Fundamental Natural Frequency of Chromite Composite Floor System

Farhad Abbas Gandomkar, Mona Danesh

***Abstract*—**This paper aims to determine Fundamental Natural Frequency (FNF) of a structural composite floor system known as Chromite. To achieve this purpose, FNFs of studied panels are determined by development of Finite Element Models (FEMs) in ABAQUS program. American Institute of Steel Construction (AISC) code in Steel Design Guide Series 11 presents a fundamental formula to calculate FNF of a steel framed floor system. This formula has been used to verify results of the FEMs. The variability in the FNF of the studied system under various parameters such as dimensions of floor, boundary conditions, rigidity of main and secondary beams around the floor, thickness of concrete slab, height of composite joists, distance between composite joists, thickness of top and bottom flanges of the open web steel joists, and adding tie beam perpendicular on the composite joists, is determined. The results show that changing in dimensions of the system, its boundary conditions, rigidity of main beam, and also adding tie beam, significant changes the FNF of the system up to 452.9%, 50.8%, -52.2%, %52.6%, respectively. In addition, increasing thickness of concrete slab increases the FNF of the system up to 10.8%. Furthermore, the results demonstrate that variation in rigidity of secondary beam, height of composite joist, and distance between composite joists, and thickness of top and bottom flanges of open web steel joists insignificant changes the FNF of the studied system up to -0.02%, -3%, -6.1%, and 0.96%, respectively. Finally, the results of this study help designer predict occurrence of resonance, comfortableness, and design criteria of the studied system.

***Keywords*—**Fundamental natural frequency, chromite composite floor system, finite element method, low and high frequency floors, comfortableness, resonance.

I. Introduction

DETERMINING of natural frequency in a structure is crucial for two reasons; firstly, from a design viewpoint, for instance, prediction about occurrence of resonance conditions on the structure, and secondly, to obtain forced response of the structure [1]. In this case, knowing about FNF of any structural floor system is an essential issue, because prediction about occurrence of resonance, comfortableness, and design criteria of any floor system is performed by its FNF. The Steel Construction Institute (SCI)-P354 proclaims that FNF of any floor system must be greater than 3 Hz in order to guarantee that the walking activities are not within the range which leads to resonant or near-resonant excitation of the basic mode of floor vibration [2]. According to the AISC, Wyatt in 1983 and Wright et al. in 1989 stated that floors with FNF greater than 7 Hz are comfortable for users. Ohlsson in 1988 suggested a new criterion for the light-weight floor and proposed the mentioned floor not be designed with FNF lower than 8 Hz. However, Bachman and Ammann in 1987 suggested the minimum FNF equal to 9 Hz for construction of concrete slab-steel framed floors. In the North America, steel framed office buildings are usually constructed with FNF between 5-9 Hz and they are comfortable to users [3]. The evaluation of comfortableness of floors is not considered to be satisfactory by controlling FNF only. In floors with FNF greater than the above-mentioned FNFs, vibration still exists when occupants carry out activities. It is important to assess those vibrations and to compare them with limiting values, even though the floor has a high FNF. In line with Middleton and Brownjohn in 2010, there is little energy in the higher harmonics after four harmonics of a walking force (approximately 10 Hz). A floor is considered as High Frequency Floor (HFF) if its FNF is above 10 Hz. But, it is known as a Low Frequency Floor (LFF) if it is dominated by resonance from the first four harmonics of a walking force [4]. In the case of design criteria of a floor system, the AISC [3] recommended an acceleration limit for LFFs and HFFs with a minimum static stiffness of 1 kN/mm under concentrated load as an additional check for HFFs. Therefore, categorization of a floor system as LFF or HFF is an important issue.

In the last few decades, numerous studies were carried out on determining dynamic characteristics of structural floor systems with a special focus on their natural frequencies. In recent studies, Ferreira and Fasshauer in 2007 performed a free vibration study on a composite plate using an innovative numerical method. Results of the study were determined and discussed for different thickness-to-length ratios [5]. Ju et al. in 2008 developed a new composite floor system (consisting of steel beams and concrete slab) and measured its natural frequencies and damping ratios via experimental tests for three different construction steps; steel erection stage, concrete casting stage, and finishing stage. They compared the results with codes to evaluate serviceability of the proposed floor system [6]. Xing and Liu in 2009 derived natural frequencies of a rectangular orthotropic plate using an exact solution of mathematical equations for three different boundary conditions [7]. Gandomkar et al. in 2011 measured natural frequencies of an innovative composite floor system known as Profiled Steel Sheet Dry Board (PSSDB), experimentally and numerically [8]. In another study, Gandomkar et al. focused on determining natural frequencies of the PSSDB system with concrete infill (PSSDBC). In the both mentioned studies,

Farhad Abbas Gandomkar is with the Department of Civil, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran (Corresponding author, phone: 00986133348356; Fax: 00986133348356; e-mail: Farhad@iauahvaz.ac.ir).

Mona Danesh is with the Department of Civil, Institute of Higher Education ACECR Khouzestan, Ahvaz, Iran (e-mail: mona_danesh69@yahoo.com).

effects of various parameters were determined on changing FNFs of the PSSDB and PSSDBC systems [9]. Hashim et al. in 2013 measured dynamic characteristics of damaged and undamaged concrete slab. They compared natural frequencies and mode shapes of both mentioned slabs and found that the natural frequencies of damaged slab were lower than the natural frequencies of undamaged slab up to 53% [10]. Zhang et al. in 2013 presented a study on the measurement of modal frequencies, modal shapes, and damping of a new timber floor system known as metal web engineered timber joists. They determined experimentally the vibrational performances of the system for various conditions of the floor system and presented some important factors which increase FNF of the system [11]. Neves et al. in 2014 determined natural frequencies and modes vibration of a composite steel-deck floor system in a multi-story multi-bay building. They utilized the natural frequencies of the system to evaluate its comfortableness [12]. da Silva et al. in 2014 evaluated acceleration of a steel-composite floor system to predict its comfortableness. For this purpose, they estimated natural frequencies and mode shapes of the studied panels with real spanning of 40m by 40m [13]. In 2015, Jarnero et al. determined natural frequencies, damping ratios, and mode shapes of a prefabricated timber floor system, experimentally. They found results under various boundary conditions and different stages of construction [14]. Devin et al. in 2015 revealed effect of non-structural partitions on modal properties of a concrete slab floor system. They compared the natural frequencies of the proposed floor with partitions and the bare floor. They found that partition can increase FNF of the floor system by 30% [15].

The main aim of this paper is determining the FNF of the Chromite floor system. The studied system is illustrated in Fig. 1. As it is shown in Fig. 1, the system is consisting of a concrete slab and composite joists. The composite joist is consisting of open web steel joist and concrete.

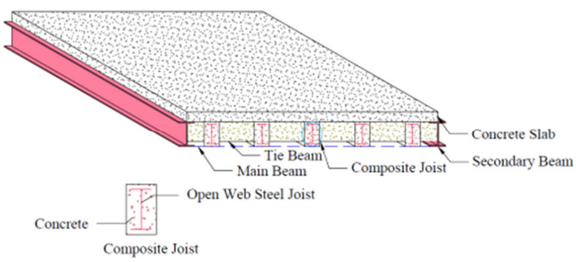

Fig. 1 The Chromite floor system

To achieve the main aim of the paper, effect of various parameters on changing FNF of the studied system is revealed. These parameters are: i) dimensions of the studied system, ii) boundary conditions, iii) rigidity of main and secondary beams, iv) rigidity of the floor system, and v) using tie beam perpendicular on the composite joists. In addition, the studied panels are categorized to predict occurrence of resonance, comfortableness, and design criteria in them.

II. Structural Model

The structural model of the studied system is depicted in Fig. 2.

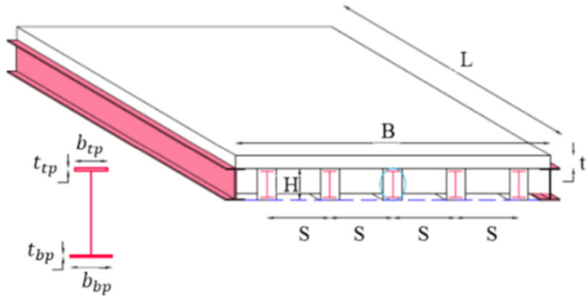

Fig. 2 Structural model of the Chromite floor system

Dynamic Young's modulus of the materials was adopted as input of the FEMs. According to the AISC [3], the dynamic Young's modulus for steel can be chosen similar to its static value [16], i.e. 2.10×10^5MPa. In this study, grade 30 concrete was used. In accordance with BS 8110 [17], the static Young's modulus of concrete was determined as 24597 MPa for grade 30 concrete. Pavic et al. in 2001 reported that according to some researchers, the dynamic modulus of elasticity of concrete is recommended as the static modulus with increasing by 10%-25% [18]. On the other hand, da Silva et al. in 2003 discussed that according to the AISC [3] in situations where the composite slab is subjected to dynamic excitations concrete becomes stiffer than the case when it is subjected to pure static loads. This issue suggests a 35% increase in the Young's modulus of the conventional concrete [19]. Therefore, in this study a 33206 MPa dynamic modulus of elasticity was adopted for grade 30 concrete. The Poisson's ratios were adopted as 0.3 for steel and 0.2 for concrete. Also, the density of steel and concrete were chosen 7850 kg/m^3 and 2273 kg/m^3, respectively.

III. Computational Model

The FNF of the studied system was determined by development of FEMs in ABAQUS finite element computer program [20]. In this study, undamped natural frequencies of the system are uncovered by using the "Block Lanczos" method. In the FEMs, the concrete slab and also top and bottom plate of open web steel joist were assigned by S4R element. In addition, concrete of composite joist and also tie beam were represented by C3D8R element. In the end, the main and secondary beams were modeled by B31 element [20].

IV. Verification Study

The AISC in Steel Design Guide Series 11 [3] presents a fundamental formula to calculate FNF of a simply supported steel framed floor system. This formula is presented in:

$$f = \frac{\pi}{2}\sqrt{\frac{gEI}{WL^4}} \tag{1}$$

where f: FNF (Hz); g: acceleration of gravity ($9.806^{m}/_{s^2}$); E: modulus of elasticity of steel; I: transformed moment of inertia; W: uniformly distributed weight per unit length (actual, not design, live and dead loads) supported by the member; L: member span.

In the case of verification study, results of the FEMs were compared with results calculated by (1). For this purpose, a panel of the Chromite floor system (Panel Number 1 (PN1)) was developed in ABAQUS computer program. Fig. 3 shows FEM of the PN1. Also, characteristics of the PN1 are presented in Table I. In addition, boundary conditions of the PN1 are depicted in Fig. 4.

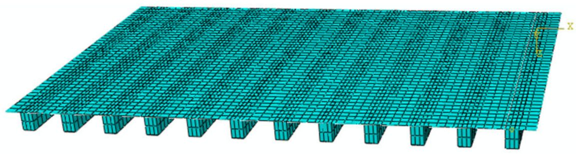

Fig. 3 Finite element model of the PN1

TABLE I
THE CHARACTERISTICS OF THE PN1

Panel Name	L (M)	B (m)	t (m)	H (m)	S (m)	b_{bp} (m)	b_{tp} (m)	t_{bp}, t_{tp} (m)	Main Beam	Secondary Beam	Number of tie beam	B.C
PN1	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.1

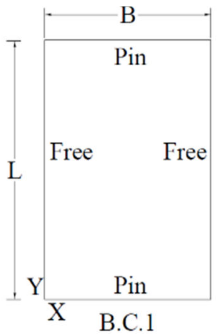

Fig. 4 The boundary conditions of the PN1

As a result, FNF of the PN1 was determined 36.384 Hz and 36.44 Hz by the finite element method and (1), respectively. Therefore, error of the finite element method was calculated by 0.15%. The mentioned error shows that the developed FEM can predict the FNF of the system with high accuracy.

V. Results and Discussion

To achieve the main purpose of the study, 28 models were developed by ABAQUS computer program with considering five various boundary conditions (Fig. 5). The supports had been considered in situation of the columns at the corners of floor and were different (B.C.2-B.C.6 in Fig. 5) depends on the way of connection between floor and column. The characteristics of the studied models are presented in Table II.

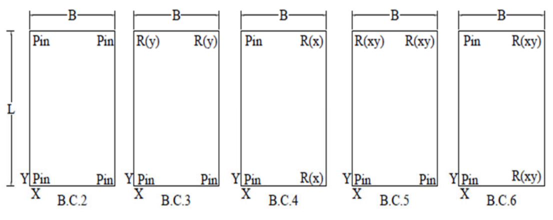

Fig. 5 The boundary conditions of the studied panels, R(y): Roller (y), R(x): Roller (x), R(xy): Roller (xy)

To achieve the main aim of the paper, the effect of various parameters on changing FNF of the system is revealed. The FNFs of the studied panels are presented in the following sub-sections (A-E) and Tables III-VI.

The status of the studied panels about occurrence of resonance, comfortableness, and design criteria are presented in column (a), (b), and (c) of the mentioned tables, respectively. To predict about occurrence of resonance, comfortableness, and design criteria of the studied panels, their FNFs are compared with declarations of the SCI-P354 [2], the AISC [3] according to Bachman and Ammann, and the AISC [3], respectively.

A. Effect of Dimensions of Floor Panel

The effect of dimensions of the floor panel on its FNF is presented in Table III. The results demonstrate that increasing and decreasing in both length and width of the system, decrease and increase the FNF of the system, respectively. It is shown that the width of the panel plays an effective rule on changing its FNF. So that, resonance occurs in the PN8 which has large width; but all other studied panels are safe in the case of resonance. In addition, all studied panels are uncomfortable for users and are in the category of LFF, except the PN6 and PN7 which have small widths. The mentioned panels are comfortable for users and are in the category of HFF.

B. Effect of Boundary Conditions

Table IV presents the effect of boundary conditions on changing FNF of the studied system. As it is shown in the table, the type of boundary conditions shows much effect on changing FNF of the system. In addition, the results show that resonance not occurs in the all studied panels. Moreover, all studied panels are shown uncomfortable for users and are in the category of LFF.

C. Effect of Rigidity of Main and Secondary Beams

The effect of rigidity (size) of the main and secondary beams on changing FNF of the studied system is shown in Table V. The results uncover that the FNF of the system significantly increases when the size of the main beam increases. However, alteration in the size of the secondary beam not varies the FNF of the system considerably. The resonance not occurs in the all studied panels except a panel with small size of the main beam (PN13). Also, all the studied panels are in the category of LFF and are uncomfortable for users.

TABLE II
THE CHARACTERISTICS OF THE STUDIED PANELS

Panel Name	L (M)	B (m)	T (m)	H (m)	S (m)	b_{bp} (m)	b_{tp} (m)	t_{bp}, t_{tp} (m)	Main Beam	Secondary Beam	Number of tie beam	B.C
PN2	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN3	2	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN4	6	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN5	8	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN6	4	2	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN7	4	4	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN8	4	8	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN9	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.3
PN10	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.4
PN11	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.5
PN12	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.6
PN13	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE14	IPE24	0	B.C.2
PN14	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE18	IPE24	0	B.C.2
PN15	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE27	IPE24	0	B.C.2
PN16	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE14	0	B.C.2
PN17	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE18	0	B.C.2
PN18	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE27	0	B.C.2
PN19	4	6	0.07	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN20	4	6	0.09	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN21	4	6	0.11	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN22	4	6	0.05	0.22	0.4	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN23	4	6	0.05	0.22	0.6	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN24	4	6	0.05	0.20	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN25	4	6	0.05	0.25	0.5	0.14	0.05	0.005	IPE24	IPE24	0	B.C.2
PN26	4	6	0.05	0.22	0.5	0.14	0.05	0.003	IPE24	IPE24	0	B.C.2
PN27	4	6	0.05	0.22	0.5	0.14	0.05	0.007	IPE24	IPE24	0	B.C.2
PN28	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	1	B.C.2
PN29	4	6	0.05	0.22	0.5	0.14	0.05	0.005	IPE24	IPE24	2	B.C.2

TABLE III
EFFECT OF DIMENSIONS OF SYSTEM ON ITS FNF AND STATUS

Panel Name	FNF (Hz)	PD (%)	Status of studied panels		
			(a)	(b)	(c)
PN2	5.2271	0	Ok	Failed	LFF
PN3	8.4027	60.7	Ok	Failed	LFF
PN4	4.3056	-17.6	Ok	Failed	LFF
PN5	3.6673	29.8	Ok	Failed	LFF
PN6	28.903	452.9	Ok	Ok	HFF
PN7	11.24	115	Ok	Ok	HFF
PN8	2.9703	-43.2	Failed	Failed	LFF

PD: Percent of Difference, (a) Occurrence of resonance [2], (b) Comfortableness of panels for occupants [3], (c) Categorization of system as LFF or HFF [3]

TABLE IV
EFFECT OF BOUNDARY CONDITIONS OF SYSTEM ON ITS FNF AND STATUS

Panel Name	FNF (Hz)	PD (%)	Status of studied panels		
			(a)	(b)	(c)
PN2	5.2271	0	Ok	Failed	LFF
PN9	6.4604	23.6	Ok	Failed	LFF
PN10	5.2278	0.013	Ok	Failed	LFF
PN11	6.4606	23.6	Ok	Failed	LFF
PN12	7.8817	50.8	Ok	Failed	LFF

PD: Percent of Difference, (a) Occurrence of resonance [2], (b) Comfortableness of panels for occupants [3], c) Categorization of system as LFF or HFF [3]

TABLE V
EFFECT OF RIGIDITY OF MAIN AND SECONDARY BEAMS ON FNF AND STATUS OF SYSTEM

Panel Name	FNF (Hz)	PD (%)	Status of studied panels		
			(a)	(b)	(c)
PN2	5.2271	0	Ok	Failed	LFF
PN13	2.4961	-52.2	Failed	Failed	LFF
PN14	3.3813	-35.3	Ok	Failed	LFF
PN15	6.2357	19.3	Ok	Failed	LFF
PN16	5.2259	-0.02	Ok	Failed	LFF
PN17	5.2263	-0.015	Ok	Failed	LFF
PN18	5.2272	0.002	Ok	Failed	LFF

PD: Percent of Difference, (a) Occurrence of resonance [2], (b) Comfortableness of panels for occupants [3], (c) Categorization of system as LFF or HFF [3]

D.Effect of Rigidity of Floor

Table VI demonstrates the effect of four various parameters on changing FNF of the studied system. These parameters are: thickness of concrete slab, height of concrete joists, distance between concrete joists, and thickness of top and bottom flange of open web steel joist. The results show that the FNF of the system increases up to 10.8% by increasing thickness of concrete slab. But changing other mentioned parameters not show significant effect on changing FNF of the system. Also, width of the top and bottom flanges of the open web steel joist not change the FNF of the system significantly, therefore mentioned widths not vary in the Table II. In addition, the results show that resonance not occurs in the all studied panels. However, all of them are in the category of LFF and are uncomfortable for users.

TABLE VI
EFFECT OF RIGIDITY OF FLOOR ON ITS FNF AND STATUS

Panel Name	FNF (Hz)	PD (%)	Status of studied panels		
			(a)	(b)	(c)
PN2	5.2271	0	Ok	Failed	LFF
PN19	5.2161	-0.2	Ok	Failed	LFF
PN20	5.4203	3.7	Ok	Failed	LFF
PN21	5.792	10.8	Ok	Failed	LFF
PN22	4.908	-6.1	Ok	Failed	LFF
PN23	5.4775	4.8	Ok	Failed	LFF
PN24	5.3367	2.1	Ok	Failed	LFF
PN25	5.0686	-3	Ok	Failed	LFF
PN26	5.2774	0.96	Ok	Failed	LFF
PN27	5.1772	-0.95	Ok	Failed	LFF

PD: Percent of Difference, (a) Occurrence of resonance [2], (b) Comfortableness of panels for occupants [3], (c) Categorization of system as LFF or HFF [3]

E. Effect of Using Tie Beam

The tie beam may use as additional element in the Chromite floor system. Using this element increases both stiffness and mass of the system, therefore, prediction about increasing or decreasing in the FNF of the system is not conceivable. The results show when one tie beam added in the middle of the span of the PN2, the FNF increases by 25%, from 5.2217 Hz to 6.5285 Hz. Also, by adding two tie beams in 1/3 and 2/3 of the span of the PN2, the FNF increases by 52.6%, from 5.2217 Hz to 7.9773 Hz. Therefore, using tie beam in the Chromite floor system increases its FNF significantly.

VI. CONCLUSION

This paper reveals the FNF of the Chromite floor system under various conditions. The results demonstrate that changing in dimensions, boundary conditions, rigidity of main beam, and also using tie beam changes the FNF of the studied system, significantly. In addition, variation in thickness of concrete slab, rigidity of secondary beam, height of composite joist, distance between composite joists, and thickness of top and bottom flanges of the open web steel joists insignificant changes the FNF of the system. The results of this study help designer to predict occurrence of resonance, comfortableness, and design criteria of the studied panels.

REFERENCES

[1] W. Soedel, “Vibrations of shells and plates,” New York: Marcel Dekker, 2004.
[2] The Steel Construction Institute (SCI-P354), *Design of floors for vibration: A new approach*, UK, 2007.
[3] American Institute of Steel Construction, *Floor vibration due to human activity: 11th Steel Design Guide Series,* Chicago, USA, 1997.
[4] C. J. Middleton and J. W. W. Brownjohn, “Response of high frequency floors: A literature review,” *Engineering Structures*, vol. 32, pp. 337-352, 2010.
[5] A. J. M. Ferreira and G. E. Fasshauer, “Analysis of natural frequencies of composite plates by an RBF-pseudospectral method,” *Composite Structures*, vol. 79, pp. 202-210, 2009.
[6] Y. K. Ju, D. Y. Kim, S. D. Kim, S. W. Yoon, Y. K. Lee, and D. H. Kim, “Dynamic characteristics of the new composite floor system,” *Steel Structures*, vol. 8, pp. 347-356, 2008.
[7] Y. F. Xing and B. Liu, “New exact solutions for free vibrations of thin orthotropic rectangular plates,” *Composite Structures*, vol. 89, pp. 567-574, 2009.
[8] F. A. Gandomkar, W. H. Wan Badaruzzaman, S. A. Osman, and A. Ismail “Experimental and numerical investigation of the natural frequencies of the composite Profiled Steel Sheet Dry Board (PSSDB) system,” *Journal of the South African Institution of Civil Engineering*, vol. 55, pp. 11-21, 2013.
[9] F. A. Gandomkar, H. W. Wan Badaruzzaman, and S. A. Osman, “The natural frequencies of composite Profiled Steel Sheet Dry Board with Concrete infill (PSSDBC) system,” *Latin American Journal of Solids and Structures*, vol. 8, pp. 351-372, 2012.
[10] H. Hashim, Z. Ibrahim, and H. A. Razak, “Dynamic characteristics and model updating of damaged slab from ambient vibration measurements,” *measurements,* vol. 46, pp. 1371-1378, 2013.
[11] B. Zhang, A. kermani, and T. Fillingham, “Vibration performance of timber floors constructed with metal web joists,” *Engineering Structures,* vol. 56, pp. 1321-1334, 2013.
[12] L. F. C. Neves, J. G. S. da Silva, L. R. O. de Lima, and S. Jordao, “Multi-story, multi-bay building with composite steel deck floors under human-induced loads: the human comfort issue,” *Computers & Structures*, vol. 136, pp. 34-46, 2014.
[13] G. S. da Silva, A. L. de Andrede, and D. C. Lopes, “Parametric modeling of the dynamic behavior of steel-concrete composite floor,” *Engineering Structures,* vol. 75, pp. 327-339, 2014.
[14] K. Jernero, A. Bradt, and A. Olsson, “Vibration properties of a timber floor assessed in laboratory and during construction,” *Engineering Structures,* vol. 82, pp. 44-54, 2015.
[15] A. Devin, P. J. Fanning, and A. Pavic, “Modelling effect of non-structural partitions on floor modal properties,” *Engineering Structures,* vol. 91, pp. 58-69, 2015.
[16] British Standards Institution, *BS 5950-Part 4 (Code of practice for design of composite slabs with profiled steel sheeting: Structural use of steelwork in building),* UK, 1994.
[17] British Standard Institute, *BS 8110- Part 1 (Structural use of concrete: Code for practice for design and construction),* UK, 1997.
[18] A. Pavic, P. Reynolds, P. Waldron, and K. Bennett, “Dynamic modeling of post-tensioned concrete floors using finite element analysis,” *Finite Elements in Analysis and Design*, vol. 37, pp. 305–323, 2001.
[19] J. G. S. da Silva, P. C. G. da S. Vellasco, S. A. L. de Andrade, F. J. da C. P. Soeiro, and R. N. Werneck, “An evaluation of the dynamical performance of composite slabs,” *Computers and Structures*, vol. 81, pp. 1905–1913, 2003.
[20] ABAQUS Analysis User’s Manual Version 6.12.