

Reducing ground-borne noise due to railways. Part I: assessing the problem

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ABSTRACT

The vibration field along a railway line was measured and modeled to predict its impact on a future real estate project. Indeed, vibration levels due to rolling stocks evaluated near the tracks are usually evaluated on the vertical axis and at one or a few positions, supposed to be representative of the entire vibration field around the tracks. When the project size is rather extended along the tracks, this assumption might be incorrect, especially if the project site is located near a train station, where stresses in the tracks can be very different depending on the direction of the train due to acceleration or deceleration. This paper presents vibration measurements performed in the different directions before buildings construction along the tracks. Furthermore, the attenuation of ground vibration as a function of distance from track is used to evaluate the loss factor in the ground based on a comparison with a 2.5D BEM model of the ground including the different layers. The model is then used to identify equivalent forces in the different directions associated to train passage to obtain similar vibration transmission behavior in the ground. The mitigation measures to limit low frequencies noise and vibration immission in buildings are discussed in a companion paper.

Keywords: Low frequency, Ground-borne noise, Railways

1. INTRODUCTION

In densely populated areas, the rarefication of land leads to the construction of buildings very close to railway tracks. Alternatively, the construction of new lines will impact existing buildings. In both cases, vibration and noise levels in offices, shopping malls or lodgings might be severely impacted by the proximity of passing trains and mitigation measures effective at low frequencies must be found. The situation reported in this paper is that of an existing embanked railway line 20 km East of Paris, where buildings are envisaged to be constructed right above the embankment and close to a station. Consequently, as the tracks cannot be modified the mitigation measures must be taken if necessary on the receiver side, i.e. the buildings and/or the environment between the buildings and the tracks. In order to tackle this problem, the approach employed mixes in-situ measurements prior to the construction and numerical calculations to evaluate various scenarios encompassed. The experimental phase of the project is presented in this paper. Ground vibration levels attenuation with distance from the tracks is first used to tune the soil properties. Then by correlating measurements and numerical estimations, equivalent force spectra of passing trains both in the vertical and tangent directions to the rails are estimated at different locations along the railway. Based on these estimated data, a companion paper (1) presents the computational model used to evaluate different scenarios in order to reduce low frequencies vibration levels and ground-borne noise levels in the future buildings, as well as the performance of the considered mitigations measures. Note that a more detailed discussion on the measurements is proposed in (2).

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2. SITE AND FUTURE BUILDINGS

2.1 Description

The site which is 180m long is located on both sides of the RER A line, near a train station (140m to the west). As seen in Figure 1 (left), both sides of the railway are occupied: the south side holds a parking lot and the north side is overgrown by natural vegetation. The trains on the north side (track 1) are accelerating and they are going away from Paris. Trains on the south line (track 2) are slowly decelerating and going toward Paris. The train speed along the site is between 60 and 70 km/h. Figure 2 depicts the railway tracks from and to Paris. Three sections along the site (see Figures 1 and 2) were considered since the train speed was not constant over the length of the site. Section 1 is the closest to the train station while Section 3 is the farthest away; the three sections were selected with respect to the envisioned buildings arrangement at the time of the measurements.

The project wants to build housing and services activities buildings with two parking levels and different areas from 4 to 9 floors levels. These buildings would be located at 12m from the existing track.

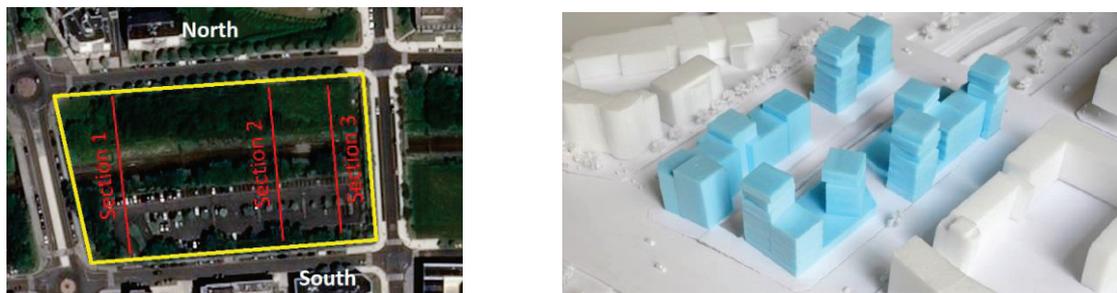


Figure 1 – Site overview (© IGN – 2019) and an example of one of the envisioned real estate programs (Contractor : CoBe, Tolila + Gilliland, Franck Boutté – Client : Linkcity).

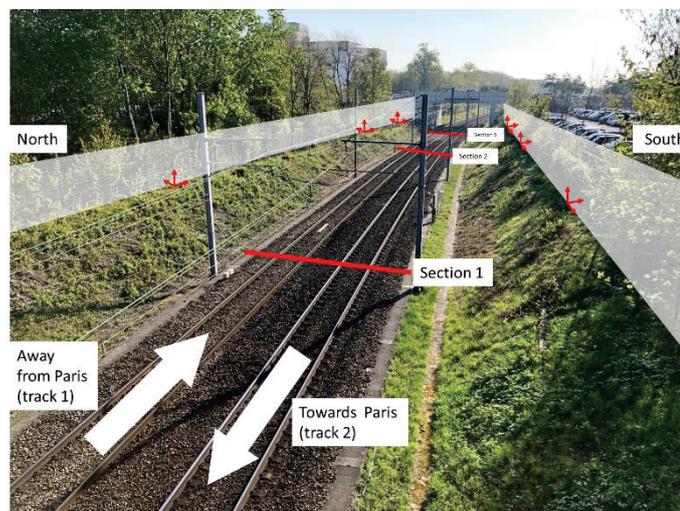


Figure 2 – Measurement site description. Three sections on both sides of the track.

2.2 Rolling-stock and track

The track is circulated only by double decked, coupled trains (224m long) very similar in terms of vibration emission (MI09 (more than 80%) and MI2N). The track is a ballasted track, with bi-block sleepers and a UIC-60 rail profile. The rail surface of both tracks was grinded four months before measurements. The track follows a very light curve (radius 1500m) in a cutting.

No detailed measurements of the track quality such as roughness or dynamics at low frequencies were performed. Therefore, the purpose of the measurement was to evaluate an average behavior of the ground during train pass-by in order to deduce propagation behavior as well as equivalent excitation forces representing the train pass-by.

3. MEASUREMENTS

3.1 Description

Two series of measurements were carried out. The first series concerned Section 3 North side only and measurements at different distances from the tracks. The second series concerned all three sections on both sides of the tracks (North and South sides): vibration levels were monitored in the three directions (vertical, parallel and perpendicular to the track). One track is excited by trains in acceleration (north) and the other by decelerating trains (south). The accelerometer signals were analyzed over the pass-by duration in one-third octave bands between 8 and 315 or 500 Hz; a 7 Hz high-pass filter was applied on the measured signals.

Measurements were performed using steel spikes (50 or 60 cm long with T or X cross sections) to mount accelerometers. Accelerometers were firmly screwed on top and on the sides of the spikes.

For the first measurement series, two sets of data were captured. The first set concerns 4 accelerometers measuring vertical vibrational velocity and placed at 6 m away from each other; the first (reference position) being at a distance from the closest track of about 12 m. A second set of measurements concerned vibrational velocity measurements in three directions (vertical, parallel and perpendicular to the tracks) at two positions (reference point and 12 m away in the direction perpendicular to the track). Vibration levels are averaged over 12 to 14 pass-by depending on the track. All the measurements were performed the same mid-afternoon to early evening.

For the second measurement series, vibration levels are averaged over at least 19 pass-by on each track. The measurements were carried out over two days; velocity levels on each section are evaluated during the same period of the day, one day apart for the north and the south (Section 1: late morning; Section 2: beginning of the afternoon; Section 3: mid-afternoon). The trains load might therefore not be responsible for the differences between the two railway sides observed in the results presented below. The recorded vibration levels for the two types of train circulating on the railway were indeed found very similar and therefore no distinction is made between the train types in the results.

It should also be mentioned that both measurements series were performed around the limit of the railway domain; however, for the first measurements series, the location is outside of the limit of the railway domain, while for the second series inside at the limit of the railway domain. Furthermore, the two series were performed 2 months apart, the first one in summer the second one in the fall.

3.2 Results

3.2.1 Measurements series 1

Figure 3 presents the average vertical vibration level spectra at different positions away from the track (in Section 3 North side) for each train circulation direction (the scale is the same on both graphs). In general, as the distance increases the vertical vibration level decreases especially above the one-third octave band 31.5 Hz. For the trains going away from Paris, there is little difference between the reference point and the one 6 m away in the frequency range 40-80 Hz. For the trains going toward Paris, there is little difference between the reference point and the one 6 m away at the one-third octave bands of 63 and 80 Hz. This could be associated to the ground inclination between these two positions.

It is surprising that the vibration velocity level at 40 Hz is higher at the reference point for the trains going towards Paris than the trains going away from Paris since the corresponding track is farther away (the standard deviation for that one-third octave band is less than 1 dB for both directions). However, this effect was not observed during the second measurements series (see 3.2.2).

The second set of measurements in that first series concerned ground vibration measurements in the vertical direction, as well as in the parallel and perpendicular direction with respect to the tracks. These measurements (not shown here) were still carried out on the North side in Section 3. Some of the recorded vibration levels are presented in Figure 4 and discussed below.

3.2.2 Measurements series 2

Figure 4 presents a comparison between the measurements performed in both measurements series on the north side of Section 3. It should be recalled that the measurement positions between both series are not identical: they are located on each side of the railway domain limit, separated by a distance evaluated to be less than 2m. Differences between the two measurements series can be clearly observed. They are smaller for levels in the vertical direction than for the other two directions (parallel and perpendicular to the track). Indeed, for the parallel direction, the difference in the frequency average velocity level is about 10 dB for trains travelling either towards or away from Paris. This is probably due to the difficulty in evaluating vibration levels in directions other than the vertical one

(2-3). It could also be related to the different ground conditions at the time of measurements (much drier in the summer than in the fall), and to the different daytime hours during which the measurements were performed. Furthermore, the fact that trains are either accelerating or decelerating, could also induce that vibration levels in the direction perpendicular and parallel to the track are higher than those in the vertical direction.

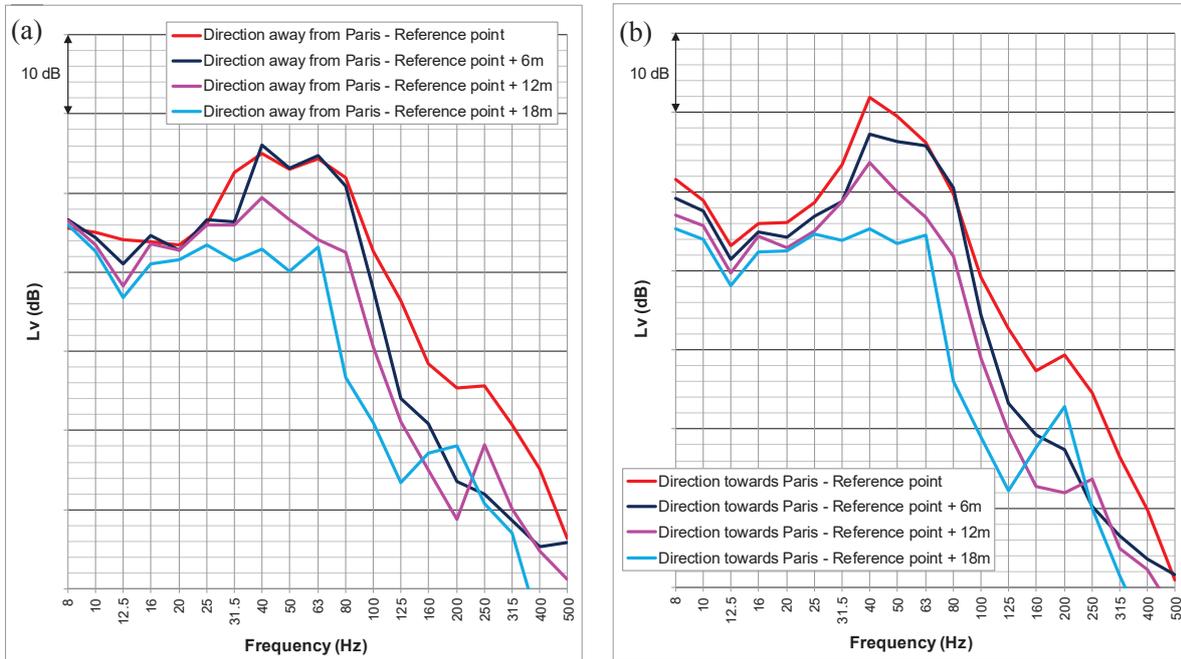


Figure 3 – Average vertical vibration levels in one-third octave band; all graphs are given with the same scale.; Direction (a) away from Paris and (b) towards Paris.

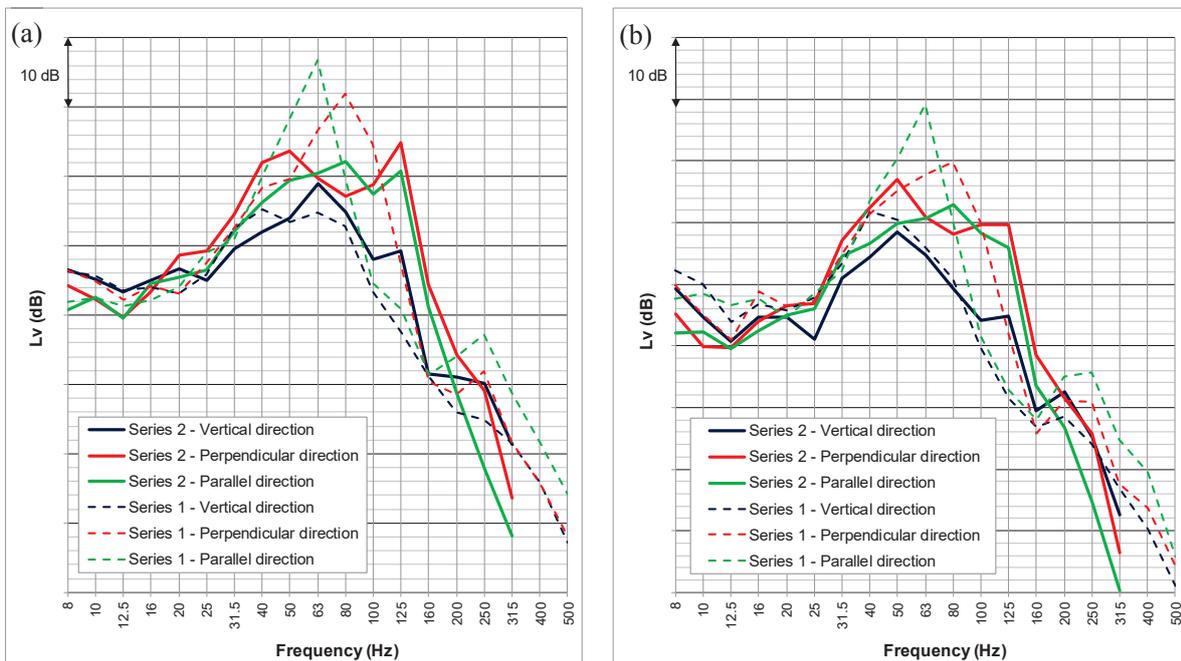


Figure 4 – Average vibration levels in Section 3 North side; all graphs are given with the same scale; Direction (a) away from Paris and (b) towards Paris.

The results for Sections 1 and 3, and for all directions are given on Figure 5. First, it should be pointed out that, for each point the velocity levels are very reproducible. For clarity reason standard deviations are not displayed on the graphs but their range in terms of global value is from 0.2 to 1.8dB, i.e. rather small. Figure 5 shows that the velocity levels are in coherence with the velocity of the trains along the test site. The train station is located at 170 m away from Section 1. The velocity of the train

is then quite low for this section. When the train is getting away from the station (direction away from Paris), its velocity increases, and the velocity levels rise. The measurements show greater levels (around 5 dB for the averaged global level) for lateral axis. Comparing north and south measurement shows that shorter distance to the track implies greater velocity levels.

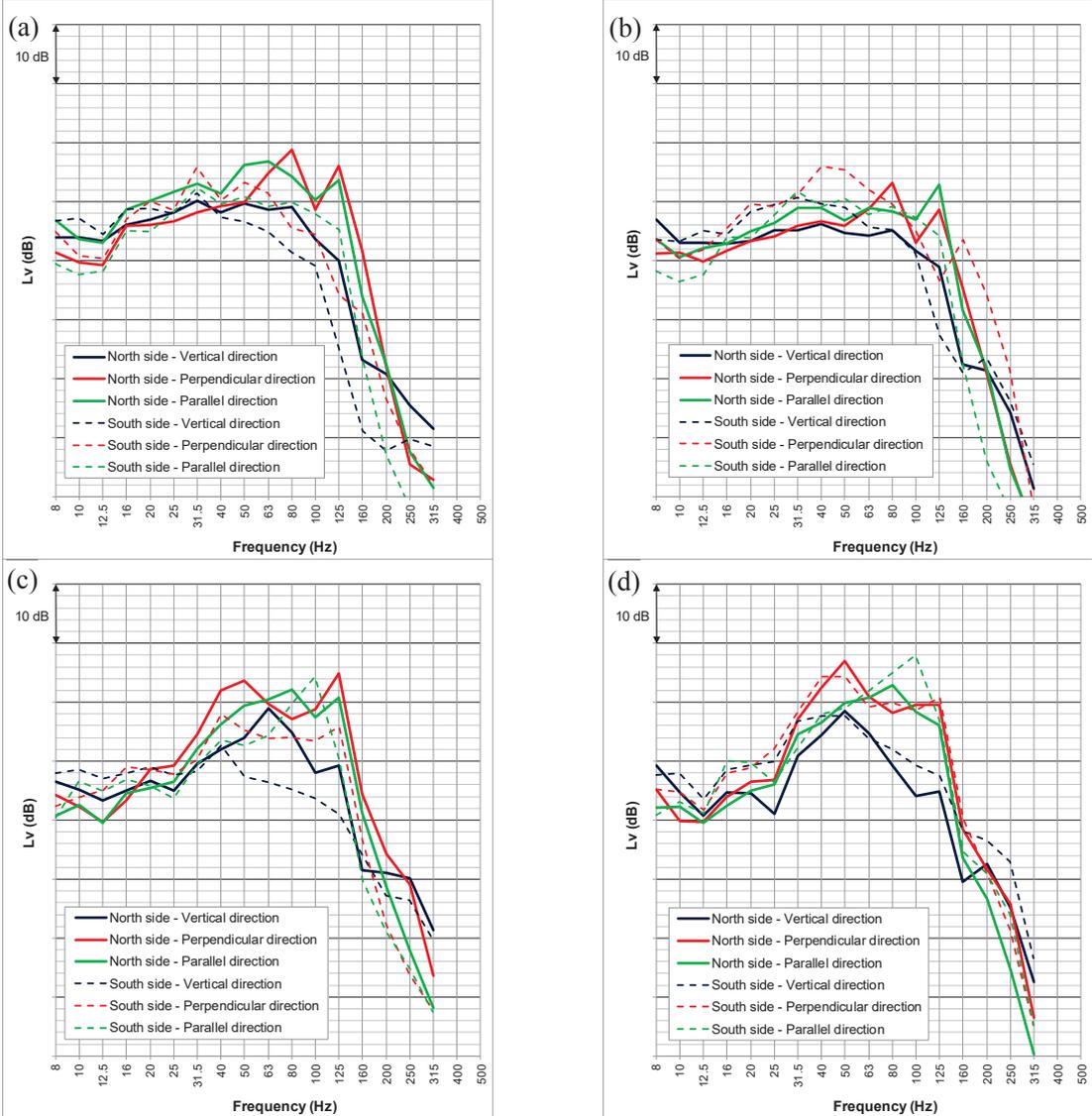


Figure 5 – Average pass-by vibration velocity level spectra; Section 1 (a) and (b); Section 3 (c) and (d); Train going away from Paris (a) and (c); Train towards Paris (b) and (d).

4. ANALYSIS

The prediction results have been obtained using CSTB developed 2.5D BEM/FEM software MEFISSTO (4-5) which assumes a 2D description of the geometry while accounting for 3D aspects of both excitation and wave propagation. From geochemical analysis a model of the ground layer was selected and the characteristics of the ground layers (see (1)) deduced from CSTB database.

4.1 Attenuation with distance

Damping coefficient (hysteretic type) was adapted in order to match the attenuation trends of the measured vibration levels from the first measurement series. Figure 6 presents a comparison of the attenuation at 12 m from the reference point obtained from the prediction model and the measurements, based on the vertical velocity levels. It can be seen that a damping coefficient of 8% for all the ground layers provides an acceptable evaluation of the measured behavior. Figure 7 presents the attenuation obtained at the different distances from the reference point when a damping coefficient of 8% for all the ground layers is used. The comparison between measurement and prediction appears satisfactory

especially for the 6 and 12 m distances; for the longer distance (18 m) the attenuation is under-evaluated by the prediction compared to the measurement (note that above the one-third octave band 125 Hz the measurement captured at 18 m from the reference point shows an increase in vibration level as seen in Figure 3 reducing the obtained attenuation in this frequency range).

It should be noticed that predicted attenuation of the vibration velocity levels in the three different directions (vertical, parallel and perpendicular to the tracks) was also compared with measurements. Choosing a damping coefficient of 8% for all ground layers was again found acceptable.

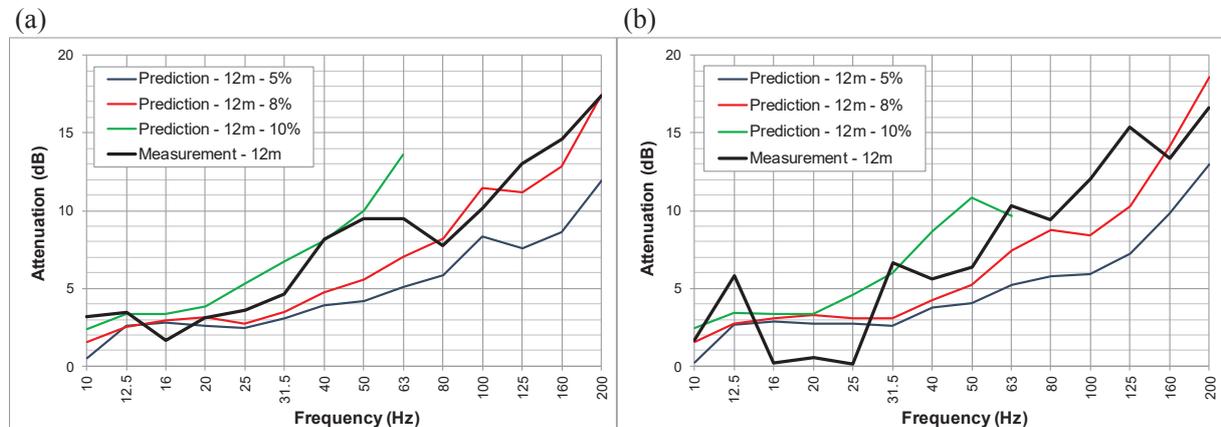


Figure 6 – Attenuation at 12 m with respect to the reference point for different damping coefficients; Direction (a) away from Paris and (b) towards Paris

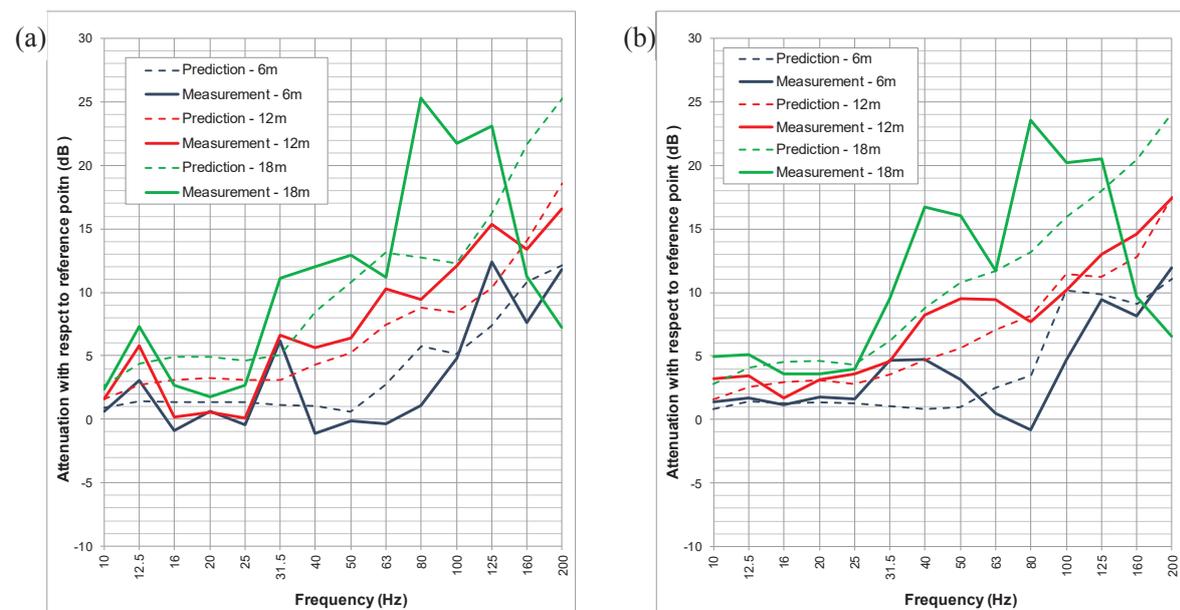


Figure 7 – Attenuation with distance from the reference point; Direction (a) away from Paris and (b) towards Paris.

4.2 Equivalent excitation forces

In order to evaluate the impact of ground vibration on buildings it is necessary to obtain equivalent forces representing the train passage to inject in the model. This allows to assess floors vibration levels and ground-borne noise levels in the different buildings considered and compared these levels to selected targets (these targets should be chosen to allow a certain level of comfort in the buildings).

At first as it is generally the case, a vertical equivalent force spectrum for the train passage was evaluated in order to match with the prediction tool the measured velocity levels in the different three sections considered. An example of the obtained results in terms of vibration velocity levels is shown in Figure 8 for site Section 1 and for the train circulating towards Paris. It can be seen that if the vertical velocity levels are well evaluated the velocity levels in the directions perpendicular and parallel to the track are underestimated, especially in the parallel direction (about 10 dB in global level).

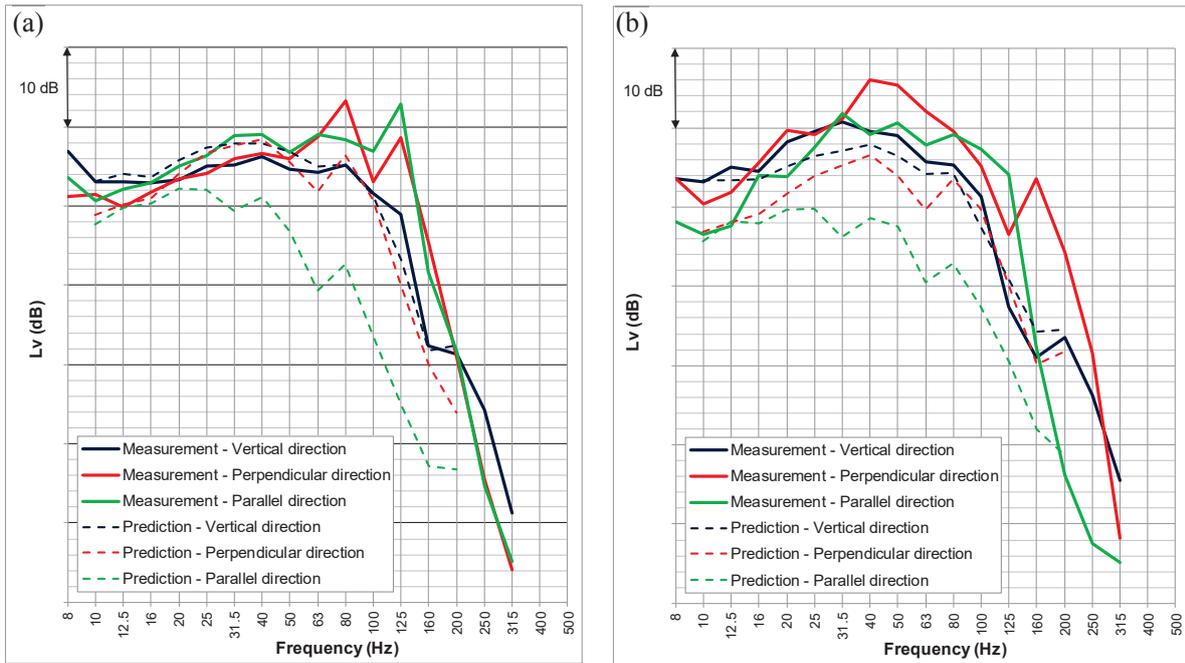


Figure 8 – Vibration velocity level associated to train passage towards Paris for an equivalent vertical force only; graphs are given with the same scale; Section 1 (a) North side and (b) South side.

Therefore, it was decided to use an equivalent force in both directions vertical and parallel to the tracks; these equivalent forces represent a least square solution. Figure 9 presents the obtained results for site Section 1 and for the train circulating towards Paris. This time, it can be seen that the velocity levels are well evaluated in the three different directions; in global level a difference of 3 dB at the most is obtained between prediction and measurement. The equivalent forces in both directions vertical and parallel to the tracks for the different sections along the sites are shown in Figure 10. It can be noticed that globally the vertical equivalent force is slightly lower than the equivalent force in the parallel direction. Furthermore, the equivalent forces are globally slightly higher for the train going towards Paris (decelerating trains).

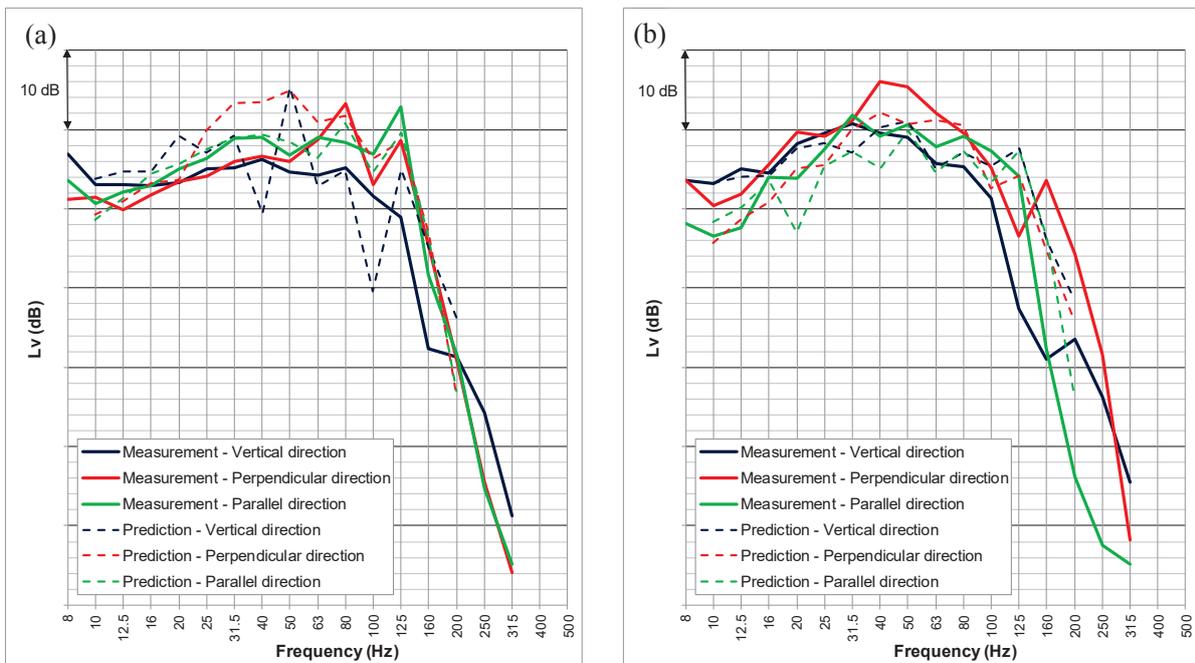


Figure 9 – Velocity level associated to train passage towards Paris for equivalent forces in directions vertical and parallel to tracks; graphs are given with the same scale; Section 1 (a) North side and (b) South side.

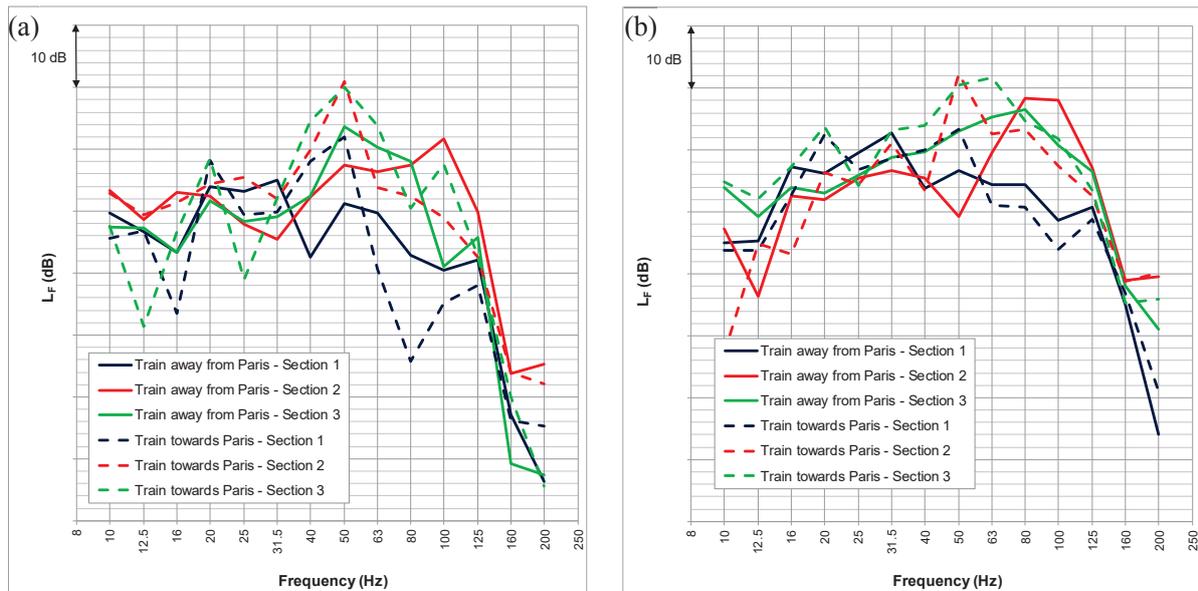


Figure 10 – Equivalent forces; graphs are given with the same scale;
 (a) Vertical direction and (b) Parallel to tracks direction.

5. CONCLUSIONS

The construction of buildings close to railway lines may lead to high vibration and acoustic levels if no mitigation measure is taken. Measurements and prediction results have been presented in order to assess the situation prior to the construction of the buildings project. Since the train speed is not constant over the entire construction site several zones of the site were investigated.

Measurements at different distances from the tracks were used to evaluate damping coefficient in the different ground layers. Then equivalent forces representing the train passage at the different considered zones along the site were deduced for each track; it was shown that considering equivalent forces in the vertical direction, as it is often the case, was not sufficient to represent the measured vibration levels in the different directions (vertical, parallel and perpendicular to the tracks). Equivalent forces in the vertical and parallel to the track directions had to be applied; this is believed to be due to the fact that the trains were either accelerating or decelerating since they were either leaving or approaching the station. However, it should be emphasized that measurements in the directions other than the vertical direction are difficult due to coupling between accelerometers mounting system and ground. Based on these results, different mitigation measures were investigated to limit low frequencies annoyance for future buildings occupants due to train vibration emission (1).

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