



**HAL**  
open science

# Dynamic Analysis and Vibration Control of Steel-Concrete Composite Floors Submitted to Human Rhythmic Activities

Cássio Gaspar, José Guilherme S. Silva, Elvis Dinati Chantre Lopes, L.F.  
Costa-Neves

► **To cite this version:**

Cássio Gaspar, José Guilherme S. Silva, Elvis Dinati Chantre Lopes, L.F. Costa-Neves. Dynamic Analysis and Vibration Control of Steel-Concrete Composite Floors Submitted to Human Rhythmic Activities. EUROSTEEL 2014 - 7th European Conference on Steel and Composite Structures, Sep 2014, Naples, Italy. <hal-04812623>

**HAL Id: hal-04812623**

**<https://hal.science/hal-04812623v1>**

Submitted on 30 Nov 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

## DYNAMIC ANALYSIS AND VIBRATION CONTROL OF Steel-Concrete Composite Floors Submitted to Human Rhythmic Activities

Cassio M. R. Gaspar<sup>a</sup>, José Guilherme S. da Silva<sup>a</sup>, Elvis D. C. Lopes<sup>a</sup>, Luís F. C. Neves<sup>b</sup>

<sup>a</sup>State University of Rio de Janeiro, UERJ, Structural Engineering Department, ESTR, Brazil  
cgaspac@yahoo.com.br, jgss@uerj.br, elvis\_lopes@hotmail.com

<sup>b</sup>University of Coimbra, UC, Civil Engineering Department, INESCC, Portugal  
luis@dec.uc.pt

### INTRODUCTION

Nowadays, the technological advance in the materials field allows the use of more resistant and low weight materials that result in slender and more flexible structural systems. In the particular case of a composite floor, this flexibility is due to the use of larger spans, thus leading the structural system to a lower inherent damping [1]. On the other hand, it is well known that most disturbing vibrations related to human perception are in the range of 4 to 8 Hz [2] [3] and at the same time most of the natural frequencies of composite floor systems lie also in this range. In addition, the excitation force frequencies due to human activities occur in this range as well. This combination makes the structural systems more susceptible to the resonance phenomenon, causing undesirable vibrations in the frequency range that is the most noticeable to humans.

Regarding all these aspects, this paper is intended to investigate the vibration levels of a real building steel-concrete composite floor submitted to rhythmic activities. Hence, the floor dynamic response in terms of accelerations was obtained by numerical simulations and compared to the limiting values proposed by several authors and design codes [2] [3] [4] [5] [6].

The investigated structural model was based on a real building steel-concrete composite floor spanning 40m by 40m with a total area of 1600m<sup>2</sup> and is currently subjected to gymnastics (aerobics). Besides, the investigated floor structural system presents very close natural frequencies and a multimodal behaviour. This way, a vibration control strategy was used, based on the use of multiple tuned mass dampers (MTMDs) to improve the human comfort.

### 1 STEEL-CONCRETE COMPOSITE FLOOR STRUCTURAL MODEL

The investigated structural system represents a typical interior floor of a commercial building used for gym. The steel-concrete composite floor is supported by steel columns and is currently submitted to human aerobic rhythmic loads.

The structural system is made of steel beams and a 100 mm thick concrete slab, see *Fig. 1*. The columns height is equal to 4 m. The steel sections used were welded wide flanges (WWF) made from a 345 MPa yield stress steel grade. A  $205 \times 10^3$  MPa Young's modulus was adopted for the steel beams. The concrete slab has a 30 MPa specified compression strength and a  $26 \times 10^3$  MPa Young's Modulus. *Table 1* depicts the geometrical characteristics of all steel sections used in the investigated structural model.

*Table 1.* Geometric characteristics of the building composite floor [mm]

Profile Type	Height (d)	Flange Width (b <sub>f</sub> )	Top Flange Thickness (t <sub>f</sub> )	Bottom Flange Thickness (t <sub>f</sub> )	Web Thickness (t <sub>w</sub> )
Beams - W 610 x 140	617	230	22.2	22.2	13.1
Beams - W 460 x 60	455	153	13.3	13.3	8.0
Columns - HP 250 x 85	254	260	14.4	14.4	14.4

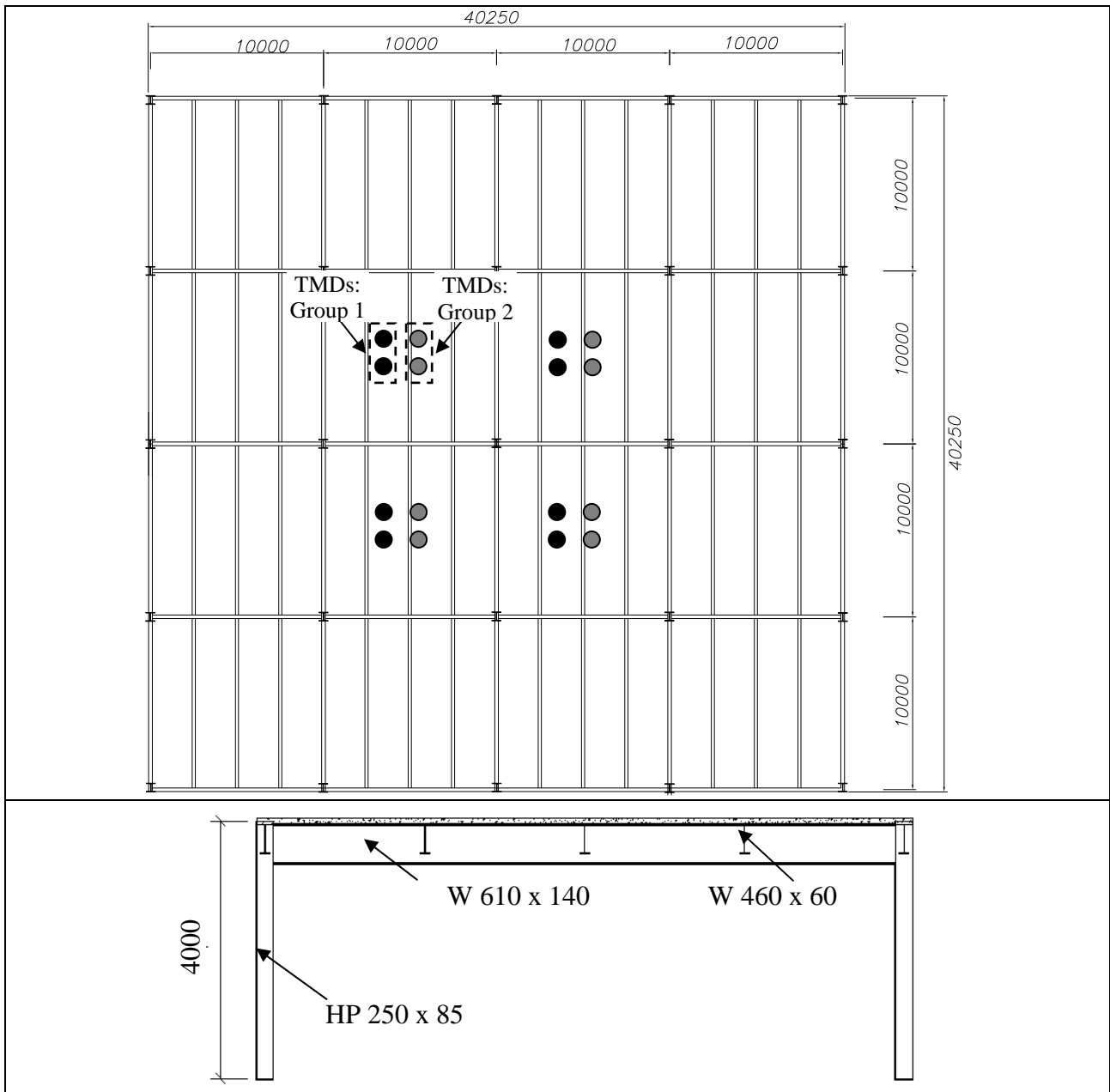


Fig. 1. Investigated structural model: plan view and typical floor bay cross section (dimensions in mm)

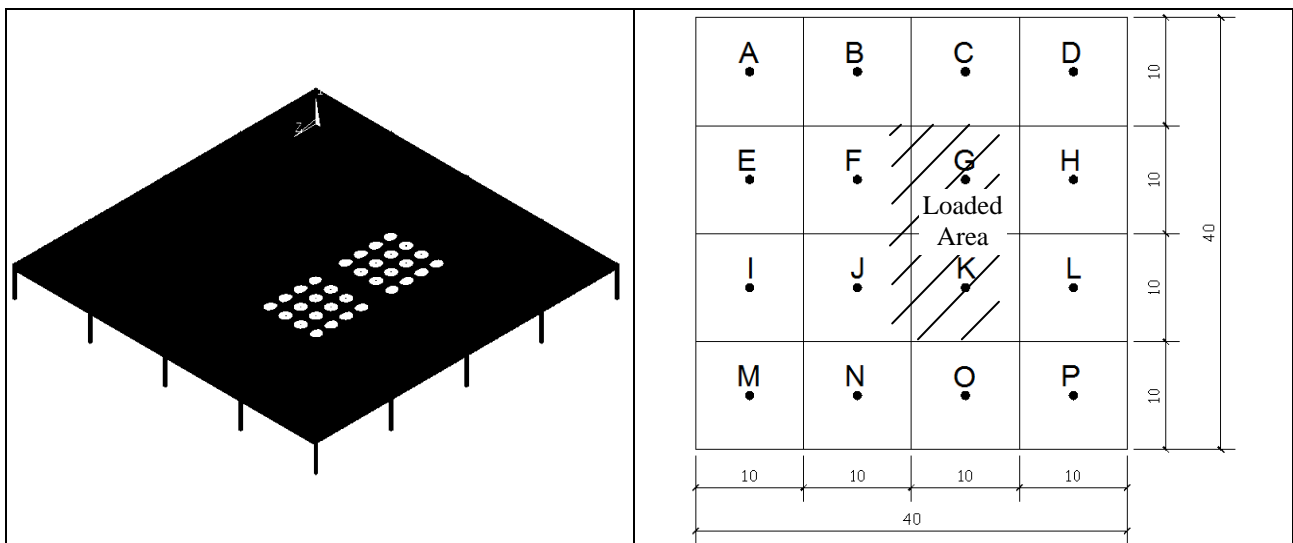
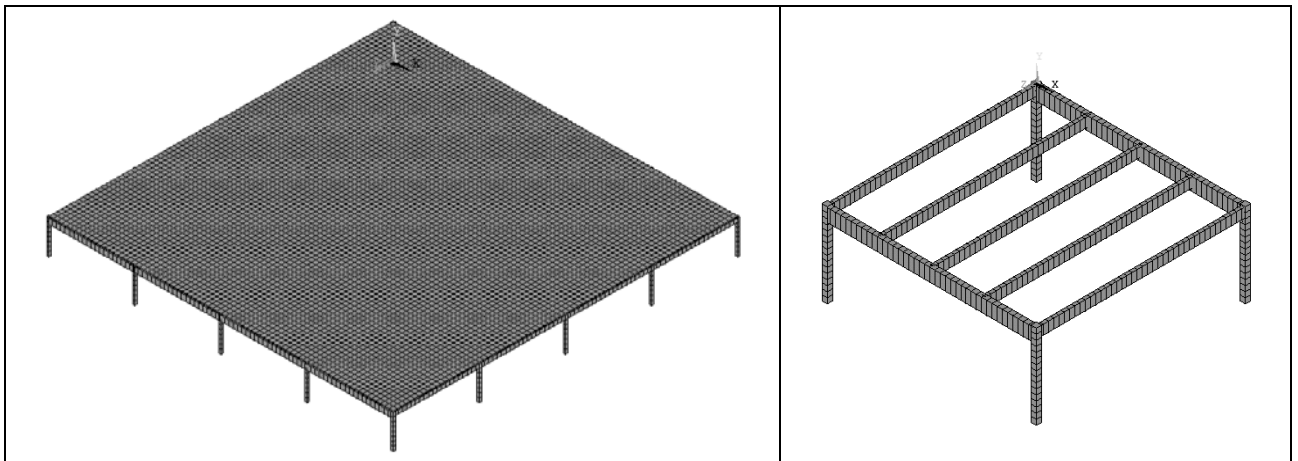


Fig. 2. Thirty-two individuals practising aerobics and investigated sections of the floor (dimensions in mm)

The human rhythmic dynamic loadings were applied on the investigated structural model corresponding to thirty-two individuals practising aerobics. This study has considered the dynamic loads obtained by Faísca [7], based on the results achieved through a long series of experimental tests with individuals carrying out rhythmic and non-rhythmic activities. The individuals' positions are shown in *Fig. 2*. The live load considered in this analysis corresponds to one person for each 4.0m<sup>2</sup> (0.25 person/m<sup>2</sup>) [2]. It is also assumed that a single person's weight is 800N (0.8kN) [2]. In this study a structural damping ratio of  $\xi=1\%$  ( $\xi = 0.01$ ) was considered [4].

## 2 FINIT ELEMENT MODELLING

The proposed computational model, developed for the composite floor dynamic analysis, adopted the usual mesh refinement techniques present in finite element method simulations implemented in the ANSYS program [8]. In this computational model, the floor steel beams were represented by three-dimensional beam elements, where flexural and torsion effects are considered. The concrete slab was represented by shell finite elements. The present investigation considered that both materials (steel and concrete) have an elastic behaviour. The steel-concrete composite floor finite element model is illustrated in *Fig. 3*.



*Fig. 3.* Finite element steel-concrete composite floor model and typical finite element composite floor bay

The complete interaction between the concrete slab and steel beams was considered in the analysis and simulated by spring elements so that the numerical model coupled all the nodes between the beams and slab, to prevent the occurrence of any slip.

Regarding the behaviour of the structural connections present in the investigated composite floor, the beam-to-beam connections were modelled as flexible joints using spring elements. The beam-to-column connections were considered as rigid joints.

In respect to the modelling of the passive tuned mass damper system (TMD), a spring-damper element and a mass element were used, in order to simulate a mass-spring-damper system. Thus, these two elements were attached to the main structure such that they represent a TMD system.

The final computational model was made of 29874 nodes, 3920 three-dimensional beam elements and 25600 shell elements, resulting in a finite element model with 167069 degrees of freedom.

## 3 DYNAMIC ANALYSIS AND VIBRATION CONTROL

The modal analysis was carried out and the first sixteen natural frequencies of the analysed steel-concrete composite floor, varying from 6.06 to 7.79 Hz, are close to the excitation frequency range (aerobics). In this situation, the third harmonic, varying from 5.66 to 8.57 Hz [7], of the forcing function may match these natural frequencies and therefore lead the composite floor to resonance. Consequently, such situation might result in undesirable vibrations and thus human annoyance [2]. With the objective of avoiding unwanted vibrations the fundamental composite floor frequency should be at least equal to 9.2 Hz for aerobics, considering the structural system as a light floor [3].

Concerning the human comfort analysis, to the authors' knowledge, it is worth to note that there is no generally agreed acceptance criterion for human rhythmic activities [4]. In others words, several authors [2] [3] [4] [5] [6] have been established comfort limits in function of acceleration assessment methods.

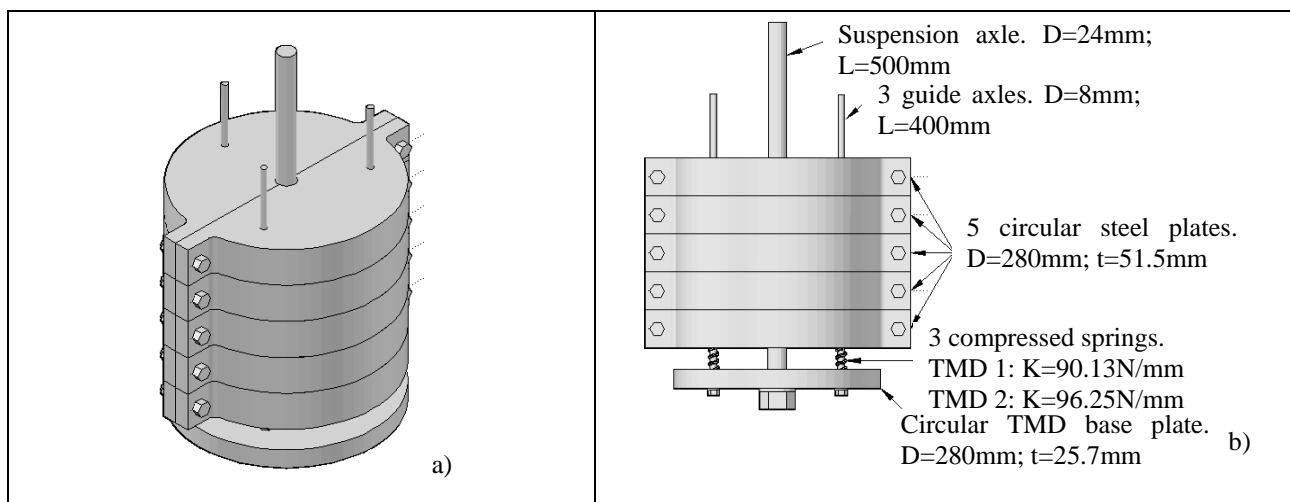
Therefore, considering all these aspects, the steel-concrete composite floor accelerations herein were evaluated based on peak unweighted accelerations (steady-state response),  $a_p$ , RMS weighted accelerations,  $a_{w,rms}$ , and vibration dose values, VDV. *Table 2* shows the RMS weighted accelerations and the VDV acceptance criteria respectively. The limiting value concerning aerobics and related to the peak unweighted acceleration is equal to 5%g ( $a_{lim} = 0.49 \text{ m/s}^2$ ) [3].

*Table 2.* Human comfort criteria for human rhythmic activities

SCI [4]	Ellis and Littler [5]	Setareh [6]	Person's Reaction
$a_{w,rms}$ (m/s <sup>2</sup> )	VDV (m/s <sup>1.75</sup> )	VDV (m/s <sup>1.75</sup> )	
< 0.35	< 0.66	< 0.50	Reasonable limit: passive persons
0.35 - 1.27	0.66 - 2.38	0.50 - 3.50	Disturbing
0.35 - 24.7	2.38 - 4.64	3.50 - 6.90	Unacceptable
> 24.7	> 4.64	> 6.90	Probably causing panic

The dynamic analysis was performed through an extensive parametric study so that the third harmonic of the force frequencies (aerobic activity) matches each natural floor frequency as much as possible in order to induce resonance. Thus, it was found that the eleventh (11<sup>th</sup>) and fifteenth (15<sup>th</sup>) vibration modes were predominantly excited resulting in excessive vibrations from the point of view of the human comfort. In sequence, *Tables 3 and 4* display the obtained acceleration values regarding the uncontrolled system.

Then, based on a TMD system proposed and experimentally tested by Varela [9], two TMD groups were tuned to the eleventh (group 1:  $f_{11} = 7.35 \text{ Hz}$ ) and fifteenth (group 2:  $f_{15} = 7.72 \text{ Hz}$ ) vibration modes, in order to minimize unwanted floor vibrations in case of resonance state. Thus, the two TMD groups were divided proportionally in eight TMDs with the same tuning, totalling sixteen TMDs, aiming to make them lighter and easier to be attached on the floor bottom. The effective mass of each TMD is equal to 130 kg, which corresponds to five steel plates of 26 kg. Note that each TMD does not have a physical dashpot, but an inherent damping due to its mechanism and the friction between the steel plates (*Fig. 4*). The damping value obtained experimentally [9] varies in the range of 1 to 1.5 % and in the present investigation was considered equal to 1.5 %. *Fig. 4* shows the properties of each individual TMD corresponding to each group. The TMDs were designed according to the Den Hartog's formulation [10].



*Fig. 4.* Proposed tuned mass damper (TMD) system: a) TMD isometric view; b) TMD physical characteristics

Table 3. TMDs effectiveness comparison ( $f = 7.35$  Hz)

Node	Floor Dynamic Response ( $f=7.35$ Hz)			
	Vibration Control	Acceleration ( $m/s^2$ )		VDV ( $m/s^{1.75}$ )
		$a_p$	$a_{w,rms}$	
F and J	<i>uncontrolled</i>	0.420	0.283	<b>0.575</b>
	<i>controlled</i>	0.067	0.035	0.074
	<i>reduction (%)</i>	-84	-88	-87
G and K	<i>uncontrolled</i>	<b>0.802</b>	<b>0.435</b>	<b>0.933</b>
	<i>controlled</i>	0.348	0.177	0.394
	<i>reduction (%)</i>	-57	-59	-58

Table 4. TMDs effectiveness comparison ( $f=7.72$  Hz)

Node	Floor Dynamic Response ( $f=7.72$ Hz)			
	Vibration Control	Acceleration ( $m/s^2$ )		VDV ( $m/s^{1.75}$ )
		$a_p$	$a_{w,rms}$	
F and J	<i>uncontrolled</i>	<b>0.843</b>	<b>0.536</b>	<b>1.101</b>
	<i>controlled</i>	0.074	0.042	0.087
	<i>reduction (%)</i>	-91	-92	-92
G and K	<i>uncontrolled</i>	<b>1.000</b>	<b>0.548</b>	<b>1.150</b>
	<i>controlled</i>	0.316	0.178	0.370
	<i>reduction (%)</i>	-68	-67	-68

From *Tables 3 and 4*, a very good percentage reduction varying from 57 to 92% was obtained for thirty-two people practicing aerobics on the steel-concrete composite floor investigated. Notice that the floor dynamic response related to the nodes F, J, G and K (see *Fig. 2*) presented a symmetrical behaviour so that these nodes were grouped for simplicity. Besides, these nodes represent the points of greatest magnitude associated with annoying excessive vibrations considering the human comfort. It is important to note that the acceleration values obtained after the installation of the two TMD groups were sufficient to respect the human comfort criteria according to the three evaluation methods used in this work. *Fig. 5* presents the steel-concrete composite floor dynamic response in time domain when the force frequency is set to be equal to 7.35 Hz and 7.72 Hz, respectively. It must be emphasized that the black line in *Fig. 5* is related to the steel-concrete composite floor controlled response.

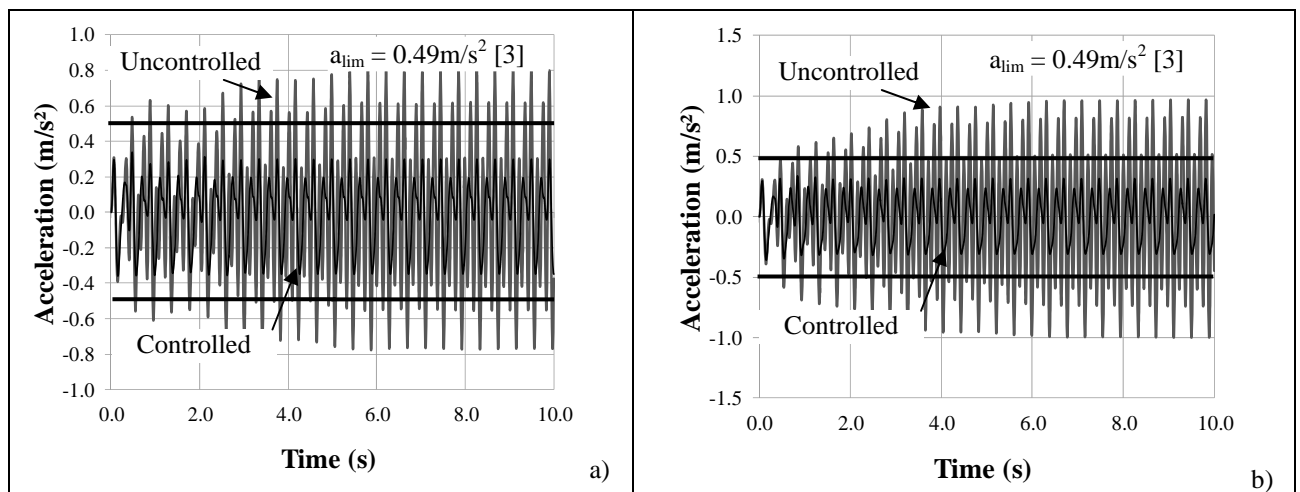


Fig. 5. Composite floor dynamic response: a) Nodes G and K ( $f = 7.35$ Hz); b) Nodes G and K ( $f = 7.72$ Hz)

## 4 CONCLUSIONS

The excessive vibration problems due to human rhythm activities concerning building steel-concrete composite floors have been related by several authors in the last few years. Having this problem in consideration, this paper analysed a typical building steel-concrete composite floor spanning 40 m by 40 m used for aerobics.

The developed computational model adopted the usual mesh refinement techniques present in finite element method simulations, based on the ANSYS program. This numerical model enabled a complete dynamic evaluation of the investigated steel-concrete composite floor in terms of human comfort and its associated vibration serviceability limit states.

The modal analysis performed indicated that the first sixteen natural frequencies of the composite floor lie in the frequency range of aerobics. Consequently, this condition may lead the investigated structure to a possible resonant condition. The dynamic analysis carried out shown that the peak accelerations values obtained when thirty-two persons practising aerobics were higher than the limits proposed by three different methods of human comfort evaluation. This situation led to human discomfort for the individuals practising aerobics on the studied composite floor.

Aiming to mitigate such excessive vibrations on the investigated floor, the use of sixteen passive tuned mass dampers (TMDs) were simulated as they were attached to the floor system. The control TMD system used in this study was based on an actual TMD system [9]. The maximum reduction obtained for thirty-two individuals practising aerobics (worst design case) was about 68%, which resulted in an unweighted peak acceleration, RMS acceleration and VDV of  $0.32\text{m/s}^2$ ,  $0.18\text{m/s}^2$  and  $0.37\text{m/s}^{1.75}$ , respectively.

Therefore, the controlled steel-concrete composite floor dynamic response was enough to attend the human comfort criteria. This way, the use of tuned mass damper systems has shown to be a low-cost alternative to respect the intended human comfort criteria for composite floors submitted to human rhythm activities.

## 5 ACKNOWLEDGEMENTS

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

## REFERENCES

- [1] Gaspar, C.M.R., "Dynamic Analysis and Vibration Control of Building Floors when Submitted to Human Rhythmic Activities", MSc Dissertation (In Portuguese), Civil Engineering Post-graduate Programme, PGEIV, State University of Rio de Janeiro, UERJ, Rio de Janeiro/RJ, Brazil, 2013.
- [2] Bachmann, H., Ammann, W.J., Deischl, F., Eisenmann, J., Floegl, J., Hirsch, G.H., et al., *Vibration Problems in Structures - Practical Guidelines*, Birkhäuser, Switzerland, 1995.
- [3] Murray, T.M., Allen, D.E., Ungar, E.E, *Floor Vibrations due to Human Activity*, Steel Design Guide Series, American Institute of Steel Construction, AISC, Chicago, USA, 2003.
- [4] Smith, A.L., Hicks, S.J., Devine, P.J., *Design of floors for vibrations: A new approach*, SCI Publication P354, Ascot, UK, 2009.
- [5] Ellis, B.R, Littler, J.D., "Response of cantilever grandstands to crowd loads. Part I: Serviceability evaluation", Proceedings of the Institution of Civil Engineers. Structures and Buildings 157(SB4): pp. 235-241, 2004.
- [6] Setareh, M., "Evaluation and assessment of vibrations owing to human activity", Proceedings of the Institution of Civil Engineers - Structures and Buildings 165(SB5): 219-231, 2012.
- [7] Faísca, R.G., "Characterization of Dynamic Loads due to Human Activities", PhD Thesis (In Portuguese), Civil Engineering Department, COPPE/UFRJ, Rio de Janeiro/RJ, Brazil, pp. 1-240, 2003.
- [8] ANSYS Swanson Analysis Systems, Release 11.0, SP1 UP20070830, 2007.
- [9] Varela, W.D., Battista, R.C., "Control of vibrations induced by people walking on large span composite floor decks", Engineering Structures, Vol. 33, No. 9, pp. 2485-2494, 2011.
- [10] Hartog, J.P.D., *Mechanical Vibrations*, Mcgraw-Hill, 1956.