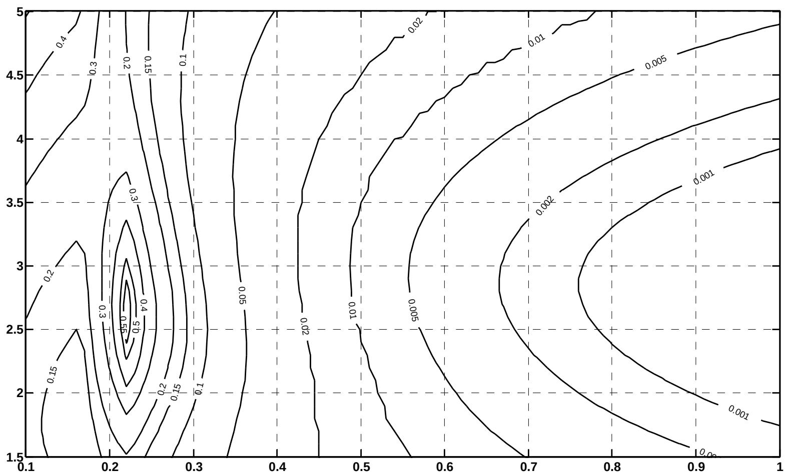

Figure 2.7 energy factor of torsional spectrum

2.7 *Combination of along-wind, cross-wind and torsional wind load*

Along-wind, cross-wind and torsional wind load given as following should be combined according to Table 2.5.

$$F_{\mathrm{Dk}} = (w_{\mathrm{k1}} - w_{\mathrm{k2}})B \tag{2.21}$$

$$F_{\mathrm{Lk}} = w_{\mathrm{Lk}} B \tag{2.22}$$

$$T_{\mathrm{Tk}} = w_{\mathrm{Tk}} B^2 \tag{2.23}$$

Table 2.5 Wind load combination

Load case	Along-wind	Cross-wind	Torsional
1	F_{Dk}	-	-
2	$0.6F_{Dk}$	F_{Lk}	-
3	-	-	T_{Tk}

3. CRITERIA AND GUIDELINE FOR WIND TUNNEL TESTING OF BRIDGES

With the origination and development of boundary layer wind tunnels by Jack E. Cermak and Alan G. Davenport in the 1960's, the effects of wind for bridges and structures have been commonly determined through wind tunnel model studies, which include measurements of various types of information of interest, such as cladding loads, structural loads and pedestrian level wind speeds. In order to assist researchers and engineers who may become involved with the wind tunnel model testing, each country, area or institute may have their own appropriate criteria and guideline to specify wind tunnel testing with various models, which results in several guidelines or manuals of practice in the world, for example, the ASCE Manual of Practice for Wind Tunnel Studies of Buildings and Structures in 1987 and 1999 [6], the Wind Tunnel Testing: A General Outline (University of Western Ontario) in 1991 and 2007 [7], the AIJ Guideline for Wind Tunnel Testing of Buildings in Japan in 1994 and 2009 [8], the Wind Tunnel Experiments for Honshu-Shikoku Bridges in Japan in 1980 [9], the Wind Resistant Design Guidelines for Highway Bridges in China in 1996 [10], the Wind Resistant Design Specification for Highway Bridges in China 2004 [11], and so on. While the first three guidelines or manuals of practice published mainly involve in buildings and structures, the next three certainly relate to bridges. These documents may have some underlying differences between one to another.

Under the globalization of the construction industry and the development of unified international codes and standards, it is believed that it is necessary to provide practical unified experimental methodology on the aerodynamics and aeroelastics of a wide range of bridges and bridge elements, such as decks, pylons, cables, hangers and so on. Thus Chinese wind engineering community, under the leadership of State Key Laboratory for Disaster Reduction in Civil Engineering and Tongji University, are working to provide a contribution towards a specific and agreed criteria and guideline of wind tunnel testing of bridges, in particular with long spans. In order to achieve this goal, following studies are being conducted:

(1) To study model law and similitude theory of wind tunnel testing of bridge aerodynamics and aeroelastics;

(2) To investigate testing procedures and experimental techniques of model studies in boundary layer wind tunnels;

(3) To assess the validity and consistency of interpreting or extrapolating methods for model testing results to the prediction of full-scale prototype behavior.

4. GUIDELINE FOR WIND TUNNEL TESTING OF BUILDING STRUCTURES

In the Chinese wind engineering community, currently there is no official guideline on the wind tunnel tests of building structures. Practically people often refer to ASCE Manual of Practice for Wind Tunnel Studies of Buildings and Structures [6], the AIJ Guideline for Wind Tunnel Testing of Buildings in Japan [8] and others. China Academy of Building Research is taking the action in establishing a guideline for wind tunnel testing of building structures, which is estimated to function as a national code. All the wind engineering groups in China are invited into the technical committee, and the documental work is proceeded through intensive discussions.

One feature of this guideline is that it covers the numerical approach (CFD) for assessing the wind load on structures.

3 REFERENCES

1 Xinyang JIN, Jida Zhao, Development of design code for building structures in China, Structural Engineering International, SEI Volume 22, Number 2, (2012)195-201.
2 Xinyang JIN, Principles and main points for the revision of Load code for the design of building structures, Journal of building structures, Vol. 32 No.12, 2011, 29-35.
3 Yi Tang, Ming Gu, Xinyang Jin, Research on Wind-Induced Response of Structurally Asymmetric Tall Buildings[J], JOURNAL OF TONGJI UNIVERSITY(NATURAL SCIENCE), 38(2), 2010
4 M. Gu, Y. Quan, Across-wind loads of typical tall buildings[J], Journal of Wind Engineering and Industrial Aerodynamics, 92(2004) 1147-1165.
5 QUAN Yong, GU Ming, Power Spectra of Across- wind Loads on Super High- rise Buildings[J], JOURNAL OF TONGJI UNIVERSITY(NATURAL SCIENCE), 30(5), 2002.
6 American Society of Civil Engineers, ASCE Materials and Reports on Engineering Practice No. 67, Wind Tunnel Studies of Buildings and Structures, the first edition in 1987, the edition of 1999.
7 Boundary Layer Wind Tunnel Laboratory of University of Western Ontario, Wind Tunnel Testing: A General Outline, the first issue in 1991 and the latest issue in 2007.
8 Architectural Institute of Japan, Guideline for Wind Tunnel Testing of Buildings (in Japanese), the first edition in 1994, the second edition in 2008.
9 Honshu-Shikoku Bridge Bureau, Wind Tunnel Experiments for Honshu-Shikoku Bridge (in Japanese), 1980.
10 H.F. Xiang, et al., Wind Resistant Design Guidelines for Highway Bridges (in Chinese), People’s Communication Press, Beijing, China, 1996.
11 Ministry of Communications, Wind Resistant Design Specification for Highway Bridges (in Chinese), People’s Communication Press, Beijing, China, 2004.