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MEASUREMENT OF THE NATURAL FREQUENCY AND DEFLECTION OF THE WIDESPAN-FLOOR SYSTEM DUE TO DYNAMIC LIVE LOAD

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ABSTRACT: Study on the natural frequency of a floor-structural system is a key parameter to determine how the floor system will respond to forces causing vibrations. Measurement of frequency and displacement of the floor system was the focus of this research. The main objective of this investigation is to develop a boundary of the natural frequency of the floor system for the widespan building. The observation was conducted for two different human activity that is walking (during graduation ceremony) and dancing (during live music). The results of the study shows that the frequency of floor system due to human walking activity was measured between 3.54 to 5.32, while, rhythmic dance and jumping activity yields the frequency between 4.17 to 5.08 Hz. At the range of the measured frequency, the human walking induced maximum deflection of the floor about 1.76 to 7.81 mm. The deflection is double about 15.36 to 33.18 mm when 30 to 35 peoples were dancing/jumping in unison in response to live music.

Keywords: Human activity, Vibrations, Natural frequency, Displacement, Widespan floor

1. INTRODUCTION

High strength concrete (HPC) has a valuable contribution to design a high-rise building such as an auditorium, convention hall, exhibition hall, sports hall, and other building which has a widespan floor. The typical of widespan floor is supported with long-span beams, and the column spacing is far enough. Although, the dimensions of the structure elements are strong enough to support the static load and earthquake load. However, the system has a tendency to decrease the natural frequency of the building. Furthermore, the decreasing can result in a resonance of natural frequency and dynamic live load. This situation should be paid attention of the researchers and structural engineers.

In Indonesia, a widespan-floor structure was commonly designed subjected to a static load. Bachmann et al. [1] (1995) mentioned that the fundamental frequency of the widespan-floor system of due to static loads ranges between 4.5 to 5.5 Hz. Floor vibration induced by human activation e.g. walking, running, jumping, were very complex problems [2]. Sensitivity within each occupancy also varies with duration of vibration and remoteness of the source. The natural frequencies of most floors are greater than 3 Hz (they often fall between 4 Hz and 8 Hz) [3]. When the floor was subjected to a rhythmic load such a group of people were dancing for more than 20 seconds, people apply repeated forces to the floor, ranging from 2 to 3 Hz. This frequency was known as the step frequency. For dancing, resonance occurs if the natural frequency of the floor is between 2 and 3 Hz [4]. Allen [5] reported a case history of vibration problems of the concrete buildings that the natural frequency of dance floor was about 2.9 Hz. Bachman [6] proposed a design criterion for floor-structural system of prestressed concrete that the minimum fundamental frequency shall not be lesser than 7.0 Hz. General criteria for design required that the fundamental frequency shall be double or more of the frequency of dynamic load due to rhythmic human activities. Mast [7] observed that the natural frequency of the wide precast prestressed concrete slab was 4.2 Hz when served as stadium floor system.

Study on the natural frequency of a floor-structural system is necessary to determine how the floor system will respond to forces causing vibrations, and determining how human occupants will perceive the vibrations. It has been found that certain frequencies set up a resonance with internal organs of the human body, making these frequencies more annoying to people. The main objective of this research is to develop a boundary of the natural frequency of the floor system for widespan building. In the principles of the dynamic design, the frequency resonant of the dynamic live load and building's natural frequency have to be avoided. Hence result of the research

Fig.1 Front view and side view of the Graha Sabha Pramana building

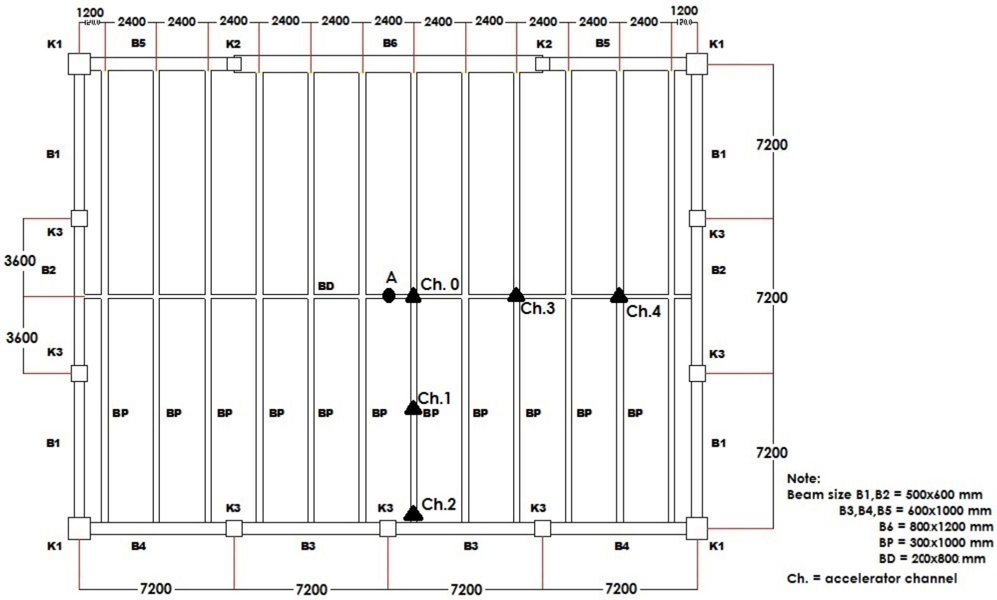
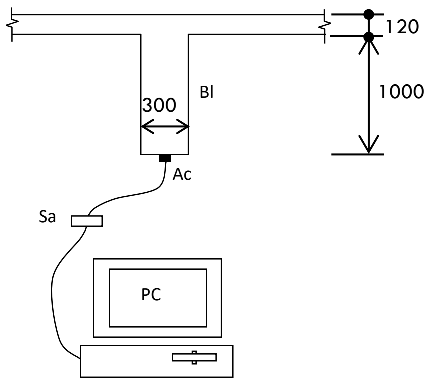


Fig. 2 The plan of the floor structure and the installation point of accelerometer



B1 : the floor/beam structure
Ac : Accelerator
Sa : Sensor Amplifier
PC : Personal Computer + A/D Convertion Card PCL-812G

Fig. 3 The arrangement diagram of observation station at floor structure

can contribute to a new building code for dynamic loading limits especially for wide span floor concrete structure.

2. RESEARCH METHOD

Measurement of frequency and displacement of the floor system was the focus of this research. A widespan-floor building of Graha Sabha Pramana Auditorium in Gadjah Mada University was observed (Fig. 1).

A series of accelerator was installed at some points of the floor structure as illustrated in Fig. 2. The slab thickness was 120 mm. The accelerator (Ac) was used to measure acceleration, velocity, and displacement of a point. Amplifier sensor (Sa) was additionally placed to strengthen the signal response from the accelerator. The sensor was connected to a personal computer which was equipped with A/D Conversion Card PCL-812G (see Fig. 3). The signal was monitored and processed by using PC-SCOPE. This software can display the vibration during the test period. Figure 3 and 4 shows the arrangement of the sensor and the picture of the installation at the beam. The observed frequency was analysed by Fast Fourier Transform (FFT) using FFTSCOPE. The results of FFT analysis were maximum amplitude and frequency.

The observation was conducted for two different live load patterns. The first was live statics load which was measured during the graduation ceremony. At this situation, the floor was loaded by about more than 1000 persons who were approximately a hundred tonnes of live load. In general, the duration of graduation ceremony was about two hours. At this stage, the human activity was walking. The second type of the live load was a dynamic pattern. The loading was modeled by a cohort of students who was jumping and dancing during the live music. The cohort of students was about 30-35 persons (equivalent to 1.8 – 2.1 tonnes in total). The duration of live music was about 10-15 minutes. The observed area during dancing was limited on the size of 4 x 4 m^2.

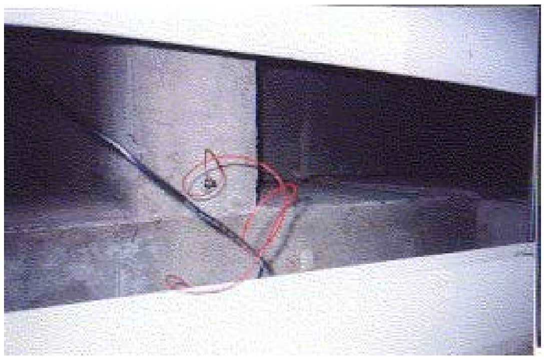


Fig.4 The situation of the sensors arrangement at the floor/beam structure

The measurements were conducted as four times for walking activity, and two times for dancing activity. During the graduation ceremony, the observed point was at the centre of the floor (see point A in Figure 1). Meanwhile, the frequency of the floor was measured at five points (see Figure 1, i.e. channel 0, channel 1, channel 2, channel 3, and channel 4) for dancing activity.

3. RESULTS AND DISCUSSION

3.1 Effect of the human activity on natural frequency

A typical of the spectrum from the observed point to determine the maximum amplitude and frequency is shown in Fig. 5. Then, the frequency of the observed points was recorded during the graduation ceremony and dancing activity. Figure 6 and 7 shows the distribution of the measured natural frequency of the floor structure due to

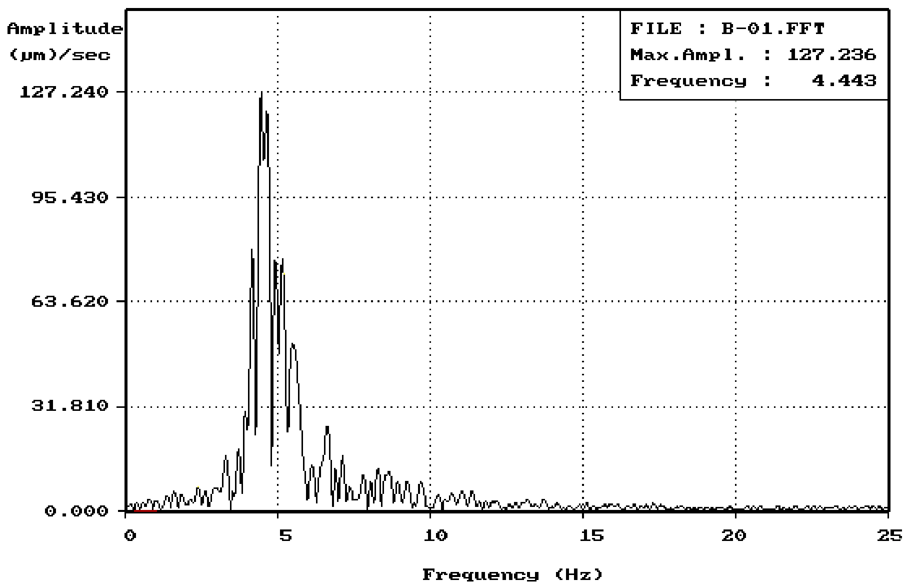


Fig. 5 The typical frequency spectrum obtained from a measured point

human walking and dancing activities respectively. The distribution can be approached by a normal distribution probability function as shown in full-line and dashed line in Fig. 6. Each observation was recorded by two sensors (i.e. Obs.1 and Obs.2 in Fig. 6) to control the quality of the results.

The results from Fig. 6 show that the frequency of floor system due to human walking activity was measured between 3.54 to 5.32. While from Fig. 7, the frequency induced by rhythmic dance and jumping activity range between 4.17 to 5.08 Hz. Table 1 summarises the average measured frequency of floor system for each observation. The measured frequency of the floor-structural system due to walking and dancing activities, in general, range from 4.46 to 4.76 (see Table 1). This results deal with the range given by Bachmann et al. [1], Allen [3], and close to the result from Mast [7] for precast prestressed concrete slab.

In the principles of vibration, the natural frequency of a vibrating floor system and the beam is determined by the ratio of its stiffness to its mass (or weight). In the most textbook give formulas for the natural frequency that are unfamiliar to most structural engineers who deal with static loads [7]. However, in this research, the weight of live load seems to be uncorrelated with natural frequency of the floor system. But, Allen [3] indicated that the frequency was influenced by the acceleration and type of human activity on the floor.

3.2 Effect of the human activity on maximum displacement

The serviceability of a structural element is commonly defined by the deflection of the element. The deflection is an indicator of the comfortability of occupancy. Table 1 summarise the average maximum displacement at the middle of the floor due to human walking activity. The measured maximum displacement ranges from 1.76 to 7.81 mm. Based on Table 1, it indicates that the deflection of the floor is a function of the weight of the live load. A traditional stiffness criterion for concrete floors limits the live load deflection of beams or girders supporting "plastered ceilings" to span/360 [8]. Hence, the limit of deflection of the observed floor shall be lesser than 30 mm, if the length floor structure is 10.8 m. Then, the floor system is acceptable for human walking activity.

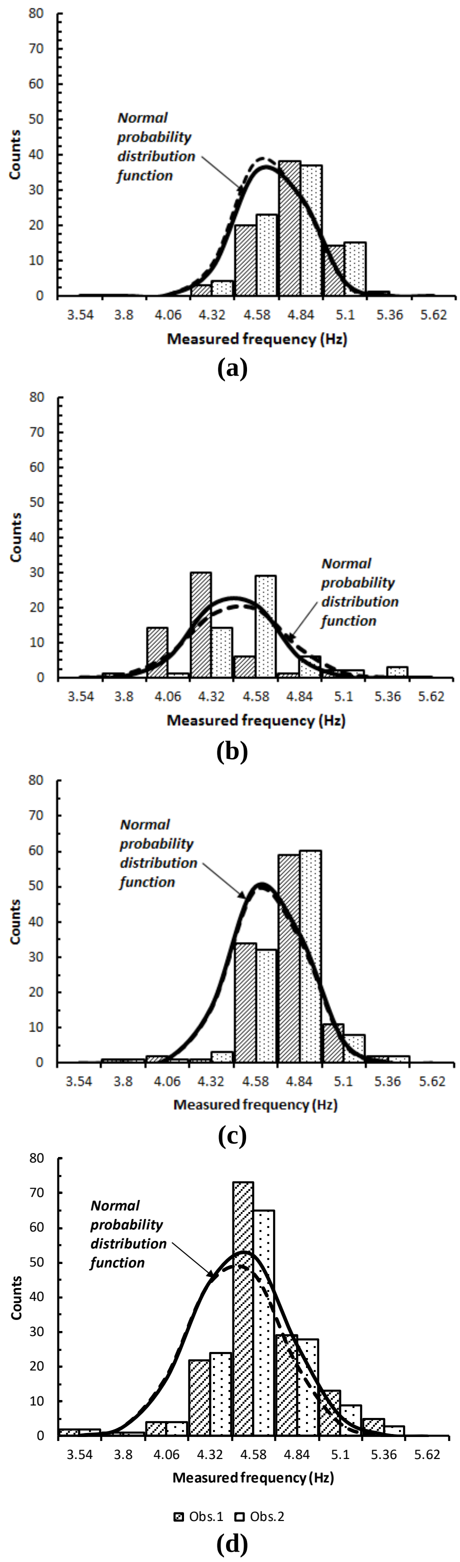


Fig. 6 The distribution of the measured frequency at the centre of floor due to static live load (a) 1st observation, (b) 2nd observation, (c) 3rd observation, (d) 4th observation

Table 1 Average measured frequency and maximum displacement of the floor structure due to human walking rhythmic during graduation ceremony

Observation	W (tons)	f (Hz)		Measured δ_{max} (mm) at				
		Mean	Std.Dev	Ch.0	Ch.1	Ch.2	Ch.3	Ch.4
a. Human activity: walking (graduation ceremony) :								
1st: 19 May 2001	108 (1800)	4.67	0.197	6.86	-	-	-	-
2nd: 20 August 2001	117 (1951)	4.46	0.248	7.81	-	-	-	-
3rd: 20 May 2002	72 (1200)	4.65	0.214	2.69	-	-	-	-
4th: 19 August 2002	80 (1342)	4.48	0.281	2.64	-	-	-	-
b. Human activity: dancing & jumping (live music)								
1st	1.8 (30)	4.76	0.169	15.36	11.77	0.022	0.061	0.214
2nd	2.1 (35)	4.51	0.227	33.18	-	-	-	-

Note: W = estimated weight live load, Number in ( ) is the total number of persons, f = measured frequency, $\boldsymbol{\delta_{max}}$ = maximum displacement, Ch. = Channel

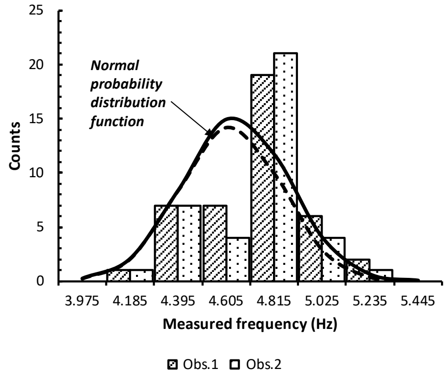


Fig. 7 The distribution of the measured frequency at the centre of the floor due to rhythmic dance.

Table 1 presents the maximum deflection of the floor structure due to dancing/jumping activity. As shown in Fig. 2, the deflection at the middle of the floor (Channel 0) is maximum and then decrease gradually to the near edge of the floor (Channel 2 and Channel 4). The highest deflection at the centre of the floor was 15.36 mm after first observation. At this remark, a number of persons were 30 students, who were dancing and jumping in unison in response to live music. After the 2nd observation, which were 35 students dancing/jumping, the maximum deflection is 33.18 mm. The results are alluding to conclude that the deflection is double when the floor induced by rhythmic human activity. The possible reason, it was attributable by the resonance of the frequency of dancing/jumping and frequency of floor. Mast [7] mentioned that it had been found that people have difficulty synchronising their jumping at frequencies greater than 3 Hz.

4. CONCLUSION

The results of the study shows that the frequency of floor system due to human walking activity was measured between 3.54 to 5.32, while, rhythmic dance and jumping activity yields the frequency between 4.17 to 5.08 Hz. The deflection is an indicator of the comfortability of occupancy. At the range of the measured frequency, the human walking induced maximum deflection of the floor was about 1.76 to 7.81 mm. The floor system is acceptable for human walking activity if it is designed using the traditional stiffness criteria. However, the deflection is double about 15.36 to 33.18 mm when 30–35 peoples were dancing/jumping in unison in response to live music.

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