Journal of Wind Engineering & Industrial Aerodynamics 178 (2018) 80–90

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Aerodynamic shape of transition curve for truncated mountainous terrain model in wind field simulation

Guoqing Huang [a,b,*], Xu Cheng [a], Liuliu Peng [b], Mingshui Li [a]

[a] School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China
[b] School of Civil Engineering, Chongqing University, Chongqing 400044, China

ARTICLE INFO

Keywords:
Transition curve
CFD simulation
Flow characteristics
Mountainous terrain
Deep-cutting valley
Wind tunnel contraction

ABSTRACT

For the wind-resistant design of infrastructures such as long-span bridges, transmission lines and wind turbines in the complex mountainous terrain, simulating the associated wind field is an important task. Due to the existence of many rolling mountains, the mountainous terrain model should be truncated at the proper distance from the site of bridge or other structures. The truncation will result in the sudden drop between the top edge of terrain model and the wind tunnel floor or the bottom of computational domain. This "artificial cliff" causes the flow separation and the unrealistic flow pattern. In order to minimize adverse effects caused by the "artificial cliff" and make the flow smooth, a transition section connecting the wind tunnel floor or the bottom of the numerical computational domain and the top terrain edge is necessary. Based on the wind tunnel contraction, a novel transition curve is proposed for modeling mountainous deep-cutting valley terrain in the wind tunnel test or numerical simulation. Firstly, a set of transition curves are derived from the wind tunnel contraction. Then, a novel curve derived from Witoszynski curve is determined by comparing flow characteristics of several transition curves using 2D Reynold-averaged Navier-Stokes (RANS) simulation. Finally, the applicability of the proposed curve in 3D wind field numerical simulation for a deep-cutting valley is verified based on field measurement data.

1. Introduction

The construction of infrastructures such as long-span bridges, transmission lines and wind turbines in the mountainous terrain are receiving great attention from many countries, especially in China. Typical long-span bridges include Daduhe bridge in Sichuan, China and Aizhai bridge in Hunan, China. On the other hand, numerous deep-cutting valleys with nearly vertical walls exist and their elevations may drop up to several hundred meters. Two typical valleys in Southwest China are shown in Fig. 1. The wind accelerates when wind flows along valley due to the channel effect, while the wind may be obstructed by mountain and the separation forms in wake flow if wind flows over valley. Clearly, wind loading and its distribution are different from those for homogeneous terrains such as plain and coastal areas, and even larger in some situations. Hence, it is of great importance to understand the characteristics of winds flowing over the complex mountainous terrain for the wind-resistant design of wind-sensitive structures such as long-span bridges in mountain areas.

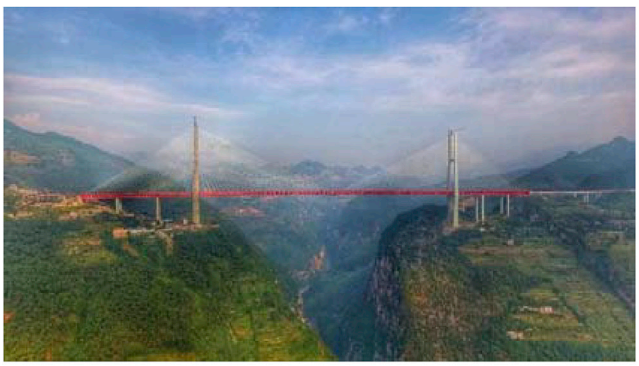
Based on the homogeneous terrain, current design code cannot be used directly for the determination of wind loading on structures built on complex terrains (e.g., Chock and Cochran, 2005; Li et al., 2010). In order to obtain wind field characteristics for complex terrains such as deep-cutting valley terrains, the field measurement can be used (e.g., Huang et al., 2015; Huang et al., 2016). Although this approach can provide the first-hand information about winds, it is costly and easy to be effected by environmental factors such as the weather, and also provides wind speed data on only limited points. Hence, other approaches including the wind tunnel test and numerical simulation are widely used in studying wind characteristics in mountain terrains.

Compared with field measurement, the wind tunnel test is easy for modeling and control, convenient in the change and repeat of the test conditions, and less affected by environmental factors. Thus, the wind tunnel test was used in the wind field simulation of the complex terrain decades ago (e.g., Meroney, 1980; Teunissen et al., 1987). In recent years, due to bridge constructions in mountain terrains, some researchers have simulated the large-scale complex terrain centered on the deep-cutting valley at bridge site by the wind tunnel test. Li et al. (2010) studied wind characteristics of a typical deep-cutting valley terrain with a diameter of 4 m in a scale of 1:500. They pointed out that mean wind speed profiles and vertical wind attack angles varied noticeably due to

* Corresponding author. School of Civil Engineering, Chongqing University, Chongqing 400044, China.
E-mail address: ghuang1001@gmail.com (G. Huang).

https://doi.org/10.1016/j.jweia.2018.05.008
Received 5 February 2018; Received in revised form 10 May 2018; Accepted 11 May 2018
Available online 21 May 2018

(a) Puli bridge site (Yunnan, China)



(b) Beipanjiang bridge site (Guizhou, China)

Fig. 1. Typical deep-cutting valleys.

the effects of the deep-cutting valley. Li et al. (2017) conducted a wind tunnel test on the deep-cutting valley terrain with a diameter of 15 m in a scale of 1:1000 at a bridge site. They found that the mountainous terrain resulted in a much larger vertical wind attack angle than the homogeneous terrain, which makes the wind resistant design of the bridge more difficult.

With rapid development of computer technology, the computational fluid dynamics (CFD) simulation has become a very useful method in wind field simulation on complex terrain due to its advantage in less cost and energy consumption, and providing the whole flow field characteristics. Castro et al. (2003) applied Reynold-averaged Navier-Stokes (RANS) method to wind field numerical simulation of Askervein hill. The comparison with field measurement shows that RANS method is reliable in the mean wind field. Paiva et al. (2009) completed the numerical simulation of atmospheric boundary layer flowing over isolated and vegetated hills based on RANS method. Numerical results indicated that vertical profiles of mean velocity and speedup were reasonable. Recently, the large-eddy simulation (LES) has been found to perform well in capturing turbulence characteristics (Chow and Street, 2009; Bechmann and Sørensen, 2010). However, the application of LES over real topography is not very common owing to the numerical challenges such as reproducing realistic upstream boundary conditions (Tabor and Baba-Ahmadi, 2010) and the setup of surface roughness (Cao et al., 2012). Furthermore, a significant challenge regarding LES simulation is the high computational cost due to the very dense grid needed. Hence, RANS method is still widely used in the study of the mean wind field characteristics (Prospathopoulos et al., 2012).

Although there exists rich literature in the study of wind characteristics of complex mountain terrains, few studies focus on modelling these terrains, especially mountainous deep-cutting valley terrains, in wind field simulation by the wind tunnel or numerical method. Due to the existence of many rolling mountains and limited size of wind tunnel or numerical computational domain, the deep-cutting valley terrain model should be truncated at the proper distance from the site of the bridge or other structures, which results in "artificial cliff" at the terrain-model edge as shown in Fig. 2. As mentioned previously, the mountainous deep-cutting valley may fall up to several hundred meters. Accordingly, "artificial cliff" between the top edge of the terrain model and the wind tunnel floor or bottom of the computational domain will form a large drop and cause the flow separation at the edge of the model, which may speed up the flow, change the vertical wind attack angle and produce the unrealistic flow pattern. In order to reduce variation in flow characteristics caused by "artificial cliff", a transition section connecting the wind tunnel floor or the bottom of the numerical computational domain and the top terrain edge is necessary. Hu et al. (2015) derived a theoretical curve based on the potential flow theory around a circular cylinder and compared the flow transition performance between the theoretical curve and traditional ramp transition in a wind tunnel. Results showed that the theoretical curve had a better flow transition performance. Li et al. (2017) applied this 2D theoretical curve to model the deep-cutting gorge terrain in the wind tunnel. Hu et al. (2018) revised this 2D theoretical curve and simplified its expression. Although the theoretical curve by Hu et al. (2015) has a better performance than the ramp, its derivation process does not take the air viscosity into account. Hence, the effectiveness of this curve in simulating wind field over the real terrain deserves further examination.

It is well known that the wind tunnel contraction has been successfully used to transition wind flow in wind tunnel tests. However, it has not been used to transition the flow from the bottom of the computation domain (or wind tunnel floor) to the truncated terrain edge in modeling the complex terrain. In this paper, a set of transition curves will be derived from the wind tunnel contraction, and an appropriate curve based on Witoszynski curve is proposed based on the detailed evaluation using RANS method. The proposed transition curve is applied to a deep-cutting valley to verify its effectiveness in 3D wind field simulation. Finally, some conclusions will be drawn.

2. Transition curve derived from wind tunnel contraction

When the appropriate transition section is used in modeling mountainous deep-cutting valley terrain, it should provide smooth flow transition without flow separation at the leading terrain-model edge. According to Hu et al. (2015), two criteria should be satisfied when designing a terrain transition section. Firstly, the main wind field characteristics (e.g., mean wind speed and vertical wind attack angle) should be consistent with those of the 'undisturbed' upstream wind profile. Secondly, the horizontal length of the transition section should be as short as possible. Obviously, the design of transition curve requires the compromise between these criteria.

Wind tunnel contraction curve can successfully transition the airflow in a wind tunnel. Inspired by this, the transition curve, starting from $S(0, 0)$ and ending at $E(L, H)$ in Fig. 3, can be derived from the contraction curve. The derivation is addressed in Appendix 1. Then bi-cubic transition curve (BCTC) can be obtained as

$$y = \begin{cases} H\dfrac{(x/L)^3}{(x_f/L)^2} & x \le x_f \\ H\left[1 - \dfrac{(1-x/L)^3}{(1-x_f/L)^2}\right] & x > x_f \end{cases} \tag{1}$$

where H is the height of transition curve, x_f is the horizontal distance of inflection point and is taken as 0.5 here, and L is the length of transition curve. Corresponding to Fig. A1, the ordinate of the curve at abscissa x in Fig. 3 is H_i-h and H is H_i -H_o. Note that the equivalent slope and angle are defined as $K = H/L$ and $\alpha = tan^{-1}(K)$.

Similarly, quantic transition curve (QTC) is given by