



## KOREAN PROGRAM FOR ENHANCING DRIVING STABILITY OF VEHICLES IN HIGH WINDS

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### ABSTRACT

The driving safety based on the risk index was evaluated from the lateral deviations of various vehicles under side wind computed by the dynamic motion simulation software. The critical wind speeds for the driving safety were respectively found as 35m/s for sedan and minivan, and 30m/s for bus and truck. The road-side wind screens were studied in the wind tunnel tests to protect the traffic accidents caused by high side wind. From the wind tunnel tests, the minimum height of a wind barrier required to reduce the wind speed by 50% was found to be 12.5% of the road width. It was also found that the speed reduction ratio on bridge did not decrease until the gap reached 30m if wind screens were equipped at both sides of the decks. All benefits drawn by installing wind screen and all costs caused by construction of wind screen were defined quantitatively. And then the decision making process for wind screen installation was proposed based on the benefit-cost ratio.

**KEYWORDS:** SIDE WIND, VEHICLE, WIND SCREEN, DRIVING STABILITY, ACCIDENT RISK

### Introduction

Vehicles running at coastal region or valley area sometimes deviates from its desired path because of the strong side wind accelerated by the concentration of flow over the bridges or valleys [Baker (1986), Wyatt (1992), Smith and Barker (1998)]. Continual compensation of steering wheel against the side wind gives stress to a driver, and then leads to increase of accident risk. Developing a reasonable vehicle protection plan to reduce probability of accident risk, it is firstly required to define the quantitative relations between side wind velocity and driving safety. Main objective of this study is to establish the safety criteria for vehicle under side wind. Numerical approach was used to evaluate the deviation under wind for various vehicles. The second purpose of this study is to design wind screen and to verify it. Wind tunnel tests were performed to find proper geometry of wind screen. Finally the decision making process for wind screen installation was proposed based on the accident risk analysis of vehicles.

### Driving Stability Criteria

To evaluate the wind velocity for traffic restriction and road closure, "definition of accident" should be given first. The accident types can be classified as severe lateral deviation from desired path and overturning. Except for overturning, it is assumed that accident happens when vehicle approaches adjacent lane in present study (see Figure 1). The following risk index,  $F_Y$ , is introduced to describe the danger level from zero to infinity. Risk level is gradually increase as vehicle deviates from original path, and become infinite at accident.

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

where  $Y = 2y/y_{allow}$ . A vehicle is considered to be lost its driving stability when the risk index exceed 3 where the risk index increases rapidly [Emmelman (1981)].

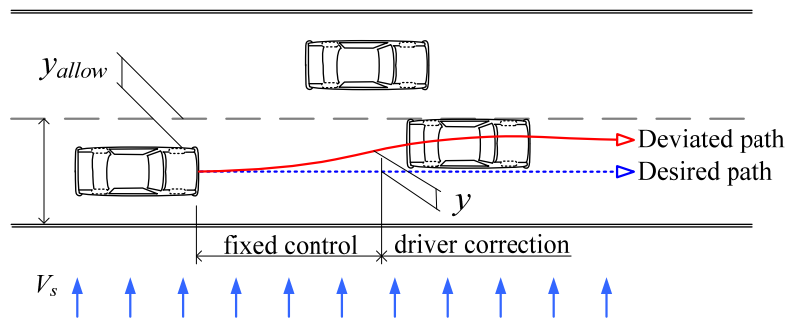


Figure 1: Vehicle under High Cross Wind

To analyze the dynamic behaviour of a car running on windy road, the commercial code named the CarSim(ver. 7.1a) and the TruckSim(ver. 7.1) were used. Figure 2 shows various vehicle models used in the analysis. The vehicle models are provided in the library of the simulation software. In the dynamic analysis, the vehicle speeds, wind speeds, surface friction coefficients and driver models were adjusted to simulate actual condition of roads. The sedan and minivan were driven at fixed control, yet the truck was leaded by driver.



Figure 2: Vehicle Models Used in Dynamic Analysis

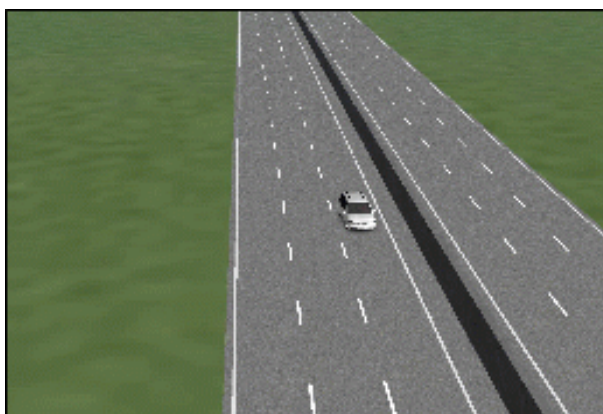


Figure 3: Dynamic Vehicle Motion Simulator, CarSim and TruckSim

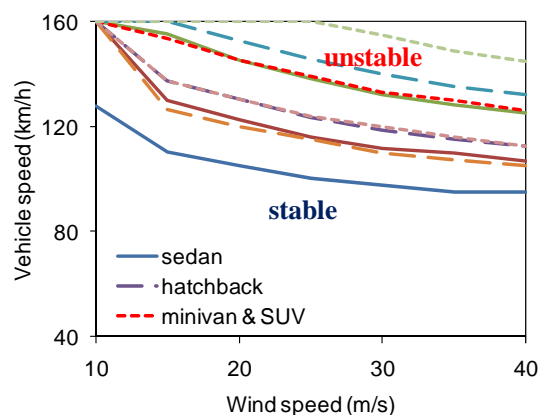


Figure 4: Safety limits for driving stability of small passenger cars

Fig. 3 shows a typical view of simulation. The deviations from its desired path after 0.8 second were computed by the CarSim and TruckSim. Then the risk indices according to vehicle speeds and wind speeds were evaluated from the Eq. (1). The results are given in

Figure 4. If a sedan running at 100km/h exposed to 30m/sec wind attack, then risk index exceeds 3.0 which means the car cross the traffic line. Then 30m/sec is considered as critical wind speed in this case. Other types of vehicles were also analyzed likewise. From the analysis, it was concluded that the critical wind speed for sedan and minivan is 35m/s and that for bus and truck is 30m/s. Those wind speed is three second averaged value.

**Performance of wind screens**

To reduce the accident risk by side wind, two types of wind screen were tested at the KOCED wind tunnel in Chonbuk National University which has test section with 12m(W)×2.5m(H)×40m(L). The first wind screen is made by the so called expanded metal and the other is folded porous plate. Wind screens are assumed to be placed on the embanked road and on the elevated bridge. Figure 5 shows photographs of the tests.

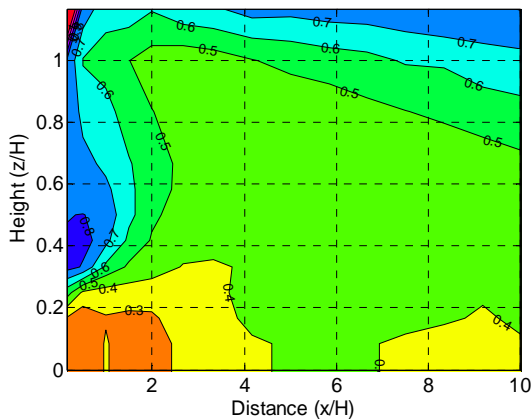


(a) Wind Screen at embanked road

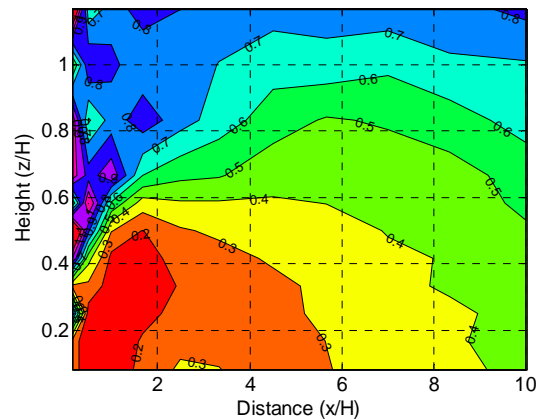


(b) Wind Screen at elevated bridges

Figure 5: Wind Tunnel Tests for Wind Screens



(a) Expanded Metal



(b) Folded Porous Plate

Figure 6: Normalized Wind Speeds According to Free Stream Velocity Behind Wind Screen

In the wind tunnel tests, horizontal(along wind) and vertical axes are normalized by wind screen height. Wind speeds behind the screen are also normalized by the free stream velocity. Figure 6 shows the distribution of speed ratios behind the screen. Wind passing the screen seems to reduce to 50~60% of inlet wind speed. The effect of wind screen covers more than 10 times the wind screen height. The minimum height of a wind barrier required to reduce the wind speed by 50% was found to be 12.5% of the road width.

On bridge, the gap between two adjacent bridge decks may affect the performance of wind screen. It was found that the speed reduction ratio did not decrease until the gap reached 30m if wind screens were equipped at both sides of the decks. The gap for the separated decks in Korea is within 30m mostly.

## Cost based decision making

When a wind screen is installed on a road at which high speed wind blows frequently, the drivers feel comfortable and thus car accident risk can be reduced. However, if no severe wind is expected, it may not be economical to install a wind screen. Hence the probabilistic distribution of wind velocity should be considered in making a decision whether the wind screen is needed or not. Expected cost due to wind induced accident can be defined as the multiplication of accident probability and average car accident cost. Then, the benefit (B) from wind screen installation can be calculated by subtracting the expected cost with screen from that without screen as follows

$$B_{ii} = \sum_{T=1}^{20} b_i \left( \frac{1+j}{1+r} \right)^T Q_d R_i \left[ \sum_{k=1}^3 I_{nk} \Delta_{nk} \left( \frac{\tau_{nk}}{24} \right) - \sum_{k=1}^3 I_{fk} \Delta_{fk} \left( \frac{\tau_{fk}}{24} \right) \right] \quad (i = s, v, t) \quad (2)$$

where  $T$ ,  $j$ ,  $r$ ,  $Q_d$ ,  $R_i$  denote year count, inflation rate, discount rate, averaged daily traffic, car mixture ratio (sedan, van, truck) respectively;  $T$ ,  $j$ ,  $r$ ,  $Q_d$ ,  $R_i$  denote probability of wind speed, passing time for risk zone, lasting time for wind speed respectively; the subscript  $n$ ,  $f$  mean the case without/with wind screen.

While the total cost (C) for screen installation can be calculated by multiplying unit cost for screen and the length of road. Finally, wind screen may be suggested to install when the ratio B/C becomes larger than 1.0.

## Concluding remarks

This paper introduces the Korean program for protecting vehicle against side wind. The lateral deviations of various vehicle models caused by side wind were computed from the numerical dynamic motion simulation programs. Then, those were used to evaluate the driving safety based on the predefined risk index. The critical wind speeds for the driving safety were respectively determined as 35m/s for sedan and minivan, and 30m/s for bus and truck which is three second averaged velocity.

The wind shielding performance of road-side wind screens were studied in the wind tunnel tests. It was found that the minimum height required for a wind barrier to reduce the wind speed by 50% was found to be 12.5% of the road width. A procedure to calculate the benefits that can be gained from wind barrier installation and the cost for the installation were derived. It is recommended to install wind barrier if the benefit obtained from the barrier installation exceeds the construction cost. Since accident probability is very influential in calculating benefit and cost, one should be careful in estimating the probability and more accident statistics data with high quality is necessary for enhancing the decision making.

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