INFRASTRUKTUR

RESPONSE OF THE HIGH FREQUENCY LONG-SPAN LIGHTWEIGHT FLOOR DUE TO HUMAN WALKING: HARMONIC RESPONSE ANALYSIS

Respon Lantai Bentang Panjang yang Memiliki Frekwensi Alami Tinggi terbuat dari Beton Ringan: Analisa Respon Harmonik

Atur P. N. Siregar
Jurusan Teknik Sipil, Universitas Tadulako, Jl. Soekarno Hatta Km. 9, Palu, Sulawesi Tengah, Indonesia (94118)
Email: atur_pns@yahoo.com

ABSTRACT

This paper is an investigation of high natural frequency long-spanlightweigtht floor subjected to dynamic footfall loading of human activities. This study was carried out to examine the vibration response of the high natural frequency long-span lightweight floor, when harmonic response analysis was applied. Acceleration root mean square (RMS) was used as a method to determine the vibration response of the high natural frequency long-span floor model. The parametric studies of natural frequency of 7 up to 20 Hz and damping ratio of 0.5% and 2% were employed to investigate the response of the model.Increasing damping ratio of the model was found to have a significant effect on reducing acceleration RMS. However, increasing natural frequency of the high natural frequency long-span lightweight floor model demonstrated to have an insensitive influence on the acceleration RMS.

Keywords: acceleration RMS, high natural frequency floor, harmonic response analysis

ABSTRAK

Tulisan ini merupakan investigasi terhadap lantai beton ringan dengan perletakan yang panjang dan memiliki frekuensi alami yang tinggi serta mengalami pembebanan akibat aktivitas manusia. Studi ini dilakukan dengan menentukan respon terhadap getaran yang terjadi pada lantai beton ringan tersebut dengan menggunakan pendekatan analisis respon secara harmonic. *Acceleration root mean square (RMS)* dipakai sebagai nilai untuk menentukan respon getaran lantai tersebut. Parameterik yang dipakai dalam uji ini adalah frekuensi alami dari lantai mulai 7 sampai 20 Hz dan damping ratio dari lantai dari 0.5% sampai 2%. Dari hasil uji tersebut diperoleh hasil bahwa peningkatan damping ratio dapat mereduksi secara signifikan percepatan RMS, akan tetapi peningkatan frekuensi alami dari lantai beton ringan menunjukan pengaruh yang tidak seignifikan pada percepatan RMS.

Kata kunci: *fly ash, microsilica, ternary cementitious system*

INTRODUCTION

Office or apartment building floors are subjected to the dynamic forces as a result of human activities such as walk, run, jump or dance. The last three activities are found where an office building contains facilities such as running tracks on roof, exercise room, dance floor, or gymnasia; even it is a small size. In corridors or long-span floors, running could be intended, but this will be likely occurring only in isolated instances.

The nature of floor vibrations in office and residential buildings are influenced by many factors such as configuration of partitions, furnishing, ceiling structures, load concentrations and geometric shapes of floor area. These factors do not only affect the mode shape and natural frequency of the floor, but also damping ratio. Rational calculation of vibration amplitudes induced by dynamic forces becomes complicated and uncertain.

Dynamic behaviour of long-span lightweight floors becomes important gradually for two different forms of loading. First, vibrations produced by walking people on the floor can give a discomfort result to other users on the same floor. Although this is a serviceability problem, it may be a lack of consideration in design and hence can be significant in occupant discomfort. Second, loads from dancing or exercise room may significantly subject to the vibration problem and, if resonance occurs, it may lead to safety problem as well as a serviceability problem. Either the designer can avoid the problem of resonance by producing a floor with a sufficient high-fundamental frequency or calculate the response of the floor with a specific-applied load with considering serviceability problem. This paper investigates the vibration response of the high frequency floor subjected to loads arisen from human walking.

CHARACTERISATION OF HUMAN WALKING-TYPE LOADS

The vertical accelerations of the body mass of the human are closely associated with reactions of the floor, which are periodic (sinusoidal) at the pace frequency. Therefore, fluctuation can be resolved as a series of sinusoidal components (i.e. a Fourier series), and the fundamental term is suggested to use as in Figure 1 (The SCI, 1989).

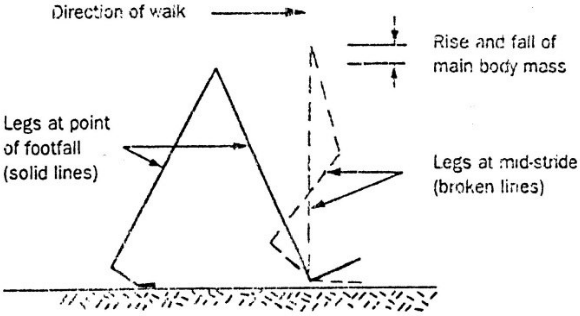

Figure 1. Simplified geometry of walking (The SCI, 1989)

The dynamic excitation proposed by the Steel Construction Institute (1989) is given as the sum of the concurrent foot forces of the walker. It is shown as a heavy solid curve in Figure 2. The original form of human walking can be resolved and approached as a series of sinusoidal components of Fourier series, Figure 2. The basic pace of frequency is clearly represented by the second Fourier component and it is representing excitation twice, is also important. The third component is smaller, and succeeding components can generally be ignored, except that there is a significant impulsive effect of very short duration as the footfall contacts the ground. Therefore, it has been suggested that the first three Fourier components of the walking load are primarily concern (Ellis, 2000). He described that the vertical loads produced by both feet during walking, in the mathematical description, will be similar to equation (1):

$$F_R(t) = G(0.5 + \sum_{m=1}^{\infty} R_m \sin(\frac{2m\pi}{T_p} t + \phi_m) \tag{1}$$

where:

$F(t)$is the time-varying load

G is the weight of the walker

M is the index of the Fourier term

R_m is the Fourier coefficient

$\phi_m$is the phase angle

MODELLING ASSUMPTION

An important feature of real walking loads is that they are not stationary in space. Only the most sophisticated analysis techniques, such as time domain finite element (FE) analysis, are capable of considering this loading characteristic. As a result, walking functions are frequently assumed to act as a single point on the structure, therefore give the highest response to the dynamic loading. Eriksson (1994) demonstrated that this simplification would not result in a severe loss of accuracy. However, Mourning and Ellington (1993) reported an overestimation of the calculated peak acceleration of 28% for stationary excitation, compared with the calculated equivalent of moving excitation. Furthermore, Pavic (1999) carried out a more detail study by applying three walking forcing functions to FE models of structures, which had also been dynamically tested. The performance of these walking forcing functions was assessed when both stationary dynamic and moving were applied. He found that the most reliable model for walking excitation was that proposed by Eriksson (1994), when it is applied as a stationary dynamic load as intended.

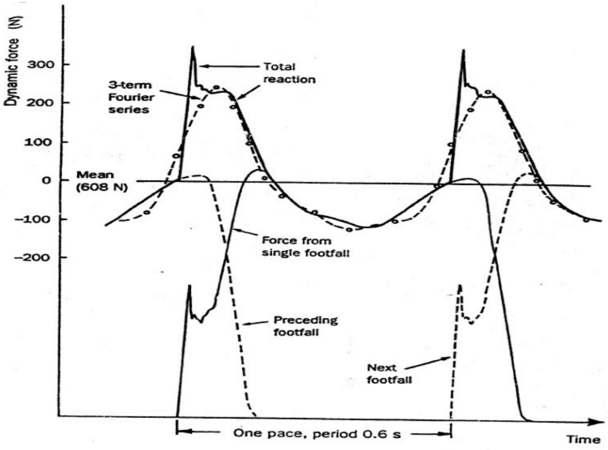

Figure 2. Footfall force and reaction on floor (The SCI, 1989)

To perform the work, it is necessary to select a commercial finite element package that is suitable for linear elastic modal and dynamic response analysis. The choice of a package is ANSYS since the ANSYS finite element software is widely use in the Mechanical and Aeronautical Engineering disciplines and has powerful linear dynamic analysis capabilities.

Since the interest of this study is on the response of the high frequency long-span floor due to human walking based on harmonic response analysis, the slab used in this study was a simply supported slab of 11 m length, 2 m width, 0.275 m depth, concrete density of 336.7 kg/m^3 and young modulus of the slab was varied from 15.55x10^9 up to 127 x10^{9}MPa. Using all those parameters, it would produce a model with a mass structure of 1000 kg. The model was varied its parameters in order to get the required fundamental natural frequency from 7 up to 20 Hz, although most of floors are found to have natural frequencies between 10 and 30 Hz (Steffens, 1966). On the other hand, the damping ratio of the floor was 0.5% and 2% as common value of damping ratio for floors in modern building and footbridge are between 0.002 and 0.02 (Pretlove*et al.*, 1995).

In the analysis, the slab is assumed as a beam that is modelled as a SDOF system with force applied centrally, as a point load (Figure 3).

Figure 3. SDOF model of the Slab

The modelling performed in this work was considered as linear elastic, a BEAM3 linear elastic element was then chosen. BEAM3 is a two dimensional elastic beam with three degree of freedoms (DOFs) at each nodes.

HARMONIC RESPONSE ANALYSIS

Harmonic response analysis is a technique used to determine the steady-state response of linear structure to loads that varies in a sinusoidal manner with time. The idea is to calculate the structure's response at several frequencies and obtain a graph of some response quantity (displacement, velocity and acceleration) versus frequency. Response of the structure and the peak responses are then identified on the graph (**Figure 4**).

A typical frequency response function (FRF) of the SDOF model having natural frequency 16 Hz and damping ratio 0.5% that is applied as a harmonic excitation at the middle span of the model can be seen in **Figure 5**.

The peak RMS acceleration ($\ddot{a}_{peak}$) of the model is 0.1 m/s^2. Therefore, the $\ddot{a}_{RMS}$ is 5.66 m/s^2 and the RMS acceleration ($\ddot{a}_{RMS}$) of models related to parametric studies that are used in this study can be seen in **Table 1**.

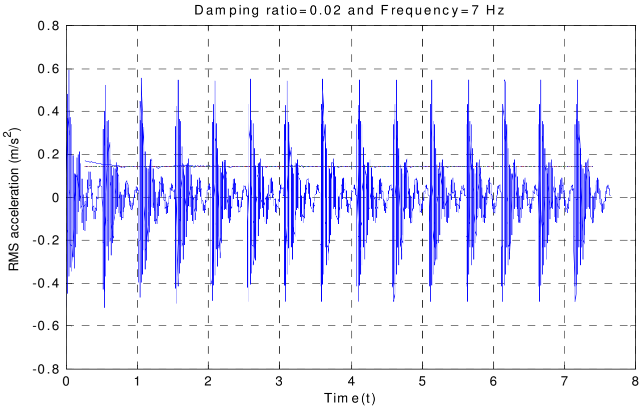

Figure 4.Time history response of the model with damping ratio of 2% and natural frequency of 7 Hz

The effect of damping ratio to the floor can be seen on Figure 6 and the response of the floor with increasing the fundamental natural frequency is determined on **Figure 7**.

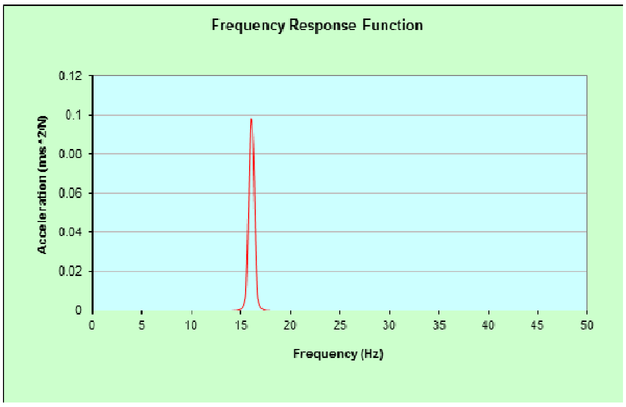

Figure 5. Frequency response function of the SDOF model havingnatural frequency of 16 Hz and damping ratio of 0.5%

RESULT AND DISCUSSION

a. Effect of Damping Ratio on High Frequency Floor Response

Figures 6 illustrate the influence of damping ratio on a high frequency model (high frequency floor) response caused by human walking. It shows that the damping ratio strongly affects the structure response, which the higher increase in damping ratio, the less response of the structure occurs. Thus, damping ratio is a factor to examine the vibration acceptability of the high frequency floor.

Table 1. RMS acceleration of SDOF models

Frequency (Hz)	RMS Acceleration (m/s^2)	
	Damping Ratio 0.5%	Damping Ratio 2%
7	5.66	1.414
8	5.66	1.414
9	5.66	1.414
10	5.66	1.414
11	5.66	1.414
12	5.66	1.414
13	5.66	1.414
14	5.66	1.414
15	5.66	1.414
16	5.66	1.414
17	5.66	1.414
18	5.66	1.414
19	5.66	1.414
20	5.66	1.414

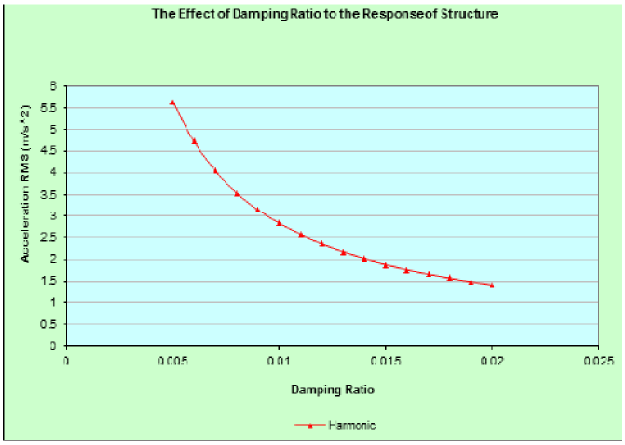

Figure 6.The effect of damping ratio on high frequency model

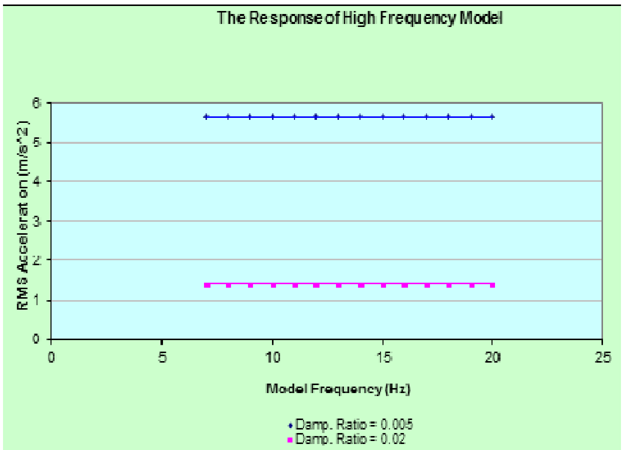

Figure 7. The response of the high frequency model

In harmonic analysis, the response, which is RMS acceleration, is calculated from the single point, i.e. the peak value of Frequency Response Function (FRF) of model using following equation (Thomson, 1993) instead of using finite element analysis:

$$\ddot{a}_{peak} = \frac{1}{2\xi m} \qquad (m/s^2/N)$$

where

$\ddot{a}_{peak}$ is peak value of FRF of the model

m is modal mass

ξ is damping ratio

This Equation shows that the response (RMS acceleration) mostly depends on modal mass (m) and damping ratio (ξ). In this case, the model has the same modal mass, i.e. 1000 kg but it varied in its damping ratio from 0.5% to 2%. Thus, the damping ratio becomes the most factors influencing the response of the model. Moreover, the response establishes only on a single point of the Frequency Response Function, which is the peak response. As a consequence, the damping ratio increase causing the response of the model is very sensitive.

b. Effect of Stiffness on the Model (High Frequency Floor Response)

Figure 6 points out that as higher damping ratio of the structure, the less response would occur when it analysed using harmonic analysis. However, there is no effect on the model response while increasing its natural frequency. Equation (2) can be used to describe that phenomenon. As can be seen, the system response, which is analysed with harmonic analysis, depends only on modal mass (m) and damping ratio (ξ). Natural frequency of the model is not involved in the Equation (2) so that the increment of natural frequency does not influence the response of the system. It can be concluded that response of a system is not influenced by its stiffness if it is analysed using harmonic analysis. Therefore, harmonic analysis is very sensitive analysis to the damping ratio but not for natural frequency of the system.

CONCLUSIONS

This paper presents a method for calculating the response of floors subjected by human walking using harmonic analysis. The main conclusions drawn from this study are as follows:

1. The higher increase in damping ratio, the less response of the high frequency floor occurs.
2. Increment of natural frequency of the floor in harmonic analysis does not influence its response.

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