Specifications on Building Wind Resistance Design and Wind Environmental Issues in Taiwan

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ABSTRACT: Taiwan lies in the path of severe tropical cyclones known in East Asia as typhoons. With their violent winds and extremely heavy rainfall, these storms often cause severe damages. Also, dense populated urban areas and numerous ongoing economic activities have caused serious environmental problems, especially the air pollution problems. Most Asia-Pacific Economics face the same problems as Taiwan. This paper provides the information of wind structural loading codes and wind environmental problem overviews of Taiwan as references for neighborhood countries to improve individual standard/specification and to harmonize the wind load and wind environmental specifications in APEC.

KEYWORDS: buildings, design wind load, wind code, Air Polution, Environmental Issue, Taiwan

1 INTRODUCTION

Wind and earthquake loads are two primary lateral loadings for land based structures and buildings; unfortunately, Taiwan locates at an area that both effects are severe. In the most cases, under the shade of possible catastrophe, strong earthquake tends to cause great anxiety to the general public. As for the strong wind, the impact is relatively less dramatic, and therefore, attracts less attention from both general public and engineering community. In Taiwan, almost all residential buildings are in the form of reinforced concrete, which is generally sturdy for the wind loads. However, for tall or long span structures, or the lightweight industrial buildings, wind load is an important, or even the dominant, lateral loading concern. The official wind load provisions in the current building code, published in 1973, is based on the early version of Uniform Building Code (United States) and has yet been revised. In 2003 a wind code working team was assembled to update the wind load provisions to meet the recent development in wind engineering. The new draft of wind load provisions for Taiwan building code and a *Specifications for Building Wind Resistant Design* has been submitted to the authority and expected to go through the formal codification process in early 2005.

Wind environmental problems especially air pollution problems in Taiwan were big issues in past years. In 2001, in the Taiwan area, there were 619 people, 489 vehicles, 2.69 factories, and 2,372 tons (equivalent fuel) of consumed energy per unit square kilometer. Comparing with the population and vehicle densities of other countries, these densities are about 1.8 times those of Japan, 2.6 times those of Germany and the UK, and 22 times those of the US. In addition, the factory density ranged 2.4 to 69.5 times, and the amount of the consumed energy per square kilometer was about 1.7 to 10.2 times that of the mentioned countries. With the heavy environmental loading, the air quality improvement tasks would be getting harder and harder in pursuing the same air quality level as that of the advanced countries.

2 DESIGN WIND LOADS FOR BUILDINGS AND STRUCTURES

2.1 *Framework of the Wind Load Provisions*

The revised Taiwan *Specifications for Building Wind Resistant Design* is compiled primarily based on the wind load provisions in the ASCE Standard: Minimum Design Loads for Buildings and Other Structures (ASCE 7-02), with augmentations on the acrosswind and torsional design wind loads from the AIJ Recommendations for Loads on Buildings (AIJ-96). The design wind loads for both main wind force resisting system and components and cladding are allowed to be determined by either of three approaches pending on the nature of the target building and structure: (i) Analytical Procedure; (ii) Simplified Procedure for small and low-rise buildings; (iii) Wind Tunnel Procedure for irregular shaped and/or tall buildings.

The draft of *Specifications for Building Wind Resistant Design* consists of six chapters, including (i) General (ii) Design Wind Loads for Main Wind Force Resisting Systems (iii) Design Wind Loads for Components and Cladding (iv) Wind Induced discomfort (v) Wind Tunnel Test (vi) Other Issues.

The wind speed data taken at 24 weather stations over the past 50 years were collected and analyzed (Chern, Tsai and Hsiang, 1995). By using the Type-I extreme distribution, the 10-minute wind speed with return period of 50 years, at 10m height in open country is used as the basic design wind speed. The range of basic design wind speed varies from 47.5 m/s at east coast to 22.5 m/s in the mid-Taiwan; whereas the highest basic design wind speed is 65 m/s at Lanyu, an off-coast island at southeast of Taiwan. Due to lacking of sufficient typhoon data, the directionality is not to be considered on the basic design wind speed unless authority approves the statistical and/or simulation method. However, similar to the ASCE 7-02, a directional reduction factor of 0.85 is applied to the wind load factor for the limit state design approach.

The mean wind speed profiles are classified into three categories, it includes Exposure A (large city) with power law exponential $\alpha = 0.32$ and gradient height $\delta = 500m$; Exposure B (suburban) with $\alpha = 0.25$ and $\delta = 400m$; Exposure C (open country) with $\alpha = 0.15$ and gradient height $\delta = 300m$. Buildings and structures are classified into three categories: Open Building, Partially enclosed Building and Enclosed Building. The definition of each category is same as ASCE 7-02.

2.2 *Wind Loads for Main Wind Force Resisting System*

2.2.1 *The Alongwind Design Wind Load*

The alongwind design wind loads for the main wind force resisting system is basically the multiplications of wind speed pressure, external and internal pressure coefficient (force coefficient in the case of open type buildings), and the Gust Response factor.

For the enclosed and partially enclosed buildings,

$$p = qGC_p - q_i\left(GC_{pi}\right) \tag{1}$$

For the open buildings,

$$F = q(z_{A_f})\, GC_f A_f \tag{2}$$

The wind speed pressure has the following form,

$$q(z) = 0.06\, K(z)\, K_{zt}\, [I\, V_{10}(C)]^2 \tag{3}$$

In which, $K(z)$ is for the conversion of wind speed between different terrain categories. K_{zt} is the factor for special topographical situations, such as hill, ridge, or escarpment. I is the importance factor, which corresponds to return period of 25 years, 50 years and 100 years, for "less important buildings", "ordinary buildings" and "important buildings", respectively. $V_{10}(C)$ is the basic design wind speed. G is the gust response factor for the dynamic effect. There are two different forms of gust response factor, as it is in the ASCE 7-02, for rigid and flexible structures. C_p and C_f are pressure and force coefficients. Since the residential buildings are all in the form of reinforced concrete, the main concern of wind resistance design in Taiwan is for tall buildings. Therefore, a simpler version of coefficients were used in the new draft, which were complied primarily based on ASCE 7-88, with some input from SAA and NRCC.

2.2.2 *The Acrosswind and Torsional Design Wind Loads*

The acrosswind and torsional loads induced by separation and vortex shedding are included in the draft of *Specification for Building Wind Resistant Design* by adopting the corresponding articles in AIJ-96. These empirical wind load formulae, derived from measurements on rectangular prisms, are applicable to the rectangular shaped buildings that satisfy the following condition: $3 \le h/\sqrt{BL} \le 6$, $0.2 \le L/B \le 5$, $f_t\sqrt{BL}/V_h \le 0.4$, provided buildings are not in danger of vortex induced resonance. The acrosswind and torsional design wind loads are given as follows:

$$W_{Lz} = 3q(h)C_L' A_z \frac{Z}{h} g_L \sqrt{1+\frac{1}{\beta}R_{LR}} \tag{4}$$

$$M_{Tz} = 1.8q(h)C_T' A_z B \frac{Z}{h} g_T \sqrt{1+\frac{1}{\beta}R_{TR}} \tag{5}$$

in which, W_{Lz} and W_{Tz} are acrosswind and torsional design wind loads at height z. C_L' and C_T' are acrosswind and torsional force coefficients as function of building geometry. A_z is the projection area at height z, B is the building width, h the building height, and β is the structural damping ratio. R_{LR} and R_{TR} are acrosswind response factor and torsional response factor, respectively. R_{LR} and R_{TR} are complicated empirical functions of buildings' side ratio, L/B, and reduced frequency, $V^* = V(h)/f_0 B$, f_0 is the structural fundamental frequency. Tables of non-dimensional acrosswind and torsional loads were complied as functions of L/B and $V^* = V(h)/f_0 B$, as an alternative to the lengthy calculations.

2.2.3 *Wind Load Combination*

The wind load provisions recognize that the design (peak) wind loads in the alongwind, acrosswind and torsional directions are peak values, i.e., need not occur simultaneously. Therefore, the following formulae considering the wind load combination is given for structural member design:

$$W = \max(W_1, W_2) \tag{6}$$

$$W_{1,2} = \overline{W}_D + \sqrt{\left(\hat{W}_D - \overline{W}_D\right)^2 + \left(\left|\hat{W}_L\right| + \left|\hat{W}_T\right|\right)^2} \tag{7}$$

in which, W is the design wind load effects on a structural element, W_1 & W_2 are combined wind load effects under wind direction in x & y axis. $\overline{W}_D$ is the structural effect due to mean drag force, $\hat{W}_D, \hat{W}_L, \hat{W}_T$ are structural effects caused by fluctuating drag, lift and torque, respectively.

2.3 *Design Wind Loads for Components and Cladding*

The wind loads and wind pressure design formulae for the components and cladding are given in the draft of *Specification for Building Wind Resistant Design*. The basic forms of wind loads and wind pressure are similar to ASCE 7. For the same reason as the design of main wind force resisting system, a simpler version of coefficients were used for the components and cladding design, which were complied primarily based on ASCE 7-88, with some input from SAA and NRCC.

2.4 *Provision on the Human Comfort and Serviceability*

For most of the building design in Taiwan, high-rise buildings included, the design lateral loads for main structural systems are generally dominated by seismic loads. In some cases, wind loads become the dominant design lateral loading due to the serviceability concern instead of structural strength. The draft wind load provisions retain the existing building serviceability requirement that the peak lateral acceleration at corner of a building's highest inhabited story , under the wind speed corresponds to six months return period, should not exceed 0.05 m/s^2. The peak acceleration at buildings' corner should include the lateral acceleration induced by alongwind, acrosswind and torsional motions. The following formula is given:

$$\widetilde{A} = \sqrt{A_D{}^2 + A_L{}^2 + A_T{}^2\left(\frac{B^2}{4} + \frac{L^2}{4}\right) + LA_L A_T} \tag{8}$$

in which, A_D, A_L, A_T are peak accelerations in alongwind, acrosswind and torsional directions, B & L are building dimensions.

2.5 *Wind Tunnel Test*

In the draft of Taiwan *Specifications for Building Wind Resistant Design*, the wind tunnel test is formally recognized as one of procedures to determine buildings' design wind loads. For buildings or structures with irregular shape, or unusually long natural period, or height over 100 meters, wind tunnel tests are recommended. The structural wind loads and cladding wind pressure obtained through proper wind tunnel tests can be used to replace the design wind loads and wind pressure based on wind code. Important wind tunnel simulation factors, such as conformity of scaling ratio, features of atmospheric boundary layer, simulation of surrounding buildings and topography, blockage ratio and Reynolds number effects are to be properly considered, and a general specifications on these issues are given in the new draft.

2.6 *Wind Environment for Pedestrian Comfort*

In Taiwan, in order to obtain the construction permit for a building with height exceeding 60 meters, the propose construction project must go through an environmental impact evaluation study. Among the many environmental issues, the effect of new project on the wind environment for pedestrian comfort is one of the evaluation items. Usually wind tunnel test is recommended to study the impact of the proposed construction project on (i) wind environment of the neighborhood area (ii) wind environment within the project site that is designated as a “public area”. However, there is no official pedestrian comfort standard yet.

3. AIR POLLUTION OVERVIEW IN TAIWAN

In terms of controlling sources of air pollution, the Environmental Protection Administration (EPA) of Taiwan has set gradually tightening emissions standards and continues to promote improvement of the quality of oil products. Collection of the Air Pollution Fee began in 1995 to ensure that air quality in Taiwan reaches a level comparable to that of advanced nations. From the collection of this fee the Air Pollution Control Fund was established to support air pollution prevention and control work. These steps have already resulted in a gradual reduction in the number of poor air quality days. Current air pollution prevention and control working plans encompass the following main items:

1. *Improving Air Quality and the Planning and Implementation of Air Pollution Control Policies*
The EPA continues to formulate and amend regulations under the Air Pollution Control Act. Further, the EPA carries out assessments of Taiwan's air pollution monitoring network. Other work in this area includes the analysis of air quality trends and the formulation of appropriate countermeasures, delineation of air pollution control districts, planning of air pollution total quantity controls, poor air quality emergency response system and other implementation work.

2. *Promoting International Environmental Protection*
The EPA actively promotes protection of the ozone layer protection, greenhouse effect control strategies, acid rain control, response to relevant international environmental agreements, and participation in related international exchange activities.

3. *Control of Stationary Sources of Air Pollution*
In terms of administrative controls, aside from setting emissions standards for different industrial sectors and improving inspections, other EPA work items in this area include the establishment of a permit system, provision of technical assistance, oil product quality control, and auditing and subsidy of county and city government implementation of air quality improvement plans.

Furthermore, the EPA provides economic incentives in order to encourage enterprises to actively make improvements to air pollution emissions. The Air Pollution Fee is already collected based on actual emissions quantities, which means the less pollution the lower the fee that must be paid. In addition, the EPA has set regulations concerning exemption and reduction of air pollution fees and statutes encouraging pollution reduction.

4. *Control of Mobile Sources of Air Pollution*
In addition to carrying out inspection of new vehicle-models and testing of new-vehicles in accordance with the law, the EPA has already implemented a comprehensive motorcycle emissions testing system and is actively promoting the widespread use of clean alternative fuels (such as LPG and CNG..) and electric vehicles (such as electric buses, motorcycles and bicycles). Furthermore, subsidies are offered to promote the elimination of older, heavily polluting vehicles in order to reduce air pollution emissions.

3.1 Air Quality and Air Quality Standard of TAIWAN

3.1.1 Air Quality

The Air Pollution Control Act, enacted in 1975 and newly revised in June 2002, empowers the government at various levels to establish air quality standards for different areas across Taiwan and monitoring stations at appropriate sites. Air quality is currently monitored through the Taiwan Area Air Quality Monitoring Network. The network comprises 72 stationary automatic air quality monitoring stations, two mobile monitoring stations, and one air quality assurance laboratory. Next-day air quality forecasts for eight areas of Taiwan are issued daily based on the data collected from this network.

Air quality improvement measures include stringent emission standards for industrial plants and motor vehicles (5.72 million cars and 11.7 million motorcycles in 2001), regular exhaust inspections for motorcycles, the promotion of low-pollution transportation vehicles, strict standards on the composition of petroleum products, increased inspections of construction sites, and road-cleaning. The Environmental Protection Administration (EPA) levies an air pollution control (APC) fee on both stationary sources, such as factories and construction sites, and mobile sources, such as motor vehicles. This APC fee covers such pollutants as fine suspended particulates, nitrogen oxides, sulfur oxides, and hydrocarbons.

Since its implementation in 1995, the APC fee levying system has led to marked improvement in Taiwan's air quality, with sulfur dioxide concentration decreasing 46 percent from 7.5 ppb in 1994 to 4.0 ppb in 2001. Taiwan's pollution standard index (PSI) exceeded 100 on only 3.06 percent of the days in 2001, compared to 6.8 percent in 1994. In the heavily polluted Kaohsiung and Pingtung area, the PSI exceeded 100 on 8.62 percent of the days in 2001, compared to 17.5 percent in 1996, after the successful implementation of an air quality improvement project launched in 1997. The EPA expects to lower the average figure for all of Taiwan to 2 percent by 2006 and 1.5 percent by 2011.

In fiscal year 2001, the APC fee system generated US$58 million. These funds are allocated to air pollution control programs, such as planting trees along major thoroughfares and on closed garbage dump sites, establishing environmental conservancy parks, building bicycle lanes, and reducing dust particles on school premises.

3.1.2 Air Quality Standard

According to the Air Pollution Act Enforcement Rules of EPA, Taiwan, the air quality standards for major air pollutants are summarized in the Table 1.

Table 1 Summary of the air quality standards for major air pollutants.

Types of air pollutants	**Standard**		**Units**
Total suspended particles (TSP)	24 hours year (by hours)	250 130	μm/m^3
Suspended particulates: Particles with a diameter of less than 10 microns (μm) (PM10)	day year (by days)	125 65	μm/m^3
Sulfur oxides (SO_2)	hour day year (by days)	0.25 0.1 0.03	ppm
Nitrogen oxides (NO_2)	hour year (by days)	0.25 0.05	ppm
Carbon monoxide (CO)	hour 8 hours	35 9	ppm
Ozone (O_3)	hour 8 hours	0.12 0.06	ppm
Lead (Pb)	month	1.0	μm/m^3

The following methods shall be used to judge the air pollutants list in the table 1 in compliance with air quality standards.

1. **Suspended particulates:** List in order from highest to lowest the daily average values for each year at each of the general air quality monitoring stations within said zones. Taking the eighth highest values, calculate the arithmetic average value for three consecutive years. List in order the arithmetic average values for three consecutive years for each station. Take the average of the first 50% of the highet values. Those stations whose average values are less than the daily average air quality standards, and those stations whose annual average values are uniformly less than annual average air quality standards, shall be in compliance with air quality standards.
2. **Ozone:** List in order from highest to lowest the highest hourly average values for every day in each year at each of the general air quality monitoring stations within said zones. Taking the eighth highest values, calculate the arithmetic average value for three consecutive years. List in order the arithmetic average values for three consecutive years for each station. Take the average of the first 50% of the highest values. Those stations whose average values are less than the hourly average air quality standards shall be in compliance with air quality standards.
3. **Sulfur dioxide and nitrogen dioxide:** List in order from highest to lowest the highest hourly average values for every day in each year at each of the general air quality monitoring stations within said zones. Taking the eighth highest values, calculate the arithmetic average value for three consecutive years. Those stations whose average values are uniformly less than the hourly average air quality standards, and those stations whose an-

nual average values are less than annual average air quality standards shall be in compliance with air quality standards.

4. **Carbon monoxide:** List in order from highest to lowest the highest eight-hour average values for every day in each year at each of the general air quality monitoring stations within said zones. Taking the eighth highest values, calculate the arithmetic average value for three consecutive years. Those stations whose average values are uniformly less than eight-hour air quality standards shall be in compliance with air quality standards.

3.2 *Indoor Air Quality Considerations and Suggestion Standards of TAIWAN*

Local indoor air quality problems: Based on the field measurements and investigation of the office building, there are four main problems in Taiwan.

1. High concentration of Carbon dioxide (CO_2) inside office building.
2. High concentration of volatile organic compounds (HCHO,TVOC) inside office building.
3. High concentration of respirable particulate matter (RSP, PM_{10})in regions of south of Taiwan
4. Biological contaminants Problems.

There is no bylaws/specifications for indoor air quality in Taiwan. Table 2a and 2b show the two stages of suggestion specification of indoor air quality in Taiwan.

Table 2a Indoor air quality suggestion standards for public and office buildings (first stage)

Pollutants	**Other Countries' Standard**	**Taiwan's Suggestios**	**Remarks**		
			75%	**50%**	**25%**
PM_{10}	60μg/m³(24hourse)[Australia] 150μg/m³(24hourse)[Japrn]	A:40μg/m³ B:180μg/m³ (24 hrs-meta)	63 μg/m³	37 μg/m³	20 μg/m³
CO_2	800 ppm [Australia] 1000 ppm (ceiling)[Japan, Korea] 1000 ppm (8 hr)[Singapore] 1500 ppm (ceiling)[Germany] 1000 ppm (8 hr)[WHO]	A:600 ppm B:1000 ppm	656.4 ppm	511.2 ppm	442.0 ppm
CO	87.3 ppm (15 min)[European] 52.4 ppm (30 min)[European] 26.2 ppm (1 hr)[European] 8.7 ppm (8 hr)[European] 18 ppm (1 hr)[USA] 10 ppm (1 hr)[Japan]	A:2ppm(8hrs) B:9ppm(8hrs)	2.66 ppm	1.53 ppm	0.813 ppm
HCHO	0.1 ppm (ceiling)[Australia, Germany] 0.7 ppm (ceiling value for older buildings)[Sweden] 0.1 ppm (limit for new homes) [Sweden, ASHRAE]	A:0.02 ppm (8hrs) B:0.1 ppm (1hr-max)	0.898 ppm	0.774 ppm	0.512 ppm
TVOC	500μg/m³ (1 hr)[Australia] Total photoionisable compounds. Reference to toluene ≦	Total photoionisable compounds, reference to tolu-	12.74 mg/m³	11.76 mg/m³	8.33 mg/m³

	3ppm[Singapore] 300µg/m^3 (8 hr)[WHO]	ene≦3ppm			
Temp	24-26^{0}C [France] 24^{0}C [USA] 23-24^{0}C (dry area) [Russian] 24-25^{0}C (wet area) [Russian]	summer： 24-28^{0}C winter： 20-25^{0}C	26.8	24.7	23.3
			24.2	22.7	21.2
Humid-ity	40-70% [Japan] 40-60% [Hong kong] 30-60% [France] 50% (dry area) [Russian] 50-55% (wet area) [Russian] 30-80% (summer) [Canada] 30-55% (winter) [Canada]	40-70%	Concerning the biological pollutants growth Reter to ASHRAE Standard 55a		
Wind velocity	<0.5 m/s [Japan, Taiwan] <0.25 m/s [Hong Kong] >0.1 m/s [France] 0.2 m/s [USA] 0.15 m/s (dry area) [Russian] 0.2-0.25 m/s (wet area) [Russian] 0.25 m/s [Singapore]	<0.5 m/s (Mean Speed) <0.25 m/s (work area)	Concerning the micro-climate in Taiwan More Ventilation is accepted Refer to Japan Standard Prevent Cold Draft		

Table 2b Indoor air quality suggestion standards for public and office buildings (second stage)

Pollut-ants	Other Countries' Standard	Taiwan's suggestions	Remarks		
			75%	50%	25%
$PM_{2.5}$	40µg/m^3(long term)[Canada] 100µg/m^3(1 hour)[Canada]	No suggestion			
SO_2	500 ppb (10 min)[Australia] 250 ppb (1 hour)[Australia] 20 ppb (1 year)[Australia] 19 ppb (long-term)[Canada] 380 ppb (5 min)[Canada]	A:20 ppb B:Ambient	Meta-Analysis Result		
NO_2	Ambient 50 ppb (1 year)[USA] 75 ppb (24 hrs)[European WHO] 200 ppb (1 hr)[European WHO] 210 ppb (1 hr)[Mexico]	A:75ppb 150µg/m^3 (24 hrs) B:200ppb (1 hr)	Meta-Analysis Result		
O_3	120 ppb (1 hr)[Australia, Canada] 50 ppb (8 hrs)[Singapore] 100 ppb (8 hrs) [UK] 120µg/m^3[Hong Kong]	A:0.03 ppm (8 hrs) B:0.05 ppm (8 hrs)	Meta-Analysis Reference to ASHREA 62 long term standard		
Bacteria	1000CFU/m^3 [WHO, Hong Kong] 500CFU/m^3 [Singapore]	A:500 B:1000 CFU/m^3	2469.5	995.3	435.6
Fungi	1000CFU/m^3 [WHO] 500CFU/m^3 [Singapore, Hong Kong]	A:500 B:1000 CFU/m^3	2840.9	1560.9	824.3
VOCs	Toluene, Benzene, Nicotine Methoxyethoxyethanol, Xylene, Methycyclohexane, Hexane,	No suggestion			

	Tetradecane, Cyclobenzene Pentadecane		

Remark: A class: High Standard., B class: Normal Standard.

4 CONCLUSIONS

In this article, the latest draft of the specifications on building wind resistant design and air pollution problems are briefly explained. Several main features of the reported specifications can be summarized as follows:

1. Taiwan's new *Specification for Building Wind Resistant Design* is primarily based on ASCE 7-02, with augmentations on the acrosswind and torsional design wind loads from AIJ-96.
2. The design wind loads are allowed to be determined by either of three approaches: (i) Analytical Procedure; (ii) Simplified Procedure; (iii) Wind Tunnel Procedure
3. For the wind resistant design of tall buildings, the design wind loads in the alongwind, acrosswind and torsional directions needed to be considered simultaneously.
4. Collection of air pollution control (APC) fee and efficient usages make improvement in Taiwan's air quality.
5. The *Air Pollution Control Act* enacted in 1975 and newly revised in June 2002. It is air quality standards for outside of building. There is no bylaws/specifications for indoor air quality in Taiwan.

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