Investigation of Hollow Core Slab Floor Vibration due to Human Activities

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ABSTRACT
Modern architecture and construction design, leading floor system to have longer spans, lighter weight, and lower damping. However, it can cause a floor system to have excessive vibration. Vibration on the floor system is the second most frequent source of complaints from building occupants. Hollow Core Slab (HCS), are precast concrete floor elements widely used nowadays in multiple construction buildings. HCS has the advantage of lightweight and prestressed that makes the possibility to create long-span floors that are in line with modern construction design. In this study, we research the HCS floor's vibration behavior and its compliance with the minimum standards for serviceability criteria. The test is carried out by giving an impact loads using the impact test method. The accelerometer sensor used to measure the vibration that occurs. The test is carried out on two treatments, first on simply supported HCS, and the second is HCS supported to the beam with a shear connector. The test location is on a two-story parking building with several variations in the floor dimension, and the HCS thickness is 150 mm. This research shows that all of the floor's natural frequency meets the minimum frequency requirement, 3 Hz. Some floor's natural frequency had gotten in the human body's sensitive frequency range 4-8 Hz. The majority of the slabs have low-frequency floor categories. The natural frequency tends to be higher if the span of floors is smaller, and the natural frequency tends to be higher on HCS supported to the beam using a shear connector.

Keywords: *Hollow Core Slab, precast slab, vibration, floor serviceability, impact test.*

1. INTRODUCTION

Modern architecture and construction design, leading floor system to have longer spans, lighter weight, and lower damping. However, it can cause a floor system to have excessive vibration. Vibration on the floor system is the second most frequent source of complaints from building occupants [1].

Various things can cause vibration on the floor, one of them is human rhythmic activities. It is well-known that most disturbing vibrations related to human perception are in the range of 4 to 8 Hz, and at the same time, most of the natural frequencies of floor systems are in this range [2-5]. Excitation frequency due to human rhythmic activities is in the same range as well. So, the resonance phenomenon can be occurred and causing a higher vibration response to the floor system. [2-5].

Hollow Core Slab (HCS), are precast concrete floor elements that are widely used nowadays in multiple construction buildings, like multi-story buildings, offices, parking garages, and apartments. HCS have longitudinal voids and prestressed using steel strands along the full length. Void area of the slab makes HCS have lighter weight than reinforced concrete slab, and prestressing makes the load capacity of the slabs is increased, which

two of them is the advantage of this type of floor slabs [6]. The combination of the lighter weight and prestressing makes the possibilities to create long-span floors.

1.1. Related Work

According to the floor vibration response, several research has previously been conducted on various precast and prestressed floor systems.

Rahimi et al. [9] have researched the HCS floor system's ambient vibration response using finite element modeling and experimental test. The thickness of the HCS is 265 mm + 75 mm of reinforced concrete topping. The result is that the floor classified as a low-frequency floor, and the floor's serviceability is weak. Liu et al. [10] research the vibration behavior of composite slab with precast ribbed panels due to transient impact. The research shows that CSPRP has lower peak accelerations, and stiffer than RC slabs under transient impacts. Zhou et al. [11] research the vibration serviceability of a prestressed concrete floor system under human activity. The results show that the floor system found to have a low frequency and modal damping ratio. The floor system's peak acceleration response is lower than the acceleration threshold value given in The China's Code [12] and the AISC design guide [5]. The floor system exhibits good vibration perceptibility overall.

1.2. Our Contribution

This paper presents an experimental study on a two-story building to determine the vibration behavior of prestressed precast HCS floors on two types of treatment, which is on simply supported HCS to beam and HCS supported to the beam using a shear connector.

1.3. Paper Structure

The rest of the paper organized as follows. Section 1 introduces the preliminaries used in this paper, and Section 2 presents a guide summary of a floor vibration design, structural floor details, and the experimental test of HCS to get the natural frequency of the floor. Section 3 concludes the paper and presents directions for future research.

2. BACKGROUND

2.1. Floor Vibration Design Guide Summary

There are several design guides regarding to floor vibration serviceability such as American Institute of Steel Construction Design Guide Series 11: *Vibration of Steel-Framed Structural Systems Due to Human Activity* [5], SCI P354: *Design of Floors for Vibration: A New Approach* [7], PCI MNL-126-15E: *Manual for the Design of Hollow Core Slabs and Walls* [13], and the Concrete Center: *A Design Guide for Footfall Induced Vibration of Structures* [8]. Based on AISC DG11 [5], the most disturbing vibrations related to human perception are in the range of 4 to 8 Hz (Figure 1), so if the natural frequency of floor systems are in this range, resonance phenomenon can be occurred and causing a higher vibration response to the floor system. [2-5]. Based on SCI P354 [7] and PCI MNL-126-15E [13], floor and floor systems with natural frequencies lower than 3 Hz are not recommended because people may more readily synchronize their actions at lower frequencies. Based on SCI P354 [7], and the Concrete Center [8], both divide the floor systems into two types, which are low-frequency floors and high-frequency floors. The low-frequency floors are floor systems that have a natural frequency below 10 Hz. To check the serviceability criteria, steady-state and transient response analysis are required. The High-frequency floors are floor systems with a natural frequency above 10 Hz, and to check the serviceability criteria, only transient analyses are required.

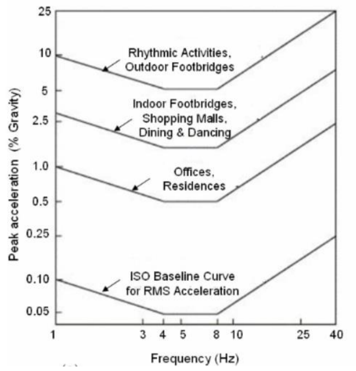

Figure 1 Recommended peak acceleration levels acceptable for human comfort in different environments based on AISC DG11.2.2. Structural Floor Details

A two-story building constructed using steel I-Beam and I-Column. The thickness of the HCS is 150 mm, with various spans. The building consisted of a span of 8,3 m x 26 m.

There are two test scenarios carried out, first on a floor slab that simply supported by an HCS, and on an HCS that supported to the beam using a shear connector. The plan of the first test scheme is shown in Figure 2. Then the plan of the second test scheme is as shown in Figure 3.

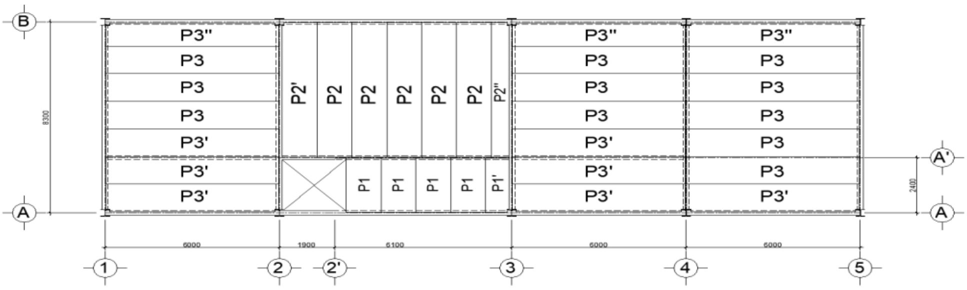

Figure 2 Test scheme layout of simply supported HCS.

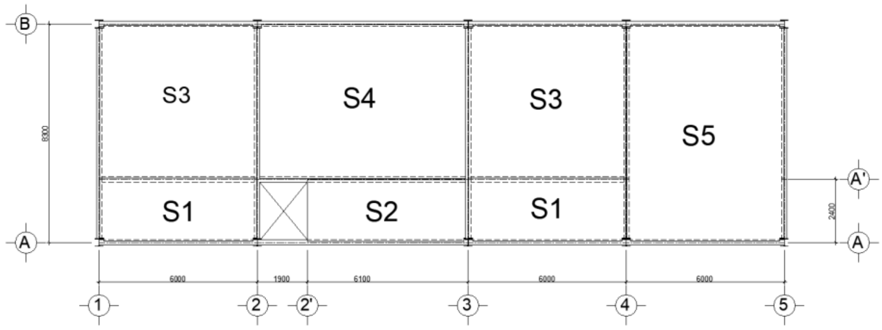

Figure 3 Test scheme layout of HCS supported to the beam using a shear connector.

2.3. Experimental Test

The test is carried out using the impact test method to see the floor's natural frequency value. The impact test is carried out three times at each test point. To read the frequency value, an accelerometer is used, which is placed on the floor slab. The location of the impact test is the same as the location of the accelerometer. The accelerometer placement location is as shown in Figure 4 (a) and (b).

This floor is categorized as General floors, open plan offices etc., from [7, 8], so the low to high-frequency cut-off is 10 Hz.

The test results from each point on the floor are recapitulated. The results of the simply supported HCS test are presented in Table 1, Table 2, and Table 3.

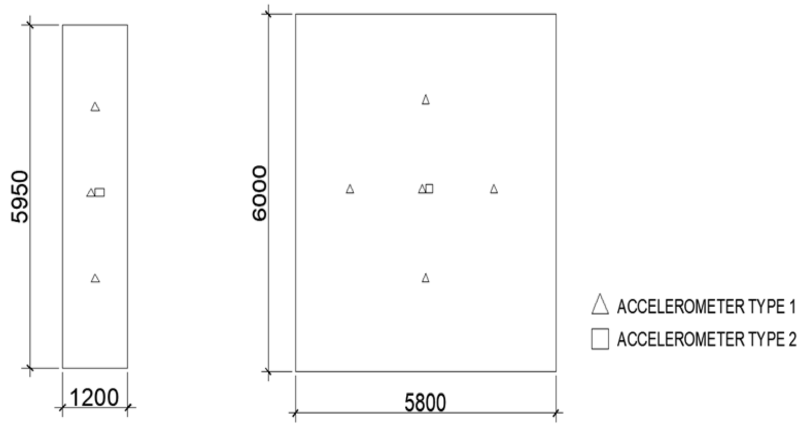

Figure 4 (a) Location of accelerometers of simply supported HCS, and (b) Location of accelerometers of HCS supported to the beam using a shear connector.

Table 1 Natural frequency of simply supported HCS and frequency differences to similar floor width

Floor Size	Frequency	Span Ratio To Similar floor Width	Frequency Differences
(cm)	(Hz)		(%)
P1' (235X60)	14,8	1	-
P2" (585X60)	9,16	2,43 (P1')	-38%
P1 (235X120)	17,11	1	-
P2 (585X120)	9,14	2,43 (P1)	-47%
P2' (585X120')	9,15	2,43 (P1)	-47%
P3 (595X120)	8,93	2,53 (P1)	-48%
P3' (595X120')	7,76	2,53 (P1)	-55%
P3" (595X100)	8,14	-	-

Table 2 Simply supported HCS on the low-frequency floor to high-frequency floor cut-off

Floor Size	Frequency	Low-Frequency Floor to High-Frequency Floor Cut-Off	Note
(cm)	(Hz)	(Hz)	
P1 (235X120)	17,11	10	HFF
P1' (235X60)	14,8	10	HFF
P2 (585X120)	9,14	10	LFF
P2' (585X120')	9,15	10	LFF
P2" (585X60)	9,16	10	LFF
P3 (595X120)	8,93	10	LFF
P3' (595X120')	7,76	10	LFF
P3" (595X100)	8,14	10	LFF

Table 3 Natural frequency of simply supported HCS compared to SCI P35, PCI MNL126-15E, and AISC DG11

Floor Size	Frequency (Hz)	Minimum Floor Frequency [7,13]	Note	Sensitive Human Response [5]	Note
(cm)	(Hz)	(Hz)		(Hz)	
P1 (235X120)	17,11	3	Ok	4 - 8	Ok
P1' (235X60)	14,8	3	Ok	4 - 8	Ok
P2 (585X120)	9,14	3	Ok	4 - 8	Ok
P2' (585X120')	9,15	3	Ok	4 - 8	Ok
P2" (585X60)	9,16	3	Ok	4 - 8	Ok
P3 (595X120)	8,93	3	Ok	4 - 8	Ok
P3' (595X120')	7,76	3	Ok	4 - 8	Not Ok
P3" (595X100)	8,14	3	Ok	4 - 8	Ok

Based on the test results on an HCS supported to the beam using a shear connector, the natural frequency values were obtained from 7.76-17.11 Hz with various floor slab size variations. Table 1 shows that the floor's natural frequency tends to be lower if the span of the floor is longer. For example, on P2" which has 2,43 times longer span to P1', the frequency has 38% lower, from 14,8 Hz on P1' to 9,16 Hz on P2".

Based on Table 3, all the natural frequencies meet the minimum frequency requirement of floors higher than 3 Hz [7,13], but on P3', the floor has the same frequency on the most sensitive human response of vibration [5]. So, on P3' floor, if any vibration occurs on the floor, the human body will have a higher response to the vibration and probably can cause resonance if the vibration type is continuous vibration [2-5].

Based on Table 2, two of the floor slab have been categorized as a high-frequency floor (P1 and P1'), and the other slab is categorized as a low-frequency floor.

The results of the simply supported HCS test are presented in Table 4, Table 5, and Table 6.

Table 4 Natural frequency of HCS supported to the beam using a shear connector and frequency differences to similar floor width

Floor Size	Frequency	Span Ratio To Similar Floor Width	Frequency Differences
(cm)	(Hz)		(%)
S1 (600X240)	14,85	1	-
S2 (610X240)	14,9	1,01 (S1)	0,34%
S3 (600X560)	9,19	1	-
S4 (800X560)	7,95	1,3 (S3)	-13%
S5 (830X600)	8,44	-	-

Table 5 HCS supported to the beam using a shear connector on low-frequency floor to high-frequency floor cut-off

Floor Size	Frequency	Low-Frequency Floor to High-Frequency Floor Cut-Off	Note
(cm)	(Hz)	(Hz)	
S1 (600X240)	14,85	10	HFF
S2 (610X240)	14,9	10	HFF
S3 (600X560)	9,19	10	LFF
S4 (800X560)	7,95	10	LFF
S5 (830X600)	8,44	10	LFF

Table 6 Natural frequency of HCS supported to the beam using a shear connector compared to SCI P35, PCI MNL126-15E and AISC DG11

Floor Size	Frequency (Hz)	Minimum Floor Frequency [1-2]	Note	Sensitive Human Response [3]	Note
(cm)	(Hz)	(Hz)		(Hz)	
S1 (600X240)	14,85	3	Ok	4 - 8	Ok
S2 (610X240)	14,9	3	Ok	4 - 8	Ok
S3 (600X560)	9,19	3	Ok	4 - 8	Ok
S4 (800X560)	7,95	3	Ok	4 - 8	Not Ok
S5 (830X600)	8,44	3	Ok	4 - 8	Ok

Based on the test results on an HCS supported to the beam using a shear connector, the natural frequency values were obtained from 7.95-14.85 Hz with various floor slab size variations. Table 4 shows that the floor's natural frequency tends to be lower if the span of the floor is longer. For example, on S4 with 2,43 times longer span to S3, the frequency has 13% lower, from 9,19 Hz on S3 to 7,95 Hz on S4.

Based on Table 5, all the natural frequencies meet the minimum frequency requirement of floors higher than 3 Hz [7,13], but on S4, the floor has the same frequency on the most sensitive human response of vibration [5]. So, on the S4 floor, if any vibration occurs on the floor, the human body will have a higher response to the vibration and probably can cause resonance if the vibration type is continuous vibration [2-5].

Based on Table 6, two of the floor slab have been categorized as a high-frequency floor (S1 and S2), and the other slab is categorized as a low-frequency floor.

3. CONCLUSION

In this research, there were eight-floor size variations on the simply supported HCS, and five-floor size variation on an HCS supported the beam using a shear connector. The test is conducted with an impact test. It was found that the value of the natural frequency of HCS floors, varying based on the spans of the floor, the width of the floor, and the supporting. All the floor's natural frequency is to meet the minimum frequency requirement, which is 3 Hz based on SCI P354 [7] and PCI MNL-126-15E [13]. Some floors natural frequency got in the sensitive frequency range of the human body 4-8 Hz based on AISC DG11 [5]. The majority of the floors have low-frequency floor categories based on SCI P354 [7] and the Concrete Center [8]. The natural frequency tends to be higher if the span of floors is smaller, and the natural frequency tends to be higher too on HCS supported to the beam using a shear connector.

4. RECOMMENDATIONS

There are some parameter and variation of HCS floors that can be researched for further research by:

- Conduct other test methods to know more parameters, like peak acceleration, velocity, etc., to fulfill the codes requirement for serviceability criteria.
- Add other variation of supporting or finishing of the floors
- Conduct research on other HCS floors thickness
- More standard can be used and compared
- Create finite element modeling to verification the test result
- Compare the test results to other floor systems, like reinforced concrete floors, steel deck floors, composite floors, etc.
- Conduct vibration research on other types of building floor.

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REFERENCES

[1] Zhou, X.H., Li, J., & Liu, J. (2016). Vibration of prestressed cable RC truss floor system due to human activities. Journal of Structural Engineering, 42, 04015170. DOI: https://doi.org/10.1061/(ASCE)ST.1943-541X.0001447

[2] Campista, Fernanda & Santos da Silva, José Guilherme. (2018). Vibration analysis of steel–concrete composite floors when subjected to rhythmic human activities. Journal of Civil Structural Health Monitoring. 8. DOI: https://doi.org/10.1007/s13349-018-0303-6.

[3] Campista, Fernanda & Santos da Silva, José Guilherme. (2017). Dynamic Analysis of Steel-Concrete Composite Building Floors Subjected to Human Rhythmic Activities. ce/papers. 1. 4000-4009. DOI: https://doi.org/10.1002/cepa.456.

[4] Setareh, Mehdi. (2012). Evaluation and assessment of vibrations owing to human activity. Proceedings of the ICE - Structures and Buildings. 165. 219-231. DOI: https://doi.org/10.1680/stbu.10.00016.

[5] Murray, T.M., Allen, D.E., Ungar, E.E, (2016). Floor Vibrations due to Human Activity, Steel Design Guide Series, American Institute of Steel Construction, AISC, Chicago, USA.

[6] Monisha, K. M., & Srinivasan, G. (2017). Experimental Behaviour of Prestress Hollow Core Slab, Rc Hollow Core Slab and Normal Rc Solid Slab. International Journal of Engineering and Technical Research (IJETR), Vol. 4(4), 1090–1093.

[7] Smith AL. (2009) Design of Floors for Vibration: A New Approach. London: The Steel Construction Institute.

[8] Willford MR, Young P. (2006). A Design Guide for Footfall Induced Vibration of Structures. London: The Concrete Center.

[9] Rahimi, Muhammad & Abd Ghafar, Nor Hayati & Mohd Jaini, Zainorizuan. (2020). Ambient Vibration Response of Precast Hollow Core Flooring System. International Journal of Engineering and Advanced Technology. 9. 2393-2367. DOI: 10.35940/ijeat.C5747.029320.

[10] Liu, Jiepeng & Huang, Shu & Li, Jiang & Chen, Y.. (2019). Vibration Behavior of Composite Slab with Precast Ribbed Panels due to Transient Impact. International Journal of Structural Stability and Dynamics. 19. DOI: 10.1142/S0219455419501487.

[11] Xuhong Zhou, Jiepeng Liu, Liang Cao & Jiang Li (2016): Vibration serviceability of prestressed concrete floor system under human activity, Structure and Infrastructure Engineering, DOI: 10.1080/15732479.2016.1229796

[12] Lou, Y., Huang, J., & Lv, Z.C. (2012). 楼板体系振动舒适度设计 [Vibration serviceability design of floor system]. Beijing: Science Press.

[13] PCI. (2015). PCI Manual for the Design of Hollow Core Slabs. In PCI Hollow Core Slab Producers Committee.