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# Microvibration control platform for high technology facilities subject to traffic-induced ground motion

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## Abstract

This paper investigates the possibility of using a microvibration control platform to isolate a batch of high tech equipment from the floor of a building subject to nearby traffic-induced ground motion. The governing equation of motion of the coupled platform–building system is derived in the absolute coordinate to facilitate the feedback control and performance evaluation of the platform based on the BBN vibration criteria with the absolute velocity being targeted. A hybrid control system composed of passive mounts and active hydraulic actuators with a sub-optimal control algorithm is designed to actively control the platform. Hydraulic actuator dynamics are also considered in the modelling of the control system to avoid possible instability of the platform. The performance of actively controlled platform is assessed through comparisons with the cases of the building without control, the building with passively controlled platform, and the building with passive base isolator. Simulation results indicate that passively controlled platform and passive base isolator can be effective in reducing microvibration of high tech equipment if their parameters are properly selected. The actively controlled platform is superior to the passively controlled platform and passive base isolator because of its high performance and robustness.


*Keywords:* Microvibration; High tech equipment; Actively controlled platform; Traffic-induced ground motion

## 1. Introduction

High tech equipment, such as that used for the production of semiconductors, integrated circuits, optical microscopes, and laser research systems, requires the building floor, on which the high tech equipment is installed, with extremely limited vibrations. For instance, the Bolt Beranek and Newman (BBN) vibration criteria [1,2] for high tech equipment take the form of a set of one-third octave band velocity spectra labelled with vibration criterion curves from VC-A to VC-E, which correspond to the allowable root mean square (rms) velocity descending from 50 to 3 μm/s within a frequency range between 8 and 80 Hz. This stringent microscale velocity restriction makes the control of microvibration of high tech equipment inside a building subject to traffic-induced ground motion different from the control of seismic response of building structures.

Using passive mounts (spring-damper systems) to isolate individual high tech equipment from floor vibration is a very common practice. However, microvibration reduction level using passive mounts is always limited due to the nature of passive control, and sometime there may be potential problems with static stability of equipment if passive mounts are too soft. To overcome this problem, hybrid control by coupling active actuators with passive mounts has recently been investigated by taking floor vibration as a direct base excitation [3–5]. Dynamic interaction between the hybrid control and the building, however, is not considered. Though this treatment may be adequate for a large building with limited amount of high tech equipment, it may not be sufficient and economic for a large building with a great amount of high tech equipment as evidenced in many modern high tech facilities.

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Recently, Yang and Agrawal [6] carried out an extensive theoretical study on the possible use of various protective systems for microvibration control of high tech facilities under horizontal traffic-induced ground motion in consideration of dynamic interaction between control and building. The protective systems they investigated included passive building base isolation, hybrid building base isolation, passive floor isolation, hybrid floor isolation, passive energy dissipation system, and active control system. They concluded that hybrid floor isolation could be the most effective and practical means in satisfying the design specification for microvibration of high tech equipment. Since the governing equation of motion of the building with protective systems was established in terms of relative motion to the ground in their investigation, the controller was designed based on the drift and relative velocity of the floor. The use of relative velocity as feedback to control the absolute velocity of the floor may not be consistent.

This paper aims to investigate the possibility of using a microvibration control platform to isolate a batch of high tech equipment from the floor of a building subject to nearby traffic-induced horizontal ground motion. The governing equation of motion of the coupled platform–building system is derived in the absolute coordinate to facilitate the feedback control and performance evaluation of the platform based on the BBN vibration criteria with the absolute velocity being targeted. A hybrid control system composed of passive mounts and actively controlled hydraulic actuators with a sub-optimal control algorithm is designed to actively control the platform. Hydraulic actuator dynamics are also considered in the modelling of the control system to avoid possible instability of the platform. The performance of actively controlled platform is assessed through comparisons with the cases of the building without control, the building with passively controlled platform, and the building with passive base isolator.

## 2. Governing equations of motion

Let us consider a three-storey shear building subject to a traffic-induced horizontal ground motion (see Fig. 1(a)). A horizontal platform is installed on the first floor of the building using either a passive mount (spring-damper system), as shown in Fig. 1(c), or a hybrid control system composed of a passive mount and an actively controlled hydraulic actuator, as shown in Fig. 1(d). The use of passive base isolator for microvibration control of the building is schematically shown in Fig. 1(b). It is noted that a batch of high tech equipment is supposed to be installed on the platform for the cases shown in Fig. 1(c) and (d) but on the first floor of the building for the cases shown in Fig. 1(a) and (b). Therefore, microvibration control performance is assessed in terms of the absolute velocity of the platform for the cases shown in Fig. 1(c) and (d) and the absolute velocity of the first floor of the building for the cases shown in Fig. 1(a) and (b).

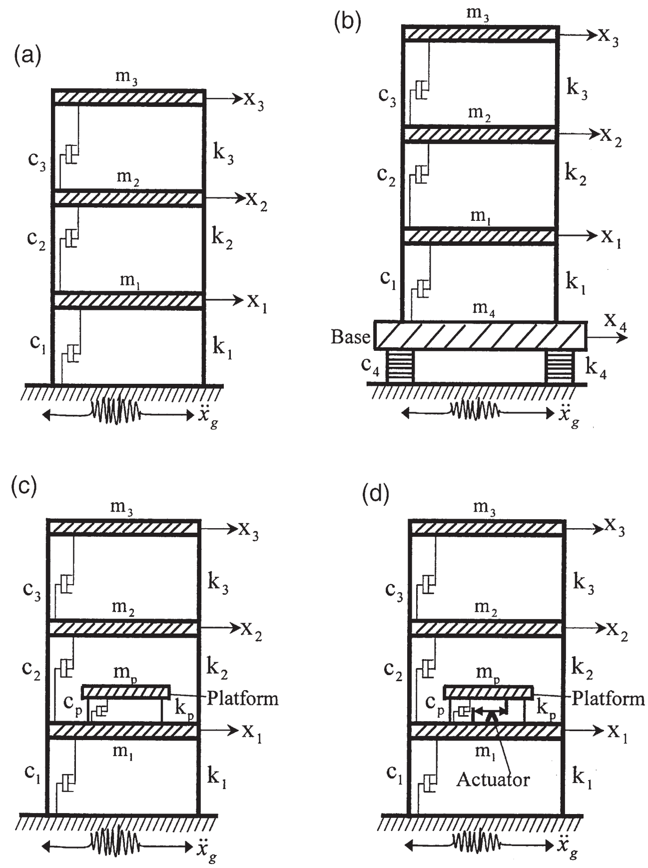


Fig. 1. Building models: (a) plain building; (b) building with base isolation; (c) building with passively controlled platform; and (d) building with actively controlled platform.

### 2.1. Equation of motion of building without control

In consideration that the feedback control and control performance evaluation of either the control platform or the first floor of the building are based on the absolute velocity as stipulated in the BBN vibration criteria, the governing equation of motion of the system is thus established in the absolute coordinate. For the building without any control device (see Fig. 1(a)), the equation of motion of the building under ground motion can be written as

$$\begin{bmatrix} m_1 & & \\ & m_2 & \\ & & m_3 \end{bmatrix} \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \end{Bmatrix}$$