WIND TUNNEL EXPERIMENT AND APPROXIMATION OF AERODYNAMIC FORCES ON THE VEHICLE PASSING BEHIND A BRIDGE TOWER

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1. INTRODUCTION A vehicle may suffer a sudden change of wind forces in the cross wind when it is passing behind a bridge tower and it may result in an accident[1]. In the past, the dynamic performance of vehicles in cross wind was often studied without any obstacles[2]. In this study, a series of experiments was conducted to measure the aerodynamic side force and yawing moment on 1/30 scale vehicle model passing behind a tower of a suspension bridge. The comparison between the experimental results and the approximation by quasi-steady theory is presented.

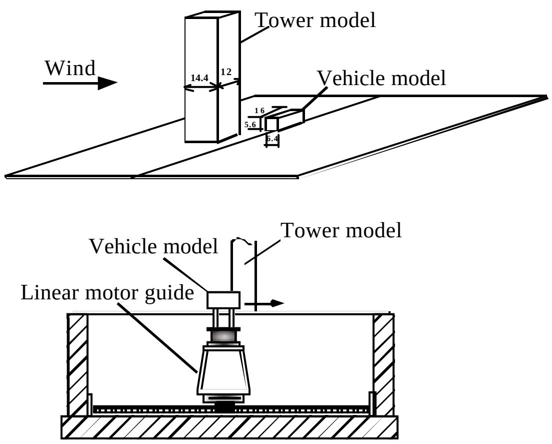

Fig.1 Experimental setup

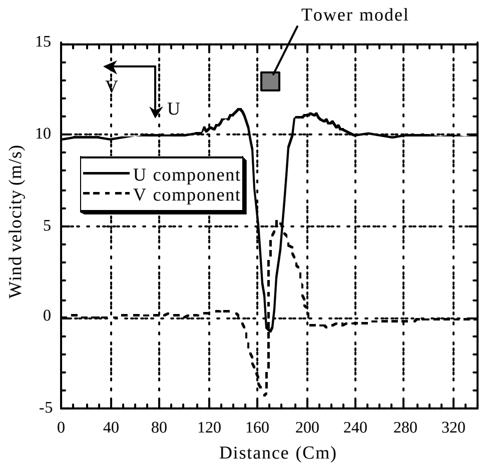

Fig.2 Wind distribution behind the tower

2. EXPERMENTAL PROCEDURE The box shape model is used in this study that is thought to be a simplified vehicle model. The vehicle model is placed in a wind tunnel (test section width: 16 m; height: 1.8 m) behind the tower on a linear motor guide (THK, model GLM20: Fig.1) so that the vehicle can move linearly in the distance of 3.4 m. The tower model is placed in the middle of the vehicle path. The model supporting structure consists of two stainless bars which has been designed to have the total system natural frequency higher than 100 Hz in both lateral and yawing movement in order to measure fluctuating aerodynamic force and moment. Two sets of strain gages are used for side force and yawing moment measurements, respectively. The strain gages are attached on the stainless bars near the base detecting the strain transferred from the movement of the vehicle model by aerodynamic forces. In this experiment, the wind velocity is always set at 10 m/s.

Fig.2 shows the wind distribution behind the tower measured by

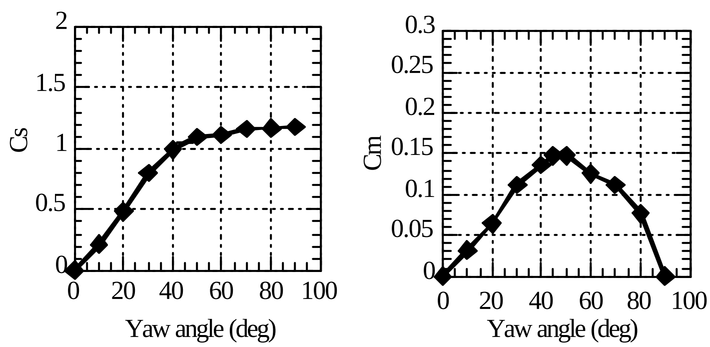

Fig.3 Side force and yawing moment coefficients

split film probe because the normal hot wire probe cannot detect the reverse flow, which can be observed at the location behind the tower.

There are two main types of aerodynamic force measurement experiment, and they are called static and dynamic experiments. In the static experiment, the aerodynamic forces acting on the model are measured when the model stops at each location along the vehicle path. In the dynamic experiment, the aerodynamic forces are measured when the model is moving. In this experiment the model velocity is always set at 3 m/s.

In order to compute the quasi-steady aerodynamic forces, the aerodynamic force coefficients, Cs and Cm, are necessary. These two coefficients are obtained from the steady-state test, where the model is placed at the center in the wind tunnel without the tower and the aerodynamic forces are measured at each yaw angle relative to the flow direction. The side force and yawing moment coefficients from steady-state test are shown in Fig.3. It can be seen that the side force reaches the maximum when the wind comes from the direction perpendicular to the model.

Key word: Vehicle aerodynamics, Cross wind, Side force, Yawing moment, Quasi-steady theory
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For the yawing moment, the maximum moment is observed at the yaw angle of approximately 45 degree.

3. DISCUSSION OF RESULTS Fig. 4 shows the comparison of the side force, *F*, and yawing moment, *M*, between the static experiment and the quasi-steady forces (using wind information from Fig.2 and the coefficients from Fig.3) and change them to the non-dimensional values by using following equation[3],

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

A is the total side area of the model, *r* is the air density, *l* is the wheelbase of the vehicle (in this case, *l* is the distance between two stainless bars), *U* is the wind velocity used in the experiment and V_c is the vehicle velocity. It can be seen that the approximation by quasi-steady agrees well with the experiment results only for the side force, but for the moment, the agreement of the approximation and the experiment is not good at the location behind the tower. The reason is that the conventional quasi-steady theory considers the uniform flow condition, but this is not true in this experiment because the change of wind velocity is significant at the location behind the tower. This bad agreement of the approximation with the experiment results is also observed in the dynamic experiment as shown in Fig.5. In order to improve the agreement, the effect of wind non-uniformity should be considered. Therefore, the strip theory is applied; the improvement by using this approximation is shown in the graphs both for static and dynamic experiment. The idea of strip theory is to separate the total side area of the vehicle into many small areas, then compute the aerodynamic forces by quasi-steady theory for each small area based on wind velocity at that location; the summation of these small side force components over the total area is assumed to represent the side force acting on the model body at that location; the summation of the small quasi-steady moment components together with the moment components caused by eccentricity of side forces acting on each small area is assumed to represent the yawing moment. It can be seen that the approximation by quasi-steady with strip theory gives significant improvement as shown in Fig.4 and Fig.5.

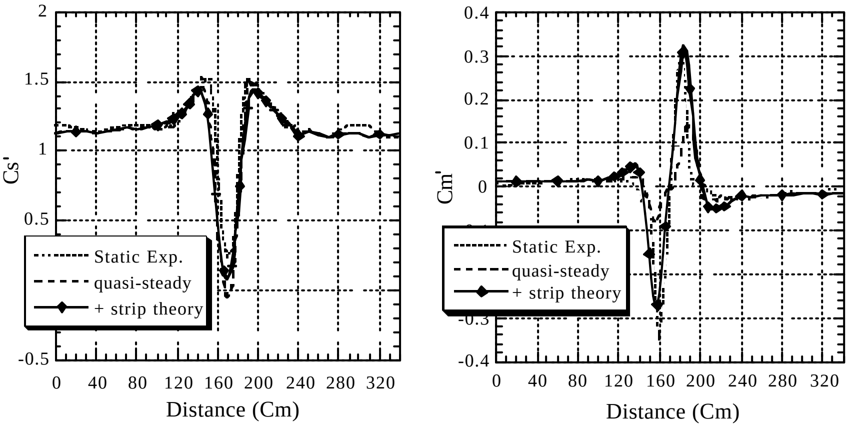

Fig.4 Comparison of Cs' and Cm' for static case.

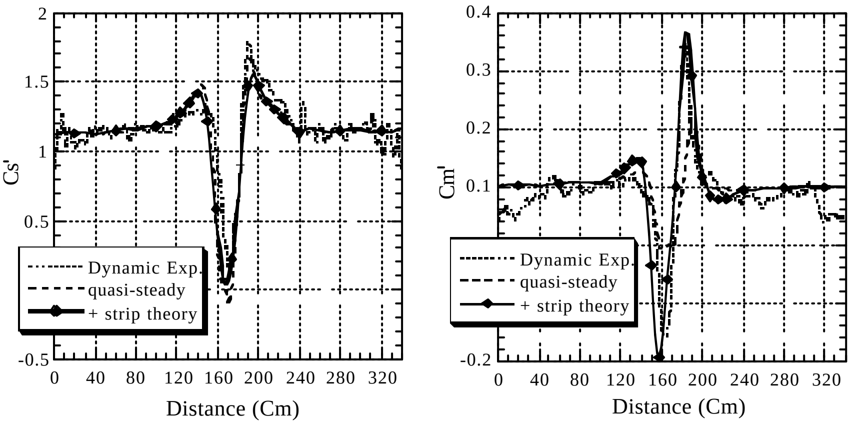

Fig.5 Comparison of Cs' and Cm' for dynamic case.

4. CONCLUSIONS This paper has shown the wind tunnel experiment results and approximations of aerodynamic forces acting on the running vehicle behind the tower. Because of the wind non-uniformity behind the tower, the conventional quasi-steady aerodynamic forces theory does not provide good agreement with the experimental results. To obtain better approximation, the wind non-uniformity has to be considered. The study should be continued for other wind direction cases so that the applicability of the approximation can be clarified.

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