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Vehicle wind load evaluation according to bridge sections

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SUMMARY

Unlikely general bridges, long-span sea bridges are easily exposed to strong winds, so aerodynamics significantly affect them (Kim et al. (2021)). In particular, the wind speed distribution on the bridge is diversified due to the unexpected wind flow, which acts as one of the critical factors in driving vehicles. In this paper, we selected the long-span sea bridge where two vehicle accidents officially occurred at the exact position of the approach bridge. Although the elevation from the sea level is only 57% of the main bridge, the approach bridge is considered a section where driving stability evaluation must be performed when considering the circumstances of the accident. This study utilizes a model of a vehicle and a cable-stayed bridge in Korea where an accident occurred for wind tunnel tests. Unexpected wind flow due to the abrupt shape of the bridge and structure arrangement was identified, compared, and analyzed through wind tunnel test. These results can be aerodynamically hazardous for driving vehicles.

Keywords: long-span sea bridges, wind speed distribution, driving stability

1. INSTRUCTIONS

Moving vehicles on long-span bridges at high altitudes are exposed to intense wind load compared to general roads or bridges. There have been several reports of accidents caused by strong crosswinds on long-span bridges in the world over the years (Baker and Reynolds, 1992; Zhu et al., 2012). According to Kim et al.,2020, through wind tunnel test, It was identified that the wind speed of the lower deck, which consists of a double-deck truss girder, accelerated, and the wind loads increased rapidly. In addition, the shape of the girder changes along the vehicle driving section so that the wind speed distribution in the driving section is significantly different for each lane and vehicle position. It has a significant influence on vehicle driving stability. And it seems to be one of the leading causes of the wind load on moving vehicles due to the section where the lanes merge. Several wind tunnel tests using scaled models were conducted to find the correlation between the causes of the two accidents.

2. WIND TUNNEL TEST SETUP

2.1. Test scaled model

Figure 1 shows the approach bridge located at a lower height than the cable bridge divided into two parts: the approach bridge section that continuously has the same shape (=general section) and the approach bridge section that shape changes abruptly (=transition section). Each model was determined by the length scale 1/70 and 1/80, respectively, considering the size of each bridge section. As for the vehicle type, trucks with a higher risk than passenger cars were adapted and made the same scale as each bridge section model. The test wind speed was set to 10 m/s, and the lane number was designated 1 to 3 lanes based on the central parapet.

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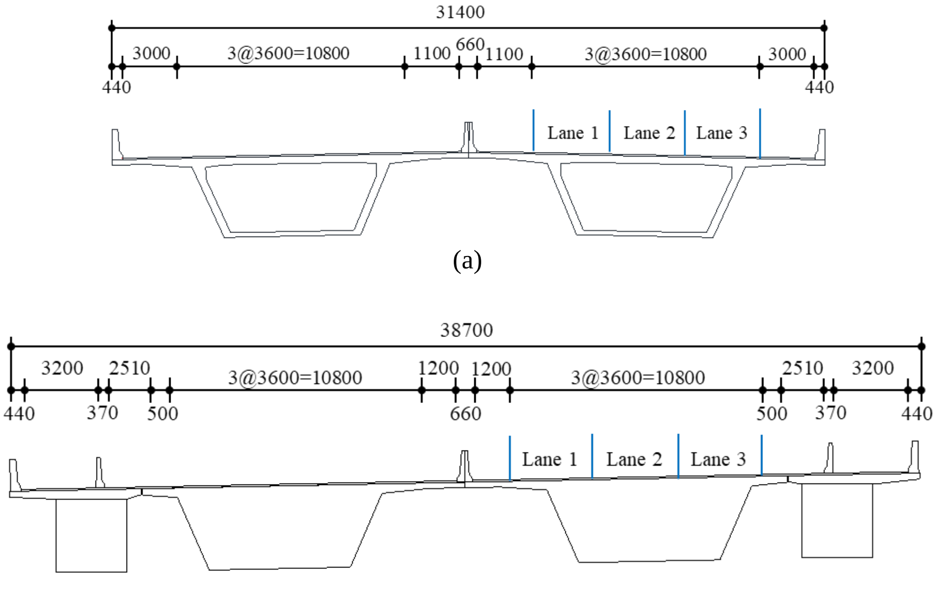

Figure 1. Sections of the investigated bridge (a) general section (b) transition section

2.2. Measurement method

A six-axis sensor was installed inside the vehicle model to measure wind loads (Eqs. (1),(2)) to minimize wind flow disturbance. Before the scaled bridge experiment, a flat round plate with a diameter of 1.2m and a height of 0.47m was installed inside the wind tunnel to measure the wind loads of the vehicle when the wind flow was not disturbed (Undisturbed wind). After that, vehicle aerodynamic coefficients between 60 and 120° were extracted at 15° intervals on each bridge section and compared through influence factors (IF), which was calculated (Eqs. (3)) as the ratio of the vehicle coefficient value on the bridge (C^B) and the undisturbed wind coefficient value (C^U). If this IF is more than 1, it means that the wind load received by the vehicle in the bridge section is more dangerous than in undisturbed wind conditions.

$$F_D = 0.5C_D A\rho V^2 \quad F_S = 0.5C_S A\rho V^2 \quad F_L = 0.5C_L A\rho V^2 \tag{1}$$

$$M_R = 0.5C_R Ah\rho V^2 \quad M_P = 0.5C_P Ah\rho V^2 \quad M_Y = 0.5C_Y Ah\rho V^2 \tag{2}$$

$$\text{Influence factor(IF)} = \frac{C^B}{C^U} \tag{3}$$

Where C_D, C_S, C_L, C_R, C_P and C_Y are aerodynamic coefficients of a vehicle for drag force, side force, lift force, rolling moment, pitching moment, and yawing moment, respectively; A and h are the front area of the vehicle, the center of gravity of the vehicle, respectively; ρ is the density of air(=1.225 kg/m^3) and V is the incoming wind speed.

3. Result of wind tunnel test

Figure 2 shows the location of the vehicle's wind load measured under the most dangerous wind angle (β = 60°) condition in the transition section. The black circle marked for each lane means that the wind load of the vehicle was measured at the location. At the same time, the most critical location where accidents can occur in each lane is marked with a red circle. Also, to determine the cause of the increasing wind load in the transition section, the wind load changes of the vehicle in the transition section were closely examined by removing the numbered parapet one by one, as shown in figure 2.

3.1 Result of sections

The results of the two sections are shown as rolling moment influence factors in Figure 3. According to the results, the influence factor in the 4~16m transition section for each lane is greater than 1, which means that the vehicle wind load in the transition section is more significant than in the undisturbed wind condition, which affects vehicle driving stability. It can be seen that this is the most vulnerable section of the bridge. On the other hand, in the general section of the bridge, vehicles in the third lane are subject to the most wind load. However, the influence factor is less than 1, and the vehicle wind load values of other lanes are very small. So this section is considered relatively safe for vehicle driving.

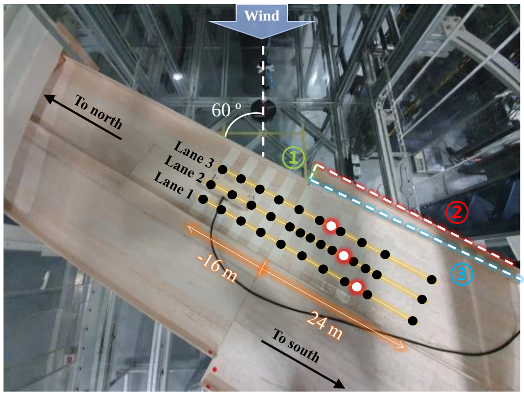

Figure 2. Wind tunnel test of the transition section

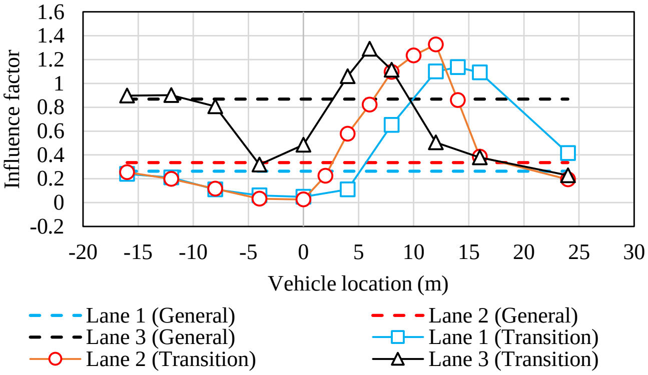

Figure 3. Vehicle rolling moment influence factors according to location

3.2 Major causes of increasing wind load

Figure 3. shows the results when the most vulnerable wind angle (β = 60°) conditions to vehicle accidents to determine the cause of the increase in wind load. Influence factors were compared by sequentially detaching the parapet forming the transition section.

Compared to the black bar "as-is"' case of the transition section, the influence factors were significantly reduced when parapets 1 and 2 were removed (yellow bar) simultaneously, which decreased by up to 40% in the second lane. Also, when removing parapet 1 (gray bar) decreased by up to 14% in the third lane, and removing parapet 2 (red bar) decreased by up to 13%. On the other hand, the effect of parapet 3 was very insignificant.

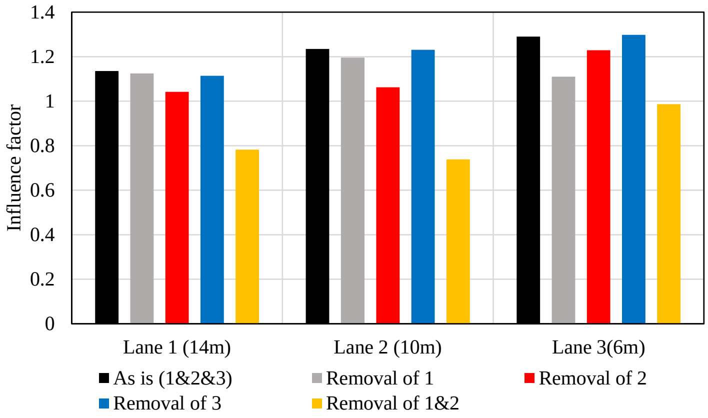

Figure 4. Rolling moment influence factor according to the removal of parapet

4. CONCLUSIONS

This study attempted to determine the cause of the accident by comparing the wind load of vehicles driving in various sections of the bridge through wind tunnel test. In the case of a general section, the wind load is less affected. But in the transition section, results exceeded the undisturbed wind condition. In addition, it was found that the magnitude of the wind load applied to the vehicle when the wind blew at a specific angle could cause a serious vehicle rollover accident. In conclusion, even within a bridge, the shape of the girder varies depending on the investigated section, and the aerodynamic coefficient differs accordingly. When evaluating the moving vehicle stability against strong winds for bridges, the evaluation must consider the shape of all girder sections.

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