

博士論文 （要約）

Numerical study of crosswind response of railway vehicles considering multi-body dynamics and unsteady wind effects

（マルチボディダイナミクスと非定常風効果を考慮した横風による鉄道車両の動的
応答の数値予測）

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Recently, railway vehicles have been showing a trend to be high speed and lightweight, which may conserve energy, reduce track damage and improve the capacity of transportation. However, these developments may also have a negative effect on the crosswind stability of railway vehicles. In addition, the quasi-static method proposed by RTRI is widely used to evaluate the crosswind response of railway vehicles in Japan. It was a two-dimensional and half car model which includes only three degrees of freedom. For steady or quasi-steady winds, the dynamic response of railway vehicles can be predicted by the quasi-static method accurately. However, for unsteady winds, such as the tunnel exit wind which means a railway vehicle coming out of the tunnel and being hit by crosswind simultaneously, and tornado winds, the quasi-static method might underestimate the unsteady crosswind response of railway vehicles because the dynamic effects was neglected. In fact, unsteady winds might pose a threat to the safety operation of railway vehicles and cause severe damage, like the Uetsu line railway accident in Japan which is suspected to be induced by tornado winds.

Therefore, it is necessary to accurately predict the unsteady crosswind response of railway vehicles by multi-body dynamic simulations and quantitatively evaluate underestimations by the quasi-static method considering both the tunnel exit wind and tornado winds. Besides, the effects of natural frequency and damping ratio of railway vehicles should be studied.

In Chapter 1, background and motivation of this study, literature review, objectives and structures of this thesis are presented.

In Chapter 2, numerical models including wind and wind load models are introduced. Both the quasi-static and multi-body dynamic methods are presented respectively as well. Based on the wheel unloading calculated by these two methods, the dynamic amplification factor is proposed and defined.

In Chapter 3, the scale railway vehicle model (103 series) is updated by identifying parameters and the real train model (E233) is validated by the field test. For the scale railway vehicle model, the unknown parameters including the stiffness of vertical bump stop and the damping value are identified by the bisection method. Then, using the identified parameters,

the natural frequency and damping ratio calculated by numerical simulations show good agreement with experiment results. Finally, considering the track irregularity, the rolling angle of car body of the scale train model matches well with the experiment result. Furthermore, for the real train model (E233), the average wheel unloading ratio is around 2% larger than that measured by experiments and this result is totally acceptable.

In Chapter 4, the dynamic amplification factor (DAF) is proposed to evaluate the dynamic amplification effect for railway vehicles in tunnel exit wind and results show good agreement with simulation results for different damping ratios. Firstly, the one-minus-cosine gust model is used to simulate the tunnel exit wind. Then, aerodynamic forces caused by the tunnel exit wind are evaluated by the equivalent wind pressure method and validated by experiments. At last, the dynamic amplification factor (DAF) for railway vehicles against the tunnel exit wind is defined as the ratio of the maximum dynamic wheel unloading ratio to the static wheel unloading ratio and the passing time Δt showing how long the railway vehicle moves out of the increase part of the tunnel exit wind is defined as well. It is observed that the DAF for railway vehicles in the tunnel exit wind increases as the passing time Δt decreases. Furthermore, a simple exponential formula to predict the DAF is proposed and prediction results show good agreement with numerical simulations. In addition, the effects of natural frequency and damping ratio of railway vehicles are investigated. It can be found that the DAF increases as the natural frequency decreases and the DAF increases as the damping ratio decreases obviously.

In Chapter 5, the dynamic amplification factor for railway vehicles in tornado winds is proposed considering different natural frequencies and damping ratios and the Uetsu line railway accident is investigated by multi-body dynamic simulations. Firstly, the Burgers-Rott model can give an accurate prediction of the wind field of a two-cell type tornado, for both the stationary and translating tornadoes and it is validated by field tests, laboratory experiments and CFD simulations. Then, aerodynamic forces acting on the railway vehicle induced by tornado winds are also validated by experiments. Finally, the dynamic amplification factor (DAF) for railway vehicles in tornado winds is studied and a simple

formula to predict the DAF is also proposed. The DAF increases initially and then decreases afterwards as the passing time decreases mainly because the wind distribution is different from the tunnel exit wind. The effect of the natural frequency and damping ratio of railway vehicles are studied. It is observed that the DAF increases as the natural frequency decreases and the DAF increases as the damping ratio decreases obviously. In addition, the application of the DAF is discussed, and it becomes conservative to calculate the unsteady crosswind response of railway vehicles by the quasi-static method if the DAF is considered. Furthermore, the numerical construction of the Uetsu line railway vehicle is carried out to accurately investigate the railway accident. It is also recommended that the railway vehicle run at low train velocity at high-incidence areas for tornadoes.

In Chapter 6, conclusions of this study are summarized.

The contents in Chapter 3, 4 and 5 are scheduled to be published as a journal within 5 years.