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A robust time integration for dynamic interaction of high-speed train and railway structure including derailment during an earthquake

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1 Introduction

When a high-speed train runs on the railway structure during an earthquake, there is a radical dynamic interaction between the train and railway structure. The huge impact force between wheel and rail creates lifting of wheel, derailment and post-derailment behavior during a strong earthquke. What is difficult of the phenomenon to solve is that it shows a high-frequency response higher than several hundred Hz due to the impact between the train and railway structure during an earthquake that is mixed with a low-frequency fundamental response less than about 20 Hz of the railway structure. This is the so-called multiscale phenomenon of frequency. The time increment Δt to solve for the interaction of the train and railway sturucture including derailment must be small enough for the convergency in nonlinear iterations during each time increment that may cause a round-off error in the numrical time integration, since the low natural frequency of the railway structure with the large mass of the base ground attached and a huge term in the order of $1/\Delta t^2$ are included in the dynamic stiffness in the standard numerical time integration such as the Newmark method [1].

In this paper a robust and efficient computational method to solve for the dynamic interaction of a high-speed train and railway structure including derailment and post-derailment behaviors during an earthquake is given. Some examples are demonstrated.

2 Mechanical model for the interaction of the train and railway structure

The motion of the train is expressed in multibody dynamics where nonlinear springs and dampers are used to connect all components [2]. Mechanical models to express contact-impact behaviors between wheel and rail before derailment and between wheel and the track structure after derailment are given to solve the interaction during an earthquake effectively.

The motion of railway structure is modeled with various finite elements. The nonlinear dynamic response during an earthquake is obtained by solving equations of motions of the train and railway structure subjected to the interaction between wheel and the track structure including derailment and post-derailment behaviors [3].

3 Numerical method

Modal reduction has been developed to solve nonlinear equations of the combined motion of the train and railway structure during an earthquake effectively. A robust time integration using an exact time integration in the modal coordinate has been developed to solve for the radical dynamic interaction to avoid a round-off error that normally occurs in the numerical time integration such as the Newmark method for a very small time increment needed to solve the interaction in the derailment and post-derailment during an earthquake.

4 Applications

The present method is applied to solve for the dynamic interaction of a Shinkansen train (high-speed train in Japan) and the railway structure with 10 spanned viaduct with guards attached to prevent wheel deviating from the track during an earthquake as shown in Fig.1. Derailment and post-derailment behaviors of the train on the railway structure during the earthquake are studied.

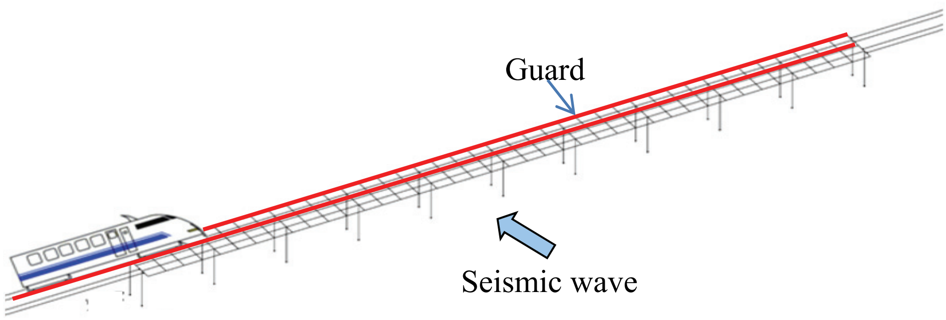

Fig. 1 A Shinkansen car on a 10 spanned viaduct with guards attached during an earthquake

5 Conclusions

The computational method using the modal reduction and exact time integration given here is shown to be effective to solve for the dynamic interaction of a high-speed train and railway structure during an earthquake where a very small time increment is needed to solve the radical dynamic behavior such as derailment and post-derailment.

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