Proceedings of the Sixteenth International Conference on
Computational Structures Technology
Edited by: P. Iványi, J. Kruis and B.H.V. Topping
Civil-Comp Conferences, Volume 14, Paper 4.1
Civil-Comp Press, Edinburgh, United Kingdom, 2026
ISSN: 2753-3239, doi: 10.4203/ccc.14.4.1

Vibration Analysis of Steel-Concrete Composite Floors when Subjected to Rhythmic Human Dynamic Loadings

M. G. de Carvalho Junior and J. G. Santos da Silva

Civil Engineering Postgraduate Programme (PGECIV), Rio de Janeiro State University (UERJ), Brazil

Abstract

In recent years, with the advancement of materials technology and construction methodologies combined with modern architecture, which prioritizes large spans and more slender structures, dynamic analyses have become indispensable due to reports associated with excessive vibration problems. This way, the main objective of this work is to assess the dynamic structural behaviour and human comfort of a steel-concrete composite floor subjected to actions associated to rhythmic human activities (aerobics). The investigated structural model is based on a building floor, with dimensions of 45 m x 32 m and area of 1440 m². The numerical model was developed based on techniques used by the Finite Element Method (FEM) and implemented in the ANSYS software. implemented in ANSYS software. The investigated dynamic load models considered a group of twenty people practicing aerobics on the floor, represented by traditional loading models (only force models). In sequence, the natural frequencies and vibration modes were determined, and after that the dynamic structural response was obtained based on the peak (a_p) and RMS accelerations ($a_{w,RMS}$) and vibration dose values (VDV). The results pointed out there are excessive vibrations and human discomfort when the investigated steel-concrete composite floor is subjected to aerobics, and is only recommended for activities involving walking.

Keywords: steel-concrete composite floors, dynamic structural analysis, finite element modelling, rhythmic human dynamic actions, vibration analysis, human comfort assessment.

1 Introduction

In the current context of civil engineering, the introduction of new construction methodologies that prioritize quality, efficiency, and lower costs, aligned with modern and bold architectural designs, has become increasingly frequent. This way, the construction of buildings using steel-concrete composite structural systems is consolidating itself as a relevant alternative, being increasingly adopted in residential, commercial, and parking buildings in Brazil [1,2]. The Mater Dei Hospital (see Figure 1) is an example of a composite building located in Salvador/BA [3].

Figure 1: Mater Dei Hospital - Salvador/BA, Brazil [3].

Recent advances in computing, combined with lighter and high-strength materials, and market demand for structures with large spans, have contributed to an increase tendency in excessive vibrations in lightweight floors. Nowadays, many vibration problems occur in spaces intended for rhythmic human activities (gyms) [1,2,4,5,6].

In general, the initial design purpose did not predict the impacts associated by rhythmic human activities. The result of these factors is more flexible and slender structures, leading to lower natural frequencies and low structural damping, which is related to the types of materials, construction, non-structural elements, construction age, and quality of construction [1,2].

In addition, the reduction of dynamic characteristics such as natural frequency values and damping coefficients induces the natural frequencies to approximate the excitation frequencies related to human activities such as walking, jumping, aerobics, and dancing, which makes building floors more susceptible to excessive vibrations, resulting in human discomfort [1,2]. The use of these structural systems for rhythmic human activities (aerobics), such as gyms and sports centres, is a complex problem because these activities present harmonic frequencies close to natural frequencies considered disturbing which can result in resonance phenomenon, causing people discomfort [1,2].

Thus, in this research work, rhythmic human dynamic actions are considered based on the use of mathematical functions associated with traditional loading models (force models only), such as the formulation proposed in the AISC design guide [4], and mathematical models that take into account the results of experimental tests such as the model from the SCI guide [5] and the one proposed by Faisca [6].

Therefore, the main objective of this investigation is to assess the dynamic structural behaviour and human comfort levels of a steel-concrete composite floor, on the 46^{th} floor of a building, with dimensions of 45 m x 32 m and total area of 1,440 m², when subjected to dynamic loads from a group of twenty people performing aerobic activities on the structure. The dynamic response values are compared with the limits recommended by research works, design guidelines and normative resolutions [4,5,7].

It must be emphasized that the results achieved throughout this work indicate the occurrence of excessive vibrations and human discomfort when the investigated steel-concrete composite floor is subjected to rhythmic human activities (aerobics).

2 Dynamic loading models: rhythmic activities

The mathematical model proposed by AISC design guide [4] defines the individual dynamic load as a Fourier series, representing the harmonics of excitation over time, as presented in Equation (1). For aerobics, the phase angle is not considered and formulation utilises three harmonics associated with the excitation frequency due to human dynamic actions.

$$F_{(t)} = \sum_{i=1}^{N} \alpha_i Q sen(2\pi f_{step} t - \phi_i) \quad (1)$$

In Equation (1), F(t) represents the force in (N); Q is the person's weight in (N); α_i is the dynamic coefficient; i is the harmonic number; f_{step} is the step frequency in (Hz), t is the time in (s) and ϕ_i is the phase angle in (rad).

Regarding the SCI design guide [5], the phase difference for the first three harmonics (regular jumps) is taken into consideration, also expressed by a Fourier series, as presented in Equation (2). For this dynamic load model, the phase angles for normal jumps associated with the Fourier coefficients is defined by Equations (3) to (5). The reason for applying these parameters is to account for the lack of coordination and synchronism typical of these activities when performed by large groups, which can be classified as a crowd effect.

$$\mathrm{F}_{(\mathrm{t})} = Q\{1 + \sum_{h=1}^{h} \alpha_h sen[2h\pi f_p t + \phi_h]\} \quad (2)$$

$$\alpha_1 = 1{,}61 \,.\, p^{-0{,}082} \quad (3)$$

$$\alpha_2 = 0{,}94 \,.\, p^{-0{,}24} \quad (4)$$

$$\alpha_3 = 0{,}44 \,.\, p^{-0{,}31} \quad (5)$$

In Equation (2), F(t) represents the dynamic force in (N); q is the person's weight in (N); h is the number of the Fourier term; α_i is the Fourier coefficient induced by p people; ϕ_i is the phase difference; f_p is the load frequency and t is the time in (s). In Equation (3) to Equation (5) p represents the people's number.

The dynamic loading model proposed by Faisca [6] was developed based on the use of the Hanning function, aiming to describe these loads mathematically as a time function. The mathematical formulation is supported by parameters whose value ranges were proposed based on extensive experimental tests, as shown in Equation (6). The curves for defining the lag coefficient (CD), which considers the lack of synchronism between the rhythmic human activities performed by the people are illustrated in Figure 2.

$$F_{(t)} = CD\left\{K_p P\left[0{,}5 - 0{,}5cos\left(\frac{2\pi}{T_c}t\right)\right]\right\} \rightarrow t \leq T_c \qquad (6)$$

$$F_{(t)} = 0 \rightarrow T_c \leq t \leq T$$

In Equation (6), F(t) represents the dynamic force in (N); CD represents the lag coefficient; K_p is the impact coefficient; T_c is the contact period of the activity in (s); T is the activity period in (s) and t is the time in (s).

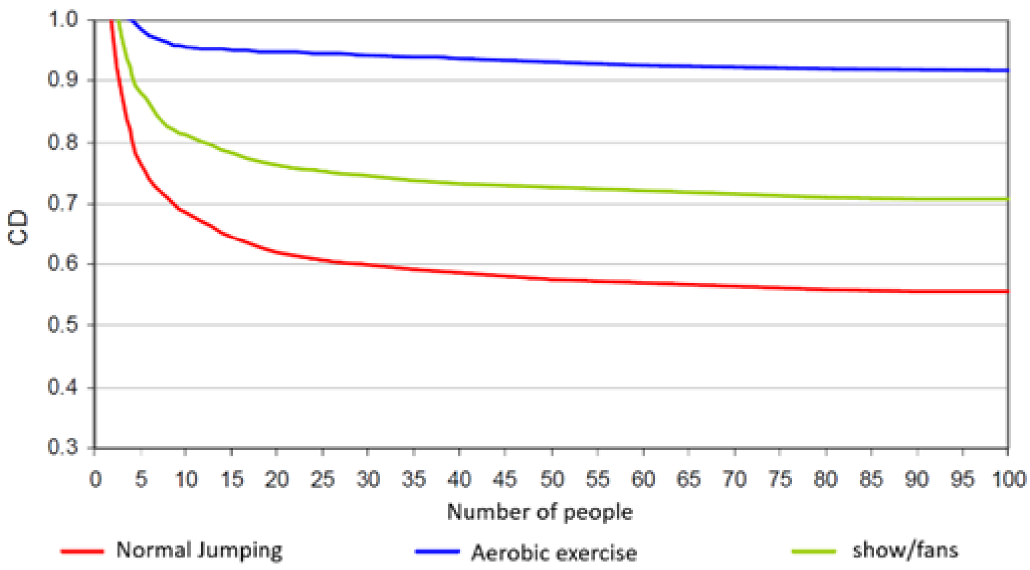


Figure 2: Lag coefficient (CD) for rhythmic human activities [6].

3 Design of the investigated steel-concrete composite floor

The investigated structural system consists to a steel-concrete composite floor, located on the 46th floor of a commercial building [1]. The composite floor presents global dimensions of 45 m x 32 m, total area of 1,440 m², steel beams and columns, and reinforced concrete slabs with thickness equal to 15 cm (see Figures 3 to 5). The beam sections are welded W-profiles ASTM A572, with W 460 x 106 for the main beams and W 410 x 60 for the secondary beams. The columns are related to HD profiles

ASTM 913, with height is equal 3.60 m, composed of with two types of structural sections (see Figure 4). It should be noted that the structural system has been verified and satisfy the design requirements for the Ultimate Limit State (ULS) [8].

The concrete slabs concrete presents a characteristic compressive strength f_{ck} of 30 MPa, longitudinal elasticity modulus E_c equal to 26 GPa, Poisson's ratio ν equal to 0.2, and specific weight ρ of 2,500 kg/m³. The steel used in the beams and columns presents the characteristic tensile strength f_y equal to 345 MPa, longitudinal elasticity modulus E_s of 205 GPa, Poisson's ratio ν of 0.3, and the specific weight ρ_s equal to 7,850 kg/m³.

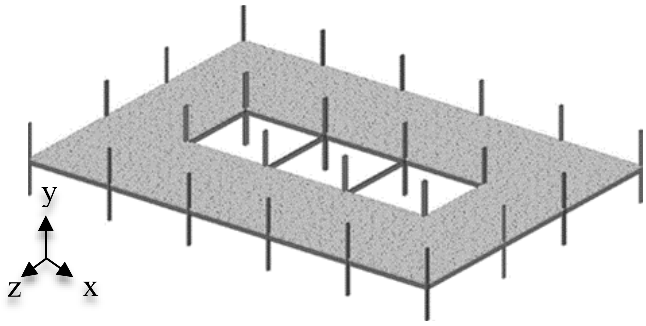


Figure 3: Investigated steel-concrete composite floor.

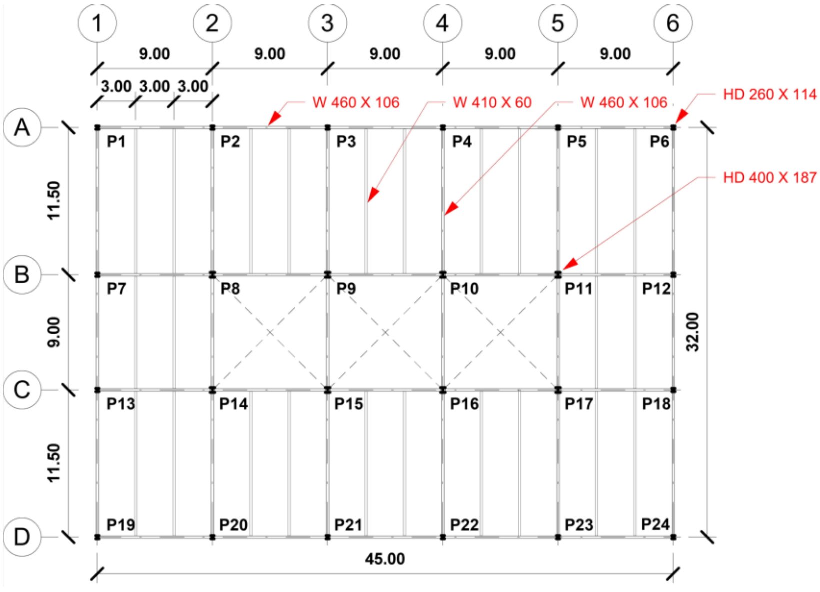


Figure 4: Floor plan of the steel-concrete composite floor.

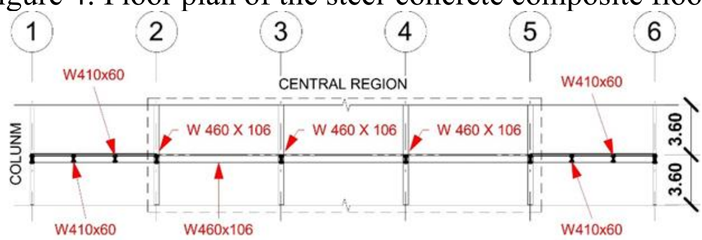


Figure 5: Cross section of the studied composite floor.

4 Finite Element modelling of the floor

The finite element model utilised for the steel-concrete composite floor dynamic structural analysis [1], adopted the usual mesh refinement techniques used in simulations based on the Finite Element Method (FEM), and implemented in the ANSYS structural analysis program [9], as presented in Figures 6 to 8.

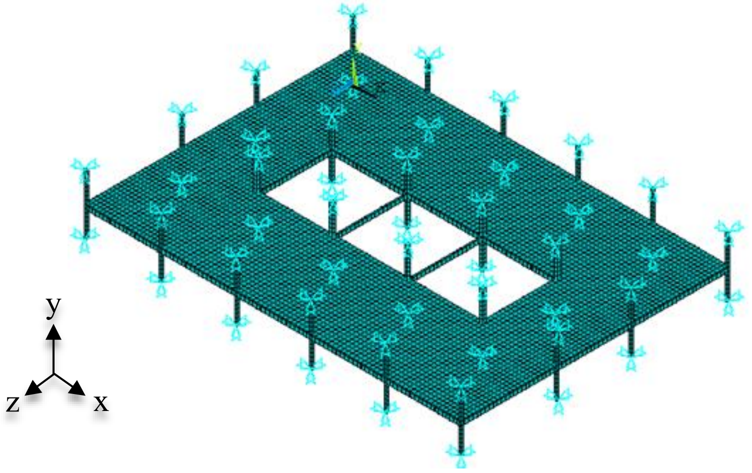


Figure 6: Finite element model of the investigated floor.

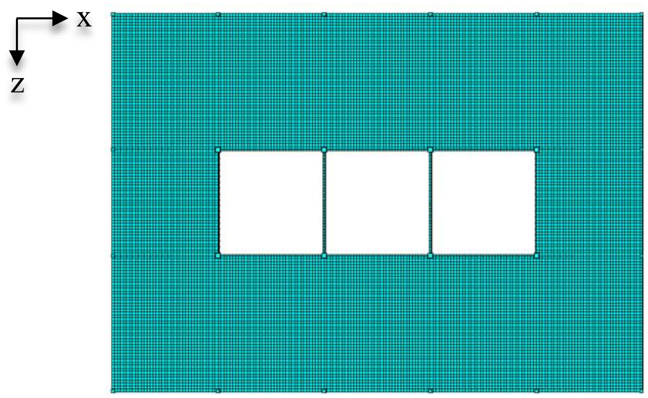


Figure 7: Finite element of the floor: top view.

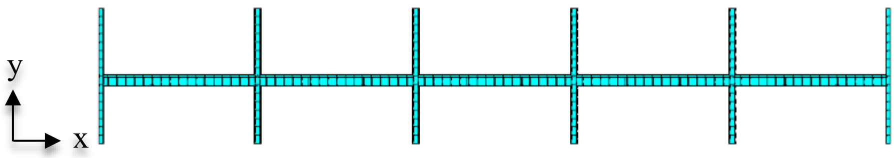


Figure 8: Finite element mode of the floor: cross-section.

The beams and columns were modelled using the three-dimensional beam element BEAM44 [9]. This three-dimensional element is uniaxial, characterized by two nodes and six degrees-of-freedom at each node, allowing three rotations and three translations considering the X, Y, and Z directions. Furthermore, the BEAM44 finite element [9] considers different geometric configurations present at opposite ends of the beam and considers the eccentricity between the centroid of the steel beams and the concrete slabs. The finite element also considers the effects of torsion and bending.

Regarding the modelling of reinforced concrete slabs, the SHELL63 element [9] was used due to its capacity to represent a shell. This element is composed of four nodes, each with six degrees-of-freedom, allowing three translations and three rotations around the X, Y, and Z axes. The element also considers the effects of torsion and bending.

In addition, the model discretization process, a refinement was conducted to ensure a uniform distribution of finite elements considering a mesh with a dimension of 0.25 m in all directions, demonstrating adequate refinement for the floor under study. The final developed finite element model presented 20,394 nodes, 22,424 elements, and 122,220 degrees-of-freedom (DOF), as illustrated in Figures 6 to 8.

The present investigation considered that both materials (steel and concrete) have an elastic behaviour. The complete interaction between the concrete slab and steel beams was considered in the analysis, and all the nodes between the beams and slabs were coupled in the finite element model, to prevent the occurrence of any slip.

5 Dynamic structural analysis

The dynamic structural analysis consists of a modal analysis of the steel-concrete composite floor aiming to determine the natural frequencies (eigenvalues) and vibration modes (eigenvectors). After that, a forced vibration analysis was carried out considering a real design case to simulate the floor structural behaviour, resulting in a dynamic response for human comfort analysis [1].

This way, twenty individuals were arranged to simulate a group of people practicing aerobics on a gym floor (see Figure 9), with a distribution rate of 0.25 people/m^2 [10]. In sequence, Figure 10 illustrates the floor plan of the structural model with the position of the group of people on panel E (20 peoples). The weight of each individual was considered equal to 800 N, and the structural damping coefficient ξ was adopted equal 1.0%, following the design recommendations from the international design standard ISO 10137 [11].

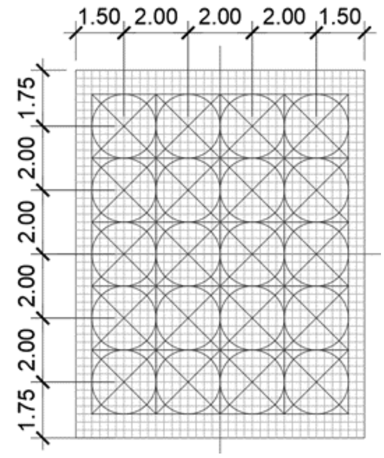


Figure 9: Peoples practicing aerobics: top view detail. Dimensions in meters.

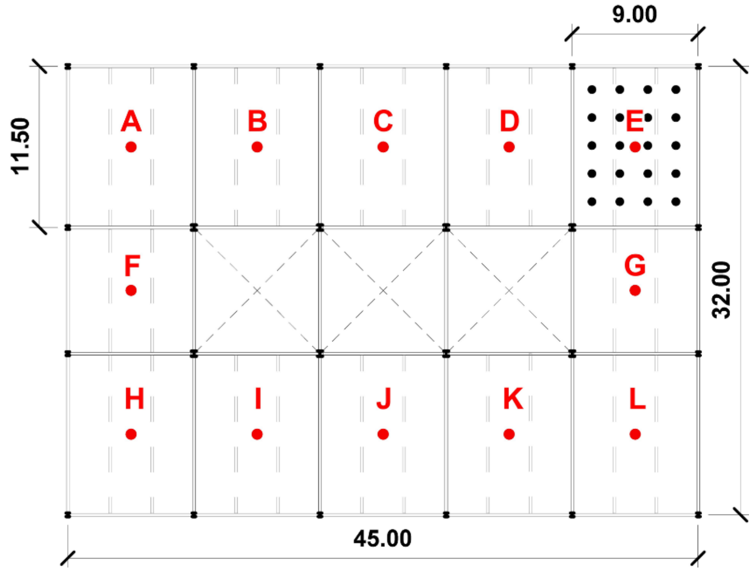


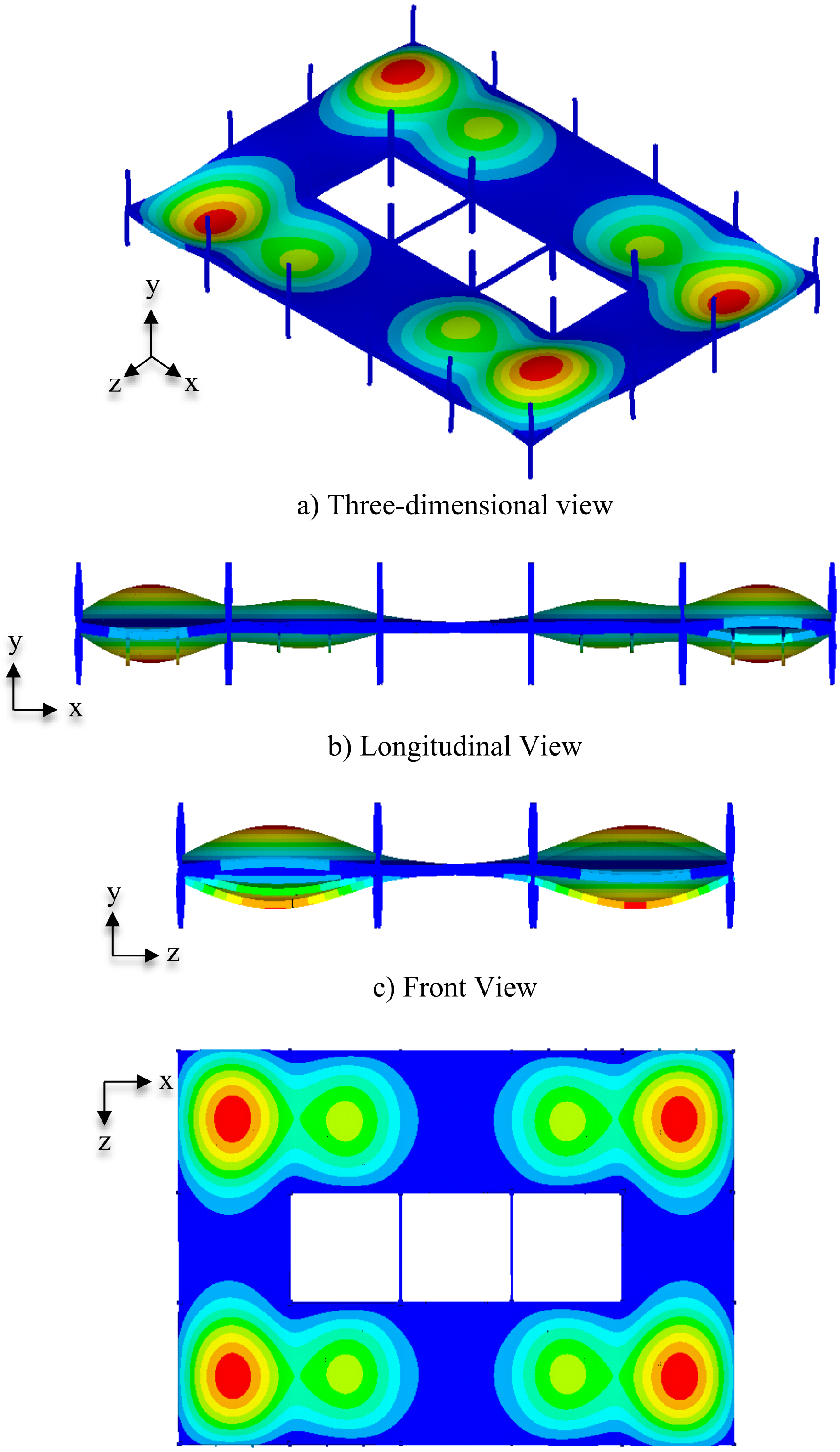
Figure 10: Position of the peoples on the composite floor. Dimensions in meters.

5.1 Natural Frequencies and vibration modes

Based on the floor modal analysis utilising the ANSYS program [9], an investigation of the structural model was carried out. Therefore, the first ten floor natural frequencies values (see Table 1) and the corresponding vibration modes were determined. It should be noted that only the 9^{th} structure vibration mode, the most relevant mode shape to the dynamic analysis was illustrated in Figure 11.

Natural Frequencies (Hz)	Modal mass (kg)	Modal stiffness (N/m)	Modal damping (Ns/m)
f_{01} = 5.41	70,960.86	8.19 x 107	4.82 x 104
f_{02} = 5.42	70,111.67	8.09 x 107	4.76 x 104
f_{03} = 5.59	71,087.18	8.75 x 107	4.99 x 104
f_{04} = 5.60	69,619.63	8.58 x 107	4.89 x 104
f_{05} = 5.74	43,035.32	5.59 x 107	3.11 x 104
f_{06} = 5.77	42,015.36	5.51 x 107	3.05 x 104
f_{07} = 5.88	74,564.38	1.02 x 108	5.52 x 104
f_{08} = 5.89	74,803.72	1.02 x 108	5.54 x 104
f_{09} = 6.03	75,162.00	1.076 x 108	5.72 x 104
f_{10} = 6.04	75,202.82	1.078 x 108	5.73 x 104

Table 1: Steel-concrete composite floor dynamic characteristics.



a) Three-dimensional view

b) Longitudinal View

c) Front View

d) Top View

Figure 11: 9th vibration mode of the analysed floor (f_{09} = 6.03 Hz).

Based on the natural frequency values (see Table 1), and having in mind that it is recommended that the steel-concrete composite floor fundamental frequency should be in the range of 8.4 Hz to 9.2 Hz for rhythmic human activities, according to the SCI design guide [5], it can be concluded that the modal analysis indicated that the floor is susceptible to excessive vibrations.

5.2 Assessment of the human comfort

The human comfort assessment of the floor was carried out using a transient dynamic analysis, following Newmark's direct integration method [12], implemented using the ANSYS computer program [9]. The human comfort levels were evaluated in terms of peak accelerations (a_p), RMS accelerations ($a_{w,RMS}$), and vibration dose values (VDV). The recommended limit for peak acceleration (a_p) is equal to 0.50 m/s² [4].

Regarding the RMS accelerations ($a_{w,RMS}$) and VDV values, there is no consensus on acceptable limits for rhythmic human activities [5,7]. Therefore, Table 2 presents the limit values found in the technical literature and the classification according to specific value ranges [4,5,7].

$a_{w,RMS}$ (m/s²) [5]	VDV ($m/s^{1.75}$) [7]	People's reactions
< 0.35	< 0.50	Reasonable limit
0.35 - 1,27	0.50 - 3.50	Disturbing
1.27 - 2.47	3.50 - 6.90	Unacceptable
> 2.47	> 6.90	Panic
Peak acceleration limit: a_p = 0.50 m/s² [4].		

Table 2: Human comfort criteria for rhythmic human activities.

Regarding to the dynamic load modelling, the forced vibration analysis was conducted aiming to tune the investigated load case with a floor natural frequency that best represents the final design, so that the excitation frequency is close to the resonance with the third harmonic of the dynamic loading, considering the 9th vibration mode of the floor (see Table 1 and Figure 11).

Then, a forced vibration analysis was performed, based on a dynamic loading represented by a group of twenty people, and considering an excitation frequency equal to 2,0 Hz (f_p = 2.0 Hz), having in mind that this frequency is in resonance with the 3rd harmonic with respect to the 9th vibration mode of the composite floor (see Table 1 and Figure 11), and also is associated to the frequency range related to the three traditional load models used in this investigation [4,5,6]. The parameters used for modelling the rhythmic human dynamic loads are presented in Table 3 (SCI [5]) and Table 4 (Faisca [6]). Furthermore, the parameters used in the modeling of the dynamic loads are described in details in references [1,2].

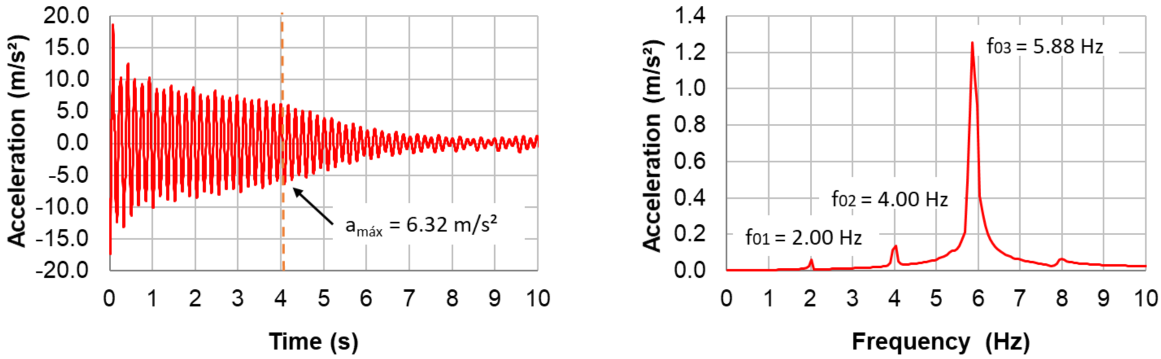
N			
	1	2	3
ϕ_n	$\pi/6$	$-\pi/6$	$\pi/2$
P = 20 Person			

Table 3: Parameters used in the dynamic loading model proposed by SCI [5].

T_c	T_s	T	K_p	CD
0.40	0.10	0.50	2.78	0.94

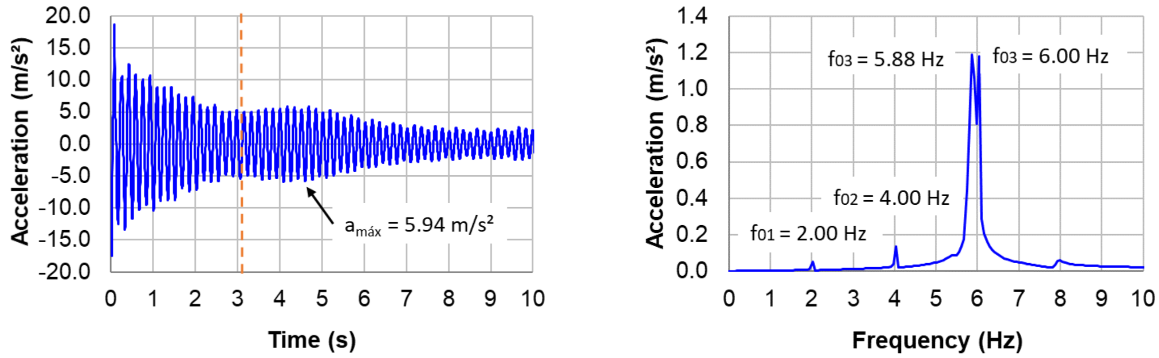
Table 4: Parameters used in the dynamic loading model proposed by Faisca [6].

In order to illustrate the dynamic structural response of the steel-concrete composite floor, Table 5 present the results based on the peak accelerations (a_p); RMS accelerations ($a_{w,RMS}$); and vibration dose values (VDV). After that, the dynamic response in the time and frequency domains related to the three traditional loading models are presented (AISC [4]; SCI [5]; Faisca [6]) (see Figures 12 to 14). In order to allow for a better graphical visualization, a colour scheme is adopted, in which red represents the response obtained through the AISC model [4], blue is related to the SCI model [5], and finally green correspond to the Faisca model [6].



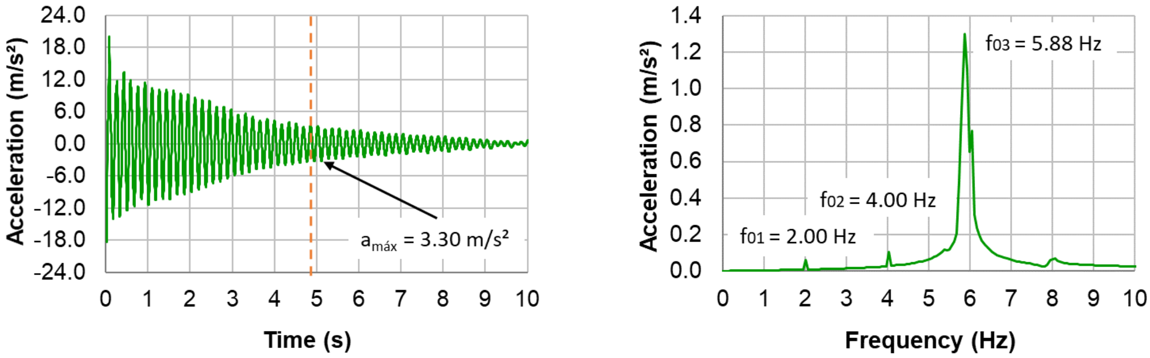
a) Time domain b) Frequency domain

Figure 12: Floor acceleration: AISC [4] section E (see Figure 10).



a) Time domain b) Frequency domain

Figure 13: Floor acceleration: SCI [5] section E (see Figure 10).



a) Time domain b) Frequency domain

Figure 14: Floor acceleration: Faisca [6] section E (see Figure 10).

Node	AISC [4]			SCI [5]			FAISCA [6]		
	a_p	$a_{w,RMS}$	VDV	a_p	$a_{w,RMS}$	VDV	a_p	$a_{w,RMS}$	VDV
	m/s²	m/s²	$m/s^{1,75}$	m/s²	m/s²	$m/s^{1,75}$	m/s²	m/s²	$m/s^{1,75}$
A	4.75	0.84	2.36	4.81	0.84	2.37	2.82	0.53	1.45
B	1.56	0.44	1.24	1.61	0.45	1.25	1.58	0.39	1.08
C	2.20	0.56	1.55	2.17	0.57	1.60	1.72	0.44	1.21
D	2.33	0.73	2.03	2.81	1.14	3.18	1.79	0.54	1.49
E	6.32	1.40	3.93	5.94	2.21	6.18	3.30	0.90	2.48
F	2.87	0.42	1.17	2.87	0.42	1.17	1.80	0.26	0.71
G	3.03	0.45	1.27	2.83	0.46	1.28	1.74	0.27	0.73
H	4.76	0.85	2.37	4.75	0.85	2.37	2.81	0.53	1.45
I	1.59	0.44	1.24	1.60	0.45	1.26	1.58	0.39	1.08
J	2.13	0.54	1.50	2.23	0.54	1.52	1.72	0.43	1.18
K	1.84	0.70	1.96	2.08	0.92	2.57	1.46	0.44	1.20
L	4.07	1.28	3.60	2.86	1.55	4.33	2.31	0.62	1.71

Table 5: Dynamic structural response of the investigated composite floor.

Based on the results determined throughout this investigation (see Table 5), the dynamic response maximum values calculated were 6.32 m/s² for peak accelerations (a_p = 6.32 m/s²); 2.21 m/s² for RMS accelerations ($a_{w,RMS}$ = 2.21 m/s²), and 6.18 $m/s^{1.75}$ for vibration dose values (VDV = 6.18 $m/s^{1.75}$). It is important to emphasize that the floor dynamic response values determined based on the mathematical model proposed by Faisca [6], referring to 3.30 m/s² for peak accelerations (a_p = 3.30 m/s²); 0.90 m/s² for RMS accelerations ($a_{w,RMS}$ = 0.90 m/s²), and 2.48 $m/s^{1.75}$ associated to the vibration dose values (VDV = 2.48 $m/s^{1.75}$), see Figure 15, Table 3, are more aligned with the reality of structural design [1,2], considering the lack of synchronism between people when performing rhythmic activities.

The values obtained using the formulations proposed by the AISC design guide [4] and by the SCI [5] are very high and far from the reality of the design project [1,2]. However, even considering the results calculated using the model proposed by Faisca [6], which are closer to the practical reality of the design, it should be noted that the results achieved throughout this research clearly indicate the occurrence of excessive vibrations and hu-man discomfort when floor is subjected to rhythmic human activities.

6 Conclusions

This research work presented an investigation related to the dynamic structural response of a steel-concrete composite floor when subjected to dynamic actions resulting from aerobic activities. Based on the floor modal analysis, it was verified that the values of the natural frequencies vary in the range of 5.42 Hz to 6.04 Hz, considering the ten most relevant natural frequencies for the analysis, and are close to and within the excitation frequency ranges associated with the third harmonic of the dynamic load (aerobic activities), making the structure vulnerable to excessive vibrations and human discomfort.

Based on the forced vibration analysis, it was concluded that the dynamic load model that produced the greatest impact on the floor (panel E) was the model proposed by the SCI [5], but with values very close to those obtained using the AISC [4]. The RMS accelerations and VDV presented higher values when the SCI design guide [5] was considered, ($a_{w,RMS}$ = 2.21 m/s² and VDV = 6.18 $m/s^{1,75}$). Regarding the peak acceleration values, the mathematical formulation of the AISC design guide [4] presented a maximum value of 6.32 m/s² (a_p = 6.32 m/s²). However, it is worth to note, again, that the formulation proposed by Faisca [6] presents fewer conservative results and is closer to the reality of structural design [1,2] [peak accelerations (a_p = 3.30 m/s²); RMS accelerations ($a_{w,RMS}$ = 0.90 m/s²); vibration dose values (VDV = 2.48 $m/s^{1.75}$)], but also produce excessive vibrations and human discomfort.

Finally, considering the results of the floor dynamic structural analysis, excessive vibrations were observed, indicating that the structural system should not be used for rhythmic human activities. The use of the floor should be limited to low-impact activities (human walking), for example, in commercial office spaces or residences.

Acknowledgements

The authors acknowledge the financial support for this work provided by the Brazilian Science Foundation's: CNPq, CAPES and FAPERJ.

References

[1] Carvalho Junior, M. G. (2026) Dynamic structural analysis and human comfort assessment of floors when subjected to rhythmic human actions, 231f. MSc Dissertation (In Portuguese). Rio de Janeiro State University (UERJ). Rio de Janeiro/RJ, Brazil.

[2] Campista, F. F. (2019) Modelling of biodynamic systems for evaluation of the dynamic structural behaviour of steel-concrete composite building floors subjected to human rhythmic activities. PhD Thesis (In Portuguese). Rio de Janeiro State University (UERJ). Rio de Janeiro/RJ, Brazil.
[3] MaterDei. About Mater Dei Salvador. Published on May 1, 2022, Available in: https://materdei.com.br/institucional/sobre-o-mater-dei-salvador. Access in: January 20, 2026.
[4] Murray, T. M.; Allen, D. E.; Ungar, E. E.; Davis, D. B. (2016) Steel Design Guide Series 11: Vibrations of steel-framed structural systems due to human activity. American Institute of Steel Construction (AISC). Chicago, USA.
[5] Smith A. L.; Hicks, S. J; Devine, P. J. (2009) Design of floors for vibrations: A new approach. The Steel Construction Institute (SCI). Publication P354. Silwood Park, Ascot, UK.
[6] Faisca, R. G. (2003). Characterization of dynamic loads due to human activities. PhD Thesis (In Portuguese). Federal University of Rio de Janeiro (COPPE/UFRJ). Rio de Janeiro/RJ, Brazil.
[7] Setareh, M. (2012) Evaluation and assessment of vibrations owing to human activity. Proceedings of the Institution of Civil Engineers. Structures and Buildings, 165 (SB5), pp. 219-231.
[8] Brazilian Association of Technical Standards (ABNT) (2024) NBR 8800: Design of steel structures and steel-concrete composite structures for buildings. Rio de Janeiro/RJ, Brazil.
[9] ANSYS Swanson Analysis Systems Inc. (2022). Release 2022 R1. Theory Reference.
[10] Bachmann et al. (1995) Vibration problems in structures - Practical guidelines. Institut für Baustatik und Konstruktion, Birkhäuser. Basel, Switzerland.
[11] International Organization for Standardization (ISO 10137) (2007). Bases for design of structures - Serviceability of buildings and walkways against vibrations, Switzerland.
[12] Clough, R. W.; Penzien, J. (1993) Dynamic of Structures; McGraw-Hill, 634p.