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Effect of Wind barrier on Wind Environment above Parallel Girders

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Abstract

Wind barrier erected on bridge girders can reduce the crosswind speed in order to create a safe driving environment on bridge deck. Generally, wind barrier are installed on both sides of girder to block the wind from both sides. However, due to economic reasons, for parallel girders, it is worth discussing whether or not wind barrier need to be installed on both sides of each girder. In this study, the computational fluid dynamics(CFD) models of both single girder and parallel girders with different gap widths are established. Based on the established CFD models, the effect of wind barrier on single girder is studied, furthermore, the effect of wind barrier on parallel girders with different gap widths is investigated. The results show that, for single girder, wind barrier set on the downstream side is useless for reducing the crosswind speed above deck., while, for parallel girders, it is advisable to install wind barrier on both sides of each girders when the gap width is larger than the width of single girder.

Keywords: Wind barrier, parallel girders, LES, wind environment

Introduction

The effect of crosswind on ground vehicles has become a research topic due to its importance in regard to vehicle safety [6]. The lateral aerodynamic force on moving vehicles could cause vehicles to deviate from their original path or even to rollover [2,4]. As an effective countermeasure, the wind barrier has been widely used to reduce the crosswind effect on bridges [5]. By adding wind barriers, most vehicles passing by the bridges could be protected from lateral wind-induced instabilities [3,7,8].

While most studies are focused on single girder, the wind barrier installation strategy on parallel girders deserves more attentions. If a pair of parallel girders are regarded as two single girders and wind barrier are installed on both sides of each girder, it is not economical. If wind barrier are only installed on the outside of the two parallel girders, the safety of vehicles on bridge could not be ensured if width of the gap width between the parallel girders is too far.

In this study, the computational fluid dynamics(CFD) models of both single girder and parallel girders with different gap widths are established. Based on these models, a series of parametric analysis about parallel girders gap width is carried out. The critical value ofgap width for decision making of wind barrier installation is found which could be a reference for wind barrier design of the similar bridges in the future.

Numerical model and computational domain

The mathematical model of flow field must obey the governing equations based on the mass conservation law and momentum conservation law. Generally, wind speed is generally less than 200km/h and the corresponding Mach number is less than 0.3, so the flow field around girders can be approximated by the incompressible flow field. In this study, a three-dimensional Large Eddy Simulation (LES) model was used to simulate the velocity field around bridges, as seen in equation (1) and equation (2).

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial \overline{\rho u_i}}{\partial t} + \frac{\partial \overline{\rho u_i u_j}}{\partial x_j} = -\frac{\partial \overline{P}}{\partial x_i} + \rho g \delta_i + \frac{\partial}{\partial x_j}[\mu_{eff}(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i})] + f_d \tag{2}$$

where the subscripts i, j=1,2,3 represent x, y, z directions, respectively, t is the time, u and P are grid filtered velocity and pressure , respectively.

In this paper, the geometric boundary of the girders is simplified, neglecting the influence of maintenance car tracks and water pipes under the flange slabs. As to the wind barrier, smooth its surface, neglect the details of anchoring parts and its vibration to reduce the computational burden. These simplifications do not have large effects on calculating the wind speed field around girders.

The computational domain is shown in Figure 1. The larger the computational domain is, the more realistic the simulation result will be. However, due to the limitation of computation capability, an appropriate computing domain must be selected to improve the computation efficiency. In this study, the whole calculated domain is $200m \times 140m \times 20m$. The study is aimed at four-lane girder with a width of 17 meters and a height of 3.6 meters. This study first focus on single girders, wind barrier layout on single girder is shown in Figure 2. And then for parallel girders, a series of parallel girder with different gap widths were established, as shown in Figure 3. The distance is from 1m to 136m.

The ICEM-CFD software is used to mesh the model in this research. Tetrahedral girds are used for better fit the surface of girders and wind barrier. While where far from the girders and wind barrier is occupied with hybrid girds to reduce gird number. Finally, total number of grids is between 1.5 million and 2 million.

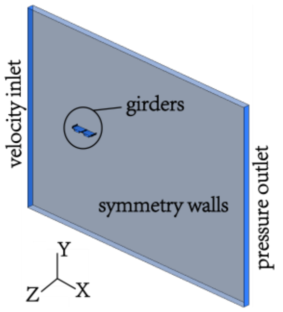
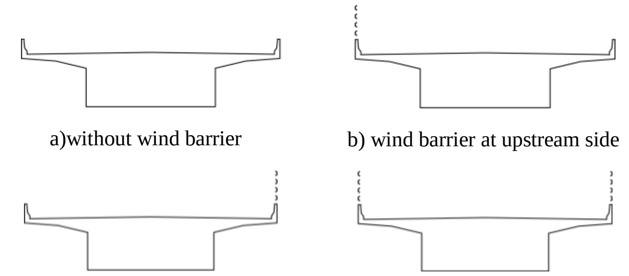


Figure 1 computational domain and boundary conditions



a)without wind barrier b) wind barrier at upstream side

c) wind barrier at downstream side d) wind barrier at both sides

Figure 2 wind barrier layout on girder

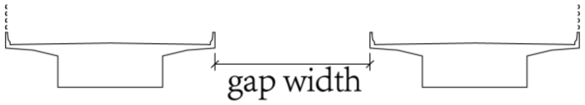


Figure 3 wind barrier layout on parallel girders

Numerical simulation verification

Wind tunnel velocity tests had been carried by Li to investigate the wind barrier performance on bridge [1]. Their research provides a reference to verify our numerical simulation. The section is shown in Figure 4 and the height of the barrier is 3m. The distribution of ratio of wind velocity at the lane shown in Figure 5 is from the wind tunnel test by Li and the CFD method by us. The same method is used to build the CFD model there to verify the validity of the method. From Figure 5, result from CFD method accords with that from tunnel test which affirms the validity of the CFD method.

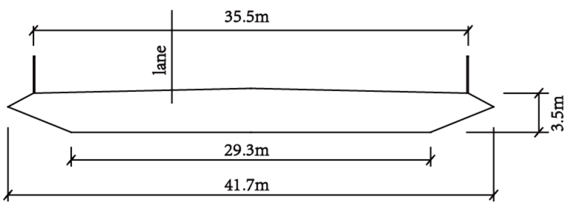


Figure 4 cross section of girder

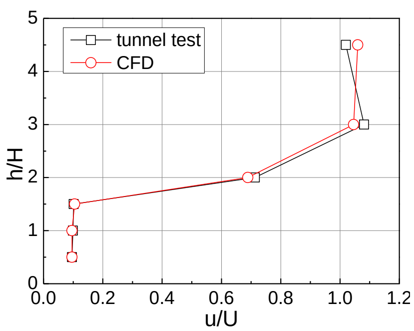


Figure 5 distribution of ratio of wind velocity

Results and discussion

Without wind barrier, wind environment on girder is shown in Figure 6 (incoming wind speed is 10m/s). As the upstream anti-collision wall blocking the wind flow, wind speed behind the upstream anti-collision wall is low, and strong vortex is created before the downstream anti-collision wall. Crosswind speed profiles on four lanes(from upstream side to downstream side) is shown in Figure 7. It can be found that wind speed at 2.5 meters above 1st lane can reach 8m/s (80% of the incoming wind speed) and wind speed at 3 meters above 1st lane is even faster than incoming wind speed. At present, the height of many trucks can be more than 3 meters, so it is necessary to install wind barrier on girder to reducing the crosswind speed above the deck.

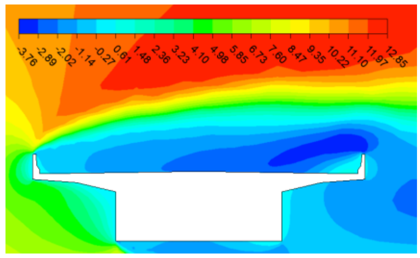


Figure 6 wind field on girder

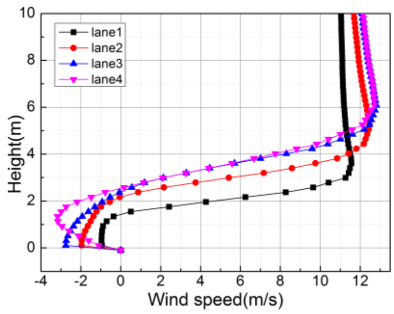
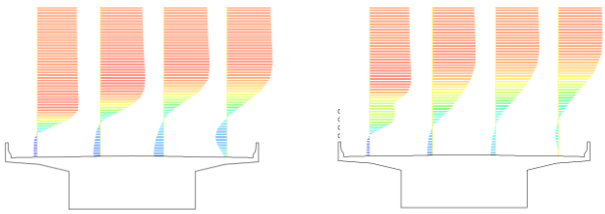
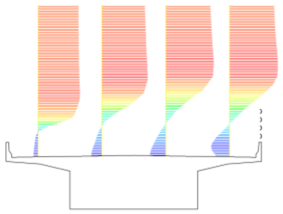


Figure 7 wind speed profile above each lanes

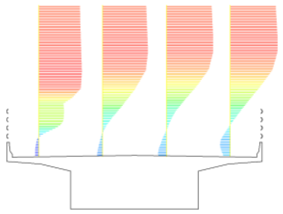
Crosswind speed profile on four lanes with different wind barrier layouts is shown in Figure 8. Compared Figure 8(a) with Figure 8(b), it can be seen that the upstream wind barrier reduces the wind speed at the same height above the level of anti-collision wall top.. Compared Figure 8(a) with Figure 8(c), it shows that the wind barrier installed on the downstream side has no beneficial influence on wind environment, and even lead to a more intense vortex, which deteriorated wind environment on the most downstream lane. Compared Figure 8(b) with Figure 8(d), in the case of a wind barrier on the upstream side, the installation of a wind barrier on the downstream side has no beneficial effect on wind environment above the deck. However, considering the changeable wind direction, wind barrier are often installed on both sides of the girder.



a) without wind barrier b) wind barrier at upstream side



c) wind barrier at downstream side



d) wind barrier at both sides

Figure 8 wind speed profile on each lanes

In order to quantitatively evaluate the wind environment of each lane, this study adopts the wind environmental reduction coefficient λ_s to evaluate the effect of wind barrier on wind environment above the deck [9]. Actually, the wind environment reduction coefficient is the ratio between wind speed square average in a certain height range and the incoming wind speed. The smaller the ratio is, the safer the wind environment will be. λ_s is defined by equation (3).

$$\lambda_s = \sqrt{(1/Z_r)\int_0^{Z_r} u^2(z)dz} / U_\infty \qquad (3)$$

In equation (3), Z_r is the calculating range of λ_s. Here Z_r equals 4m because most of the vehicle height is less than 4 meters. u is local wind speed on girder, U_∞ is the wind speed far from girder.

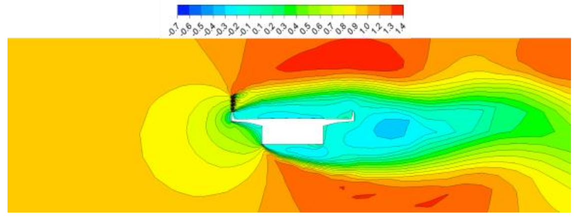
λ_s of each lane in Figure 8 is shown in Table 1. It can be seen that the wind barrier on upstream side has beneficial effect on wind environment. The installation of wind barrier on the downstream side alone not only do not improve wind environment on girder, but also deteriorate wind environment of the downstream lane due to the vortex caused by the obstruction of the downstream wind barrier.

Layout type	lane1	lane2	lane3	lane4
Figure 8(a)	0.84	0.72	0.58	0.56
Figure 8(b)	0.70	0.55	0.44	0.35
Figure 8(c)	0.83	0.70	0.61	0.66
Figure 8(d)	0.70	0.54	0.45	0.47

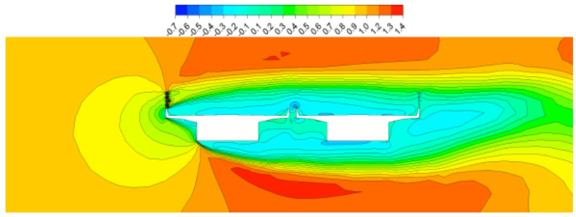
Table 1 λ_s at different lanes with different wind barrier layouts

Therefore, if the distance between parallel girders is too far, only install wind barrier on outside of parallel girders is not enough for driving safety in strong wind. In this case, installation of wind barrier at inner side of parallel girders should be taken into consideration. In this study, the gap width between parallel girders (as shown in Figure 3) is taken for parameter analysis.

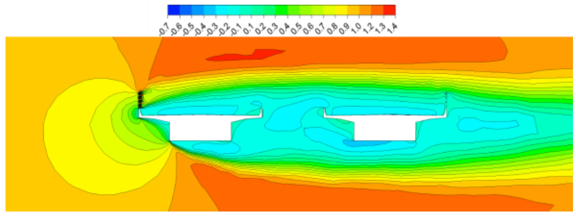
Figure 9 shows the ratio of local wind speed and incoming wind speed around single girder and parallel girders. Similar to the single girder, wind flow around parallel girder with 1m and 0.5 time girder width gap smoothly. When the gap width increases to 1 times the girder width, the downstream side girder starts to be affected by the unstable wake created by upstream girder. However, due to the closer of parallel girders, the wake created by upstream girder develops insufficiently. With continues increasing of gap width, the wind field around the upstream girder becomes similar to that of the single girder, and the downstream girder enters the full development zone of the wake created by upstream girder. Due to the disturbing of the wake, vortex begins to appear on the deck of downstream girder. Take Figure 9(f) for example, the backflow speed can reach 47% of the incoming wind speed above the deck and the wind speed at 4m above deck can reaches 90% of the incoming wind speed. At this time, the wind environment on deck becomes very disadvantageous.



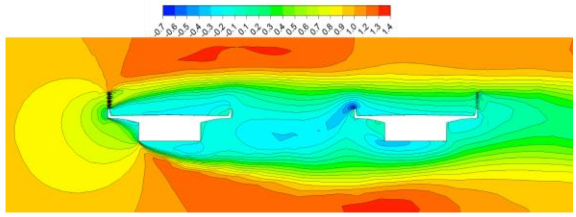
a)single girder



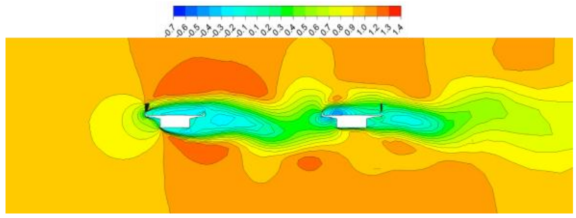
b) Gap width of 1m



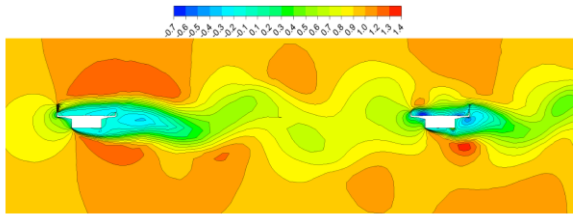
c) Gap width of half girder width



d) Gap width of one time girder width



e) Gap width of two times of girder width



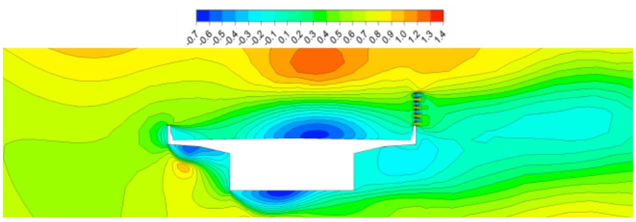
f) Gap width of four times of girder width

Figure 9 wind speed field around girders

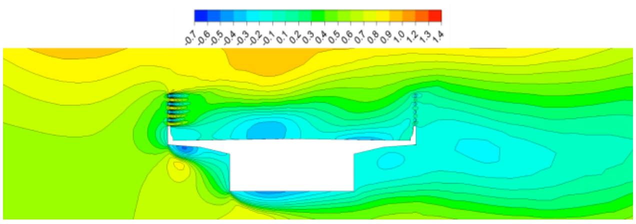
Wind environment reduction factor λ_s of the girder at downstream side is shown in table 2. Due to the blocking effect of the upstream girder, the value in table 2 is significantly smaller than that of single girder with wind barrier only installed at downstream side. However, when the parallel girder gap width reaches twice the girder width (34 m), strong backflow may appear on the deck surface of overtaking lane and at 3m above this lane, wind speed could reach 86% of the incoming wind speed. These two reverse direction winds may cause the vehicle rollover in this lane. So when the parallel girder gap width reaches a certain value, more wind barrier should be installed at the inner side of parallel girders. Take parallel girders with 51m gap width for example, after installing wind barrier at inner sides of parallel girders, the improvement of wind environment above downstream girder is shown in Figure 10. It can be seen that the backflow on bridge deck is obviously reduced after the installation of the wind barrier, so the wind environment of the deck is improved. In table 2, it is noted that when the parallel girder gap width increases from 1.5 to 2 times of the girder width, the value of λ_s adds a lot, so this study suggests that when the parallel girder gap width is more than 2 times the girder width, wind barrier installed on inner sides should be considered.

Distance(m)	Maximum
1	0.55
8.5	0.57
17	0.55
25.5	0.60
34	0.67
51	0.66
85	0.72
110.5	0.70
136	0.68

Table 2 Maximum λ_s at downstream girder



a)wind barrier at downstream side



b) wind barrier at both sides

Figure 10 wind speed around downstream girder(gap width of 51m)

Conclusions

In this study, the computational fluid dynamics(CFD) model was used to study the wind environment above parallel girders. It is found that the installation of wind barrier on the downstream side of single girder has no effect on the improvement of wind environment. Therefore, if the parallel girder gap width is too far, the downstream girder lost the protection of upstream girder, wind barrier installed on inner sides should be considered.

By parameter analysis about parallel girder gap width, it is found that if the gap width exceeds 2 times the girder width, the downstream girder will be located in the sufficient development zone of the wake caused by upstream girder, which will cause the appearance of serious vortex and high local wind speed above the deck. Based on various factors, this study suggests that if the gap width of the parallel girders exceeds 2 times the girder width, more wind barrier should be installed along inner sides of parallel girders.

Acknowledgments

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