VIBRATIONS DUE TO SOUND FIELDS IN A SENSITIVE BUILDING. DAMAGE CRITERION FOR THE NOISE LEVEL

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Abstract

The traditional buildings damage criteria for vibrations usually suppose ground borne vibration, although the limiting figures may also be used when vibrating mechanical equipments are installed on upper floors other than the ground floor. Also, noise and vibration limits are usually dealt with independent standards and regulations, as if noise and vibration were quite independent phenomena. In some cases, vibration of building elements produces noise. In the manner, sound or noise emitted inside buildings makes their partitions and structural elements vibrate. This paper relates a case study developed in a sensitive building made of steel and brick, a former power station now converted in a popular electricity museum. The study aimed the determination of such a noise level limit to be imposed on any music sound equipment operating inside this sensitive building larger room, in order to avoid damaging vibrations in the building facades. Also, vibration velocity limits were drawn from this study considering the damage limits established by current building vibrations standards and the experience of the authors. For this specific case, relationship between noise levels and vibrations on walls were experimentally prescribed.

1. FOREWORD

In this former power station, now an electricity museum, cultural and scientific events usually take place, involving sometimes musical performances. In this sensitive building, composed of a steel structure and brick outer walls integrating large windows, several cracks in the plaster were frequently noticed by the owner, and at first sight attributed to the high magnitude of the sound power produced inside the room. This situation and virtual assumption have given rise to a strong concern regarding the building stability and aesthetics.

Thus, an experimental study was carried out to determine the relationship between the sound levels, generated by the musical equipment, and the admissible velocity values for the vibration of the walls.

The aim of the study was so to find a sound level limit corresponding to the maxima velocity value of 0.7 mm/s for the root mean square velocity measured in a direction normal to the wall, and 3.5 mm/s for peak normal velocity. Besides the proposed sound level limit, an additional value of frequency constraint is given, and structural inspection procedures are recommended.

2. BUILDING INSPECTION

The building structure is composed of a framework of steel beams supported by brick outer walls integrating large windows, being the brick masonry built around the steel elements. Inside the building there are large spaces in which social and technical events take place. The walls surface are plaster finished (vd. figure 1). On masonry vertical elements, and between window openings, vertical cracks on the plaster were observed.

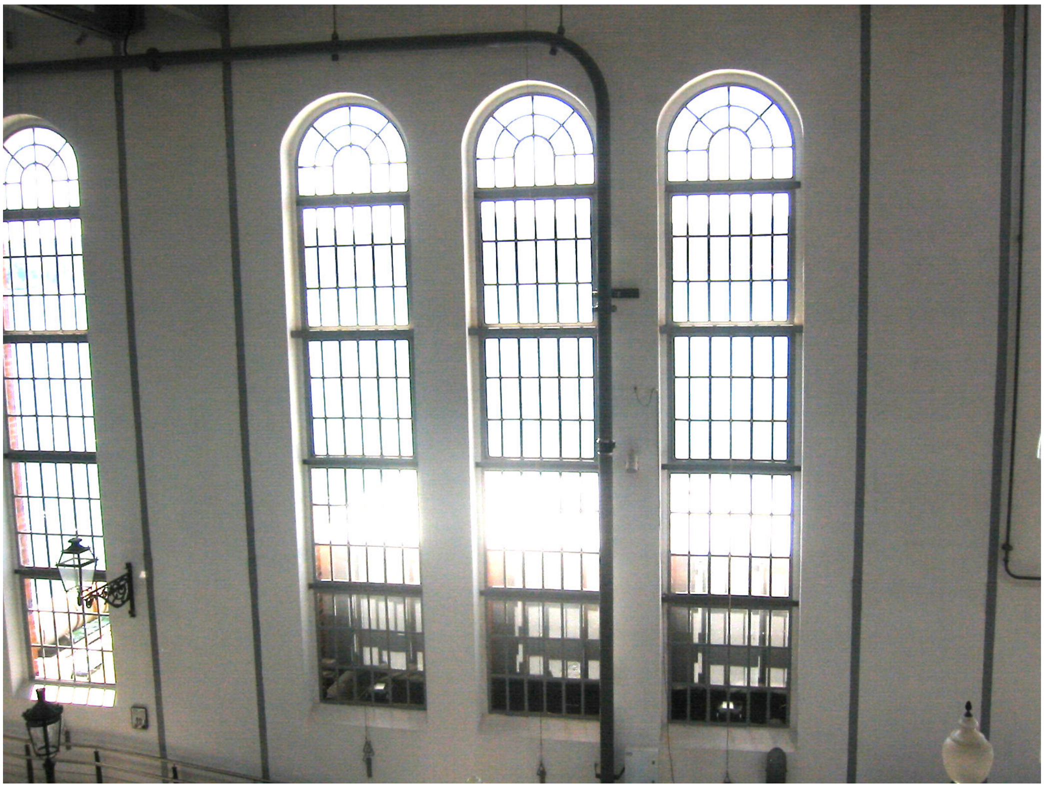

Figure 1 – Inside view of the western wall

A vertical crack, several *mm* wide, was detected on the plaster that covers one of the vertical elements between window openings. It may have resulted from the following accumulated causes:

a) Vertical compression stress;

b) Thermal stresses - the glass windows have steel frames and the building western side is cooler in the morning and hotter in the afternoon on sunny days;

c) Atmospheric humidity (from rain and riverside damp) that have entered into the masonry causing expanded rust in the imbedded steel beams, forcing consequently the bricks to separate away; and,

d) Some previous vibration.

3. VIBRATION CONSIDERATIONS. VELOCITY LIMITS

Subjected to the sound pressure, these large walls may vibrate at low frequencies which may be excited by continuous musical performance. Glass windows may also vibrate, at higher frequencies. As a guess, it is expected that the building as a whole and the walls will have their lower natural frequencies less than 20 Hz.

According to vibration standards (namely DIN 4150 and Portuguese NP 2074), and considering also its age, this building must be considered a sensitive building; its general good condition (namely the absence of differential vertical displacements at ground level) allow us to consider the foundation ground type as normal (or medium). Under these circumstances, for vibrations measured at points situated not far from mid span of the outer walls, the advisable limits considered for the perpendicular component to their surface were:

$$v_{rms} = 0.7 \text{ mm / s} \quad \text{and} \quad v_{max} = 3.5 \text{ mm / s}$$

Standard NP 2074 serves merely as guidance. It is used only when vibration reaches the building throughout soil and foundations; Concerning DIN 4150 (part 3 – 1999) it prescribes peak velocity limit of 5 mm/s for continuous vibrations in type 2 structures and 2.5 mm/s in type 3 (structures of particular sensitivity to vibration and with great intrinsic value, e. g. for listed buildings under preservation mandate), measured on the horizontal plane of upper floor. See DIN 4150, part 3 – 1999, section 6, and table 3.

Figure 2 – Velocity transducers on the western wall

4. EXPERIMENTAL TESTS

Music equipment similar to those commonly used in the technical and social events was placed inside the building, with two loudspeakers sets facing the inner sides of the larger room west and south walls.

Velocity transducers were glued to the walls to measure the normal component of the vibration velocity. Sound meters were used to measure and analyse the sound power in the 1/3 of octave frequency bands.

Two signals were used: a pink noise, and music trailer "*love to dance in wonderland*".

The sound emission was adjusted in both cases to a direct noise level L_A measured in front of the loudspeaker facing the western wall of 95 and 105 dB(A).

The more significant vibration velocity values were measured and are shown in table 1 (equipment figures were not rounded).

Table 1 – Vibration velocity on the building walls

	measurement →	west wall		south wall		frequencies of the west wall		
	input ↓	v_{ef} mm/s	$v_{máx}$ mm/s	v_{ef} mm/s	$v_{máx}$ mm/s	f_1 Hz	f_2 Hz	f_3 Hz
	ambient vibration.	0.026	0.187	0.024	0.136	6.3	10	1.25
case A	pink n., 95 dB(A)	0.067	0.273	0.064	0.244	63; 50	6.3	10
case B	pink n., 105 dB(A)	0.199	0.785	0.201	0.744	63	6.3	10
case C	music, 95 dB(A)	0.127	0.424	0.095	0.331	50; 63	6.3	10
case D	music, 105 dB(A)	0.180	1.145	0.163	0.792	63	6.3	10

The observed highest measured value of 1.15 mm/s was due to a sound peak.

All velocity values were below the limits considered above (v_{ef} = 0,7 e $v_{máx}$ = 3,7 mm / s), even for the highest noise level (105 dB(A)).

Significant components in the frequency bands of 63 Hz and adjacent bands (50 e 80 Hz) are also due to the significant components of the input in the same frequencies, both of the pink noise and of the music. The sound equipment transfer function cuts the inputs at 20 Hz and below.

Next figures show some of the vibration spectra of the recorded vibration velocities. Low frequency (6,3 e 10 Hz , sometimes 12,5) components, were also found in the ambient vibration spectrum. They could be assumed as natural frequencies of the building and walls (probably of the vertical element between window openings); note that frequency figures are the bands central frequency values.

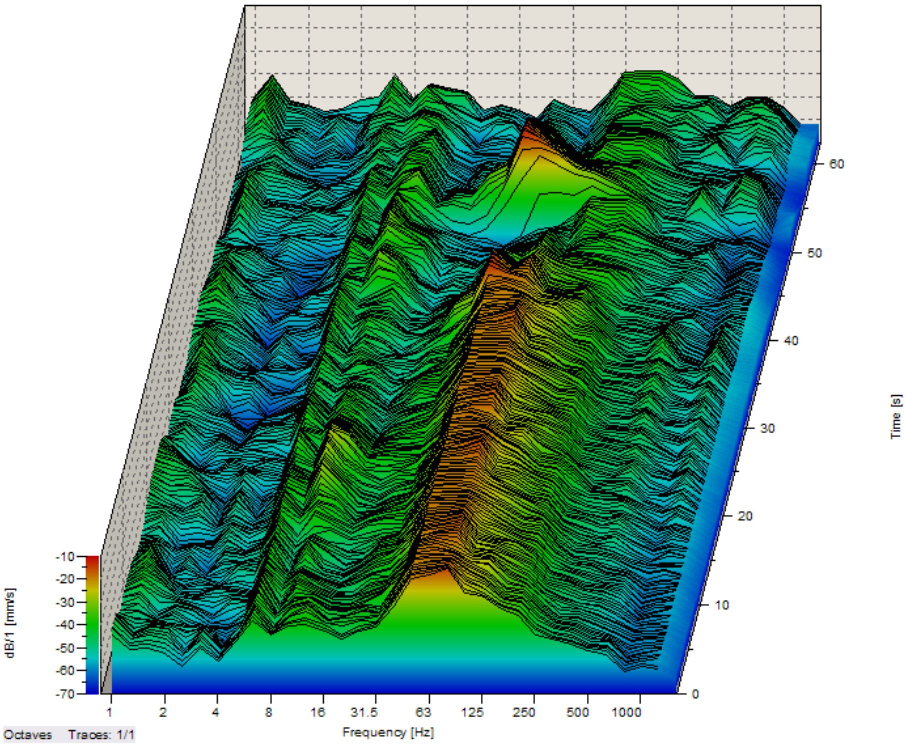

Figure 3 – vibration velocity spectrum as function of time (case D, point 2)

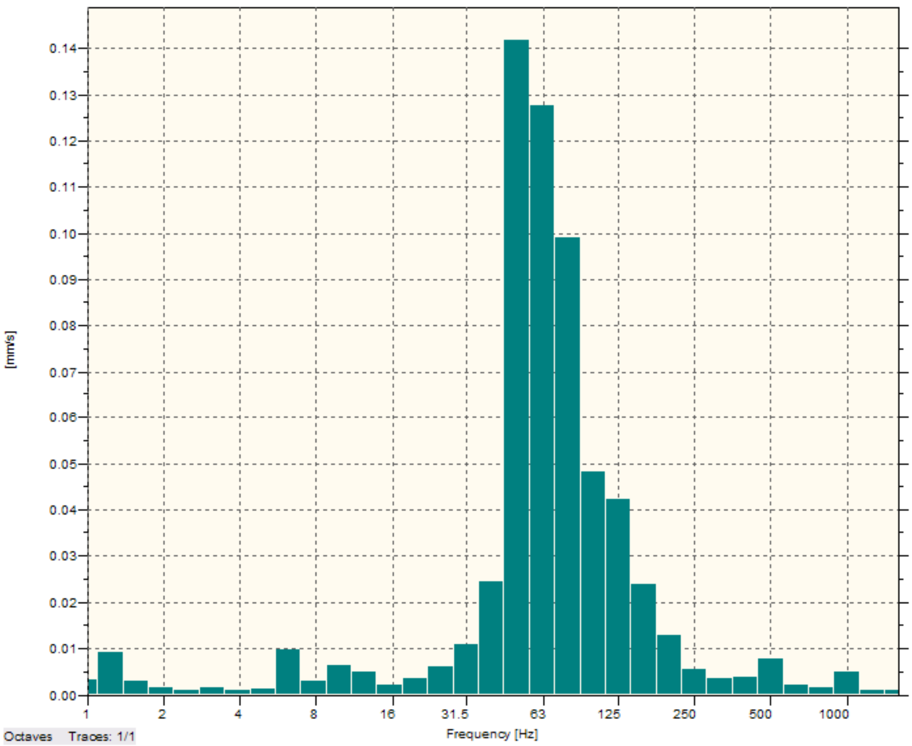

Figure 4 – Vibration velocity spectrum (case D, point 2)

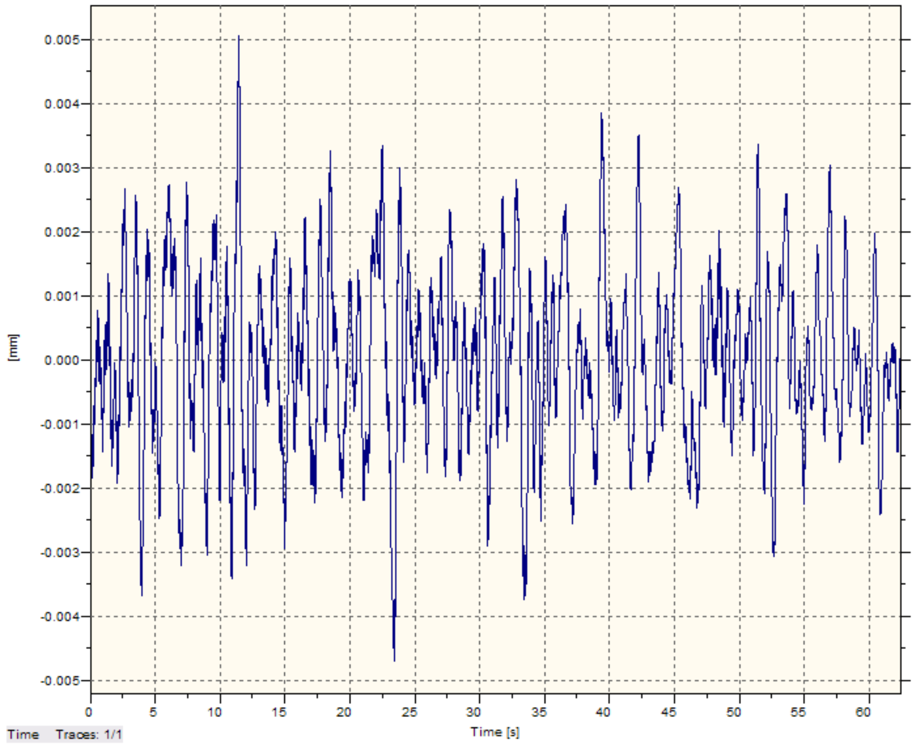

Figure 5 – Displacement in the most significant existing crack (case D, point 2)

5. PRECAUTIONS TO BE TAKEN BY THE BUILDING OWNER

In future events with music, sound level limits are to be imposed:

a) Sound level limit: $L_{adm} \leq 105$ dB(A);

b) Frequency filter: f > 20 Hz; although music equipments seem to cut low frequencies it is advisable to be sure that low frequencies near 8 to 10 Hz, may generate resonances;

c) Frequency limitation: f[63 Hz] ≤ 80 dB(A)/oit. = 106 dB(lin)/oit.

These limits should be imposed by an electronic device, connected to a microphone.

This controlling system needs to be correctly regulated in order to satisfy the previous indicated inequalities diminished in 6 dB. This value corresponds to the correlation factor between the incident sound on façades (used in the measurements) and that establishing the diffuse sound field inside the room.

The microphone is to be placed in a point where the sound pressure field is not directly affected by speakers output. The device, with a warning light, is to be seen by the sound equipment operator, and should have an adjustable timer to allow some short time overflow before cutting the electric power.

Also, the structure condition, especially where plaster cracks show, must be monitored.

6. CONCLUSIONS

Before strong sound fields are established in sensitive buildings spaces, it is advisable to carry out adequate tests in order to measure vibrations due to sound, and to establish a relationship between sound input and significant vibration on walls and light elements, or at least to monitor vibration velocity values on properly chosen points, in order to avoid damage.

This study allowed the building owner to continue to perform music events in a safe way, avoiding future damage caused by vibrations.

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References

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