Solid borne noise in buildings: how does one cope?

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In France there are regulations regarding the sound isolation of the façade with regards to road and rail noise. However, there are no provisions regarding structure borne noise from such sources. Should there be a tunnel by the building, on what basis does one conclude what the applicable target should be? Furthermore, is the end user aware of the problem and ready to implement some solid borne noise control measures? Alternatively, should there be a strong contribution of airborne noise in the low frequency range, are there any legal requirements applicable? This paper aims to address those matters through a couple of case studies.

1 Introduction

Over the years the quest for constructible space has prompted builders and end users to implement their projects much closer to transportation corridors than they used to. This means that solid borne noise has become a significant contributor to the noise from transportation systems transmitted into buildings. However, from expressed annoyance of neighbours to actual legal requirement to implement corrective measures there is quite a gap which can take a few years to fill.

In France there are regulations regarding the sound isolation of the façade with regards to road and rail noise. However, the regulations do not provide any hint regarding structure borne noise from such sources. Logically, should there be a tunnel by the building, the design team and the contractor alike (and even the railway operator for that matter) might simply forget about any solid borne noise generated by rail traffic inside the tunnel. Of course, the occupants of the building might think differently!

Due to the lack of regulation in this field, one might experience trouble deciding what the solid borne noise level target should be. In the building industry while the design team might try and steer for a rather ambitious target, the contractor might be less enthusiastic about such a move, as it implies more know-how; furthermore the end user might be even less enthusiastic as it will surely increase the cost of the project.

As concerns the railway operator, without any clear regulatory specification it might be tempting simply to forget about any vibration control implication: either the line was already there, and why bother, or should it be a brand new stretch of line, there would not be much chance of an official requirement.

Let's look first of all at the legislative implications of the problem.

2 A few legislative and practical aspects regarding solid borne noise

2.1 An interesting case of solid borne noise

The Paris Transportation authority built a new subway line in 1982 [1]. Due to the line being laid entirely in a tunnel under the rather busy street, standard track laying techniques were used.

However, on completion of the trackwork, the neighbours complained about disturbances from hearing noise from the operation of the line. They were initially turned down on the basis that the building regulations did not require anything more than the required façade sound insulation (which was reputed to have been achieved anyway due to the presence of the busy street).

Such a decision prompted the neighbours to call for an expert, who pointed out that while there was no requirement in the National Building Code, there was no dispensation from not creating undue nuisance as pointed out in the Civil Code [2]. The Transportation Authority was eventually found lacking by the Court [3].

Figure 1: Location of underground rail line (under the main street) and plaintiffs.

It seems that both the operator and the authorities are now much more careful on the matter; for example it has been specifically pointed out in the review of the project of the extension of Paris subway line 4 that "one will have to evaluate more precisely the annoyance that might be caused to neighbours of the new line, and state how the estimated vibration levels will rank with regards to the vibratory thresholds included in the authorities statements [13].

2.2 From vibration to sound

Vibrations induced in the structures of the building will eventually turn into sound radiated by floors and walls. Perception of the radiated sound will occur well before any tactile perception of the vibrations will appear [6].

In France, there is a regulation covering the vibration levels transmitted to the structures of buildings [7]. However, this regulation is primarily turned to the protection of buildings close to facilities that are classified for the protection of environment, and it is meant to protect the structures, not to provide comfort around. More to the point, it does not indulge in noise level limits.

A new text, of a more general nature, is currently under preparation. More to the point, there is a standardization committee which has been making an investigation in possible indicators for both sound and vibration in buildings and in the environment [8].

2.3 Solid borne noise from railway operation

Looking into the matter, while there is nothing on the subject in France, it does turn out that some other countries have not been idle on the matter.

There is a Swiss requirement [4] stating specific noise level limits for solid borne noise from railway infrastructures. Those limits have been specified as equivalent A weighted noise level values, on a duration of 16 hours in day time and 1 hour in night time (with, in this case, the higher of those vales not to exceed the 30 dB(A) mark).

The Austrians have a guideline stating specific noise level limits for solid borne noise from railway infrastructures [5]. Those limits have been specified as equivalent A weighted noise level values, but in addition there is a requirement on the maximum A weighted noise level values on a 1 s time span.

Other countries seem less decided on the subject. Many reasons may apply, from the general lack of exposure of dwellings to railway vibration, to the realization that such measurements may prove difficult to perform.

3 A few legislative and practical aspects regarding airborne noise

3.1 Low frequency noise

Low frequency noise is defined as noise in the 20 to 250 Hz range [6]. Structure borne noise from railway operation is only part of this larger problem.

Low frequency noise in living areas has been the subject of quite a few studies [6]. Most of the time, regulations have been shy of the problem: to start with, measurements are delicate to handle, to say the least.

Another significant factor is that most of the time, due to the shape of the A weighting curve, any intrusion of noise (e.g. through the façade, or from appliances inside the premises), will usually cover the low frequency noise of interest as far as the A weighted global noise level is concerned.

However, low frequency noise often happens to be tonal. As such, it is quite readily identifiable, and will induce a training effect in people subjected to its effects, making it a really serious cause of annoyance.

Attempting to set limits under such conditions (difficult measurements, subjective effects) is not a happy prospect, and for the time being many countries have reared from it.

3.2 An interesting case of airborne noise

The director of a public institute in Paris was blessed with a dwelling within the institute. Yet, he was quick to develop a true aversion to a strange low frequency noise that was periodically heard. This went to the extend he jut could not live in his dwelling.

Several noise control engineers were called to try and reduce the noise levels from this strange noise; which of course meant that first of all one had to try and identify the relevant noise source.

On visiting the dwelling in day time, the acoustician could actually not hear the low frequency noise the plaintiff was so adamant about! Eventually, late in the evening a proper low frequency sound was heard. It turned out that it featured a major contribution in the 31.5 Hz third octave band; more to the point, while it appeared on a rather regular basis (with a gap between noise events no greater than 10 mn) it was rather short in duration (circa 10 s)). In A weighted levels, the emergence from the background noise was a mere half decibel.

Due to the low frequency content one could not pinpoint the direction from which the sound was coming. More to the point, there was no significant difference between the noise levels measured inside the living room and outside of the dwelling. As there was a laboratory next door, at the request of the client the first part of the diagnosis was bent on trying to pinpoint the one fan responsible for that noise. It eventually turned out that none of the fan was involved as even with all equipment stopped the noise could still be heard on a regular basis.

Having declared himself unable to identify the source of that annoying low frequency noise, the acoustician dropped the matter. Till coming back a couple of years latter during night time in the same area to measure the noise of some technical equipment on the roof of a high rise building and discovering that there appeared a high contribution in the 31.5 Hz third octave band on a fairly regular basis. From this roof featuring a commanding view of the surroundings it was eventually possible to link this contribution to the rail traffic of the underground which becomes elevated in this area; the contribution actually came from the radiation of the bridge elements. Of course, while the good news were that the noise source of interest had at lat been identified, there was no cure available!

Figure 2: Location of rail bridge and plaintiff.

This example illustrates how complicated it can be to trace the source of low frequency noise, even from rather ordinary sources. More to the point, it also illustrates the sensitivity of some people regarding this kind of noise.

4 Indicators, indexes, and limit values

4.1 Scope

There are several distinct steps when dealing with noise and vibration problems linked to potential annoyance:

- Describing the physical properties of the phenomena (i.e. noise generated by the vibrations of the structure due to rail traffic nearby); this means that suitable measurement standards must be available. Typically, a single number rating will eventually be used, resulting in an index.

- Assessing the potential annoyance to be expected from the phenomena; this means that suitable guidelines must be available regarding the subject (which implicitly supposes that the required research has been performed and discussed). Typically, based on the relevant indicators of interest, an indicator will be processed.

- Setting limit values to the index (or directly to the indicators). This means that a specific law text will be required (and in Europe such a law text will typically rely on a European standard).

This means that one can hardly expect to be able to tackle the problem under the guise of either acoustic engineer or vibration specialist: much talk is needed between all the interested parties (including the one that will eventually foot the bill).

Last but not least, stating limit values implies that one is capable of a predictive assessment of the low frequency noise levels or structure borne noise levels of interest. While there now are some accepted predictive models regarding the noise emission of rail vehicles as well as its measurement, it is still pretty difficult to perform a predictive assessment of structure borne noise in a building, that is, with a reasonable degree of accuracy and without having to call for complicated and cumbersome methods [10]. Even measurements happen to be rather widely distributed [11].

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4.2 Looking for indicators

Which indicator should be used in a given situation? There has been quite a bit of work performed over the years [6]. Recently the French Standard Association AFNOR has launched a work item initially regarding the inventory of acoustic indicators [8]. The relevant workgroup was staffed from members of other workgroups (mainly from the fields of environmental acoustics and occupational acoustics). Efforts were especially aimed at indicators fitted to the feelings of the neighbours of ground transportation corridors. One tried to sort out families of indicators according to their pertinence and point out whatever specificity was featured by a given indicator.

The first results were quite illustrative of the various efforts performed over the years, as well as a testimony over the numerous attempts at characterizing a given physical situation or a given annoyance pattern.

Rapidly, especially when dealing with low frequency noise, it turned out that limiting oneself to purely acoustic indicators would not do. Colleagues from the vibrations workgroups were called to the rescue; they drew a similar inventory.

During this preliminary work, it was pointed out that existing indicators were really poorly adapted to multi-exposure situations, and the creation of something else was needed.

A distinction had to be made between indexes, that are purely physical, and indicators, that are supposed to take into account subjective aspects.

It has been made clear in this AFNOR workgroup that

- Sources must be distinguished
- Simple existing indicators can be improved
- Those indicators that best traduce the annoyance must be identified
- Structure borne noise will have to be treated together with the vibratory aspects as it results from vibrations.

A European project named RIVAS (Railway induced Vibration Abatement Solutions) has been pursued to tackle the subject of comfort descriptors pertaining to vibrations and structure borne noise from railway operation. It aims to develop at the source treatments to reduce vibrations and structure borne noise originating from rail traffic. One of the parts of this project attempts to express the reduction of vibratory levels through those treatments in terms of vibration and sound exposure as well as annoyance at the neighbour’s premises. The first step made an inventory of European (as well as international) descriptors and associated limits. First results were as follows [14]:

- There is a broad range of vibration descriptors, be they acceleration or velocity. Three types are to be found: RMS max values (more linked to sleep disturbance) with Slow or Fast constants, RMS equivalent values (more linked to life quality), and vibratory dose value VDV. One may care to note that RMS equivalent values and VDV values are linked to traffic and are often computed over day or night periods.

- The range is smaller when it comes to structure borne noise descriptors. Those usually are A weighted levels expressed in decibels. As per vibration aspects, RMS max values with Slow or Fast constants, and RMS equivalent values, can be found.

- Limits for comfort as proposed for vibrations usually are greater than the perception threshold; this implies that a percentage of people will be annoyed. There often are several classes of comfort submitted. Limit values for noise comfort usually are concerned with low frequency (under 100 Hz); they are identified through the difference between A weighted and C weighted levels. However, there are not many countries stating specific limits for railway structure borne noise.

- Vibration levels are mainly measured in the middle of floors, and several countries submit a procedure to compute structure borne noise from the vibration of floors.

- Several recent studies have shown that frequency weighting depends on the amplitude of vibration, and the current weightings underestimate the response of people. More to the point, it has been shown that both vibrations and noise contribute to global annoyance; they must be measured and their effects added. A few studies actually submit an equivalence between vibratory levels and noise levels.

A second stage of the RIVAS project will consider standard traffic, tracklaying, ground, and building, in order to estimate the treatments. This will give an opportunity to compute and compare a few existing descriptors as well as a few improved descriptors.

Studies performed in North America have pointed out [9], when “frequent service” transit systems are concerned, that

- Structure borne noise is more prevalent than feelable vibrations.
- Exposure measures accounted only for a tenth of the “highly annoyed” category of plaintiffs. This means that other factors than vibration participate to the annoyance pattern.
- While more than 200 individual vibration metrics were listed, they were only slightly variant measures of the same underlaying physical quantity, and therefore they were highly correlated with each other.
- The Federal Transit Administration states that for typical residential rooms the sound pressure level in dB is approximately equal to the floor vibration velocity level in dB.
- Care should be applied to sensitive equipment as structure borne sound can actually be an issue for those usually well vibration insulated pieces of equipment.

5 Conclusion

Much remains to be done. To start with, it would be interesting to try and correlate promising indicators with annoyance ratings. More to the point, there is a need to try and assemble acoustic indicators and vibration indicators.

In order to set limit values to such indicators specific law texts will be needed. In turn, this means that a serious standardization effort will be needed.

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