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An Efficient Sensitivity Analysis Method for Optimization of Vehicle Random Vibrations

W. T. Xu[1,2a], Y. Zhao[2], F. Lu[3b], and D. Y. Zhang[4]

[1]*Department of Engineering Mechanics, Zhengzhou University, China*
[2]*Department of Engineering Mechanics, State Key Laboratory of Structural Analysis and Industrial Equipment, Dalian University of Technology, China*
[3]*Power Plant Life Management Research Center, Suzhou Nuclear Power Research Institute, China*
[4]*Department of Ocean Engineering, Dalian Ocean University, China*

Abstract

An efficient and accuracy sensitivity analysis method for optimal analysis of random vibration of vehicle-bridge coupled system is purposed. The pseudo-excitation method is used to transform random road surface roughness into a series of deterministic harmonic excitations, and then the precise integration method is adopted to compute vehicle/bridge system response. The pseudo-excitation method and the precise integration method are both accurate and efficient, so that the first and second order sensitivity information of the responses can be obtained very conveniently. Taking ride comfort as the objective function, an optimal analysis for a vehicle/bridge system is performed.

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Keywords: Vehicle-bridge coupled systems; Pseudo-excitation method; Precise integration method Sensitivity analysis.

1. INTRODUCTION

In recent years, dynamic analysis of coupled vehicle-bridge systems has received much attention. The road surface roughness is well known to be a random process. It is very difficult to perform a vibration analysis concerning such random vibration (Lou and Zeng 2005, Xia 2000, Lei and Noda 2002, Zhai 1996). Furthermore, very little research concerning optimal analysis with the consideration of random response appears in the literature. There are two difficulties for the optimal analysis (Yamazaki et al.

[a] Presenter: Email: xukeyangzi@yahoo.com.cn
[b] Corresponding author: Email: flv@mail.dlut.edu.cn

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1988, Bouazara and Richard 2001, Cassis and Schmit 1976, Kapoor and Kumarasamy 1981, Naude and Snyman 2003): One is that the conventional method for random vibration analysis require much computational effort, the other is that, generally, the objective function for optimal analysis is highly non-linear and the calculation procedure for sensitive analysis is very complicated. Beliveau *et al* used the least-squares iteration method to compute the first two order sensitivities of eigen values (Beliveau *et al.* 1996). A matrix perturbation method and a method based on Laplace transformation were dveloped by Chen (Chen *et al.* 1993) and Zimoch (Zimoch 1987 and Durbin 1974), respectively. All the above methods are very time consuming which restrict their applications.

In this paper the pseudo excitation method (PEM) and precise integration method (PIM) are combined to promote computational efficiency, which have been described in detail elsewhere (Lin *et al.* 1994, Lin *et al.* 2001, Lin and Zhang 2005). Moreover, sensitivity analysis for dynamic optimization based on PEM and PIM is developed to calculate the first and second order sensitivities of random responses. In numerical examples, the proposed method is verified, and an optimal analysis for a vehicle is performed.

2. Equations of motion for vehicle systems

2.1. Vehicle stationary random vibration

The vibration is stationary random vibration for single vehicle. Consider the linear model of a double axle vehicle shown in Fig.1. For convenience, a 3-D vehicle model with eight DOF is introduced, of which the dynamic behavior is described by vertical, pitching and rolling motions. In this analysis, we do not consider yaw motion because its effect on vehicle ride comfort is negligible. The seat is modeled as a mount consisting of a linear spring and a damper.

The system parameters are: mass of the seat plus driver m_y; mass of the car body m_c; masses of wheel axles m_{fl} , m_{fr} , m_{rl} , m_{rr} (where fl represents front-left, rr represents rear-right, etc.); the corresponding damping coefficients $c_y, c_{fl}, c_{fr}, c_{rl}, c_{rr}$; the corresponding stiffness coefficients for the seat and wheel axles $k_y, k_{fl}, k_{fr}, k_{rl}, k_{rr}$; the tire stiffness coefficients $k_{wfl}, k_{wfr}, k_{wrl}, k_{wrr}$; and the tire damping coefficients $c_{wfl}, c_{wfr}, c_{wrl}, c_{wrr}$. l_a and l_b are the outline dimensions of the vehicle; l_f and l_r denote the distances between the body-center and the front or rear axle; d_r represents the distance between the right and left tires; r_x and r_y are the location parameters of the seat; J_x and J_y are the rotational inertias of the vehicle about its x and y axes. With pitching and rolling motions denoted by small angles φ and θ, the equations of motion for this system can be derived as:

$$\mathbf{M}\ddot{\mathbf{z}} + \mathbf{C}\dot{\mathbf{z}} + \mathbf{K}\mathbf{z} = \mathbf{f}(t) \tag{1}$$

where $\mathbf{z} = \left\{ z_y \quad z_c \quad \theta \quad \varphi \quad z_{wfl} \quad z_{wfr} \quad z_{wrl} \quad z_{wrr} \right\}^{\mathbf{T}}$ is the displacement vector and the excitation vector $\mathbf{f}(t)$ is written as

$$\mathbf{f}(t) = \mathbf{G}_1(t)\left\{ z_{rfl} \quad z_{rfr} \quad z_{rrl} \quad z_{rrr} \right\}^{\mathbf{T}} + \mathbf{G}_1(t)\left\{ \dot{z}_{rfl} \quad \dot{z}_{rfr} \quad \dot{z}_{rrl} \quad \dot{z}_{rrr} \right\}^{\mathbf{T}} \tag{2}$$

where $\mathbf{G}_1(t)$ and $\mathbf{G}_1(t)$ can be time-variant or invariant matrices, and $z_{rfl} \quad z_{rfr} \quad z_{rrl} \quad z_{rrr}$ are the corresponding wheel displacement.

Following the rule of GB7031 (Yu 2000), the road surface spectrum can be represented by $2\pi S_q(n) n_0^2 v / \omega^2$.Based on the equation of motion (1) of a vehicle, the correlation matrix of the road excitation can be written as equation (3).

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