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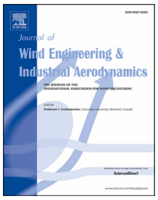

Multiscale simulation of wind field on a long-span bridge site in mountainous area

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ABSTRACT

A multiscale coupling strategy is proposed in the present study to numerically simulate the wind field at bridge sites in mountainous areas. This paper mainly focuses on resolving the difficulty of configuring reasonable inlet boundary conditions to achieve the required wind field. Firstly, the inlet boundary values of the mean wind velocity in the mountainous area were provided by the Weather Research and Forecasting (WRF) mesoscale model. Then, the local wind environmental flows over the mountainous area were computed by the large eddy simulation (LES) in such a way that the Block Polynomial Interpolation (BPI) method was employed to interpolate the data from WRF to the grids at the inlet boundary of the LES computation domain. This BPI method provided a better solution to the inlet boundary problems caused by the "artificial cliff". The inflow turbulence generating method was used for the input of the fluctuating wind speed at the inlet boundary, where the fluctuating wind field that satisfies the characteristics of the wind field in the mountainous area was simulated according to the data measured at the bridge site station by using the Weighted Amplitude Wave Superposition (WAWS) method. Finally, the proposed methodology was applied to the Lishui Bridge in China as a case study. The numerical predictions were found in good agreement with the monitored data, assuring the good capabilities of the proposed methodology and its potential uses in practical engineering. Meanwhile, the wind field from different wind directions was systematically studied and the characteristics for the detailed wind field distribution were analyzed. The presented methodology can be served as a reference to the refined simulation for the fluctuating wind field in mountainous areas.

1. Introduction

Compared with plain or marine areas, mountain gorges with undulating terrains and diverse landscapes are more geographically complicated. As wind flows over mountain gorge terrains, it is obstructed and deflected by the mountains such that flow separation usually occurs downwind along the mountains. Moreover, the wind flow can accelerate or decelerate as it moves through gorges. Therefore, wind characteristics over mountain gorge terrains are extremely complicated. Many researchers (Bitsuamlak et al., 2004; Blocken et al., 2007; Burlando et al., 2013; Hui et al., 2009; Kim et al., 2000; Li et al., 2010; Tamura et al., 2007; Wakes et al., 2010; Xu et al., 2013) have investigated the wind characteristics over complex terrains and presented many important observations for wind engineering applications. With the rapid development of economy, a growing number of long-span bridges in the mountain gorge terrains of China have emerged, including the Siduhe Great Bridge in Hubei province, the Lishui Bridge, and the Aizhai Bridge in Hunan province, China. If these bridges were designed according to the current design standards and codes based on the flat and uniform terrains, the resulted predictions of wind-induced responses would lead to significant errors (Chock and Cochran, 2005; Li et al., 2011). Therefore, it is highly necessary, theoretically and practically, to carry out elaborated studies on the wind field in mountain gorge terrains.

Computational fluid dynamics (CFD) simulations and wind tunnel experiments are two typical methods that are used to predict the wind field in mountain gorge terrains. However, the terrain domain, either analyzed or tested, is always limited and its range is generally extended from the bridge site to an appropriate distance. As a result, a sudden

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Table 1
Discretization schemes and solution technique.

Parameter	Type
Time discretization	Second order implicit
Pressure discretization	Second order upwind
Momentum discretization	Bounded central difference
Pressure-velocity coupling	Pressure-implicit with splitting operators (PISO)
Under relaxation factors	1.3 for the pressure and 0.7 for the momentum

Table 2
Information of the five-layer nested grids.

Domain	Grid Number	Grid size(km)	Domain Size(km)	Time Step(s)	Layer Number
1	50	40.5	2025 km*2025 km	243	50
2	91	13.5	1228.5 km*1228.5 km	81	50
3	161	4.5	724.5 km*724.5 km	27	50
4	181	1.5	271.5 km*271.5 km	9	50
5	101	0.5	50 km*50 km	3	50

elevation jump between the boundary top of the terrain model and the floor of the wind tunnel or the bottom surface of the numerical computation domain is expected. When the wind flows over such a model, flow obstruction and separation will occur over the edge of the terrain model, which will produce an unrealistic flow field and significant errors. Therefore, ensuring reasonable inlet boundary conditions is the key to studying the wind environment in mountain gorge terrains and this has a great impact on the results in both the wind tunnel tests and numerical simulations.

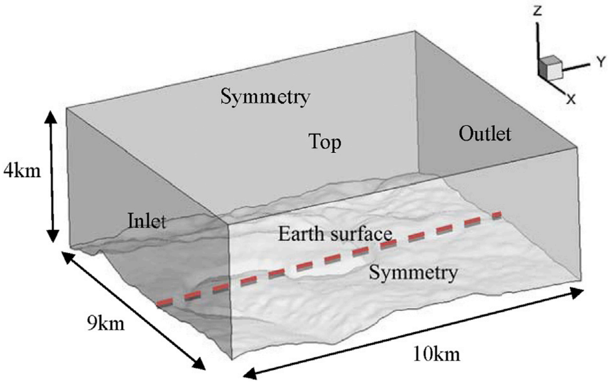


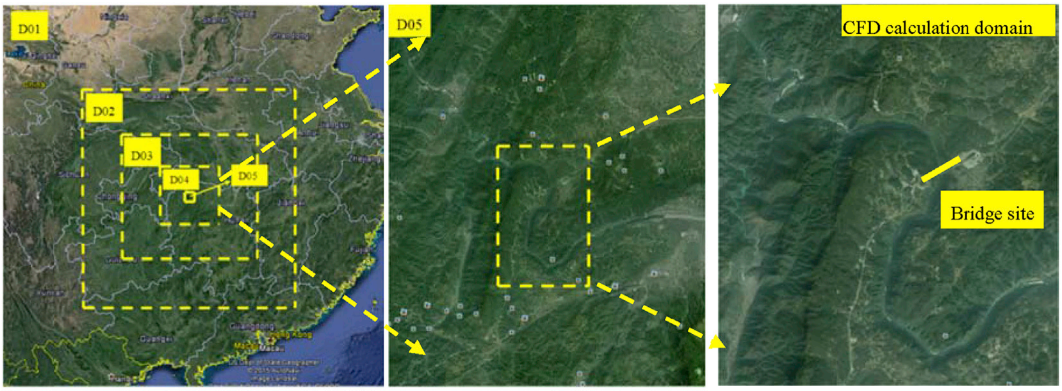
Fig. 2. Computation domain for the LES.

More specifically, both the appropriate mean wind speed and turbulent components should be ensured at the inlet boundary. For the mean wind speed, the process of setting the boundary conditions is usually simplified in both the wind tunnel tests and numerical simulations. For example, a transient section is usually adopted to develop the required model boundary after the air flow passes through the transient section (Hu et al., 2015, 2016; Maurizi et al., 1998; Meroney, 1980). Although the transition section helps generate a more realistic wind field in these complex terrains, they may result in artificial wind attack angles at the edges of the terrain model. Li et al. (2010) employed the exponential wind profile as the inlet velocity boundary to carry out a numerical investigation on the spatial distribution characteristics of the wind field for a deep gorge bridge; however, it has strong dependence on experience to give the appropriate inlet boundary conditions. With the rapid development of meteorological forecast models, the coupling method of the weather forecast model(a mesoscale model) and the CFD model(a microscale model) has been widely used. Ehrhard et al. (2000) simulated microscale wind fields in an industrial area in Germany using a CFD model and a mesoscale model. The results showed that the coupled model is capable of simulating the microscale wind field through the comparison between the measured and simulated wind speeds and directions at many locations. Baik et al. (2009) coupled the mesoscale with RANS model and studied the atmospheric flow and pollutant dispersion in Seoul. Xie and Castro (2009) pointed out that the coupling of LES and mesoscale meteorological model is the development direction for the numerical simulations regarding the urban neighborhood. Liu et al. (2012) coupled the Weather Research and Forecasting (WRF) model with LES and made a multiscale analysis of the traffic pollution in a neighborhood of Beijing with good results. Although WRF has been successfully used in the wind resource analysis (Carvalho et al., 2013), urban neighborhood pollution dispersion (Wyszogrodzki et al., 2012), and so on, there are rare such studies for the wind fields on the sites of long-span bridges located in mountainous gorge terrains.

It is noted that the above coupled method cannot provide the required wind turbulence at the inlet boundary since WRF can only obtain the wind speed data with the mesh precision of several hundred meters and the time interval of minutes. However, fluctuating characteristics of wind play a crucial role in studying the wind-induced vibration of bridges in

Table 3
Boundary conditions.

Location	Type
Inlet	User-defined
Side surface	Symmetric
Top surface	Free slip
Bottom surface	No slip
Outlet	Pressure-outlet



(a) Five nested domains (b) Innermost domain (c) LES calculation domain

Fig. 1. WRF computation domain.