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THE OVERSHOOT OF AERODYNAMIC FORCES ON A RAILCAR-LIKE BODY UNDER STEP-FUNCTION-LIKE GUSTY WINDS

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1 INTRODUCTION

In Japan, railcar vehicles are often overturned by wind gusts, such as from tornadoes, and unsteady aerodynamic forces due to gusts rising in very short times have received a lot of attention. For wind resistant designs, the wind load is based on a quasi-static aerodynamic force.

Generally, the coefficient of wind force, *C*, is supplied by empirical data from wind tunnel tests under a stationary or turbulent flow. The intensity of turbulence is, at most, about 10%, and the flow is classified as a quasi-steady flow. Although early studies (Ref. [1]-[5]) have pointed out that increasing wind velocity in a very short time increases wind force, there are few examinations focusing on the rise time of wind velocity.

In this study the effects of the rise time of a step-function-like gust on wind forces on a 2-D body of a box-section like a railcar, which is on the ground, are investigated and discussed using a specially equipped wind tunnel and a CFD approach.

2 GENERAL SPECIFICATIONS OF THE WIND TUNNEL TEST

2.1 Outline of experimental facility

We used an inhaled Eiffel type wind tunnel for this experiment. A site plan of our testing system is illustrated in Fig. (1). The working section is 1.5m×1.5m square. Step-function-like gusts from almost 0m/s to a target wind velocity in a short time of 0.2～5.0 sec are realized by rapid rotation of a blade row.

2.2 Location of Test Model

The railcar model had a box section with round edges, and measured 74mm in width, 500mm in depth, and 90mm in height, as shown in Fig. (2). This model was connected rigidly with load cells, and the drag and lift forces on the model were measured. However, if we put the model on the floor plate of the wind tunnel as the ground, the rapid change of the inside pressure of the wind tunnel caused by the rapid change of wind, must strongly affect the z-component (a lift) of the load cell which was put on the outside of the wind tunnel. And so, we fixed a perpendicular board as the ground on the floor of the wind tunnel and connected the model with the load cell perpendicularly beside the board, as shown in Fig. (2). In doing so, we thought that the influence of the rapid pressure change would be avoidable. Several spaces, of about 1mm between the board and the model, were put in so that the load cell would not measure the components of the wind forces on the board. Additionally, to realize a two-dimensional flow, a dummy model affixed to the board was placed at a distance of 3mm from the test model, as shown in Fig. (2). In this case, since the lift of the railcar model was equivalent to the lateral force of the load cell, this lateral force (the wind force in right-angle direction) was treated as the lift of the model.

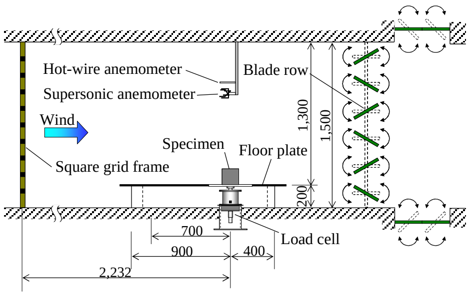


Figure 1: Site plans of the win tunnel.

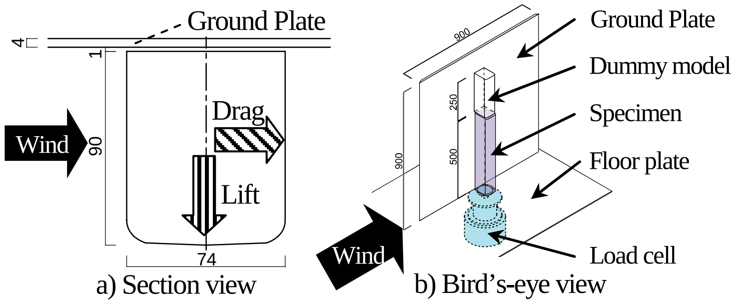


Figure 2: Specimen.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Overshoot of wind forces

Fig. (3) shows the time evolutions of the wind velocity, and the drag and lift forces, when the target wind velocity reached 3.5m/s in the rising time of 0.2 sec, and 1.4 sec. In the case of the rise time of 0.2 seconds, we saw an overshoot phenomenon of the aerodynamic forces, which reached much larger values than the steady values of the drag and lift. However, the values decreased at once, and settled down in the stationary state. On the other hand, in the case of the rise time of 1.4 seconds, we did not see the overshoot phenomenon.

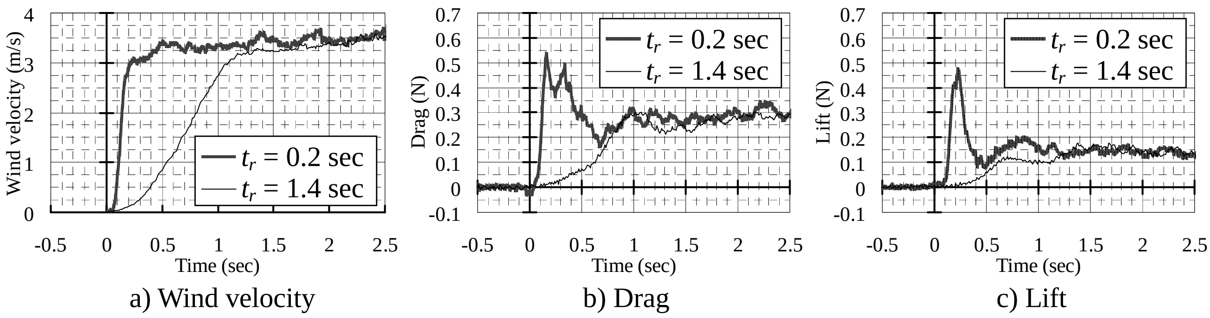
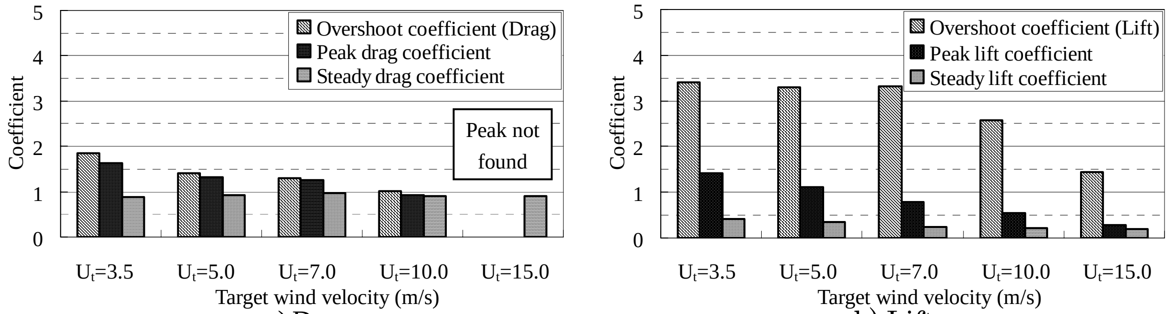


Figure 3: The time history data (U_t = 3.5).

3.2 Coefficient of wind force and the overshoot coefficient

To evaluate the overshoot phenomenon of the drag and lift, the overshoot coefficient defined by the ratio of the peak value to the steady value is shown in Fig. (4), which also includes the drag and lift coefficients. Here the wind force coefficient is defined by the reference area of the model (0.045m^2) and the steady velocity pressure. In the case of the target wind velocity of 15 m/s, only the steady drag coefficient is shown, since a peak value higher than a steady value could not be confirmed. The steady wind-force coefficients are almost constant regardless of the target wind velocity. However, the peak wind-force coefficients decreased with an increase in the target wind velocity. The overshoot coefficients increased with a decrease in the target wind velocity. In the case of the target wind velocity of 3.5m/s, the peak drag was about 1.8 times larger than the steady drag, and the peak lift was about 3.4 times larger than the steady lift, as shown in Fig. (4).



a) Drag b) Lift

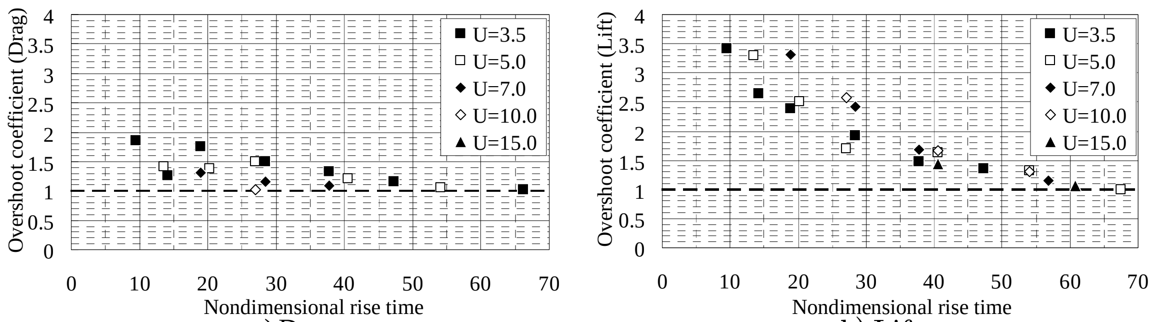
Figure 4: The overshoot coefficients and the wind-force coefficients (t_r = 0.2).

3.3 Relationship between the overshoot coefficient and the non-dimensional rise time

When the rise time was very short, it was confirmed that the overshoot phenomenon appeared in both the drag and the lift. The overshoot coefficient increased with a decrease in the target wind velocity. To compare the overshoot in the various rise times and target wind velocities, the non-dimensional time was defined by Eq. (1) in reference to Ref. [1].

$$t' = U_t \cdot t / D, \tag{1}$$

where t' is a non-dimensional time, U_t is the target wind velocity, t is time and D is a reference length (here the width of the model). Fig. (5) shows the relation between the non-dimensional rise time and the overshoot coefficient. The overshoot coefficients showed a tendency to decrease as the non-dimensional rise time increased, as shown in Fig. (5).

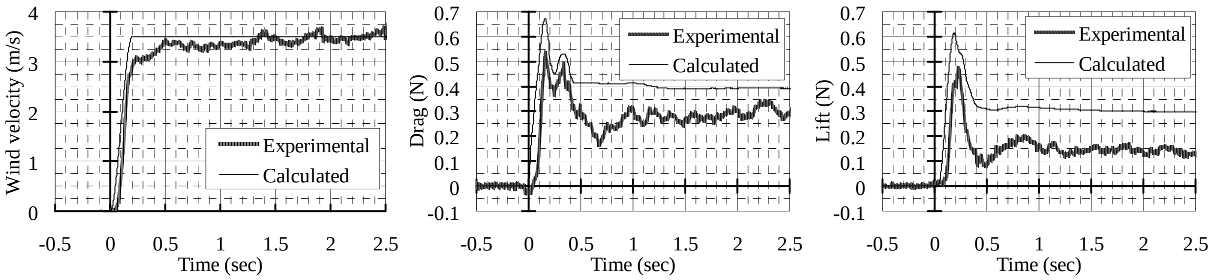


a) Drag b) Lift

Figure 5: The relationship between the overshoot coefficient and the non-dimensional rise time.

4 CFD ANALYSIS

We estimated a pressure distribution around the railcar model subjected to a step-function-like wind gust using a CFD technique based on the PISO (Pressure-Implicit with Splitting of Operators) method. The standard k-ε model was used for the turbulence model. A two-dimensional step-function-like gust flow corresponding to the measured wind velocity rising in a short time was used as an approaching flow in the wind tunnel. The drag and the lift were estimated using the simulated pressure distribution around the model. Fig. (6) shows the estimated time evolution of drag and lift in the case of the target wind velocity of 3.5m/s in the rise time of 0.2 seconds. Both drag and lift which were estimated by the simulation, were bigger than the experimental result, but the overshoot phenomenon can be recognized in the simulation as well as in the experimental results.



a) Wind velocity b) Drag c) Lift

Figure 6: Comparison between the calculated result and the experimental result (U_t = 3.5, t_r = 0.2).

5 CONCLUSIONS

The characteristics of wind-force on a railcar-like body subjected to step-function-like gusts were investigated by using a specially equipped wind gust tunnel. We confirmed an overshoot phenomenon bringing a much bigger wind force than in a steady flow. The magnitude of the overshoot is clearly correlated with the rise time of a target wind velocity, and it was found that the overshoot coefficient increased with a decrease in the target wind velocity and rise time. In addition, the overshoot phenomenon was recognized in a CFD simulation as well as in the experimental result. Finally, we concluded that the non-dimensional rise time, defined by the target wind level and the reference depth of the body, strongly affected the development of the overshoot of an unsteady force.

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