Some Background on the Draft Macau Wind Code

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ABSTRACT: This report outlines some background information on the newly drafted wind code for Macau. The code is mainly based on the Eurocode with inclusion of local wind climate and characteristics. The basis for the codified design wind speeds and wind characteristics of Macau is briefly described. There are some other modifications to the Eurocode in the Macau code, including a modified approach to pressure coefficients for building walls and the statistical probability factor. This report will describe the background to these issues.

KEYWORDS: Wind codes, Macau, Design wind speed, Wind profiles, Pressure coefficients

7 INTRODUCTION

With the rapid development in infrastructure and building projects in Macau, a revision of the Macau Wind was carried out during 2006 to 2008. The existing wind code was written in 1996 by the Land, Public Works and Transport Bureau of Macau (Direccao dos Servicos de Solos, Obras Publicas e Tansportes) (DSSOPT 1996) and was adopted mainly from the old Portuguese wind code. The revision was undertaken by the Civil Engineering Laboratory of Macau (Laboratorio de Engenharia Civil de Macau, LECM) which is a non-profit making technical and scientific organization for public works. The writer was invited by LECM to carry out a statistical extreme wind analysis for Macau and to provide expert advices on some provisions of the new code.

The new wind code is mainly drafted following the framework of Eurocode 1, EN1 (CEN 2005) with the local wind and building characteristics of Macau in place. The main areas which have been studied particularly for Macau include the design wind speeds for Macau, characteristics and profiles of mean wind speed and turbulence for Macau, and modifications of wind loading coefficients and dynamic response estimation for buildings in Macau. This report will describe these parts of the code particular to Macau.

The draft new wind code for Macau, together with the draft earthquake code, was officially introduced and opened for consultation in April 2008. The wind code is included as Chapter III – Wind Action of Macau Code of Safety and Actions for Building and Bridge Structures (Macau Regulamento de Sequranca e Accoes em Estruturas de Edificios e Pontes) (LECM 2008).

8 DESIGN MEAN WIND SPEEDS

Details of the extreme wind analysis for Macau has been reported in Lam and Metello (2008) and Lam and To (2009). The key findings are repeated here. The analysis involves a review of available wind records in Macau, anemometer corrections for topography effect from a topographical wind tunnel test, and a statistical analysis of extreme wind speeds. The set of extreme wind speeds include hourly mean wind speeds during 563 independent wind storms in the 54-year period from 1952 to 2005. The mean wind speeds are extracted from wind records at four anemometer stations and have been corrected to the standard condition of 250 m over the sea surface using the wind tunnel correction. Extreme wind analysis of the storm wind speed data is carried out using the Lieblein BLUE method (Harris 1999) following by a confidence limit analysis according to ESDU Data Item 87034 (ESDU 1990).

Eventually, the design wind speeds are obtained from the extreme values of V^2 with an additional 20% increase. The resulting design mean wind speeds are summarized in Table 1 which is included in the draft wind code as Table III.1. The characteristic product of the extreme distribution of V^2 has the value $M\alpha$ = 2.02, where M is the mode and $1/\alpha$ the dispersion of the distribution.

Table 1. Design wind speeds, referred to 250 m over sea surface.

Return period (year)	10	20	50	100	200	500	1000
Mean wind speed (m/s)	48.1	52.0	56.6	59.8	62.9	66.7	69.5
Gust wind speed (m/s)	60.7	65.6	71.9	75.5	79.4	84.2	88.2

9 WIND PROFILES AND DESIGN GUST WIND SPEEDS

There is no reported measurement of wind characteristics or vertical wind profiles in Macau. The ESDU wind profiles are thus adopted for the draft code (ESDU 2002, 2005). Macau is a small city and wind approaches it mainly over two terrain types. From the easterly and southerly directions, wind blows over the sea surface of Pearl River Estuary and an aerodynamic roughness length at z_0 = 0.0037 m is used for the log law in the ESDU Data Items. From other directions, wind blows to Macau over the region of Zhuhai City, China and a suburban terrain with z_0 = 0.3 m is appropriate. The vertical profiles of mean wind speed, longitudinal turbulence intensity and 3-second gust wind speed under the two terrain types are obtained from the reference mean wind speed at 250 m over sea in Table 1 using ESDU Data Item 01008 (ESDU 2002). In the code, the 50-year return values are normally used for assessment of wind actions and the corresponding wind profiles are plotted in Figure 1. The gust wind speeds at different return periods for the standard condition have been listed in Table 1.

It was subsequently decided that only the terrain of sea surface is specified for use in Macau. The Hong Kong wind code (BD 2004) also uses one single terrain type. The profiles of design wind speeds and turbulence intensity in the Hong Kong code are included in Figure 1 for comparison. It can be observed that the design wind speeds for Macau are higher than those for Hong Kong even though the latter design wind speeds are effectively 100-year return values.

For the convenience of calculation, the following algebraic expressions are fitted to the profiles and they are given in the draft code (z being the height above ground):

$$\bar{V} = 5.09 \times \log_e\left(\frac{z}{0.0037\text{m}}\right) \quad \text{for mean wind speed profile} \quad (1)$$

$$I_u = 0.093 \times \left(\frac{z}{250\text{m}}\right)^{-0.14} \quad \text{for turbulence intensity profile} \quad (2)$$

$$\hat{V} = \bar{V} \times (1 + 3I_u) \quad \text{for 3-second gust wind speed} \quad (3)$$

$$L_{u,x} = 325 \times \left(\frac{z}{250\text{m}}\right)^{0.39} \quad \text{for integral scale of turbulence} \quad (4)$$

The draft Macau code explicitly specified the characteristic gust wind pressure (and speed) profile in Table III.2. This is the 50-year return value and the gust wind pressure is calculated from $\frac{1}{2}\delta\hat{V}^2$, with the density of air at δ = 1.20 kg/m^3. The integral scale of turbulence is used in Appendix C to the code for the computation of dynamic response coefficient. The profile is adopted from EN1 (CEN 2005) instead of ESDU which suggests much larger values.

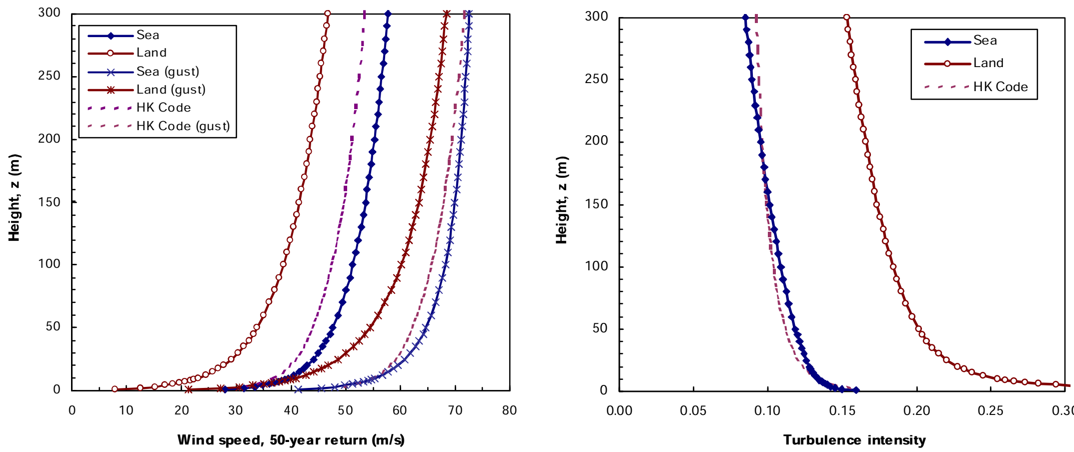

Figure 2. Vertical profiles of 50-year return mean and gust wind speeds and turbulence intensity for Macau.

10 RISK AND PROBABILITY FACTOR

In line with the Eurocode, the safety of a structure is assessed with the risk concept in the draft Macau code. The relationship between the risk ρ, the return period, R years, of wind speed being used, and the expected life of the structure, L years, is given by:

$$\rho = 1 - \left(1 - \frac{1}{R}\right)^{L}, \text{ or } \ln(R) = \ln(L) - \ln(-\ln(1-\rho)), \text{ for large } R \quad (5)$$

As with most wind codes, the draft Macau code specifies the 50-year wind speed for design. For the ultimate limit state, a load factor at 1.5 is recommended. With the wind speed values in Table 1, this means that a structure is effectively designed for the 1000-year return wind. The associated risk of a normal structure with 50-year expected life is 0.05.

In the extreme wind analysis, the V^2 data are used and the wind speed at a return period is:

$$V^2(R) \approx M + \tfrac{1}{\alpha}\ln(R) \quad (6)$$

Thus, when an acceptable risk and structure life different from 50 years are desirable, the wind speed at a particular return period (R years) should be used. With the characteristic product of the extreme distribution of V^2 at $M\alpha$ = 2.02, the ratio between this wind speed (squared) and the 50-year wind speed (squared) is thus:

$$\frac{V^2(R)}{V^2(50)} = \frac{2.02 + \ln(L) - \ln(-\ln(1-\rho))}{2.02 + \ln(50)} \quad (7)$$

This ratio is given in Appendix C to the code as the probability factor and is to be applied to the design gust wind pressure (at 50-year return).

11 TOPOGRAPHIC COEFFICIENT

The draft Macau code adopts the method of speed-up ratio to account for increase in wind speed for wind blowing over a topographic feature. The values of the s-factor, referred to as the topographic location factor, are reproduced from the Eurocode, EN1 (CEN 2005) with the permission of BSI. However, the factor is to be applied to the gust wind speed instead of the mean wind speed. Modifications to some equations are thus needed.

When blowing over a topographic feature, the increased mean wind speed is calculated as:

$$\overline{V}'(z) = \overline{V}(z) \cdot (1 + 2s\phi), \qquad \text{for } 0.05 < \phi < 0.3 \quad (8)$$

where ϕ is the upwind slope of the feature. The speed-up effect is mainly on the mean wind speed while the root-mean-square value, σ_u, remains essentially unchanged. The modified gust wind speed is thus:

$$\hat{V}' = \overline{V}' + g\sigma_u = \overline{V}\cdot(1+gI_u)\times\left(1+\frac{2s\phi}{1+gI_u}\right), \text{ or}$$

$$\hat{V}' = \hat{V}\cdot\left(1+\frac{2s\phi}{\hat{V}/\overline{V}}\right) \tag{9}$$

For the wind speed profiles in Figure 1, $2/\left(\hat{V}/\overline{V}\right) < 1.5$ for most heights below 100 m. It is therefore on the conservative side to simplify Eq. (9) to:

$$\hat{V}' = \hat{V}\cdot(1+1.5s\phi) \tag{10}$$

This is the background behind the topographic coefficient given in the code for the gust wind pressure:

$$C_t = \left(\hat{V}'/\hat{V}\right)^2 = (1+1.5s\phi)^2, \qquad \text{for } 0.05 < \phi < 0.3 \tag{11}$$

The turbulence intensity profile is also modified by topography. With σ_u unchanged, the turbulence intensity becomes lower to:

$$I_u' = \frac{\sigma_u}{\overline{V}'} = \frac{\sigma_u}{\overline{V}(1+2s\phi)} = \frac{I_u}{(1+2s\phi)} \tag{12}$$

For simplicity and without the introduction of another coefficient or factor, the following equation is used instead in Appendix C to the draft code for the modified turbulence intensity and it is on the conservative side:

$$I_u'' = \frac{I_u}{\sqrt{C_t}} = \frac{I_u}{\sqrt{(1+1.5s\phi)^2}} \tag{13}$$

12 PRESSURE COEFFICIENTS

Appendix B to the draft code lists the pressure and force coefficients. The more commonly used coefficients are external pressure coefficients on the walls of a building. The format, application rules and values of this set of pressure coefficients are adopted from Eurocode, EN1 (CEN 2005). In EN1, two sets of pressure coefficients are given: $C_{pe,1}$ and $C_{pe,10}$ and it is recommended that a loading surface of area equal to or smaller than 1 m^2 uses $C_{pe,1}$ and surfaces at 10 m^2 or larger areas should use $C_{pe,10}$. An interpolated pressure coefficient value is to be used for a surface of area between 1 and 10 m^2. In Macau, building walls are mostly larger than 10 m^2 and it is suggested in the revision of the Macau code to use only the values of $C_{pe,10}$ and to introduce additional area correction factor for a surface of area other than 10 m^2.

The recommended values are listed in Tables 2 and 3. The area correction factor is borrowed from the size effect factor in the British wind code, BS6399 (BSI 2002) which accounts for the non-simultaneous action of gusts across an external loaded surface. The A-curve in BS6399 which is applicable to the open terrain is used. Figure 2 shows a comparison of the area reduction factors between the A-curve in BS6399 and the values recommended in the draft Macau code.

For tall buildings, the code allows the building to be divided vertically into sections on which different reference wind pressures can be used. This approach follows that of EN1 and BS6399. The code also recommends pressure coefficients for use on different forms of roofs. The methodology and values are mainly adopted from EN1.

Table 2. External pressure coefficients for vertical walls of rectangular plan buildings.

D, E are windward and leeward walls, respectively. A, B, C are sub-regions of side wall. h, d are height and depth of building, respectively.

Zone	A	B	C	D	E
h/d			$C_{pe,10}$		
5	–1.2	–0.8	–0.5	+0.8	–0.7
1	–1.2	–0.8	–0.5	+0.8	–0.5
≤ 0.25	–1.2	–0.8	–0.5	+0.7	–0.3

Table 3. Area correction factor.

Loaded areas (m^2)	Area correction factor
1	1.20
5	1.06
10	1.00
50	0.95
100	0.93
500	0.88
1000	0.86
5000	0.82
10000	0.80

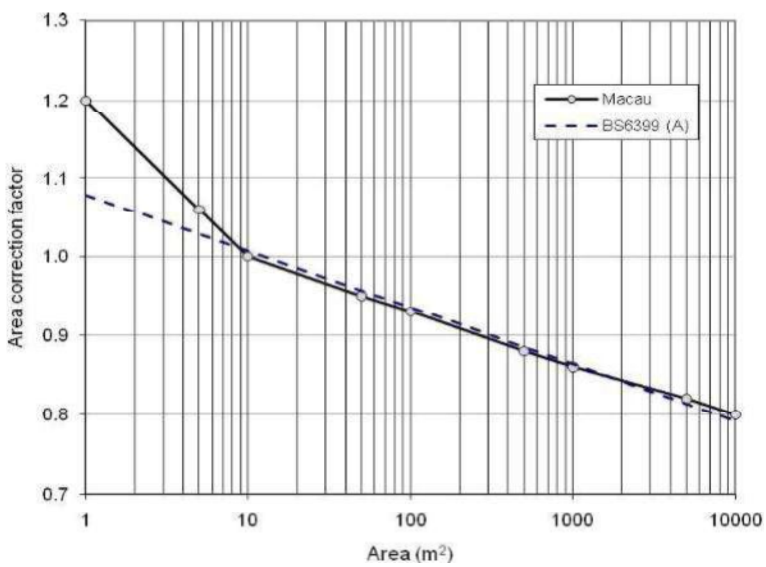

Figure 2. Area reduction factors for walls of rectangular plan buildings.

13 DYNAMIC RESPONSE COEFFICIENT FOR ALONG-WIND RESPONSE

The draft Macau code uses the first mode fundamental frequency of the structure to classify whether the structure is dynamically sensitive. For a building with natural frequency between 0.2 and 1 Hz, the gust response method is described in Appendix C to estimate the magnification of along-wind loads due to along-wind response. The procedures are adopted from the Australian Wind Code, AS/NZS1170.2 (AS/NZS 2002). To cater for the local wind characteristics, the profiles of gust wind speed and turbulence intensity in Figure 1 are used in the calculation. The integral scale of turbulence is given by Eq. (4). One additional modification is the specification of the modified turbulence intensity when affected by topography. In this case, Eq. (13) is to be used.

14 DISCUSSION AND CONCLUDING REMARKS

A new Macau code is necessary due to the rapid infrastructure development in Macau. The draft code is largely based on the Eurocode. It is now more in line with other modern wind codes with the following changes:

- The 50-year return gust wind speed, instead of the currently used 200-year return wind speed, is specified for the design (basic) wind speed
- The topographic effect is accounted for by the speed-up ratio method.
- The dynamic gust response factor method, adopted from AS/NZS1170.2, is recommended for the estimation of along-wind response of tall buildings.
- Wind loading of buildings is assessed from wind pressure on building walls and the set of pressure coefficients on building walls have similar values as EN1 or BS6399.

Subsequent to the drafting of the code, the writer personally would like to see some further modifications. The extreme wind analysis has not been carried out to specifically deal with typhoon events. The rate of increase of design wind speed with return period is smaller than that obtained from a Monte-Carlo simulation of typhoon wind speeds. One approach for mitigation of this inadequacy may be through the use of a larger load factor for building designs in typhoon-prone regions (Holmes et al. 2009). The draft code decided to specify a single terrain type. Though Macau is a small city, wind from the westerly and northerly directions has blown over significantly long fetch of open land or suburban terrain before reaching Macau. The writer would agree to the inclusion of one more terrain type for wind from the relevant directions.

The draft Macau wind code is definitely a significant improvement to the existing code. In some areas such as the calculation of building loads from wind pressure, it is more in harmonization with modern wind codes than the Hong Kong wind code. It remains to observe when it will be finally enacted and what implications and effects it will make to the building design in Macau.

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