ICSV 21
13-17 July, 2014, Beijing/China

The 21st International Congress on Sound and Vibration

13-17 July, 2014, Beijing/China

PREDICTION OF LOW FREQUENCY VIBRATION AND SOUND PROPAGATION THROUGH REINFORCED CONCRETE STRUCTURES

Ana Carreira(1), Albano Neves e Sousa(2)

(1) *ISE-DEC, University of Algarve, Campus da Penha, 8005-139 Faro, Portugal*

(2) *ICIST, IST-DECivil, University of Lisbon, Av. Rovisco Pais, 1, 1049-001 Lisbon, Portugal*

e-mail: albano.n.e.sousa@tecnico.ulisboa.pt

Prediction of low frequency sound fields generated in buildings by internal sources as machines or external sources such as road or rail traffic is a difficult task. Assuming that the source is well known, predictions are generally based on the Finite Element Method (FEM), which is used to model building structures and vibration and sound fields, but other hybrid or coupling methods also can be used. In general, these methods are too much time consuming and provide results which are reliable only below 100-150 Hz. Reliability at higher frequencies requires much larger models. It is, thus, important to develop simpler methods to be used with confidence by acousticians and other consultants. In the present paper a method for prediction of vibration propagation to building slabs based on the use of simplified transfer functions between fundamental joints of the structure is presented. The method was developed numerically for traditional multi-storey building with reinforced concrete slabs supported by reinforced concrete beams and columns and also was experimentally validated. The method can be used together with theoretical modal analysis to predict sound fields in dwellings.

1. Introduction

Prediction of low frequency sound fields generated in buildings either by internal sources as machines or by external sources such as road or rail traffic is generally a difficult task. Difficulties arise on assessing the characteristics of the sources and also on assessing the structural transmission paths, as well as on assessing sound radiation to receiving rooms from surrounding vibrating construction elements.[1] Although all aspects are important to correctly estimate sound fields, the present paper focuses only on the transmission paths.

Although analytical and hybrid methods can be used to predict structure-borne sound transmission, they are generally limited to simple geometries. For this reason, the Finite Element Method (FEM) is probably the numerical method which is most often used to simulate vibration propagation through building structures and thus estimate the resulting sound fields. This choice is generally based on the versatility of FEM computer programs, which allow modelling accurately any complex structure. However, the method also requires too much time to build the computer models and then to run them. Another disadvantage is that reliable results are generally limited to frequencies below 100 to 150 Hz.[1] Theoretically, reliability at higher frequencies would be possible with refined models, but the rapid increase not only on computer resources but also on the calculation time makes this option much less attractive. Alternative and simpler prediction methods are thus required by acousticians and other consultants in order to obtain preliminary estimates of sound fields in rooms due to vibration propagation through building structures.

In the present paper, a simplified method is presented for prediction of vibration propagation from building columns and beams to slabs. The method is based on the use of simplified vibration transfer functions between fundamental joints of the building structure and applies to traditional multi-storey building with reinforced concrete slabs supported by reinforced concrete beams and columns. Calculation of any combination of transfer functions is possible in order to predict vibration fields and then, as rooms in dwellings have generally a shoe-box configuration, since the source power is known, theoretical modal analysis can be used to predict sound fields in dwellings.

2. Method development

Considering either external or internal vibration sources, structural columns and walls, when existing, are the vertical transmission paths. Thus, propagation from or to other structural elements, such as beams or slabs, will depend strongly on the mechanical characteristics of these vertical structural elements. In the present paper, only columns are considered for vertical transmission of vibration with the following typical joints: corner column connected to two beams; edge column connected to two beams; edge column connected to three beams; inside column connected to two beams; and inside column connected to four beams.

For each case, five transfer functions (H) were defined as illustrated in Fig. 1 for the particular case of excitation at a corner column:

- Column base, C_0, to adjacent connecting slab, $S_0^{(1)}$;
- Intermediate slab, $S_n^{(1)}$, to upper adjacent slab, $S_{n+1}^{(1)}$;
- Top slab, $S_{N\text{-}1}^{(1)}$, to roof slab, $S_N^{(1)}$;
- Intermediate slab, $S_n^{(1)}$, to adjacent slab in the same floor level, $S_n^{(2)}$;
- Roof slab, $S_N^{(1)}$, to another adjacent roof slab, $S_N^{(2)}$.

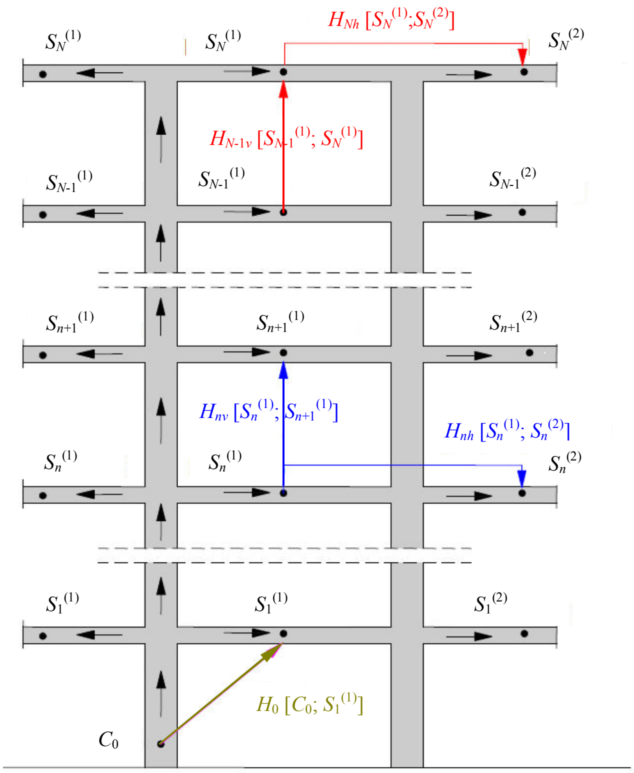

Figure 1. Plans of the: a) first floor; and b) second to fifth floors of building 1.

These transfer functions were measured in existing buildings in order to calibrate FEM working models. The calibrated FEM models then were converted into smaller models of 4-storey buildings and used in a parametric analysis in order to identify and characterize the factors which control the considered transfer functions. The following parameters were considered: column length, l_C; column cross section, $a_C \times b_C$; slab thickness, t_S; and slab aspect ratio, a_S/b_S.

For each parameter, two screening values were considered. Also three screening values of the elasticity modulus were considered. Thus, seventeen FEM models were built according to Table 1.

Table 1. Parameters considered in each FEM model.

Model	E (GPa)	l_C (m)	$a_C \times b_C$ (m×m)	t_S (m)	a_S/b_S (-)
1	34	3.47	0.25×0.50	0.19	11.25/6.10 11.25/3.40
2	34	3.47	0.30×0.70	0.19	11.25/6.10 11.25/3.40
3	34	3.47	0.30×0.70	0.30	11.25/6.10 11.25/3.40
4	27,5	3.47	0.25×0.50	0.19	11.25/6.10 11.25/3.40
5	34	3.47	0.25×0.50	0.30	11.25/6.10 11.25/3.40
6	34	2.50	0.25×0.50	0.19	11.25/6.10 11.25/3.40
7	34	3.47	0.25×0.50	0.19	6.10/5.70 5.70/3.40
8	30	2.50	0.30×0.70	0.30	11.25/6.10 11.25/3.40
9	30	2.50	0.30×0.70	0.19	11.25/6.10 11.25/3.40

Model	E (GPa)	l_C (m)	$a_C \times b_C$ (m×m)	t_S (m)	a_S/b_S (-)
10	34	2.50	0.25×0.50	0.30	11.25/6.10 11.25/3.40
11	30	3.47	0.25×0.50	0.30	6.10/5.70 5.70/3.40
12	30	3.47	0.40×0.70	0.19	6.10/5.70 5.70/3.40
13	30	3.47	0.40×0.70	0.30	6.10/5.70 5.70/3.40
14	30	2.50	0.25×0.50	0.19	6.10/5.70 5.70/3.40
15	30	2.50	0.25×0.50	0.30	6.10/5.70 5.70/3.40
16	30	2.50	0.40×0.70	0.19	6.10/5.70 5.70/3.40
17	30	2.50	0.40×0.70	0.30	6.10/5.70 5.70/3.40

In Fig. 2, the plans of typical floors with slabs having aspect ratio of 11.25/(6.10 or 3.40) and 6.10/(5.70 or 3.40) are shown.

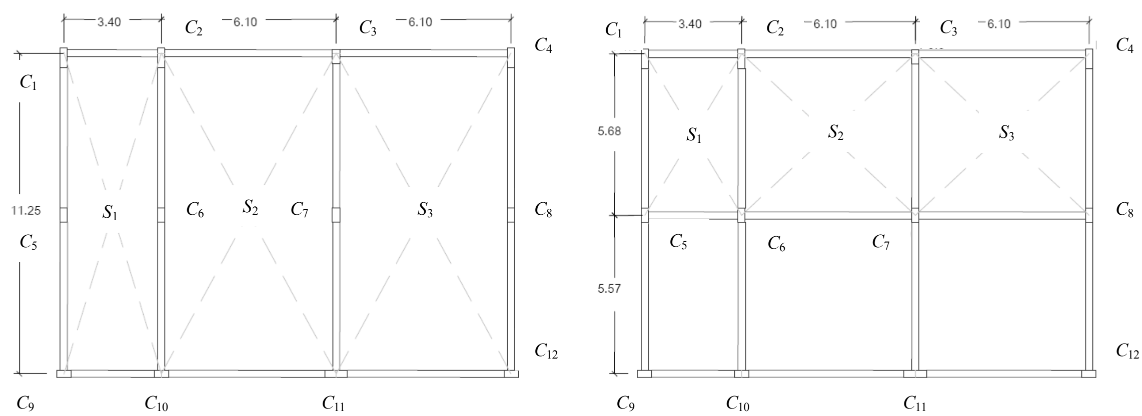

Figure 2. Plans of typical floors considered in models with slabs having aspect ratio of 11.25/(6.10 or 3.40) and 6.10/(5.70 or 3.40).

The simplified transfer functions were obtained after some statistical work on the transfer functions given by FEM models. In Fig. 3, the simplified acceleration transfer functions obtained for a corner column are shown. It is shown that vertical and horizontal transmissions are generally identical. Frequency is more important for transfer functions involving the roof.

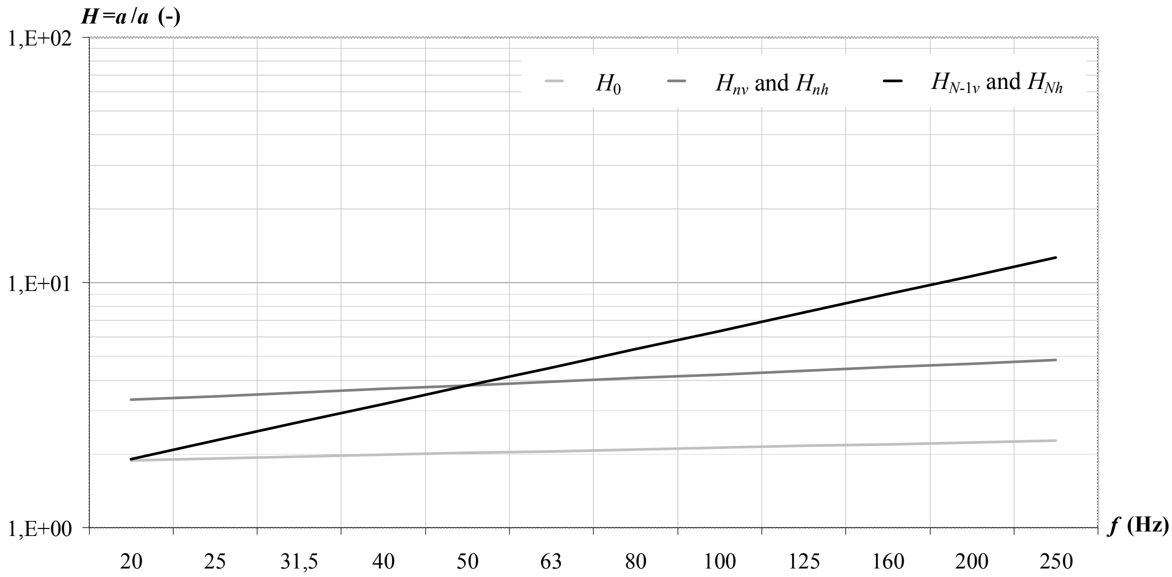

Figure 3. Simplified acceleration transfer functions for corner column.

The above simplified transfer functions were then used in real case studies in order to confirm their applicability.

3. Case studies

The method was applied to two illustrative buildings located in Algarve, in the south of Portugal. In the first case (building 1), a 5-storey building located in Lagoa was considered, whereas the second case (building 2) considers a 6-storey building located in Faro. Both buildings have concrete flat slabs, generally supported by concrete columns with beams at the edge. However, in building 1, some slab panels are mainly supported by beams.

3.1 Building 1

In Fig. 1, the plans of the first floor and the second to fifth floors of building 1 are shown.

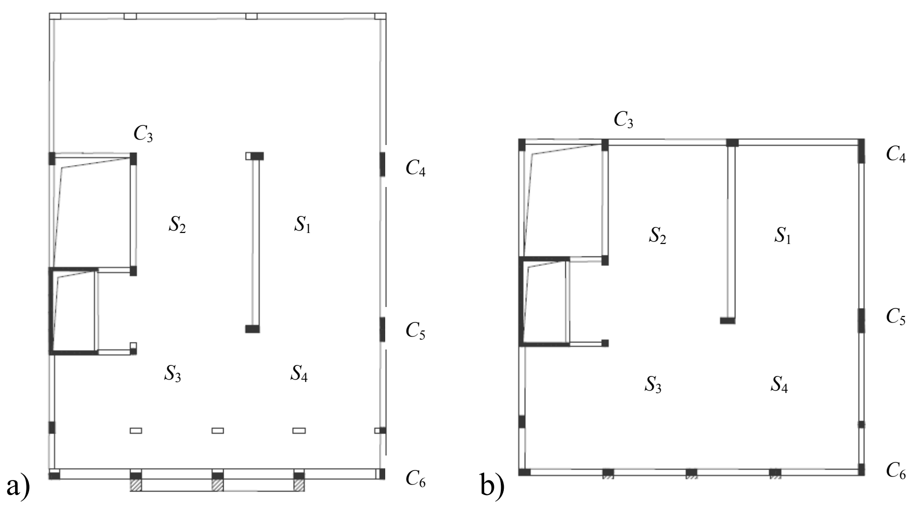

Figure 4. Plans of the: a) first floor; and b) second to forth floors (and roof) of building 1.

Figures 5 to 9 show one third-octave frequency bands spectra of acceleration transfer functions obtained for columns C_3 and C_4 by measurement (red lines) and FEM models (dashed blue lines), which are compared with the simplified transfer functions (continuous blue lines).

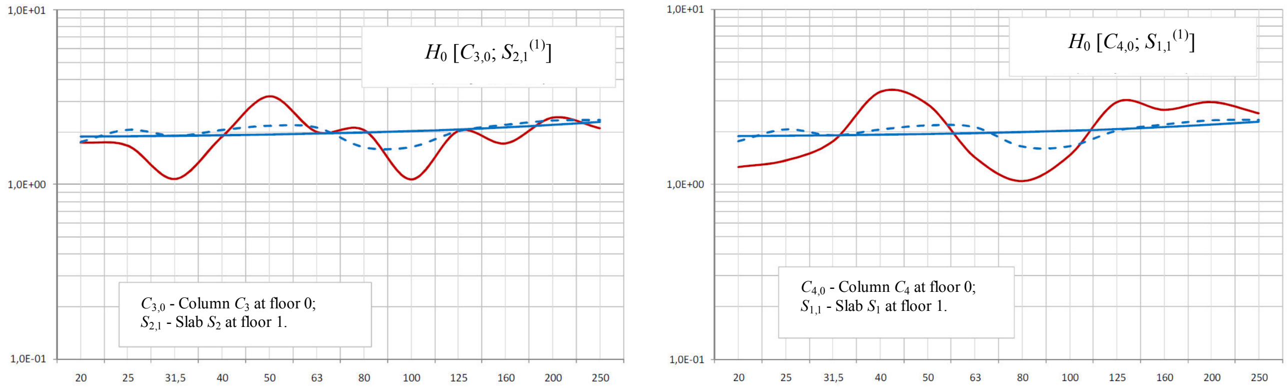

Figure 5. Acceleration transfer functions of the type H_0 for columns C_3 and C_4.

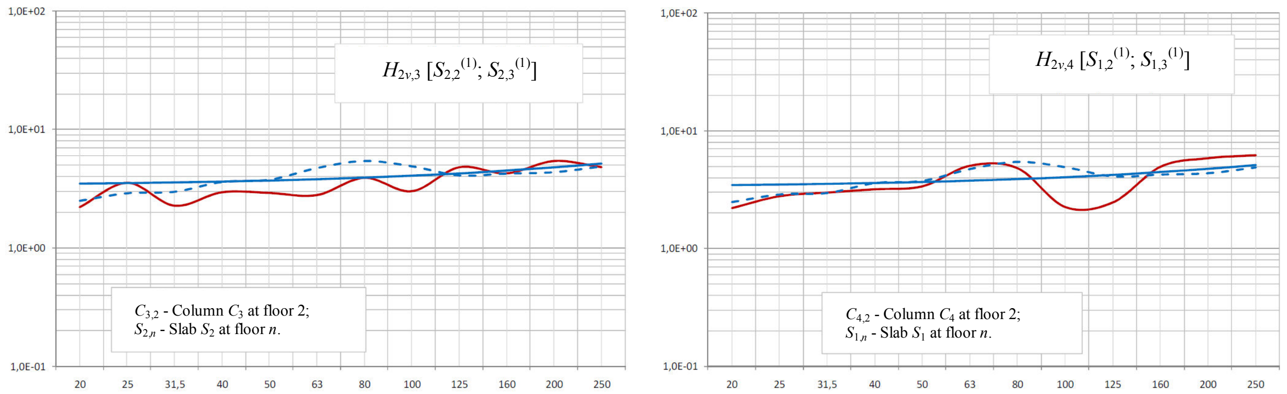

Figure 6. Acceleration transfer functions of the type H_{nv} between floors 2 and 3 for columns C_3 and C_4.

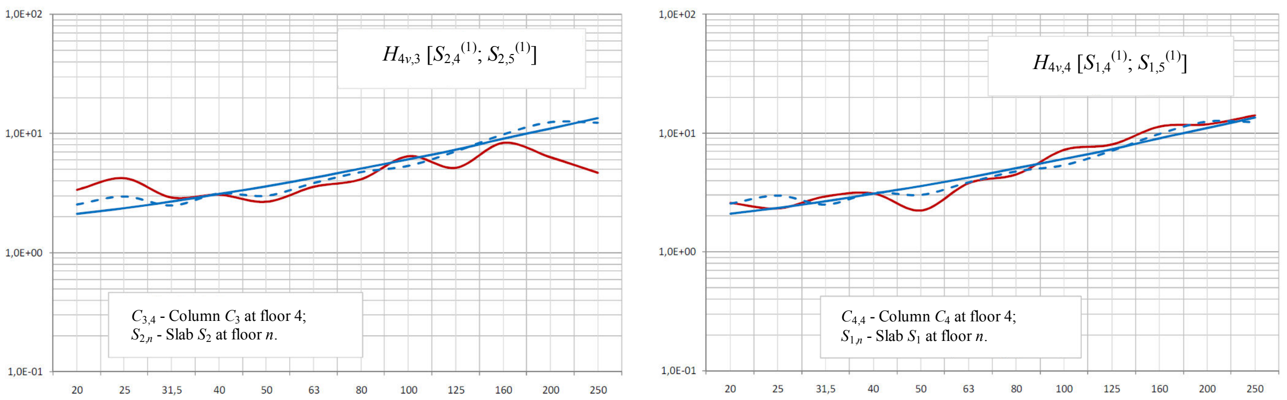

Figure 7. Acceleration transfer functions of the type $H_{N\text{-}1v}$ between floors 4 and 5 for columns C_3 and C_4.

Figures 5 to 9 indicate that, in general, agreement between measured transfer functions and those obtained with FEM models built for each case study is not much better than those obtained when measurements are compared with simplified transfer functions defined as described in section 2. Thus, for a number of situations, the simplified method can be an alternative to consider.

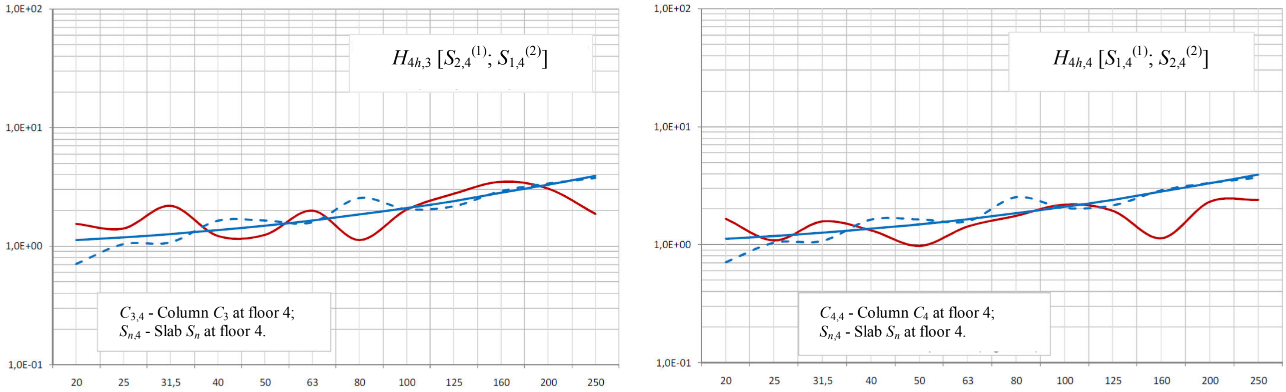

Figure 8. Acceleration transfer functions H_{nh} between slabs 1 and 2 in floor 4 for excitation at C_3 and C_4.

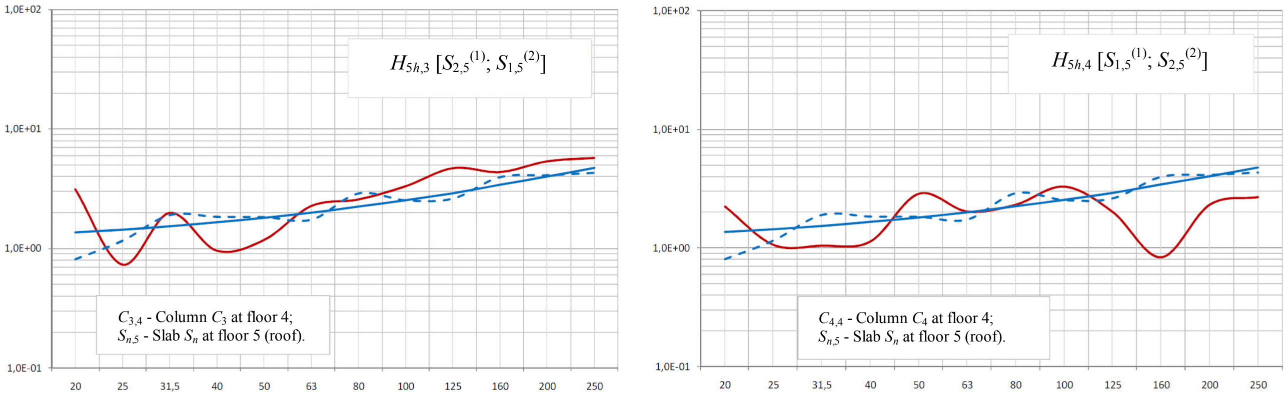

Figure 9. Acceleration transfer functions H_{Nh} between slabs 1 and 2 in the roof for excitation at C_3 and C_4.

3.2 Building 2

In Fig. 10, the typical floor plan of building 2 is shown.

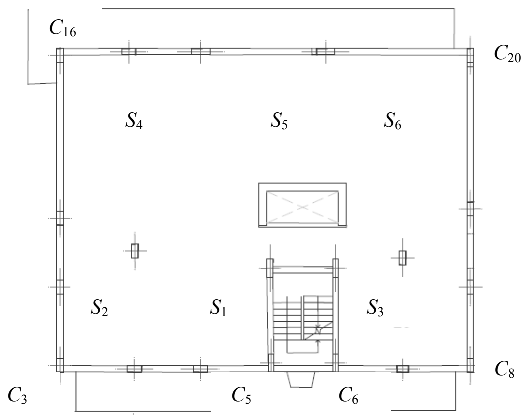

Figure 10. Typical floor plan of building 2.

Figures 11 to 15 show one third-octave frequency bands spectra of acceleration transfer functions obtained for columns C_6 and C_{20} by measurement (red lines) and FEM models (dashed blue lines), which are once more compared with the simplified transfer functions (continuous blue lines). As in building 1, Figures 11 to 15 indicate that, in spite of neglecting the modal behaviour of the building structural elements, the simplified transfer functions obtained as described in section 2 provide an acceptable agreement with measured transfer functions, which is as good as that obtained with much more effort by FEM models built for each case study. Agreement generally is better for vertical transmission of vibration between intermediate floors than for vertical transmission to the first floor or for horizontal transmission.

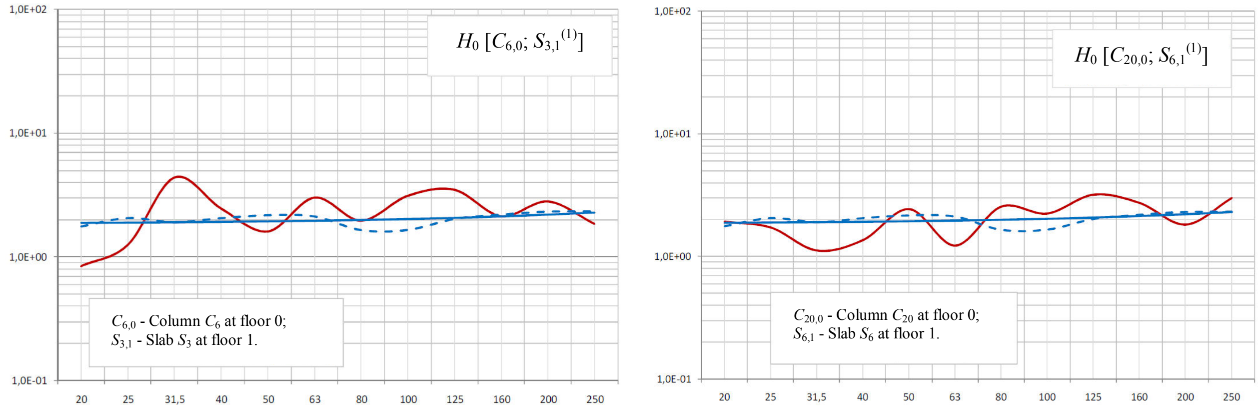

Figure 11. Acceleration transfer functions of the type H_0 for columns C_6 and C_{20}.

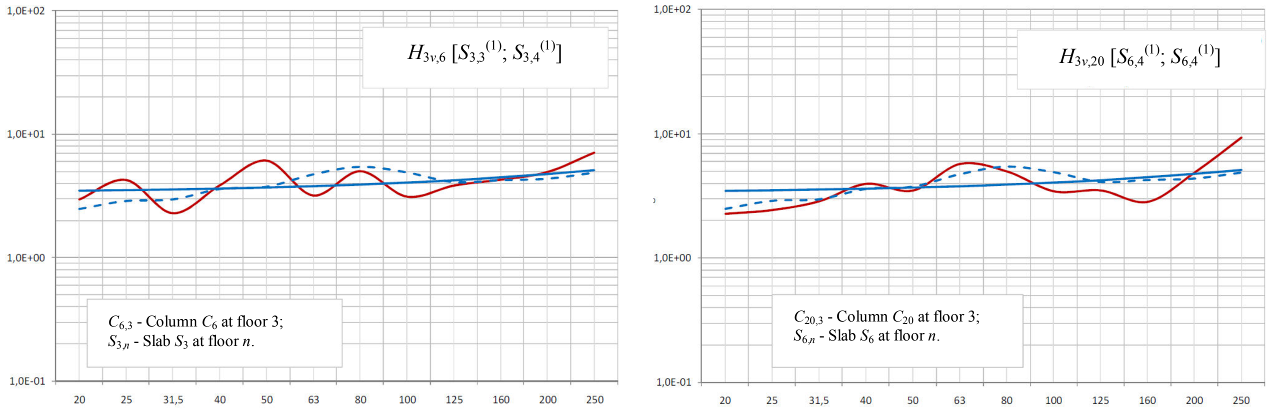

Figure 12. Acceleration transfer functions of the type H_{nv} between floors 3 and 4 for columns C_6 and C_{20}.

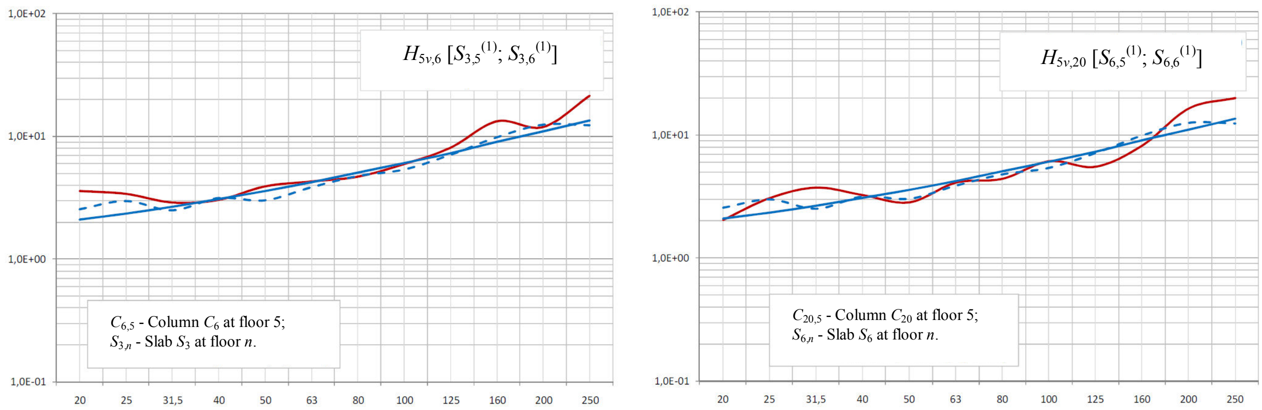

Figure 13. Acceleration transfer functions of the type $H_{N\text{-}1v}$ between floors 5 and 6 for columns C_6 and C_{20}.

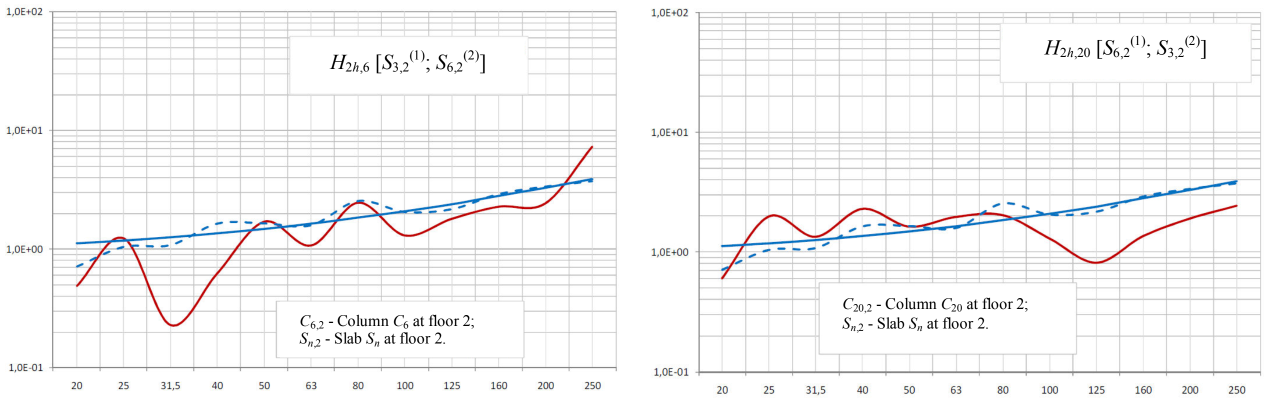

Figure 14. Acceleration transfer functions H_{nh} between slabs 3 and 6 in floor 2 for excitation at C_6 and C_{20}.

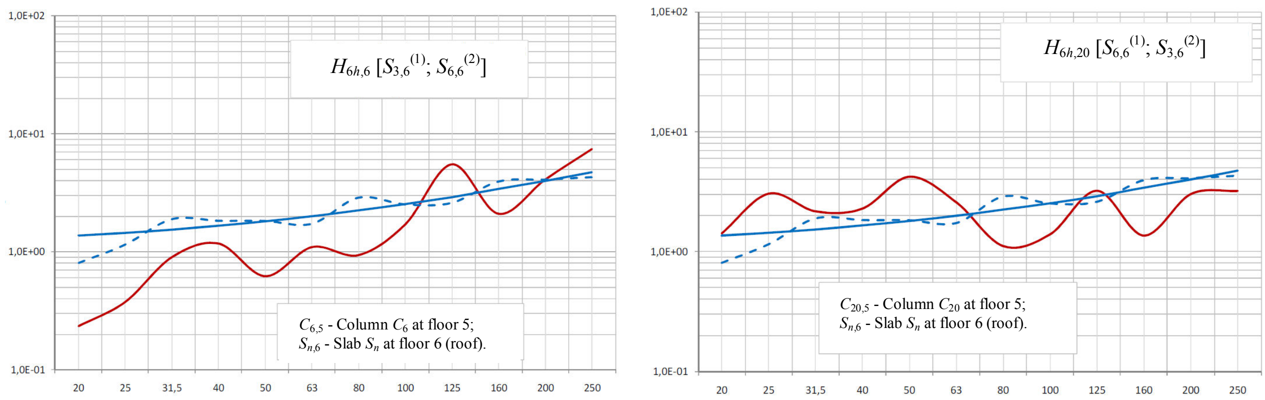

Figure 15. Acceleration transfer functions H_{Nh} between slabs 3 and 6 in the roof for excitation at C_6 and C_{20}.

4. Conclusions

A method based on the use of simplified acceleration transfer functions between fundamental joints of the building structure was developed for estimation of vibration transmission through traditional multi-storey building with reinforced concrete slabs supported by reinforced concrete beams and columns.

A set of simplified acceleration transfer functions were defined based on a calibrated FEM model and then they were applied to case studies and compared with measured transfer functions. Although the method neglects the modal behaviour of the building structural elements, vibration transfer functions obtained in this way are as accurate as those obtained by FEM models.

Although there is a need to study more cases, the obtained results indicate that it is possible to provide consultants with a set of simple acceleration transfer functions depending on a few structural characteristics of the buildings, avoiding, for buildings with similar characteristics, excessive time consumption on constructing and running complex FEM models.

REFERENCES

1 Neves e Sousa, A., Lopes, I., Carreira, A. Prediction of low frequency sound fields in buildings near railway lines, *Proceedings of the 41st International Congress and Exposition on Noise Control Engineering – Internoise 2012*, New York, USA, (2012).