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Railway vibration reduction using impact dampers

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ABSTRACT

The use of impact dampers for reducing railway vibration induced from moving wheel loads and consequent noise generation is presented. The impact dampers for efficient reduction of impact vibration induced by moving loads were designed and verified using simple dynamic models. To test the performance of the impact dampers, the vibration of a simplified beam attached with various impact dampers was measured. The performance of the impact damper on reducing the transient vibration of railway is investigated. The effects of clearance and mass ratio on vibration reduction was analyzed. The numerical solutions using finite element method were verified using the experimental results to find the vibration reduction mechanism. The result was utilized to reduce rolling noise radiation from moving trains.

Keywords: Railway, Impact damper, Structural vibration
I-INCE Classification of Subjects Number(s): 47.4

1. INTRODUCTION

Environmental noise is of increasing concern for development of a high-speed train. Rolling noise induced by a railway vibration is one of the fundamental factors contributing to high levels of environmental noise. To reduce a railway vibration induced by moving wheel loads, the impact dampers are effective in reducing transient high-level vibrations. This study presents on simulation of a mechanism of impact dampers from a simplified beam using 1 degree freedom model. Also, the effects of clearance and mass ratio on vibration were investigated. The vibration decay per length was computed using finite element method. Finally, characteristics of numerical solutions were verified using the experimental results.

2. ANALYSIS OF 1 DEGREE FREEDOM MODEL

2.1 Numerical Model

For a simulation for 1 degree freedom model of a single unit impact damper, a simplified beam like railway is modeled discrete system having linear stiffness k_1, mass m_1, viscous damping c_1 and impact damper with mass m_2 and clearance d, as shown in Fig. 1. The differential equations of motion between impacts are

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix} + \begin{bmatrix} c_1 & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} k_1 & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} F(t) \\ 0 \end{bmatrix} \tag{1}$$

The collisions are idealized as discontinuous processes governed by the conservation of momentum and definition of the coefficient of restitution. Velocities $\dot{x}_1$, $\dot{x}_2$ just before and immediately after a collision are thereby related by the equations

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$$\dot{x}_1^+ = \left(\frac{1-\mu e}{1+\mu}\right)\dot{x}_1^- + \left(\frac{\mu+\mu e}{1+\mu}\right)\dot{x}_2^-, \quad \dot{x}_2^+ = \left(\frac{1+e}{1+\mu}\right)\dot{x}_1^- + \left(\frac{\mu-e}{1+\mu}\right)\dot{x}_2^- \tag{2}$$

where μ is the mass ratio, m_2/m_1. The restitution coefficient e is defined as

$$e = -\frac{\dot{x}_2^+ - \dot{x}_1^+}{\dot{x}_2^- - \dot{x}_1^-} \tag{3}$$

The superscripts $-$ and $+$ refer to states just before and immediately after a collision, respectively. $\dot{x}_1^+$, $\dot{x}_2^+$ are obtained by differential of equation (1) with respect to time using Runge-Kutta method.

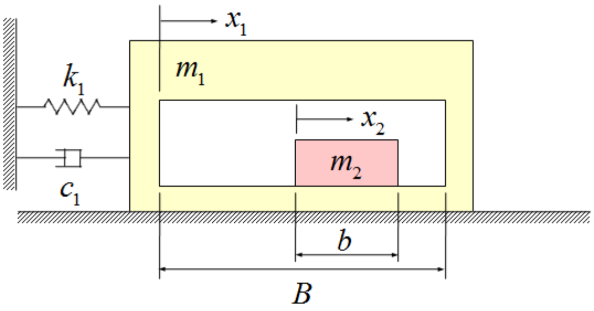

Figure 1 – Schematic diagram of model for single unit impact damper

2.2 Results

The displacement after vibration induced by initial conditions were computed. Due to a little structural damping, transient oscillations take a long time to decay without the impact damper. When impacted, oscillation amplitudes are quite comparable to those without impacts at the start. Consequently, an oscillation amplitude with impact damper attachement is smaller than those without impact damper. The decay time for a displacement of a main vibration object with impact dampers was calculated for several mass ratios and clearances.

3. ANALYSIS OF IMPACT DAMPERS USING FINITE ELEMENT METHOD

3.1 Numerical model

Using a finite element method for modeling of rails by vibrating beams, a reduction of railway vibration using impact dampers are investigated. The element mass and stiffness matrices of railway element assuming Euler-Bernoulli beam were given as

$$[m] = \frac{\rho A L}{420}\begin{bmatrix} 156 & 22L & 54 & -13L \\ 22L & 4L^2 & 13L & -3L^2 \\ 54 & 13L & 156 & -22L \\ -13L & -3L^2 & -22L & 4L^2 \end{bmatrix}, \quad [k] = \frac{EI}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \tag{4}$$

where ρ is a weight density, A is an area of cross-section, L is a length of an element, E is Young's modulus and I is a moment of inertia of beam cross-section. Using the element mass and stiffness matrices of Euler-Bernoulli beam, the global mass and stiffness matrices are obtained. The global equation of the model can be expressed as

$$\{F\} = [K]\{d\} + [M]\{\ddot{d}\} \tag{5}$$

where

$$\{F\} = \sum_{n=1}^{4N}\left\{f^{(n)}\right\}, \quad [K] = \sum_{n=1}^{4N}\left[k^{(n)}\right], \quad [M] = \sum_{n=1}^{4N}\left[m^{(n)}\right] \tag{6}$$

are the global stiffness, mass and force matrices. The collision in a contact surface between an impact damper and the rail was given as a condition similar to equation (1) as

$$\begin{bmatrix} \dot{v}_{2N+1,i} \\ \dot{u}_{2N+1,i} \end{bmatrix} = \frac{1}{m_2 + \rho AL} \begin{bmatrix} m_2 - \rho ALe & \rho AL(1+e) \\ e & \rho AL - m_2 e \end{bmatrix} \begin{bmatrix} \dot{v}_{2N+1,i-1} \\ \dot{u}_{2N+1,i-1} \end{bmatrix} \tag{7}$$

The solution of the equation (5) is obtained in the same manner as the solution of the equation (1) using a set of variables and Runge-Kutta method.

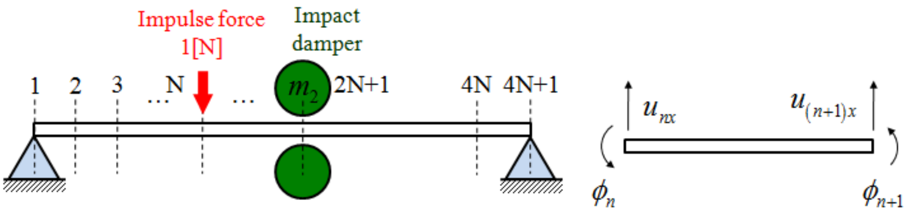

Figure 2 – Schematic diagram of model for simply supported rail using finite element method

3.2 Results

Variation of oscillation amplitudes after impact damper attachments were computed. The decay time for a displacement of a beam with impact damper is larger than those without the impact dampers. Also, the length decay has an optimum value to reduce a vibration of a beam by changing mass ratio, clearance, a position located to impact damper and a number of impact dampers.

4. MEASUREMENT

To verify the results of a solution of numerical method, acceleration responses for a simplified railway were measured using accelerometers. Impact dampers for attachments to a rail were designed, and its performance was verified by experiments. Vibration modes of a simplified railway without impact dampers were measured. Acceleration responses for a simplified railway with impact dampers reduced. Effects of changing mass ratio, clearance and a number of impact dampers on transient response of a simplified beam were similar to simulation results.

5. CONCLUSIONS

This study presents results on modeling a theoretical impact dampers that could be applied to a vibrating rail. Using a theoretical model for a simplified beam, the effect of the impact dampers to reduce vibration for actual railway was verified. The numerical results assist to design impact dampers for reduction of rolling noise to nearby residential areas.

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