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Assessment of Lateral Driving Stability of Automobiles Passing by the Pylon Zone under Cross Wind

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Abstract: In order to explore the reason of lateral instability of automobile passing by the pylon zone of cable-supported bridge under cross wind, a new evaluation method of lateral driving stability of automobile considering alternative cross wind is established based on multi-objective driving stability criteria and subjective assessment. Typical driving control process and dynamic response of automobile passing by the pylon zone is given by numerical simulation based on steering wheel fixed-control model and straight driving ideal-driver model. Finally, taking a medium-size commercial bus as an example, the reason of its lateral instability is interpreted and the influence of cross wind speed and driving speed on its lateral driving stability is shown by parameter study.

Keywords: Assessment, automobile, cross wind, lateral driving stability, pylon

INTRODUCTION

Local wind environment above deck in the pylon zone of cable-supported bridge is complicated since the typical three-dimensional characters of the flow fluid around the girder and the pylon columns (Wang *et al.*, 2005). Alternating crosswind in the vicinity of the pylon will induced bad control stability of the passing vehicles under strong wind, which likely leads to lateral instability of vehicles, such as lateral offset, yaw motion and even lateral overturning (Wang, 2010). Evaluation of lateral driving stability of vehicles is mainly described by both objective and subjective aspects. Objective evaluation is given by some key motion parameters of vehicle compared with the relative control criteria, including lateral deviation, lateral accelerate and yaw rate etc., Subjective evaluation depends on the whole feeling of the driver in process of vehicle driving.

For analysis of wind-induced lateral offset of vehicle, multi-parameters dynamic response model of vehicle should be used, which is further distinguished into closed system and opened system according to considering driving reflection of driver or not. Some investigation of aerodynamic characteristics of vehicles passing by the pylon zone through wind tunnel tests and numerical simulation of Computational Fluid Dynamics are carried out (Charuvisit *et al.*, 2004; Wang *et al.*, 2011; Argentini *et al.*, 2011). However lateral stability of vehicle passing the pylon zone under crosswind is less presented. The single vehicle is simplified into two degrees of freedom of lateral and yaw, simulates the response of vehicle passing by the pylon zone in crosswind based on fix-steering control model and driver control model (Charuvisit *et al.*, 2004). However the final evaluation of lateral stability of vehicle isn't given combined with control indexes of lateral accelerate, yaw rate and yaw angular acceleration and it is found out that the driver control model system is difficult to reproduce adequate response characteristics of vehicle because of the driver parameters sensitivity.

In this study, evaluation method of lateral driving stability of automobile under cross wind is established, according to alternating crosswind induced lateral instability of automobiles such as lateral offset, yaw motion and lateral overturning. First, multi-objective driving stability criteria is given in order to definite the three types of lateral instability accidents mentioned above, some key dynamic response parameters of vehicle is obtained, including lateral acceleration, lateral derivation and yaw rate etc., through dynamic response analysis of vehicle under crosswind based on steering wheel fixed-control model and straight driving ideal-driver model. The final evaluation includes two parts, one part is subjective assessment about the behaviors of straight driving vehicle passing by the pylon zone under control of ideal-driver and the other is objective comparison between the above response parameters of vehicle and its control criteria of lateral driving stability. Taking this method, numerical simulation and parameter analysis of lateral driving stability of a medium-size commercial bus encountered the alternating crosswind in the pylon zone is investigated. The influence of wind speed and driving speed on its lateral driving stability is evaluated and the reason for its lateral instability is discussed.

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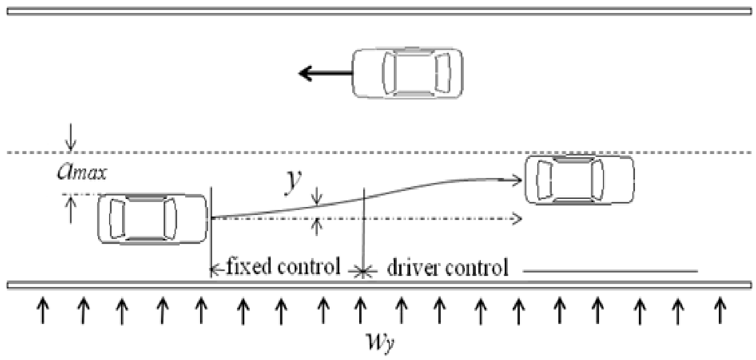


Fig. 1: Driving lateral offset of vehicle under cross wind

METHODOLOGY

Multi-objective driving stability criteria: According to the possible lateral instability accidents of vehicle under strong side wind, such as lateral offset, yaw motion and lateral overturning, multi-objective driving stability criteria is established specially based on the indexes of lateral derivation, yaw rate and lateral acceleration. The multi-objective driving stability criteria will be presented in detail as follows.

Lateral offset criterion: The reasonable driving process of vehicle under cross wind is separated two stages of fixed control and driver control, seen Fig. 1. In the first stage, vehicle reflects no feedback of driver instruction, namely steering wheel doesn't respond, so-called fixed control. For the second stage, vehicle begins to respond to the driver's instructions and then controlled by the driver. For the vehicle affected by sudden crosswind, it can be found from tests that the fixed control stage is at least 0.8 s.

It is assumed that the original route is in the drive centerline, the danger level increases with vehicle closer to adjacent lane. The accident risk sharply increases when the vehicle approaches drive edge. The risk index f_G is described as follows (Zumthor, 1992):

$$f_G = \sqrt{1/(1-Y)-1} \tag{1}$$

where, $Y = 2y/a_{max}$ in which y is lateral derivation from original route, a_{max} is the maximum distance between vehicle edge and drive edge. Commonly, it is considered that a vehicle lost its driving stability when f_G exceed 3, since that if the corresponding Y is more than 0.9 the risk index f_G increases rapidly. In sum, lateral offset criterion can be established based on Eq. (1) and in which the lateral derivation after 0.8s should be adopted through dynamic response analysis of steering wheel fixed control model.

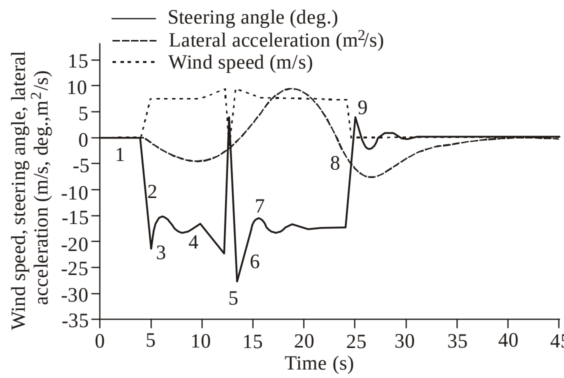


Fig. 2: Alternating cross wind speed time history acting on vehicle, the relative ideal-driver steering angle input time history and its lateral acceleration response

Lateral overturning criterion: Vehicle lateral overturning refers to vehicles in motion turning around its longitudinal axis with the angle of 90º or greater and it can be clarified into several types. In this study, lateral overturning of vehicle in curve motion is mentioned, which occurs when lateral accelerate exceeds the limitation value. The simplified formula of the lateral accelerate limitation value a_y is given as Eq. (2) (Gao, 2004):

$$a_y/g = B/2h_g + \alpha \tag{2}$$

where, B is wheel spacing, h_g is height of mass center, α is road cross slope, g is acceleration of gravity.

Yaw motion criterion: According to analysis of drive stability, sudden cross wind similar to alternating cross wind in the pylon zone maybe induce yaw motion of vehicle. It can be seen that yaw rate no more than 3 degrees per sec is a useful assessment index for vehicle yaw motion (Zumthor, 1992).

Typical process of vehicle passing by the pylon zone: Taking a medium-size commercial bus encountered the alternating crosswind in the pylon zone as an example, its lateral driving stability keeping straight driving is investigated with ideal-driver model. For the alternating cross wind speed given in Fig. 2, the wind speed amplified in the pylon zone is considered based on the results of wind environment of a real bridge and constant and zero wind speed are also given in wind speed time history acting on vehicle due to the situation of sudden cross wind far away from the pylon zone.

The main steps of the dynamic response analysis of vehicle controlled by ideal-driver passing by the pylon zone are introduced as follows. First, steering angle input of ideal-driver of vehicle keeping straight driving under alternating cross wind is obtained based on straight driving ideal-driver model, given in Fig. 2. And then, taking the above steering angle into ideal-driver curve driving cross wind model, giving wind speed and road curvature as zero, lateral acceleration time history is acquired, seen in Fig. 2. The above analysis describes the bus passing a pylon zone with driving speed of 100 km/h under a sudden cross wind outside of the deck with wind speed of 7.5 m/s.

Through comparison of alternating cross wind speed, the relative ideal-driver steering angle and its lateral acceleration response, the main conclusion are given as follows.

- For the stage of wind speed from zero to a constant (including 1, 2 and 3), ideal-driver should turn the steering wheel windward and continue to increase the steering angle to peak value at the point of wind speed reaching its maximum. And then, in the stage of constant wind speed, ideal-driver steering angle should be stabled at a certain lower level.
- For the sharp changing stage (including 4, 5 and 6), wind speed is suddenly simplified when vehicle drives adjacently to the pylon, ideal-driver should rapidly turn the steering wheel windward to a larger level. When vehicle just runs into the pylon zone with lower wind speed, ideal driver should turn the steering wheel to opposite direction back to a positive angle as soon as possible. However when vehicle just runs away from the pylon zone, because of a sudden simplified cross wind speed, ideal-driver should turn the steering wheel to opposite direction with a peak value which more than it is needed when vehicle runs just adjacent to the pylon. For so complex a process of turning steering wheel, the ideal-driver should do this only in about 1 sec. It’s to say that the most drivers could not finish so ideal control to steering wheel, it is confirmed by the fact that the accidents of side impact and even lateral overturning are easy to occur to the vehicle passing by the pylon zone in strong wind and rainy days.

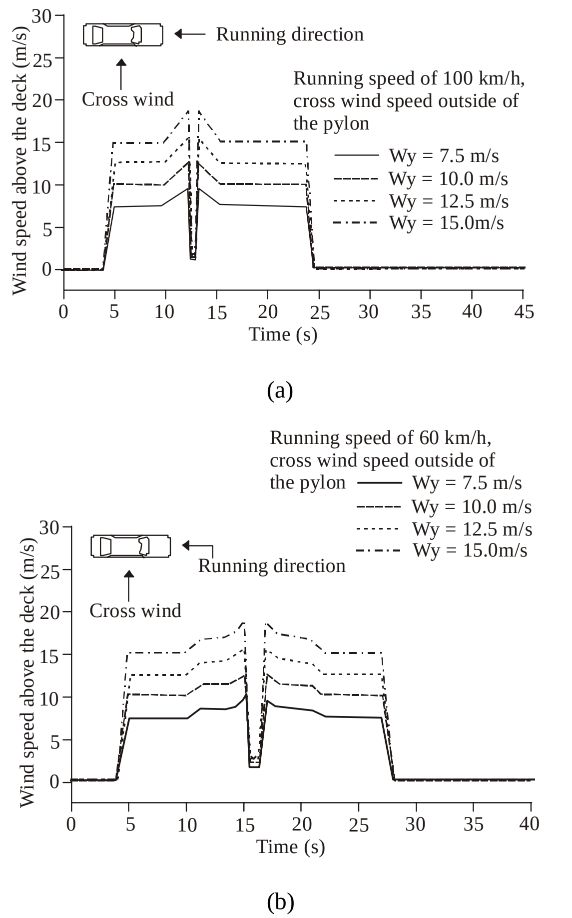
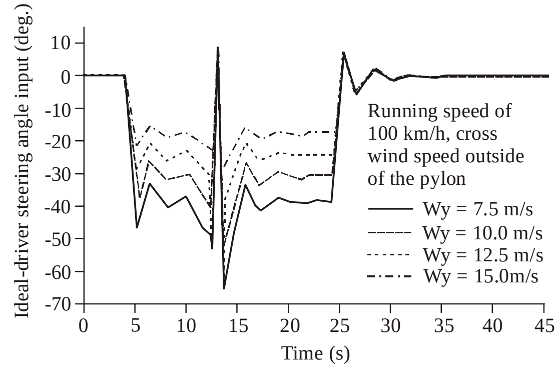


Fig. 3: Alternating cross wind speed time history acting on vehicle passing by the pylon

- With the vehicle running away from the pylon zone, the cross wind speed again reduces to a constant, the steering angle should be back to a lower level the same with the situation under previous constant wind speed. The steering wheel should be rapidly turned back to positive angle when cross wind speed from constant decreasing to zero and steering angle is gradually back to zero in order to suit for driving without cross wind.
- For lateral acceleration time history of the vehicle under ideal-driver steering angle input, it can be seen that lateral acceleration response is later than steering angle input. Compared with the sharp change of steering angle input, lateral acceleration response curve shows the character of long-period oscillation. In the whole process of vehicle passing by the pylon zone under alternating cross wind, peak value of lateral acceleration reaches 1 g, which exceeds the lower limit 0.7 times of acceleration of gravity, according to the medium-size commercial bus



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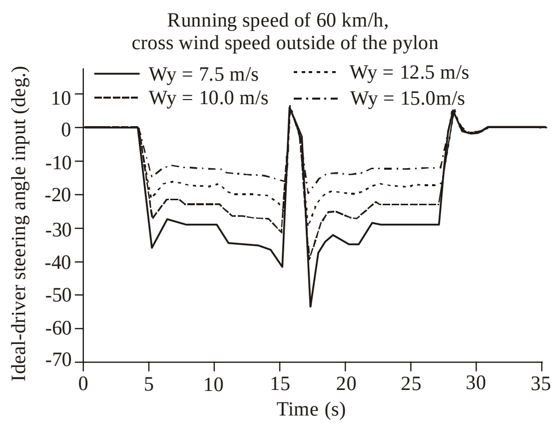
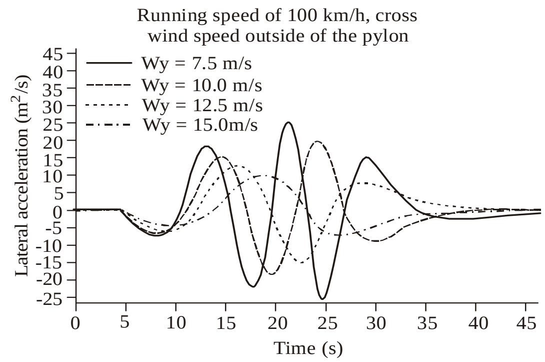


(b)

Fig. 4: Time history of ideal-driver steering angle input



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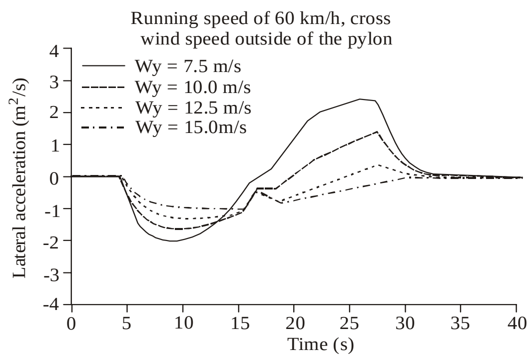

(b)

Fig. 5: Time history of lateral acceleration of vehicle under ideal-driver steering angle input

according to lateral overturning criterion. In other words, the lateral overturning risk is very high if the vehicle control by ideal-driver steering angle input.

PARAMETER STUDY

In order to investigate the influence of running speed and side wind speed, two running speed of 100 and 60 km/h, four side wind speed of 7.5, 10, 12.5 and 15 m/s is considered in the numerical simulation of dynamic response of vehicle passing by the pylon zone. Time history of cross wind speed is given in Fig. 3. Ideal-driver steering angle input time history and its relative lateral acceleration response of vehicle are, respectively shown in Fig. 4 and 5, from which it can be seen that:

- With the decreasing of running speed, the cost total time of vehicle passing by the pylon zone becomes longer, since that, under the same cross wind speed, the needed extreme value of ideal-driver steering angle input reduces. In order to ensure the driving stability, ideal-driver should quickly turn the steering wheel for three times with some large angle in the short time of vehicle passing by the pylon. The complexity of vehicle control is still self-evident.
- With the decreasing of running speed, extreme value of vehicle lateral acceleration under ideal-driver steering angle input is obviously cut down. For example, under the running speed of 60 km/h and cross wind speed of 15 m/s, positive and negative peak acceleration are all less than 0.25 times of acceleration of gravity, which are well below the lateral overturning acceleration threshold limit of 0.7 times of acceleration of gravity.
- With the increasing of cross wind speed, lateral acceleration of vehicle controlled by ideal-driver also increases, which reduces the driving stability and the vehicle control is more difficult.

CONCLUSION

In this study, we establish the evaluation method of lateral driving stability of automobiles passing by the pylon zone under cross wind, in order to explore the reason of lateral instability of automobile. First, multi-objective driving stability criteria are introduced. Based on steering wheel fixed-control model, straight driving ideal-driver model and curvature driving ideal-driver model, the process of a medium-size commercial bus passing by the pylon zone under alternating cross wind is simulated and its lateral driving stability is analyzed. The final evaluation is presented through subjective assessment about ideal-driver steering angle input and the objective comparison between lateral acceleration response and its limitation index. The influence of running speed and cross wind speed on lateral driving stability of automobile passing by the vicinity of pylon is presented through parameter analysis.

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