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VIBRATION CONTROL OF BUILDINGS: CASE STUDIES

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Abstract

Buildings erected close to rail lines (e.g. railways, streetcars and subways) usually are subjected to both sound and vibration. While the former is quite well known and has been covered in the relevant regulations in force, the latter is not as well mastered.
After a brief description of the relevant regulations and standards in force in France, the present paper submits an insight of such problems, from the definition of noise and vibration objectives to the elaboration of vibration control strategies, especially on the building. Then, it looks into the relevant kind of prescriptions and especially looks into the typical site supervision that is needed on such projects, from material approval to site visits, before covering the commissioning measurements. Those various stages are illustrated using a couple of case studies on office buildings.
The main conclusion, based on sheer experience, is that both material approval and a vigilant site supervision are needed for a satisfactory result to be obtained.

1. INTRODUCTION

Over the years, urban planning in Europe has been prompting for a rather significant densification of urban constructions. This eventually means that buildings are erected closer and closer to such transportation corridors as rail lines. They are then usually subjected to both sound and vibration impact. While the former has been quite well known and subsequently covered in the relevant regulations in force, the latter is not as well mastered.

Typically, the noise control engineer will be faced with two challenges that are: controlling the noise radiated by the vehicles in their external environment and intruding in the building through the facades, and controlling the vibrations generated in the track bed and transmitted to the rooms through the structural elements of the building.

Vibrations occurring inside the rooms may result in two different kinds of annoyance: tactile (mainly by means of the floor) should the vibratory excitation be high enough, and auditory because of the acoustic radiation of the envelope of the room under vibratory excitation. While vibratory annoyance criteria have mainly be defined through standards [6, 2] under the guise of maximal values, criteria pertaining to noise annoyance from vibratory excitation must be defined according to the nature and use of the rooms. One will easily check that annoyance from noise perception will appear far before any tactile perception [15]. More to the point, standards pertaining to vibratory limits have primarily been directed at the protection of structures [7] or equipment [16] rather than annoyance, and this also is reflected in the regulations in force [17].

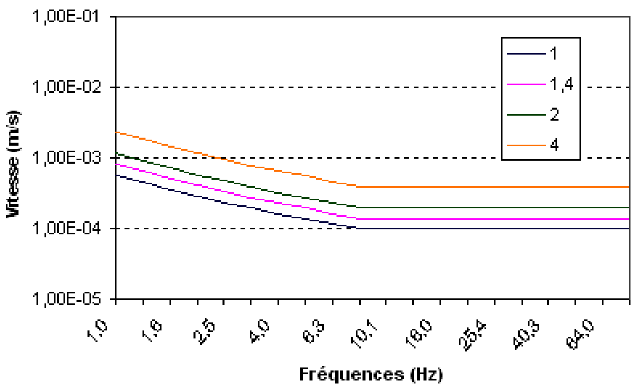
Therefore it is up to the acoustician to appreciate the risk as far as vibration induced noise annoyance is concerned, and to define suitable objectives that are adapted to the function of the rooms, as well as to help define technical solutions enabling the protection of the users.

Lastly, while various schemes have been submitted to try and predict the vibration induced noise levels inside a room, they usually rely on vibration levels (that are more or less known close to the rails) and propagation conditions (that are rather seldom known) [18]. Therefore it will also be up to the noise control engineer to define the kind of diagnosis and prediction method to be followed.

In order to illustrate the various stages of such a job, two case studies of office building projects near rail lines in Paris (France) and Prague (Czech Republic) will eventually be discussed.

2. LIMITS, STANDARDS, AND REGULATIONS

International standard ISO 2631-2 "Evaluation of Human exposure to whole-body vibration – Part 2" submits a set of vibratory velocity per third octave band curves. A significant part of those sets are devoted to the tactile annoyance according to the type of premises and the period (day or night time) for either continuous or intermittent vibrations. Those curves were drafted according to the answers from a sample of persons subjected to vibratory levels.



Space	Period	Range (mm/s)
Critical spaces (e.g. operating rooms)	Day and Night	≤1
Dwellings	Day	≤2 à ≤ 4 *
	Night	≤ 1,4
Offices	Day and Night	≤ 4

* : according to the standing of dwellings

Figure 1. Vibratory annoyance criteria (X and Y axis cumulated) according to ISO2631-2.

Regarding admissible noise levels inside rooms, there currently are neither French regulations nor standards pertaining to vibration induced noise from transportation corridors.

When attempting to protect the users of a building, the sound level objectives are intimately linked to the ambient noise levels inside the rooms, and therefore to the very nature of the activities that are carried out inside (and of course to their standing too). One may find out that it is not the absolute background noise level, in terms of L_{Aeq}, that is found to be a factor of annoyance, but the haphazard apparition of noisy happenings such as a train pass-by. This points to the importance of the signal to noise ratio: the lower the background noise level, the more important the potential annoyance of its noise.

One may try and attempt to follow the regulations applicable to building equipment in a room. However, for a tailor suited protection to train vibration induced noise, it is necessary to take into account both the time restricted apparition of the noise and the typical signature of such noise which usually is characterized by a significant low frequency rumbling.

As compared to very sensible rooms (e.g. bedrooms, hospital rooms, concert and cinema halls for example), the case of office premises usually is less stringent because of the activities carried out inside, which generates a higher ambient noise level than in a bedroom or a performance hall. More to the point the background noise level of such premises usually includes such masking sources as ventilation and office equipment, and may also feature tasks turning way the attention of the potential listener.

For our two case studies, that are of a standard standing, we aimed for a noise level objective of 38 dB(A) over the pass-by time of a train, in terms of L_{Aeq} measured inside a typical 4 m x 4 m x 2.5 m room. The definition of this objective was partly based on the recommendations of French standard AFNOR S31.080 pertaining to the acoustical performances of offices and associated spaces [1]. This standard defines three kinds of acoustical objectives according to the sought standing that are respectively “standard class”, “performance class”, or “high performance class”. Regarding the global sound levels in terms of L_{50}, here are the objectives:

Descriptor	« standard class »	« performance class »	« high perfomance class »
Global sound level *	$L_{50} \leq 55$ dB(A)	$35 < L_{50} < 45$ dB(A)	$30 < L_{50} < 35$ dB(A)

* including noise from the exterior and from pieces of equipment

Figure 3 – Objective tables according to AFNOR NFS 31-080 standard.

One can see that the « standard class » requires rather low performances which simply provide a minimal protection level to the users in order to satisfy what is thought of as basic work efficiency conditions. Actually, « performance class » performances are needed in order to provide minimal comfort conditions. On the basis of numerous measurements performed in offices, including our own, it appears that ambient noise usually is circa 40 dB(A). Our objective of 38 dB(A) looked like a good compromise between too stringent a value for offices and the usual 40 dB(A) usually encountered.

3. THE STEPS IN THE ELABORATION OF A BUILDING PROJECT SUBMITTED TO TRAIN-INDUCED VIBRATIONS

3.1 Assessing the vibration exposure of a future building

The main parameters of the vibration exposure of the future building are as follows :

- The intensity of vibration levels generated by the tracks (i.e. source). It depends from a large panel of parameters: type of trains (and their relevant suspension) and associated maintenance level, speed, characteristics of track bed and infrastructure, junctions rail/sleeper/ballast, irregularities of rails (e.g. joints, points) and associated maintenance level, etc.
- The position of the tracks with regards to the building project (underground or surface, distance) and the nature of the ground between tracks and building including eventual obstructions (propagation).
- The nature and the dimensioning of the foundations and structural elements of the building (receiver).

The typical frequency range for train induced vibrations is 20 to 200 Hz with the major contribution to be found around 63 Hz for trains and subways and 40 Hz for tramways.

The propagation conditions between source and receiver is therefore specific to each site. While the location of the building with regards to the tracks and the type of foundations come from the design, data pertaining to the vibration sources and the ground characteristics usually are collected through a diagnosis which enables the noise control engineer to assess the vibration exposure of the land and the spatial vibration decay that provides an indication of the probable spread of impact. Correlation between the vibration levels and the noise levels for a typical room of the project is carried out using a computer model. It enables deciding on the risk of vibration induced noise annoyance while pointing to the eventual need of decoupling part or all of the future building from its foundations. This initial and major part of the study requires both vigilance and mature experience as it actually often is speedily performed while directly conditioning the structural elements of the building (and its gauge).

3.2 Protecting the premises

Whenever the diagnosis shows that the future building will have to be protected from the vibrations, various actions, each featuring a different level of efficiency, can be called for:

- Source reduction: They typically involve the insertion of resilient materials either between rails and sleepers (providing an attenuation of up to 5 dB in the frequency range of interest) or under the ballast (with a larger attenuation of circa 10 dB). A decoupling of the track bed can also be proposed should a larger gain be sought (circa 15 dB). Now, while such measures can easily be proposed for a future rail link, they are (with the exception of the former) really difficult to implement on existing lines as they will require a traffic interrupt and a complex schedule of work.
- Propagation reduction: This is rather hard to implement as a minimal depth of 5 m is required in order to achieve any noticeable result.
- Receiver protection: This is the most commonly used solution for new constructions close to rail lines, for it does not imply any work on the tracks (with its inherent administrative complications and out of control costs) and is directly integrated into the building project. It typically involves the integration in the structure of the building of antivibratile elements (e.g. resilient materials or springs). It can of course be completed by source reduction measures should that be needed.

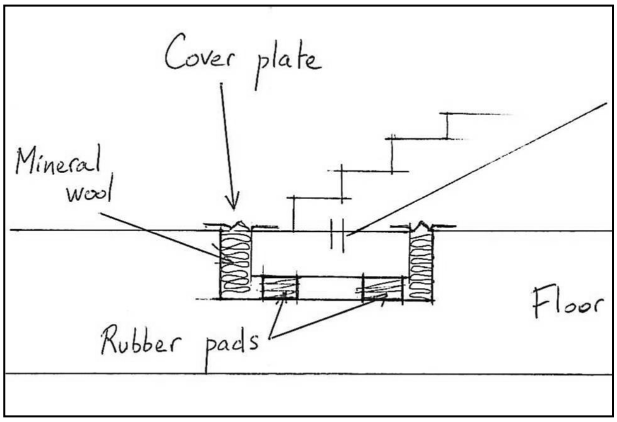
Three families of supports can be found : continuous mat in such materials as rubber or polyurethane like Sylomer by Angst & Pfister or Regupol by BSW, elastomeric pads (e.g. by CDM or Paulstra) and spring boxes (e.g. by GERB and Acousystem).

3.3 The stakes of decoupling a building

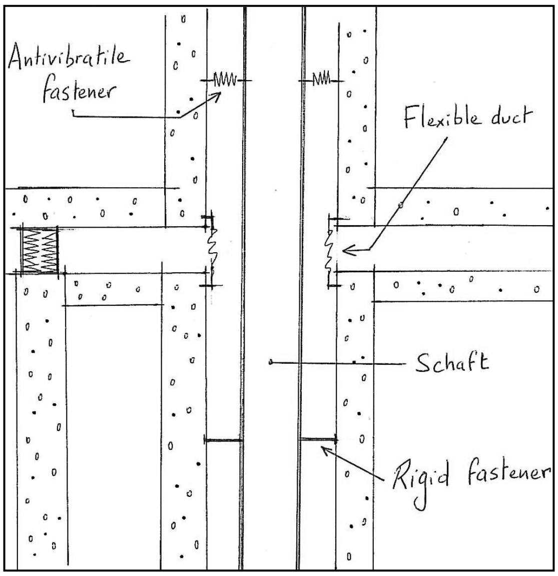
3.3.1 Prescription stage

The excitation frequency and the gain sought acoustically determine the selection of the resilient supports that will be chosen. For an optimal efficiency, the eigen frequency under load of the pads must be at least 4 times less than the maximal excitation frequency of the building. The eigen frequency of standard antivibratile mats is usually circa 12 Hz and can even go down to 8 Hz for the more performing products, which actually is similar to single elastomeric pads. Springs feature the better performance with an eigen frequency under load that can reach under 5 Hz though with a much higher cost.

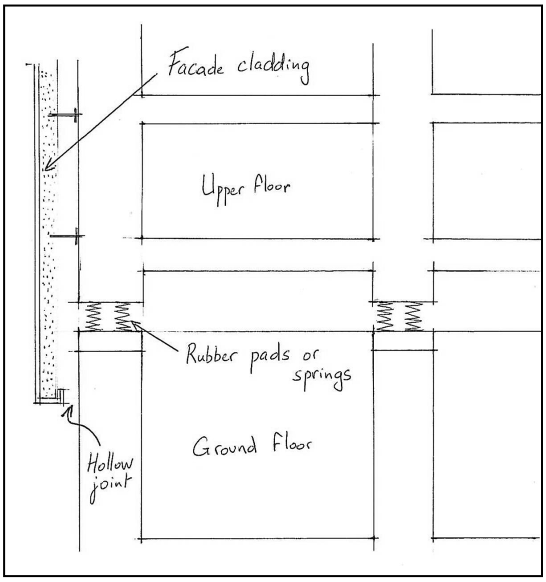
The location of the decoupling line is a subject in itself. According to whether the decoupling will be performed at low levels (i.e. at the base of the ground floor or in the basement) or at the higher levels (i.e. at the top of the ground floor or higher), it can have significant consequences both on the architectural appearance of the building (e.g. because of the decoupling line in the facade) and on the global cost of the project (because of the load applied on the pads). More to the point, this choice induces specific details in each case; therefore it must be weighted out consequently by both the design team and the end user.



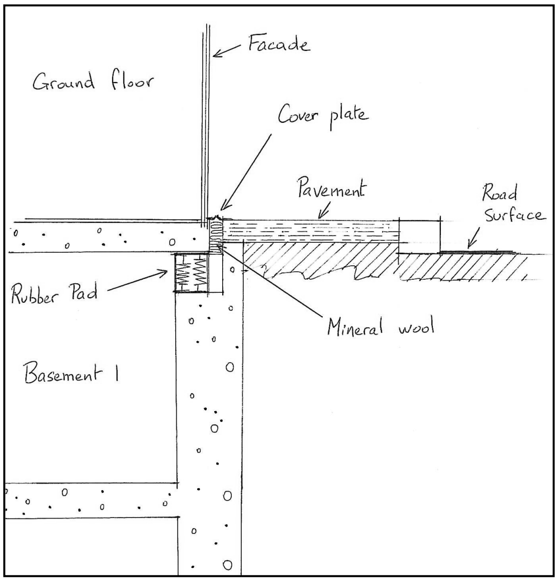
Decoupling of stairs



Decoupling of a shaft



Facade cladding connection details



Decoupling with regards to the pavement or road

Figures 4 – Examples of principles of treatment of singularities

Apart from a judicious selection of the pads, a successful decoupling of a building largely depends on the way the miscellaneous singularities of the building have been dealt with in order to prevent short-circuiting the pads. Such through elements (as stairs, technical shafts and lift shafts) are as many potential weaknesses which might create a sound transmission between founded and decoupled parts of the building. Whenever the decoupling line is located at higher levels, the façade junctions also are sensible points to be dealt with.

In case of low level decoupling, the junction with the pavement definitely must be feared as it must often be checked during building supervision but it also will remain a potential risky area after commissioning should the road or pavement be modified (which usually is not under control of the end user). The only way to attempt and prevent such a risk is to draft a specification book for the future actors by the building site…

More to the point, real decoupling joints are needed with regards to the neighbouring buildings; it can even be necessary inside the same building if different types of pads are considered according to the zoning of the building, especially if part of the building is decoupled so as to provide sufficient attenuation of vibrations according to the track distance.

3.3.2 Construction stage

In order to satisfactorily carry out the project, the construction phase is an essential part. It features both visas of the materials and site supervision so as to make sure that the prescriptions are correctly applied. One must make all actors of the project, especially contractors, conscious of the stakes. While it is essential that site supervision is implemented at regular intervals, it is not possible for the acoustician to be present all day long. Unfortunately, errors can easily be committed and their repair is cost and time consuming.

Checking and controlling the load applied on each support is critical, as it conditions both the selection of the pads and their repartition.

As expansion joints are also used as decoupling joints, they do not bear any rigid contact point along them otherwise the efficiency of the decoupling will significantly be reduced. Similarly, any singularity (e.g. pads in close contact, residues of concrete, leftovers, unscheduled fixations, etc.) preventing the pads to be correctly pressured, must be eliminated.

The final performance will totally depend on the control of those parameters, which is quite a challenge as they concern all specialties.

4. CASE 1: OFFICE BUILDING IN PARIS (FRANCE)

This building is part of a block of offices in a new business area of central Paris. It is located in an unbalanced way over a zone that will ultimately feature new rail tracks and close to existing main line tracks and subway lines.

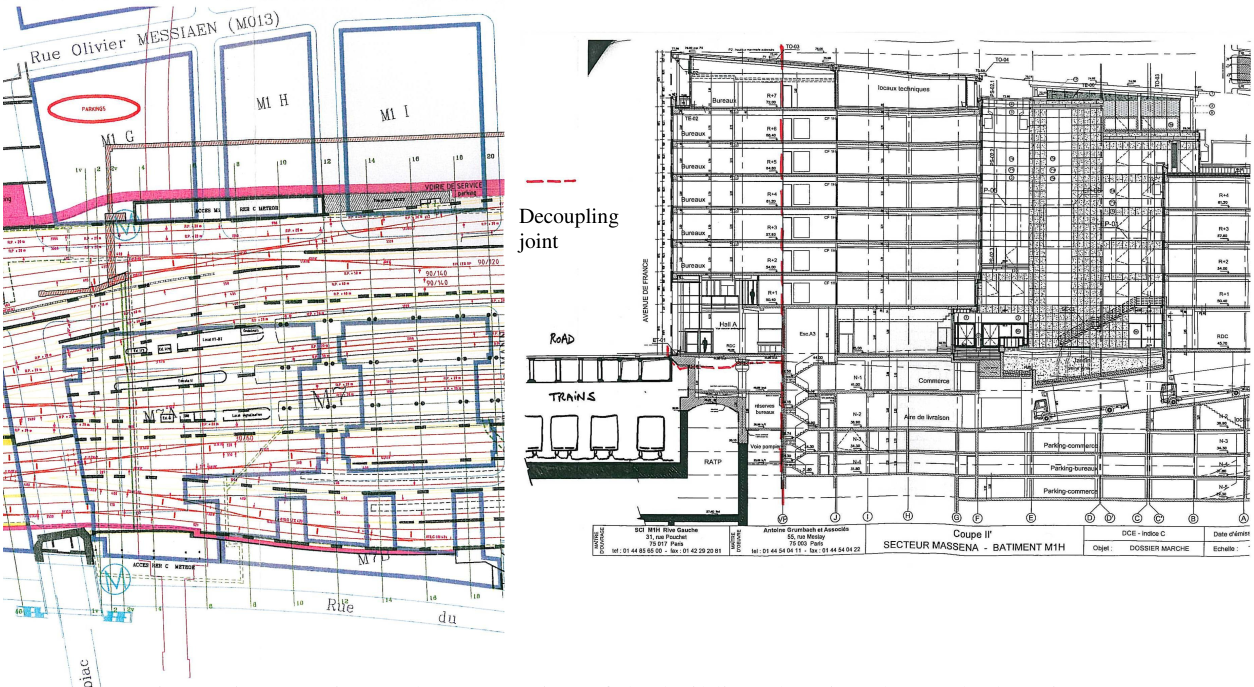


Figure 5 – Drawing and cross section of the building showing the tracks locations.

Owing to the fact that part of the tracks were not yet built, the assessment of the vibration exposure of the future building was carried out using a combination of a diagnosis through measurements in situ and computer simulations performed from french railways (SNCF) data on train composition and operations as well as envisioned track beds, with the hypothesis of a resilient mat under those tracks to be retained. The computations led to consider a partial decoupling of the building with a vertical expansion joint inside the building. The presence of such sensible spaces as meeting rooms at ground level eventually led to a low level decoupling principle to be chosen.

On commissioning, as it was not possible to experimentally check under real conditions whether the target of 38 dB(A) inside the rooms could be met, a construction tracked vehicle was used after checking that it could generate sufficient and comparable vibration levels as compared to rail vehicles. The attenuation that was measured on the pads was correctly correlated to the expected attenuation performance.

5. CASE 2: OFFICE BUILDING IN PRAGUE (CZECH REPUBLIC)

This building is located over subway tunnels and close to tramway lines; its site is exposed to high vibration levels between 25 and 160 Hz.

A diagnosis was performed. It showed that tramways and subways exposure was similar in the southern zone of the site, while subway exposure was predominant in the northern zone due to the trams being further. More surprising, the later featured much higher levels than the former for measurement points located close to the tunnel. One could note that apart from the composition and stratification of the ground, remains of old foundations, and even from an underground station, play a significant role in vibration propagation. Some measurements did show the presence of former retaining walls dating back to the construction of the subway tunnels. Those elements acted like propagation guides for the track induced vibrations. Our study led to a selection of different pads with an eigen frequency under load of 11 Hz for the southern zone and 8 Hz for the northern one. A high level decoupling was implemented at the top of the ground floor for cost and ease of implementation.

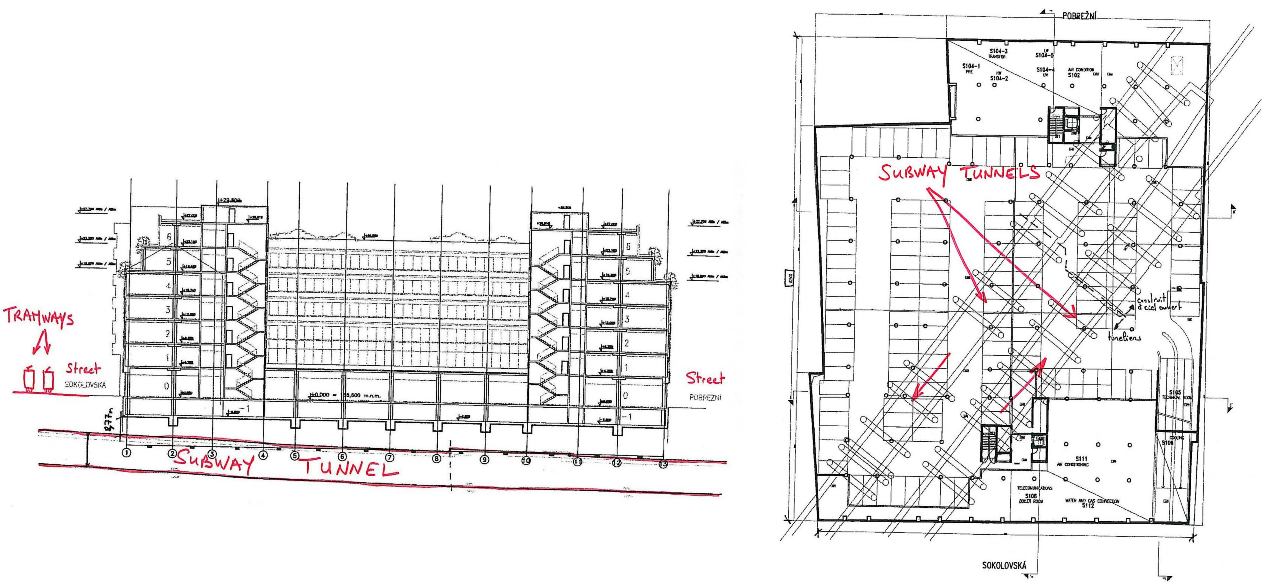


Figure 6 – Cross section and drawing of the building showing tracks location.

6. CONCLUSIONS

Decoupling buildings is a difficult but nevertheless achievable task. With the densification of the urban landscape it is more and more often needed. In order to be carried out satisfactorily, constant attention is needed, from the early stages of design that are decisive for the structure, to commissioning, including sustained site supervision.

Regarding the end results, a large dispersion may be observed on the pads that can be explained by the implementing conditions and the hazards of construction work.

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