EFFECTS OF WIND BARRIER ON THE VEHICLE PASSING IN THE WAKE OF BRIDE TOWER

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1. INTRODUCTION In a strong wind condition, a vehicle running on a suspension bridge may suffer from a sudden change of wind forces acting on the vehicle when it is passing behind a bridge tower. This causes an inconvenience in driving control which may results in miss-steering or accident. The reduction of cross wind-induced problems for the vehicle is therefore currently considered. The wind forces reduction using wind barrier has been applied in some major bridges, for example, the Severn bridge in U.K. and the Ohnaruto bridge in Japan. However, quantitative prediction of the effects of the wind barrier on the driving performance is still difficult[1] because the prediction of the aerodynamic forces acting on the vehicle passing behind the tower is still not well established. In this study, the effects of the wind barrier are studied and the comparison of the aerodynamic forces and the vehicle responses between cases with and without wind barrier are presented.

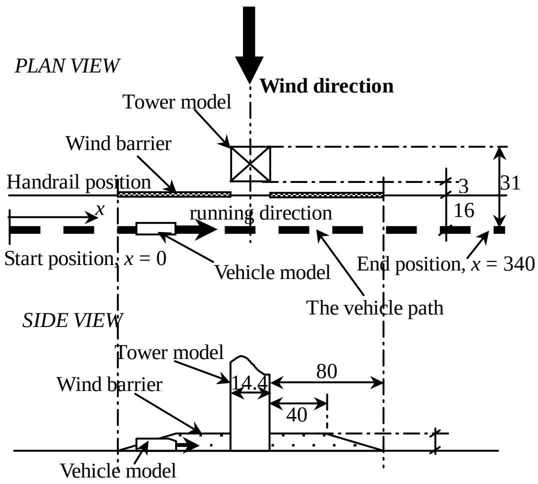

Fig.1 Experimental configuration, cm

2. WIND TUNNEL EXPERIMENT The wind tunnel experiment (test section width: 16 m; height: 1.8 m) was conducted to measure the aerodynamic forces acting on the vehicle. The box shape model (width: 6.4 cm, height: 5.6 cm, length: 16 cm, 1:30 model scale) that is thought to be a simplified vehicle model is used in this study. The experiment was also conducted for various wind directions and types of tower. However, only the results obtained from the case of rectangular tower and the wind direction normal to the bridge axis are presented. The tower was placed in the middle of the vehicle path which has the total length of 3.4 m. The wind barrier with 50% solidity was placed on the windward side of the vehicle path at the location assumed as a bridge handrail on both sides of tower as shown in Fig.1. The operating wind speed in the wind tunnel was set at 10 m/s, while the vehicle speed was set at 3 m/s.

3. EXPERIMENTAL RESUTLS AND PREDICTION The experimental results of the aerodynamic forces acting on the vehicle passing behind the tower[2] are shown in comparison between the cases with and without wind barrier in Fig.2. The presented results are non-dimensional value obtained from the actual aerodynamic forces normalized by using following equations,

$$Cs = \frac{F}{\frac{1}{2}\rho(U^2+V^2)A}, \quad Cm = \frac{M}{\frac{1}{2}\rho(U^2+V^2)Al}$$

where F is the aerodynamic side force acting on the vehicle, M is the aerodynamic yawing moment, A is the total side area of the model, ρ is the air density, l is the wheelbase of the vehicle (9.6 cm), U is the wind velocity used in the experiment and V is the vehicle velocity. It can be seen that both side force and yawing moment acting on the vehicle were much reduced close to zero for the case when the wind barrier was installed. And the sudden change of the aerodynamic forces acting on the vehicle at locations behind the tower became more gradual.

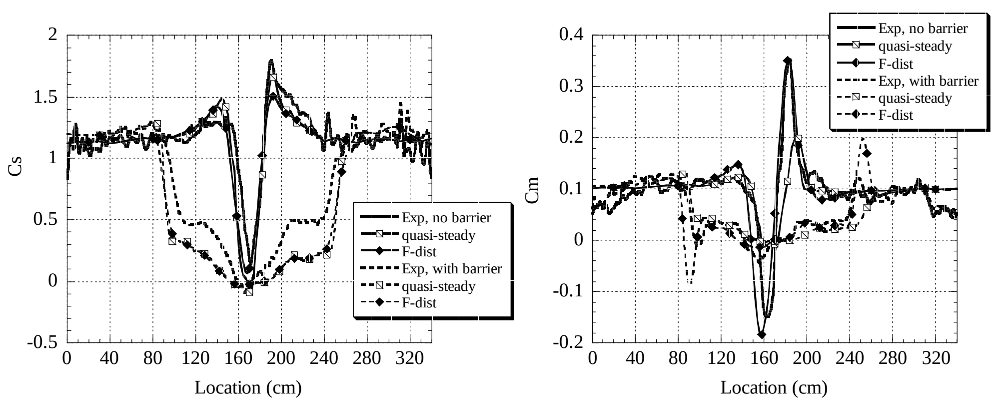

Fig.2 Experimental and prediction results of the aerodynamic forces acting on the running vehicle

In the figure, the predicted aerodynamic forces are also presented. Basically, the aerodynamic forces were computed using the quasi-steady theory based on the wind information, wind speed and direction, acting at the center of gravity of the model. However, due to the sudden change of wind forces at locations behind the tower, using the wind information acting only at the center of gravity of the model is not enough to provide a good prediction of the aerodynamic forces acting on the vehicle at those locations. For side force, the prediction by quasi-steady agreed generally well with the experimental results. But for the yawing moment, because the change of wind velocity was

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significant, the quasi-steady method cannot reproduce the moment peaks due to wind non-uniformity at locations behind the tower as can be obviously seen from the prediction results for the case without wind barrier. For the case with wind barrier, since the change of wind forces became more moderate, the effect of wind non-uniformity decreased which resulted in more or less good prediction by using quasi-steady theory.

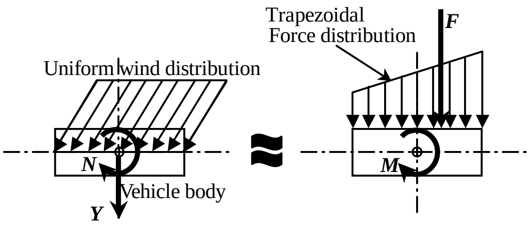

Fig.3 Force-distribution prediction method

In order to improve the prediction accuracy, the effect of wind non-uniformity has to be considered. In this study, the prediction of the aerodynamic forces considering the wind non-uniformity called "Force-distribution method" is proposed. The prediction considers the different contribution of side force acting on vehicle at each location along vehicle body depending on relative wind direction and vehicle properties on side force and yawing moment coefficients. The contribution of side force along the vehicle body is assumed to have a trapezoidal distribution which is a function of the relative wind direction and location along the vehicle body. By assuming the trapezoidal distribution, only one pattern of force distribution can be obtained for any relative wind direction as shown in Fig.3. In the figure, it shows the situation of uniform wind acting on the vehicle. For the case of non-uniform wind, by considering the force distribution in the same way for each wind component, the distribution at each location along the vehicle body can be obtained. And the total aerodynamic side force is the integrated area of the force distribution over all vehicle body, while the yawing moment is the total moment area of the distribution with respect to the location of the center of gravity of the vehicle. It can be seen that the prediction using force distribution method on the side force component still gave more or less good prediction, while for the yawing moment, the agreement with the experimental results was much improved.

4. VEHICLE RESPONSES SIMULATION The effect of the wind barrier on the driving performance is studied via simulation. In the simulation, the vehicle suspension characteristics are neglected and the steering correction by the driver is not considered since there is no driver model that is applicable to the problem concerned in this study[3]. With this "fix-steering" simulation, the response side displacement and yaw angle were found to depend largely with the starting point of the simulation, in other words, it was too sensitive with external disturbance, therefore, response side acceleration, yaw angular speed and yaw angular acceleration were used for the comparison. The simulation was performed for the real scale of vehicle. The increment responses when the vehicle is passing in the wake of bridge tower are considered. Based on the scale experiment shown in Fig.1, the location of tower in the simulation is x = 51 m, and the simulation range for the case without wind barrier is from x = 30 m to x = 70 m, while for the case with wind barrier, the simulation range is from x = 15 m to x = 90 m.

The simulation results are presented in comparison in Fig.4. It can be seen that, without wind barrier, all vehicle responses suddenly change when it is passing behind the tower. But if the wind barrier is applied, the responses at locations behind the tower become to change moderately. Note that, a sudden change of responses at locations around both sides at the end of the wind barrier can be observed. This might be caused by an inappropriate design of the wind barrier that the increase in wind barrier height from the end to the constant height was too steep. These locations are not considered as a problem in this study.

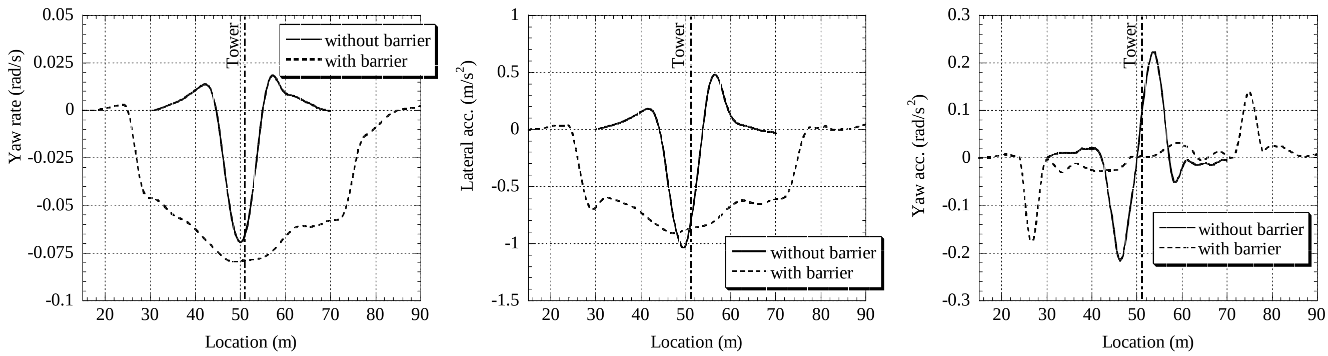

Fig.4 Vehicle simulation responses

5. CONCLUSIONS This paper has shown the experimental and prediction results of the aerodynamic forces acting on the running vehicle behind the tower with wind barrier. Because of the wind non-uniformity, the quasi-steady theory does not provide good prediction to the experimental results. To obtain better approximation, the wind non-uniformity has to be considered. And the proposed "Force distribution method" is found to give qualitatively better prediction than the quasi-steady method. The wind barrier is found to reduce effectively the wind forces acting on the vehicle, and also the vehicle responses. Especially for acceleration component which may largely affect the human response, the vehicle responses are much decreased and change moderately when the wind barrier is applied.

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