Recommendation on topographic effect correction factor for applying of Chinese National wind load code

Zheng-wei Zhang\textsuperscript{1}, Alex P. To\textsuperscript{2}

\textsuperscript{1}Assistant Engineer, Wind Engineering, Ove Arup International Consultants (Shanghai) Co. Ltd., Shanghai, PRC, zheng-wei.zhang@arup.com

\textsuperscript{2}Associate, Wind Engineering, Ove Arup & Partners Hong Kong Limited, Hong Kong, PRC, alex.to@arup.com

ABSTRACT

Complex terrain changes the wind field characteristics significantly, especially on the mean wind speed and turbulence intensity during the separation zone of steep hills and escarpments. With the acceleration of urbanization process in China, a large number of super tall buildings, large-span and high-rise structures will be built in western and southern parts of China where the topography effects cannot be ignored in the wind-resistant design. Based on the Chinese Code GB 50009-2012, Japanese Code AIJ-2004, American Standard ASCE 7-10, Australian/New Zealand Standard AS/NZS 1170:2:2011, Euro code EN 1991-1-4:2005, ISO Code 4354:2005 and Canadian code NBC 2005, the topography influences of typical terrain are analyzed in details and the main parameters on topographic effect are given. On this basis, the improved topographic correction factor formulas for mean wind speed and peak wind speed are obtained. By comparing with the numerical examples, wind tunnel test and field measurement results in literatures, the applicability of the improved formulas are verified and provides a reference for future wind loading code amendments and wind-resistant design in complex terrain areas.

Keywords: Topography effect, Wind code, Correction factor, Wind speed, Turbulence Intensity

1 Introduction

70\% of China's land is mountainous and a large number of super tall buildings, large-span and high-rise structures will be built in western and southern parts of China during urbanization process. For structures situated in hilly terrain, the speed up of the wind velocity over hills and escarpments and the turbulence intensity during the separation zone of steep hills and escarpments are important considerations (Holmes, 2007). In some low seismic zone, wind loads always play a important role in structural design.

Mean and peak wind speeds can be increased considerably by natural and man-made topography in the forms of escarpments, ridges, cliffs and hills. The topography effects were the subject of considerable research in the 1970s and the main methods used by scholars are wind tunnel test (Jackson 1979; Gong and Ibbetson 1989; Miller and Davenport 1998; Kim 1997, 2000; Cao 2006; Lubitz and White 2007) and numerical simulation (Jackson and Hunt 1975; Kaimal and Finnigan 1994; Taylor and Lee 1984; Weng 2000). Research objects are two-dimensional ridge, two-dimensional escarpment and three-dimensional axisymmetric hills (shown in figure 1). The effects of geometric dimensions of the mountain (different slopes and height) and terrain roughness categories on mean wind speed, turbulence intensity and peak wind speed are studied and the occurrence of flow separation conditions was analyzed. These research results have been reflected in the load specification of various countries. Chinese scholars do few researches on topography effects. Hu (2006) used wind tunnel test to study the wind characteristics on the bridge site at the canyon terrain; Sun(2010) gave the empirical formulas of mean and fluctuating wind speed distribution from wind
tunnel test of 10 different slope and height of the three-dimensional axisymmetric mountain model; Wei et al (2010) studied the speed-up mean wind speed used Fluent software; Li et al (2010), Li et al (2010) and Wang and Sun(2012) have carried on the wind resistance design on high-rise building, tower and transmission tower located on mountainous areas and the topographic correction factor for wind pressure on Chinese wind load code GB50009-2012 is based on developed countries wind codes.

The influence of wind field in typical terrain close to ground and the latest wind loading codes adopted in some of the developed countries and regions are compared and analyzed in depth. On this basis, the improved topographic correction factor formulas for mean wind speed and peak wind speed are obtained. And by comparison with the numerical examples and wind tunnel test and field measurement results in literatures, the precision and applicability of the improved formulas are finally verified and can provide a reference to the load specification amendments and wind-resistant design during complex terrain areas.

![Fig. 1 Definitions for Wind speed-up effect and separation zone over hill and escarpment](image)

**2 Parameters analysis about topography effects**

With flow normal to the upstanding face of a shallow escarpments and hills, the wind speed near the surface first decelerates from the approach value $V_e$ to the minimum value at the foot of the escarpments and hills. Next the flow accelerates to a maximum near the crest, before decelerating again to a constant value downwind. On steep escarpments and hills (slope greater than 0.3), flow separation will occur. Separations may occur at the start of the upwind slope, immediately downwind of the crest and on the downwind slope for hills and ridges. The “topographic multipliers” can be defined as follows for the mean and peak velocity.

\[
\Delta S = \frac{\bar{U}(z) - \bar{U}_o(z)}{\bar{U}_o(z)} M_i = 1 + \Delta S
\]

\[
\dot{U}(z) = [1 + 2g I_e(z)] \bar{U}(z) , I_e(z) = \frac{\sigma_v(z)}{\bar{U}(z)}
\]

\[
\Delta \dot{S} = \frac{\dot{U}(z) - \dot{U}_o(z)}{\bar{U}_o(z)} , M_i = 1 + \Delta \dot{S}
\]

Where, $\bar{U}(z)$ and $\dot{U}(z)$ are the mean wind speed and peak wind speed at height $z$ above the topography respectively; $\bar{U}_o(z)$ and $\dot{U}_o(z)$ are the mean wind speed and peak wind speed at the height $z$ above the upwind flat ground respectively.

\[
\Phi_v = \tan \alpha_v = \frac{L_v}{H} , \Phi_d = \tan \alpha_d = \frac{L_d}{H}
\]

Where $\Phi_v$ and $\Phi_d$ are the upwind slope $H/Lu$ in the wind direction (see Figure 1).
From Table 1, most countries use formulas for topography correction factor; only AIJ-2004 provides the correction factor for turbulence intensity and AA/NZS:2011 gives the correction factor during the separated zone. From Table 2, the effect parameters on topography correction factor are hill upwind slope, height of the hill, upwind horizontal distance X and the reference height on the structure above the average local ground level z.

Table 1: Main research contents in main wind codes / standards

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction factor</td>
<td>Formulas</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Charts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correction item</td>
<td>Mean wind speed</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind pressure</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Turbulence intensity</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peak wind speed</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hill shapes</td>
<td>2-D ridges</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>3-D axi- symmetrical hills</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-D escarpments</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>2-D Valleys</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separation zone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Terrain roughness categories</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2: Correction factors of upwind (X≤0) section for all topography**

<table>
<thead>
<tr>
<th>Main wind Codes / Standards</th>
<th>Topographic correction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB50009-2012</td>
<td>( M_i = \left( \eta_b - 1 \right) (L_u + X), \eta_b = 1 + k\Phi_u \left( 1 - \frac{z}{2.5H} \right), \text{if } \Phi_u &gt; 0.3, \Phi_u = 0.3; \ k = 2.2 \text{ for hills and ridges; } \kappa = 1.4 \text{ for escarpment} )</td>
</tr>
<tr>
<td>AS/NZS 1170:2:2011</td>
<td>( \Phi_u &lt; 0.05, M_i = 1; 0.05 \leq \Phi_u \leq 0.3, M_i = 1 + \left( \frac{H}{3.5(z + L_u)} \right)^{1/2} \frac{[X]}{L_2} )</td>
</tr>
</tbody>
</table>
EN 1991-1-4: 2005

\[ s = Ke^{-\frac{x^2}{L^2}}, -1.5 \leq \frac{x}{L} \leq 1.0, 0 \leq \frac{z}{Lu} \leq 2.0 \]

\[ M_i = \begin{cases} 1, & \Phi_u < 0.05 \\ 1 + 2\Phi_u, & 0.05 \leq \Phi_u \leq 0.3 \\ 1 + 0.6\Phi_u, & \Phi_u > 0.3 \end{cases} \]

\[ B = 0.3542 \left( \frac{z}{Lu} \right)^{-1.0577} + 2.6465 \]

Take \( s = 0 \) unless the following conditions apply.

ISO 4354:2005

\[ \hat{M}_i = 1 + \frac{V_{ref}}{V_{10}} \phi \sigma(x, z), \hat{M}_i = 1 + \phi \sigma(x, z), s(x, z) = 1 - \frac{\sqrt{\frac{u}{0.75Lu}}}{\phi} \]

AIJ 2004

\[ M_i = (C_1 - 1) \left[ C_2 \left( \frac{z}{H} - C_3 \right) + 1 \right] \exp \left( -C_2 \left( \frac{z}{H} - C_3 \right) \right) + 1, \Delta S \geq 1 \] (for wind speed)

\[ E_i = \frac{E_1}{M_i} = (C_1 - 1) \left[ C_2 \left( \frac{z}{H} - C_3 \right) + 1 \right] \exp \left( -C_2 \left( \frac{z}{H} - C_3 \right) \right) + 1, E_i \geq 1 \] (for turbulence intensity), \( E_i \) is the topography factor for the standard deviation of fluctuating wind speed.

ASCE 7-10

\[ M_i = 1 + K_1 K_2 K_3, K_1 = 1 - \frac{|x|}{1.5L_1}, K_2 = e^{c|x|}, K_3 = 0.725 \Phi_u \] and 3 (for 2-D ridges or valleys), 0.425 \( \Phi_u \) and 2.5 (for 2-D escarpments), 0.5025 \( \Phi_u \) and 4 (for 3-D axi-symmetrical hills);

NBC 2005

\[ M_i = 1 + \Delta S_{max} \left( 1 - \frac{|x|}{1.5L_1} \right) e^{c|x|}, \Delta S_{max} = 1.1 \Phi_u \] and 3 (for 2-D ridges or valleys), 0.65 \( \Phi_u \) and 2.5 (for 2-D escarpments), 0.8 \( \Phi_u \) and 4 (for 3-D axi-symmetrical hills);

Note: 1) \( L_e \) is the effective length of upwind slope, for shallow upwind slopes 0.05 < \( \Phi_u < 0.3, L_e = L_u \); for steep upwind slopes \( \Phi_u > 0.3, L_e = H/0.3 \);

2) \( L_1 \) is length scale, to determine the vertical variation of \( \Delta S \), to be taken as the greater of 0.18 \( L_u \) or 0.4 \( H \);

3) \( L_2 \) is length scale, to determine the horizontal variation of \( \Delta S \), to be taken as 4 \( L_1 \) upwind for all types, and downwind for hills and ridges, or 10 \( L_1 \) downwind for escarpments;

4) \( C_1, C_2, C_3 \): parameters determining the topography factor, depend on the topography shape, inclination \( \Phi_u \) and distance (m) from the top of the topographic feature to the construction site. When the inclination is greater than 60 degrees, the topography factor is assumed to be the same as that at 60 degrees.

5) \( K_1 \): Factor to account for shape of topographic feature and maximum speed-up effect; \( K_2 \): Factor to account for reduction in speed-up with distance upwind or downwind of crest; \( K_3 \): Factor to account for reduction in speed-up with height above local terrain.

References


Canadian Commission on Building and Fire Codes. (2005), National building code of Canada (NBC), National Research Council of Canada, Ottawa, Canada.