NOISE AT HOME EMITTED BY VIBRATING SLABS. EXPERIMENTAL STUDY ON VIBRATION EVALUATION CRITERIA

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ABSTRACT

In modern residential buildings, hotels, schools, hospitals, etc., noise, emitted by vibrating building components, namely floor or ceiling slabs and walls, is heard by people. This is due to the presence of nearby vibration sources, as fixed motorised equipments, underground railways, or next door construction works.

The traditional comfort criteria for vibration, must be completed with an "acoustic" vibration limit, to ensure that no significant noise is heard above the ambient noise.

Simple calculations led, for practical purposes, to a limit of 0.03 mm/s for the r.m.s. velocity, normal to a vibrating slab, value computed only for the 1/3 octave frequency bands of 63 Hz, and above.

This paper relates some case studies comparing them with obtained experimental results based on theoretical predictions.

1 - FOREWORD

Many complaints from inhabitants against mechanical vibration at home, look unfounded, when measurements are done and results compared with vibration standards limits. Usually people alleges discomfort and sometimes attributes to sensible vibrations plaster cracks in their flats.

Damage and discomfort criteria used by LNEC were discussed in a previous paper submitted to TECNIACÚSTICA 2001 [1]. There, it was remembered that mechanical vibration is usually classified in two types: Transient vibrations due to short term inputs (blasting, pile driving, etc.) and continuously on going vibrations, due to lasting inputs (road and rail traffic, operation of fixed motorised equipment or construction works machinery).

In this paper only the second type will be dealt with.

2 - PSYCHOLOGICAL ASPECTS

It's experienced that vibration at home seldom involves physiological discomfort, but most of the times it also involves a great deal of psychological discomfort.

If a new vibration, just perceptible, is felt (or isn't, but something in the house trembles, may be the leaves of a plant or the water surface in a glass of water), and its source is unknown (may be a vibrating cylinder in a works site nearby), a question arises: is it an earthquake coming? Ordinary vibrations (as the ones produced by railway traffic, or motorised equipment, sometimes amplified at home by sympathetic resonant items) produce on people the certainty that all the plaster cracks are due to those vibrations, and their house will be ruined.

The main task of the expert who goes to people's homes to make measurements, is to reassure them that, within the standards acceptance limits (say, v_{rms} = 0.1 mm/s for human perception and v_{rms} = 3.5 mm/s for cosmetic damage), no harm will came to them or to their house.

3 - VIBRATION ASSESSMENT CRITERIA USED BY LNEC

LNEC experience has shown that, when measuring vibrations at complaintif people's homes, it is necessary to check the results against two vibration acceptance limit criteria:

C1) The ISO 2631 limit for the **rms** floor vertical velocity (or acceleration) frequency spectrum in 1/3 octave bands, which is, basically [2]:

$v_{rms}(f) < 0.14$ mm/s for $8 < f < 80$ Hz, at home, during the night

C2) The "old" Reiher-Meister human perception limits [3,4], adapted by LNEC, as a function of the global **rms** value of the floor vertical component of the velocity:

v_{rms} (mm/s)	human perception
< 0.11	none
0.11 to 0.28	perceptible, bearable for small duration
0.28 to 1.10	annoying
> 1.10	very annoying, reducing working capability

The lower frequency considered is 1 Hz. As today measurements are made with accelerometers, low frequency noise can give a significant contribution to the velocity value, after integration. An equipment operating with a noise level of 0.1 mm / s^2, for 1/3 oct. bands, will give for the 1 Hz band a velocity value of 0.016 mm / s . Such high acceleration noise level may be needed, in an equipment with a dynamic range of 10^4, if acceleration values up to 1 m / s^2 occur.

4 - INTERRELATION BETWEEN NOISE AND VIBRATION

Standards and regulations usually deal with noise and vibration as separate realities. It is well known that sound is emitted by vibration of plates as buildings slabs and walls. And also, sometimes, actual vibration of building components is due to unheard sounds.

It's also experienced that many times vibration under perception limit is sensed by people, not only because of the noise sometimes produced by resonant stuff (glass panels, crystal or china in the cupboards, etc.), but also because people hear the sound emitted by vibrating slabs and walls.

This problem is becoming more common because in modern concrete buildings damping is small, specially in low cost apartment buildings, even in the ones complying with noise isolation regulations.

It is clearly needed some new criterion of assessing vibration from the point of view of sound emission by vibrating slabs and walls.

5 - LNEC STRUCTURAL SOUND EMISSION LIMIT

Very simple calculations, based on previous experience, led to the acceptance limit of vibration velocity normal to a slab or wall, measured in a bit off centre point:

C3) Acoustic velocity acceptance limit:

$$v_{rms}(f \geq 63 \text{ Hz}) \leq 0.03 \text{ mm/s} \qquad (1)$$

Let us suppose a vibrating slab. The noise level nearby (L_{lin} , in dBlin) assuming a plane wave is (p in Pa, v in m/s, and approximately, $p = \rho\ c\ v \approx 400\ v$):

$$L_{lin} = 10 \log (p\ v / 10^{-12}) = 10 \log (400\ v^2 / 10^{-12})$$

$$L_{lin} = 10 \log 400 + 20 \log v + 120 = 20 \log v + 146 \qquad (2)$$

The sound level, A weighted, L_A , is (in dB(A))

$$L_A = 10 \log [\Sigma_i\ 10^{0.1\times(L{lin}_i+C_i)}] \qquad (3)$$

If we assume an uniform decomposition of a **rms** v value in the 63, 125 and 250 Hz octave bands, for each band $v_i = v / 3^{1/2}$, and the C_i are the -26, -16 and -9 dB weights for those three bands. For v = 0.03 mm / s = 3.0×10^{-5} m / s, for each band v_i = 0.03 / $3^{1/2}$ = 0.017 mm / s , L_A = 42.8 dB(A).

For a uniform decomposition only in the 63 and 125 Hz octave bands ($v_i = v / 2^{1/2}$), for the same value of v , L_A = 37.2 dB(A); for only the 63 Hz band (v_i = v), L_A = 29.7 dB(A).

6 - LNEC CASE STUDIES

Measurement of vibrations and noise, in two flats in buildings near and over railway tunnels, dues to trains passing, gave the following results (in bold are the values above the referred criteria acceptance limits, reasonably confirmed by the operator; dB velocity reference value, v_o = 0.00005 mm/s = 0.5×10^{-7} m/s):

Lisbon flat, in a reinforced concrete structure building:

Table 3 - Root mean square velocity values, peak values of the **rms** velocity spectrum and acoustic velocity values of the vibrations registered, in May 2001, with trains passing in the tunnel underneath the nearby street, measurements that, at least one of the resulting values, exceeded any one of the criteria C1, C2 or C3

quantity → measuring point, d-time ↓	v_{rms} mm/s (dB) > 0.11 a 0.28	max(v_{rms}(f)) mm/s > 0.14	v_{rms}(f ≥ 63 Hz) mm/s ≥ 0.03	L_{eq} dB(A)
sitting room, 22 - 15:55	**0.137 (69 dB)**	0.099	**0.130**	-
sitting room, 24 - 22:47	0.029 (55 dB)	0.015	0.024 [1]	33.2
sitting room, 24 - 22:48	0.083 (64 dB)	0.048	**0.068**	-
sitting room, 24 - 23:09	-	-	-	39.6

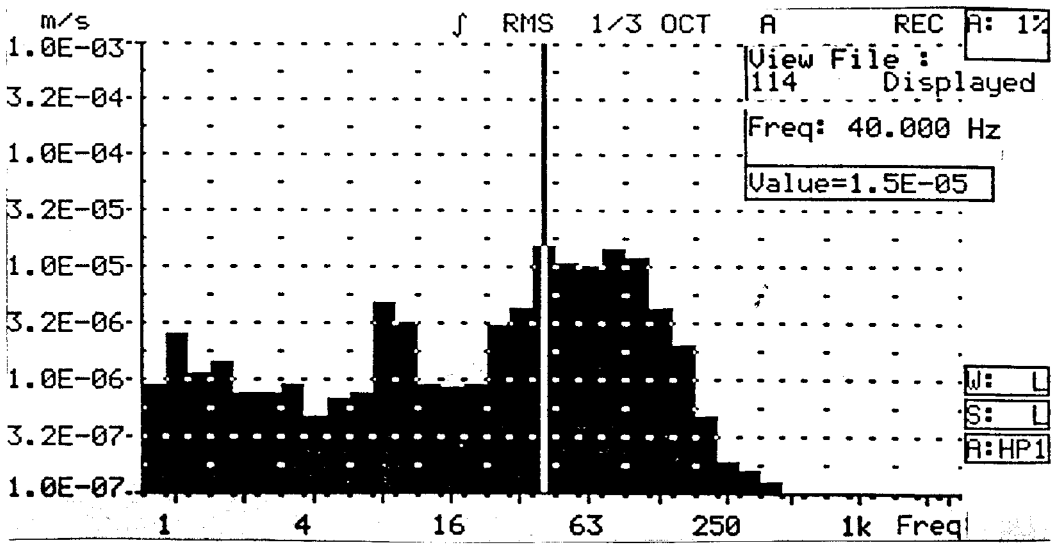
[1] The velocity value that would lead to L = 33.2 dB, under the above hypotesis (plane wave with no damping, no reflexions, etc), would be v_{rms}(f ≥ 63 Hz) = 0.019 mm/s, or 0.045 mm/s, either under the assumption of a velocity uniform decomposition only in the 63 and 125 Hz bands, or only in the 63 Hz band.

Two noise measurements in the same room, the 24th, at 22h37 and 22h58, with no train passing, gave the results: L_{eq} = 26.2 e 24.7 dB(A), values got in 34 and 33 s time. L_{eq} measurement time during train passage was 3 or 4 s.

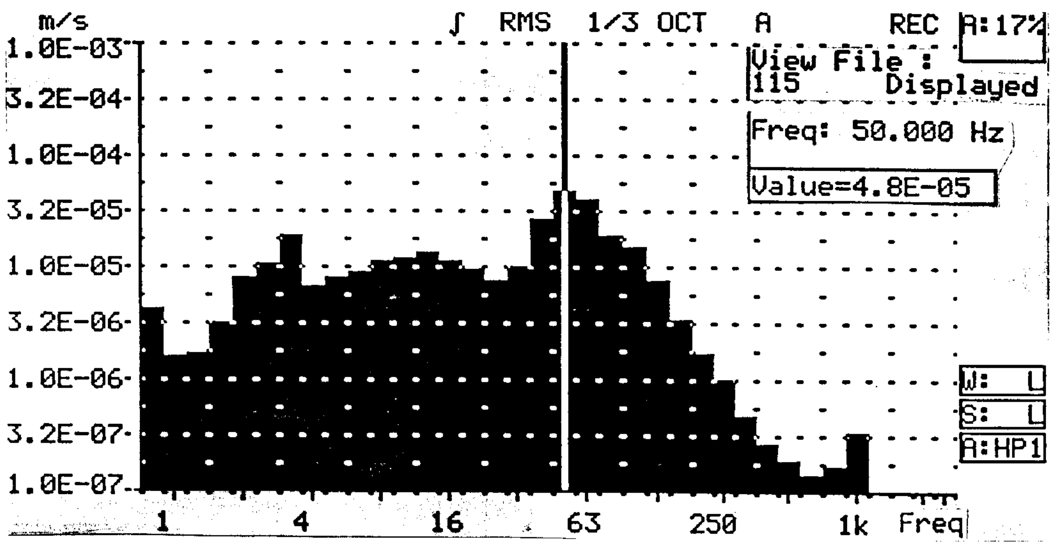
Figure 1 shows the velocity spectra for the floor vibration due to two trains passing one after the other (no sound measurement was done for the second passage). The maxima of both are found around the 63 Hz band.

For the first spectrum the octave band **rms** velocity decomposition was found to be v_{rms}(f = 63 Hz) = 0.020 mm/s, v_{rms}(f = 125 Hz) = 0.013 mm/s, and v_{rms}(f = 250 Hz) = 0.0005 mm/s.

For the second spectrum the octave band **rms** velocity decomposition was found to be v_{rms}(f = 63 Hz) = 0.065 mm/s, v_{rms}(f = 125 Hz) = 0.017 mm/s, and v_{rms}(f = 250 Hz) = 0.002 mm/s .



Train passing at 22:47



Train passing at 22:48

Figure 1 - Velocity spectra in 1/3 octave bands

House in Oporto, building of stone masonry and timber:

Table 4 - Root mean square velocity values, peak values of the **rms** velocity spectrum and acoustic velocity values of the vibrations registered, in July 2001, with trains passing in the tunnel underneath the house, measurements that, at least one of the resulting values, exceeded any one of the criteria C1, C2 or C3

quantity → measuring point, d-time ↓	v_{rms} mm/s (dB) > 0.11 a 0.28	$max(v_{rms}(f))$ mm/s > 0.14	$v_{rms}(f \geq 63$ Hz) mm/s ≥ 0.03	L_{eq} dB(A)
sitting room, 23 - 20:10	0.046 (59 dB)	0.028	**0.040**	33.8
sitting room, 23 - 21:35	0.043 (59 dB)	0.025	**0.032**	-
sitting room, 24 - 00:09	0.053 (61 dB)	0.029	**0.042**	**41.5**
sitting room, 24 - 00:36	0.037 (57 dB)	0.028	**0.034**	36.8

Two noise measurements in the same place, the 23.rd and the 24th, at 19h38 and 00h22, with no train passing, were: L_{eq} = 34.0 e 31.5 dB(A), both values got in 121 s time. L_{eq} was measured during train passage, measurement time being 3 to 12 s.

For the spectrum corresponding to the first table row, the octave band rms velocity decomposition was found to be $v_{rms}(f)$ = 0.039, 0.010 mm/s, and 0.001 mm/s, for the 63, 125 and 250 Hz frequency bands; for the third row, $v_{rms}(f)$ = 0.041, 0.009 mm/s, and 0.0006 mm/s, for the 63, 125 and 250 Hz bands; for the forth table row, $v_{rms}(f)$ = 0.034, 0.006 mm/s, and 0.0006 mm/s, for the 63, 125 and 250 Hz bands

In this house, an older one, probably less well isolated from street noise, the undisturbed levels were higher than the ones measured in the Lisbon flat. But, there isn't enough data to allow a reliable comparison between the two cases.

6 - COMMENTS

It's not intended, in the work related here, to find a good agreement between practice, and simple theory, but to confirm the goodness of the LNEC "acoustic vibration velocity" acceptance limit of

$$v_{rms}(f \geq 63 \text{ Hz}) \leq 0.03 \text{ mm/s} .$$

The vibration measurement is usually performed installing the accelerometer vertically on the floor of a room, a bit far from mid span, to allow the capture of the various frequency components. According to the position of the vibration source, horizontal components of wall vibrations may be measured.

This acceptance limit is intended to be applied, in a simple procedure, to the more important component of the velocity, measured in a single point.

So far, measurements done inside people's homes, tend to show, for that velocity value, sound measurements below the predicted L_{eq} = 40 dB(A), mainly because vibrations originated by railway train passing nearby, have little components in the 250 Hz octave band. Theoretical calculations assuming that the velocity spectrum has main components only in the 63 and 125 Hz bands, lead to lower noise levels.

Even so, the measurements that exceed that acoustic velocity limit, may correspond to an increase (from undisturbed to disturbed) in the sound level of about 10 dB(A).

7 - CONCLUSION

Experience shows that vibration measurements for which

$$v_{rms}(f \geq 63 \text{ Hz}) > 0.03 \text{ mm/s},$$

correspond to a significant increase of the noise level at home, annoying to people.

Criterion C3, see inequation 1, should also be applied in vibration measurements.

It's advisable, when measuring ambient vibrations, to measure simultaneously the noise level, and compare both results.

In buildings near vibration sources, in adition to sound isolation design and construction, care must be taken to avoid vibration emmited noise.

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