Discussion of human resonant frequency

By James M. W. Brownjohn[1], Xiahua Zheng[2]

Abstract

Human bodies are often exposed to vertical vibrations when they are in the workplace or on vehicles. Prolonged exposure may cause undue stress and discomfort in the human body especially at its resonant frequency. By testing the response of the human body on a vibrating platform, many researchers found the human whole-body fundamental resonant frequency to be around 5 Hz. However, in recent years, an indirect method has been proposed which appears to increase the resonant frequency to approximately 10 Hz. To explain this discrepancy, experimental work was carried out in NTU. The study shows that the discrepancy lies in the vibration magnitude used in the tests. A definition of human natural frequency in terms of vibration magnitude is proposed.

Keywords

Human resonant frequency, bio-mechanics, whole-body vibration, vibration magnitude

Introduction

Vehicles (air, land and water), machinery (for example, in industry and agriculture) and human activities (e.g. people walking or dancing), expose human to mechanical vibration which can interfere with comfort, working efficiency and, in some circumstances, health and safety [(1)].

Vibration transmitted to the body as a whole through the supporting surface, namely, the feet of a standing man, the buttock of a seated man or the supporting area of a reclining man, is called whole-body vibration.

Many researches have been done to evaluate the human exposure to whole-body vibration. The main concern is the body's resonant frequency. At the resonant frequency there is maximum displacement between the organ and the skeletal structure, placing biodynamic strain on the body tissue involved. Knowledge of the resonant frequency of the human body could aid the design of industrial buildings and transport systems so that the exposure to vibration close to the body's resonant frequency may be

[1] Assoc. Prof., School of Civil & Structural Engineering, Nanyang Technological University, Singapore

[2] Research Student, School of Civil & Structural Engineering, Nanyang Technological University, Singapore

minimized [2].

Measurements of the whole-body resonant frequency can be made by three methods. With the apparent mass method Fairley and Griffin got the fundamental resonant frequency of the seated human body at about 5 Hz and a second mode broadly in the region of 10 Hz. For the standing human, they got 5.5Hz as the main resonance, with a second broad resonance in the range 9-14 Hz [3].

A second method introduced the concept of absorbed power (P_{Abs}) by a human during exposure to vertical whole-body vibration. They found that P_{Abs} was strongly related to the frequency of the vibration, peaking within the range of 4-6 Hz for the sitting posture. Griffin also found that the greatest absorbed power appeared at about 5 Hz [4].

More recently, an indirect method using the motion of a suspended beam has been reported. However, this method gave different results from the previous work. Ji et al measured the resonant frequency of a standing person in the range of 8 to 10 Hz [5]. Further work with this technique indicated a range of 10 to 12 Hz using four subjects and depending on the modal mass of the person [6]. Following this way, Randall et al got the overall range of resonant frequencies of standing humans from 9 Hz to 16 Hz and independent of mass, height and mass to height ratio. The mean values were 12.2 ± 0.1 Hz for males and 12.8 ± 0.2 Hz for females with an overall mean population value of 12.3 ± 0.1 Hz [2].

It has been found that the vibration magnitude has consistent effect on the human resonant frequency. Fairley and Griffin measured eight seated subjects with four magnitudes of vibration: 0.25, 0.5, 1.0 and 2.0ms^{-2} r.m.s., and found that the resonant frequency decreased from about 6 to 4 Hz when the magnitude of the vibration was increased from 0.25 to 2.0 ms^{-2} r.m.s.[7]. In the study of the standing human body, Matsumoto and Griffin suggested that the resonant frequency of the apparent mass in the normal posture decreased from 6.75-5.25 Hz with increasing vibration magnitude from 0.125 to 2.0 ms^{-2} r.m.s. [4].

This paper is going to make use of Ji's theory to identify human whole-body resonant frequency under vertical vibration and to try to explain the discrepancy between Ji et al's outcomes with the 'classical' determination in the aspect of vibration magnitude.

Methodology

The indirect method made use of a simple rectangular beam supported at the ends. The beam was vibrated in its fundamental mode with a single blow from a soft-headed hammer near its center. In order to obtain similar vibration level as in Griffin et al's tests, in this study the hammer was replaced by a shaker to provide higher and controllable vibration magnitude.

The process was repeated with a subject standing at the center of the beam (figure 1). In both cases the resonant frequency of the beam or the human-beam system was recorded, from which the resonant frequency of the subject might be deduced in the following way.

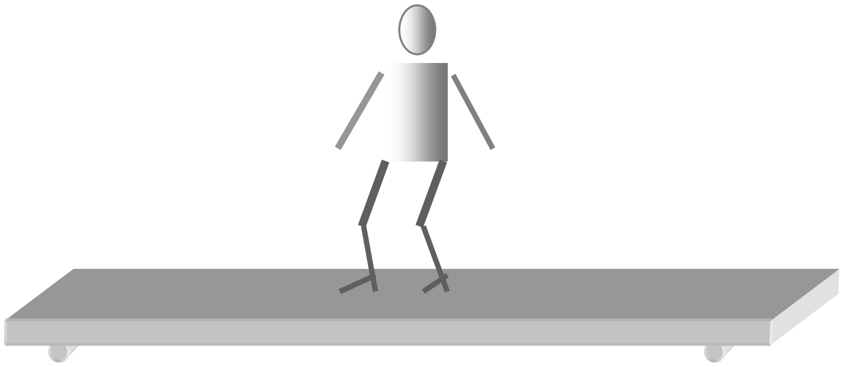

Figure 1 Indirect method setup

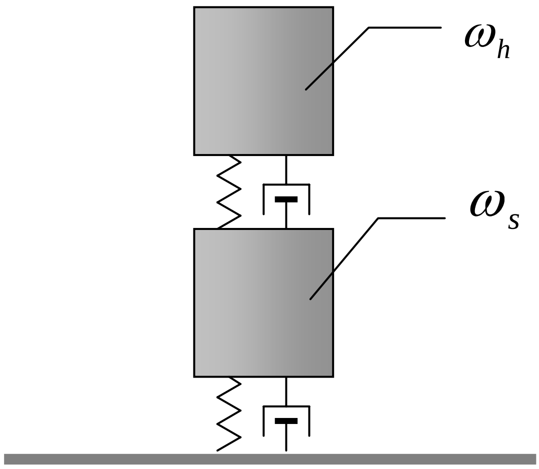

Figure 2 2DOF model

The human-structure system may be modeled by an undamped, 2 degrees of freedom model (figure 2), the human body and the structure is each a single DOF model respectively. Then Ji deduced three frequency relationships between the combined human-structure system (ω_1 and ω_2) and the independent human and structure systems (ω_s and ω_h).

$$\omega_1^2 + \omega_2^2 = \omega_s^2 + (1+\alpha)\omega_h^2 > \omega_s^2 + \omega_h^2$$

$$\omega_1 \omega_2 = \omega_s \omega_h$$

$$\omega_1 < (\omega_{s,}\omega_h) < \omega_2$$

where α =m_h/m_s

In this case, m_s refers to the modal mass of the beam [8].

The resonant frequency of the human may now be calculated from the equation

$$\omega_h^2 = \frac{\omega^2(\omega_s^2 - \omega^2)}{\omega_s^2 - (1+\alpha)\omega^2}$$

where ω is either ω_1 or ω_2. It can be seen that by measuring the frequency of the beam (ω_s) and of the system (ω) with the masses of the beam and human known (giving α), the resonant frequency of the human (ω_h) can be calculated [2].

Experimental setup

As shown in figure 3, an accelerometer and a shaker are connected to a dynamic signal analyzer (DSA). The human subject was placed at the mid-span of the slab.

Two concrete slabs and three human subjects were involved in this study.

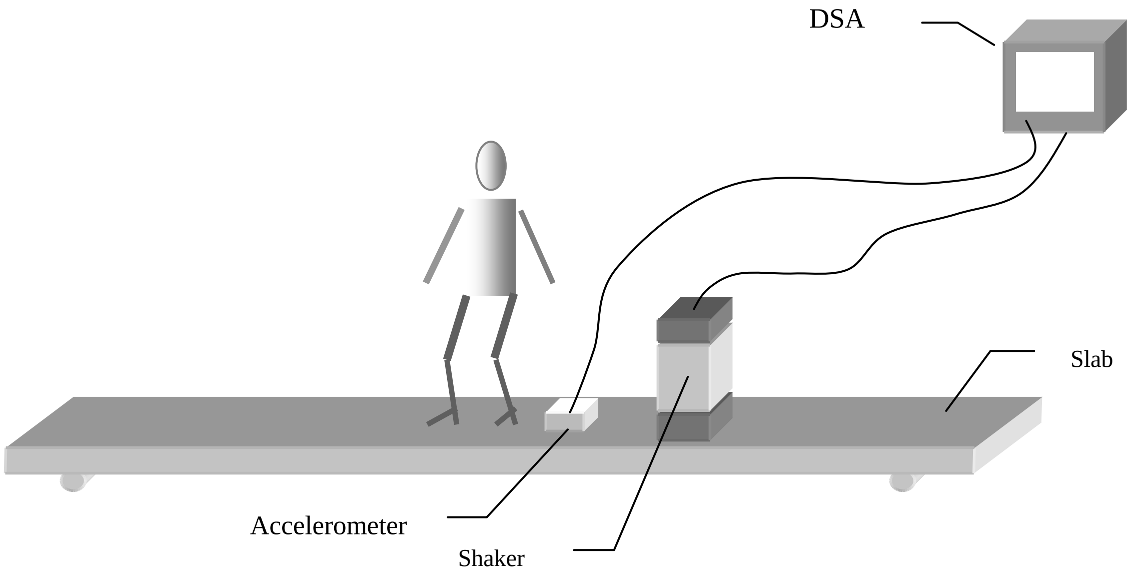

Figure 3 Experimental setup

Initially slabs B and C were tested to obtain their modal masses. Three human subjects were then tested standing upright and sitting on the slab. Their weights were also recorded.

Results

Table 1 shows that the human resonant frequencies of standing and sitting range from 3 to 5 Hz and the standing posture has slightly higher value than the sitting posture for each case.

The posture ‘stand stiff’ means the human subject stood on the slab and kept his muscle tensed as much as he could through out the test. It can be seen that the human with tensed muscle has higher resonant frequency than the normal relaxed posture.

Table 1 Human resonant frequency

Slab Modal Mass	Human Weight	Human Posture	Frequency (unoccupied)	Frequency (occupied)	Human Frequency
331kg	76kg	stand	7.03	7.62	4.78
331kg	76kg	sit	7.03	7.54	4.54
331kg	76kg	stand stiff	7.03	8.14	5.90
331kg	47kg	stand	7.05	7.42	4.73
331kg	47kg	sit	7.05	7.23	3.67
331kg	70kg	stand	6.80	7.30	4.53
331kg	70kg	sit	6.80	7.20	4.19
230kg	*70kg*	*stand*	*9.00*	*9.23*	*3.44*
230kg	*76kg*	*stand*	*9.00*	*9.28*	*3.62*

In these tests, the human bodies were subjected to obvious vibration induced by the shaker. The vibration magnitude was in the similar lever as in Griffin at al’s study. However, it is the only difference between Ji at al’s study and this study. This difference resulted in the decrease in the human resonant frequency comparing with Ji’s conclusion, but the data corresponds well with Griffin’s.

Conclusions

From the study of human resonant frequency, it can be seen that the discrepancy between Griffin et al and Ji et al’s study lies in the vibration magnitude which the human exposed to.

In Ji et al’s study, the vibration magnitude induced by the hammer is rather low and is negligible. This study followed Ji’s method but significant increased the vibration magnitude, consequently obtained the similar results as Griffin at al’s study, therefore testified Ji’s theory to be reasonable.

It has been known that the higher the vibration magnitude, the lower the detected human resonant frequency. Therefore, the definition of the human resonant frequency should refer to the vibration magnitude. This paper suggests that, for practical purpose where the vibration magnitude is higher than 0.1 ms^{-2} (such as in the study of earthquake and traffic), the human resonant frequency could be assumed in the range of 3 to 7 Hz.

No matter what the human posture is, the human body is able to damp the slab's vibration significantly. There is slight difference between various postures. If we refer to the muscle tension, it can be suspected that tensed postures can damp the vibration more effectively than the relaxed ones.

Reference

1. ISO 2631

2. J. M. Randall, R. T. Matthews and M. A. Stiles, 'Resonant frequencies of standing humans', Ergonomics, 40 (9), pp.879-886, 1997

3. Y. Matsumoto, M. J. Griffin, 'Dynamic response of the standing human body exposed to vertical vibration: influence of posture and vibration magnitude', Journal of Sound and Vibration, Vol. 212, No. 1, pp. 85-107, Apr 1998

4. N. J. Mansfield, M. J. Griffin, 'Effect of magnitude of vertical whole-body vibration on absorbed power for the seated human body', Journal of Sound and Vibration, Vol. 215, No. 4, pp. 813-825, Aug 1998

5. T. Ji, B. R. Ellis and M. Beak, 'Indirect measurement of human whole body frequencies', paper presented at the United Kingdom Informal Group on Human Response to Vibration at the Army Personnel Research Establishment, Farnborough, 20-22 September 1993

6. T. Ji, 'A continuous model for the vertical vibration of the human body in a standing position', Proceedings of the UK Group on Human Response to Vibration, Silsoe, 18-20 September 1995

7. T. E. Fairley and M. J. Griffin, 'The apparent mass of seated human body: vertical vibration', Journal of Biomechanics, Vol.22, No.2, pp.81-94, 1989

8. B. R. Ellis and T. Ji, 'Human-structure interaction in vertical vibrations', Structures and Building, Proceedings ICE, 122, pp.1-9, Feb 1997