PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Reducing ground borne noise due to railways.

Part II : mitigation measures

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ABSTRACT

The construction of new buildings very close to existing tracks with heavy commuting traffic requires careful design. Such projects must be accompanied with noise and vibration reduction measures. The practical case here considered has been analysed by first assessing the existing situation prior to construction (type of soil and traffic: results exposed in a companion paper). Here we focus on the mitigation measures which have been tested and the expected corresponding vibration and ground-borne noise levels inside the buildings. A 2.5D FEM/BEM commercial software (Mefissto), developed by CSTB, has been employed in what is a very challenging numerical context: multi-layered ground, large multi-levels buildings, large frequency range (10-200 Hz). In every situation the use of an original 2.75D approach leads to the low frequency noise levels inside the building. As the trackwork cannot be modified the solutions tested consist in inserting different types of barriers in the ground or in inserting spring-like materials in the lower part of the structure. Results are compared to target values in terms of vibration and ground-borne noise levels selected in order to limit dwellings occupants' annoyance. Satisfactory results can only be achieved with the use of the spring-like solution.

Keywords: Ground-Borne noise, train excitation, BEM/FEM

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 must be found. The situation here reported is that of an existing embanked railway line 20 km East of Paris, where buildings are being built right above the embankment, very close to a station. Consequently, as the tracks cannot be modified the mitigation measures must be taken on the receiver side. The approach here employed mixes measurements prior to the construction and numerical calculations for the various scenarios encompassed. The experimental phase of the project is presented in a companion paper (1) and uses vibrations levels on the ground free surface to tune the soil properties by correlating measurements and numerical estimations in order to estimate the force spectra of passing trains both in the vertical and tangent directions to the rails, at different locations corresponding to future buildings. In the present paper, we first describe the project and its numerical implementation and solution. The computations are made with the 2.5D BEM/FEM software mefissto (2) which assumes a 2D description of the geometry while accounting for 3D aspects of both excitation and wave propagation. The mitigation measures tested are twofold: i) insertion of a vertical barrier in the ground between tracks and foundations and ii) insertion of a resilient material (hereafter called "springs") between ground level (shopping mall) and first level (lodgings)- the parkings are below ground level (y=0), We compute vibration and noise levels in the volumes (representative of livable spaces) closest to the tracks for the different solutions tested. Finally, global velocity and pressure levels are given.

2. THE PROBLEM

A global view of the initial project is showed in Figure 1. A 2D representation is displayed since the approach employed is a 2.5D BEM/FEM model which assumes invariance of the geometry along the z axis parallel to the tracks. Previous work (2) have showed the adequacy of this approach for the type of buildings here considered (i.e. walls and slabs). The ground is composed of 4 layers atop a semi-infinite limestone sub-ground. The ground properties are listed in Table 1. The value of losses in the ground (8 %) was estimated in (1). The two tracks are modelled as point force in 2D and actual finite incoherent lines in 2.5D with 2 components F_y (vertical) and F_z (parallel to the tracks). The parking's outer wall are 35-cm thick by default.

Table 1 - Material properties (building and soil layers)

Type	Thickness(m)	Density(kg/m^3)	E(MPa)	Poisson	damping	c_s(m/s)
Concrete		2300	30000	0.15	1%	2300
Embankments	Variable	1800	780	0.30	8%	408.2
Formation de Brie	Variable	1900	1668	0.45	8%	550.1
Clay & limestone	7	1900	580	0.45	8%	324.4
Clay marls and gypsum	19	2000	1015	0.45	8%	418.3
Limestone	infinite	2100	4350	0.45	8%	845.2

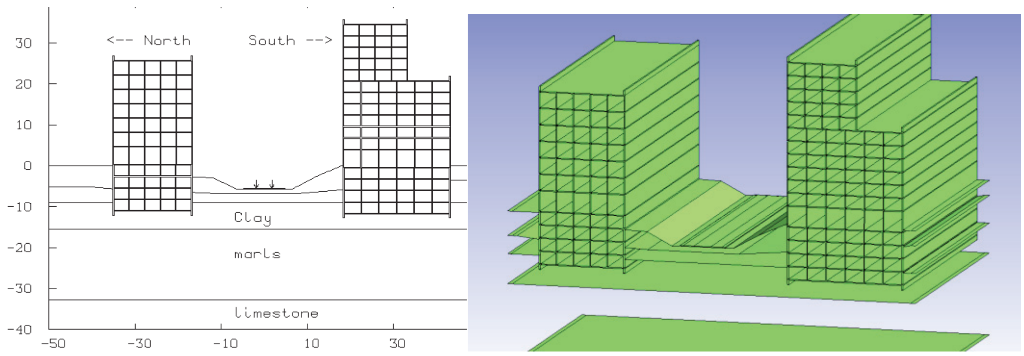

Figure 1 – 2D and extruded view. Two buildings close to a railway embankment.

3. DISCUSSION

Several aspects considering the numerical modelling are first addressed. In the course of this project, many questions were raised, and many parametric aspects were considered and analyzed. A few highlights are now given. Computations have been done between the 10 and 200 Hz third octave bands.

Mutual influence of both buildings: we have run computations with both buildings modelled simultaneously and then with only one or the other and found that no noticeable difference could be found, meaning that standing waves between both foundations could be neglected and that computations can be done with one building at a time.

Embankment: we wanted to estimate the influence of the embankment on the transmitted vibrations inside the buildings and we compared the velocity with and without embankment where two positions of the flat free surface are considered (low and high, see Figure 2). The velocity level on the ground floor is represented. The excitation is a 100 m incoherent line vertical force along z. Above 30 Hz, the case with the embankment leads to the lowest levels.

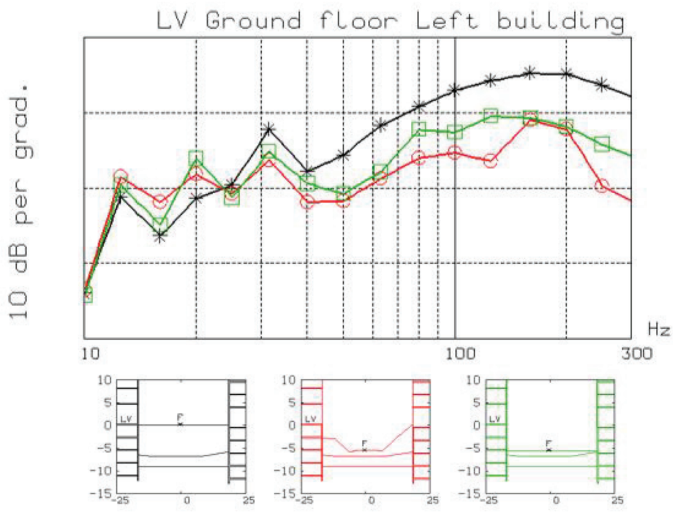

Figure 2. Influence of the soil profile between both buildings.
(*) High flat , **(O) Embankment** **(□) Low flat**

Number of underground levels: as the project evolved, the number of underground parking levels was reduced from four to two with the hope that reducing the total height of exposed foundations would lead to a reduction of velocity levels. No significant difference was found. Most of the power is likely to be input in the top underground levels. In the next paragraph the case with two subterranean levels is studied.

kz decomposition: for each frequency *f* the 2.5D computations relies on a set of computations carried for a set of *kz* wavenumbers. For each *kz* value, the problem solved corresponds to an infinite line excitation along z which varies as a kz cosine. The Fourier-like integration (3) over *kz* of any 2D solution *V(F,M,f,kz)* -with a shift of *Δ* m along z- will give the 3D velocity for a point source at (x_F,y_F,z_F) and receiver at (x_M,y_M,z_M) separated by $\Delta=z_M-z_F$

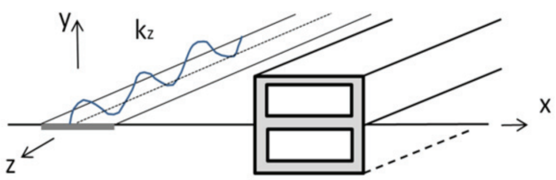

Figure 3 – 2D excitation with wavenumber kz

$$V(x,y,\Delta z,f) = \int_{-\infty}^{\infty} V(x,y,k_z,f)e^{-jk_z\Delta z}dk_z \tag{1}$$

A train of finite length D_z is modelled by a set of uncorrelated forces along z (incoherent integration of results). The integration over k_z must be done carefully with a sufficient discretization in terms of dk_z and $k_{z,max}$. Figure 3, shows typical k_z responses for 2 cases: surface response without any building and ground floor velocity for the full situation. The more complex the situation the more complex the k_z response, and the higher the frequency the higher $k_{z,max}$ must be. Automatic k_z discretization schemes are employed. The picks correspond to the propagating waves either in the ground or/and in the building (building modes).

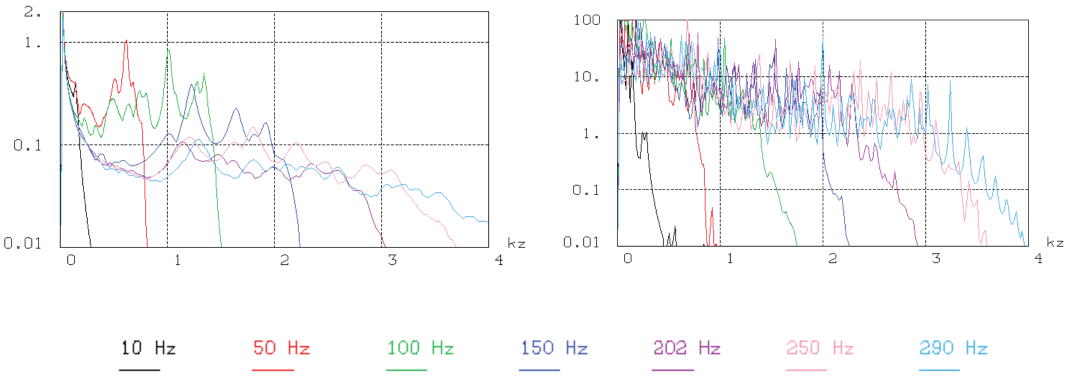

Figure 4 – *V(f,kz)* as a function of kz for different values of *f*. Left/ Right: without/with buildings.

Protection with a barrier: positioning a barrier between and the tracks and the foundations was first tested with a void (full decoupling). As this is not feasible in practice, point connections were added. As could be expected, this results in a total loss of the efficiency of the barrier. A more sensible solution consists in adding a layer of resilient material. The efficiency of the case with a void can be recovered. The 'barrier' solution thereof refers to the layer+barrier disposition. Different depths of the barrier were tested, and it was found that it should go down below the bottom of the foundations. Deeper barriers gave little extra reduction in vibration levels in the buildings. The influence of the lateral dimensions could not be estimated with a 2.5D approach and 3D FEM computations with full FEM were carried for a simple 2-levels buildings with the conclusion that for a force centered on the length (L_z along z) of the building, the barrier needs not be longer than L_z. For non-centered forces the barrier should be longer by a few meters. Figure 5 shows different barriers and a view of a 3D FEM meshing with a screen that exceeds the building's length by 4 m on each side.

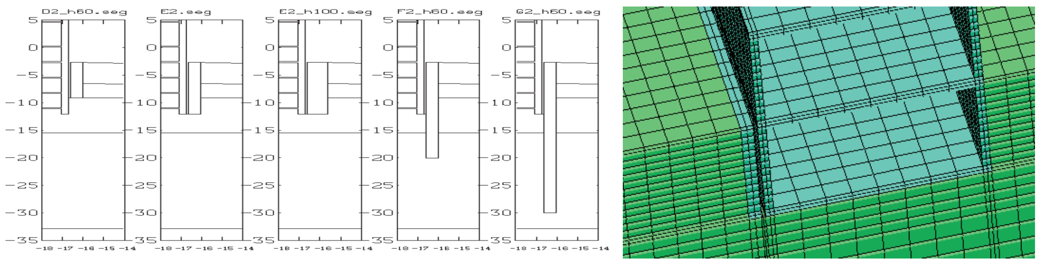

Figure 5 – (a) Barriers of different depths (b) view of the 3D FEM calculation.

The 3D barrier (Figure 6) shows a reduction of varying amplitude (0 to 15 dB according to frequency).

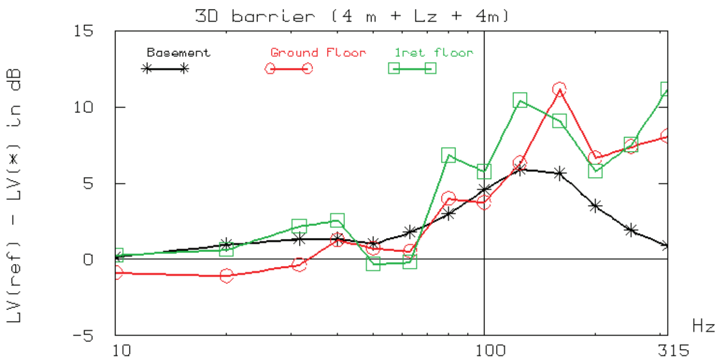

Figure 6 – 3D barrier: velocity reduction.

Increasing the thickness of the parking wall: since the vibration power mostly enters the buildings through the parking outer wall we have increased the thickness from 35 cm to 50 cm. Figure 7 shows the resultant modification of several floors' average velocity levels. The building is excited by a 100 m long incoherent line source (vertical excitation). We notice that the reduction (positive values) is not systematic through the whole spectrum and varies with the building's levels: at 100 Hz an increase is observed. Increasing the buried parking outer walls does not seem to be an optimal solution.

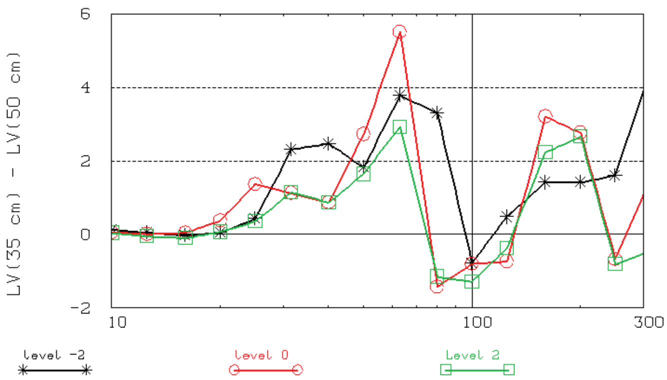

Figure 7 - Effect of an increase of the thickness of the parking outer wall on floor vertical velocity (35 cm to 50 cm).

4. Application case

In (1), excitation force spectra have been estimated for 3 positions along z corresponding to 3 projected constructions sites. A 200 m-long train is modelled. As these locations are situated in a close proximity to a railway station, the trains are either accelerating (going east) or decelerating (going west). The buildings north of the tracks have been studied for accelerating trains and the south buildings for decelerating trains (closest excitation). It was found that the tracks are excited both with vertical and tangential forces (see spectra in (1)). The tangent excitation may exceed the vertical component in the higher frequency range. The buildings here considered only have two subterranean levels.

The acoustic response in volumes is obtained by means of the 2.75D approach, recently published (2). In 2.5D, volumes are in in fact ducts of infinite length along z from which it possible to extract the velocity field on grids having a finite length L_z. The velocities on the four finite walls thus defined are coupled by means of an integral representation with the 3D green functions of volumes of the same length L_z. These functions are evaluated with a modal approach for a reasonable cost since computations are done at low frequencies (usually bellow 300 Hz). Alternatively, a SEA radiation approach can be employed for a reduced precision (2,5). Figure 8a gives an overview of the central part of the problem in the case of barriers with viscoelastic patches. Figure 8b shows the position of viscoelastic materials ("springs") (left building) with a cut-of frequency of 5 Hz. Figures 9 and 10 show the Velocity Levels and Sound Pressure Levels spectra obtained in one case, at three levels. Note that the ground floor behavior around 50 Hz (see Fig.10) is different from results at other levels: this is related to the height of these volumes.

Global velocity and sound pressure levels have been computed for the 3 buildings (left buildings for the 3 sections) with both the vertical and tangent excitations (y & z directions). In each graph, the target value is displayed: 66 dB and 30 dB(A). Results are given for the reference, barrier and "spring" solution either considering only the vertical forces (dashed lines) or both vertical and tangent forces (solid lines). The "spring" solution is successful for the velocity levels since above ground level all values obtained are below the target of 67 dB. For sound pressure levels, the target of 30 dB(A) is more difficult to satisfy even with the "spring" solution. If only the vertical force (F_y) is considered the target is mostly satisfied but not if we take tangential forces (F_z) into account. Therefore, the conclusion is very much related to the validity of the assessment (see (1) of these tangent forces and further research on this poorly documented aspect is needed. One might probably consider that reality lies somewhere in between both cases (F_y versus $F_y + F_z$). Note, also, that the difference between dB(C) and dB(A) always lies between 20 and 30 dB and is little influenced by the insertion of a barrier or springs, which confirms that this problem is a low frequency problem.

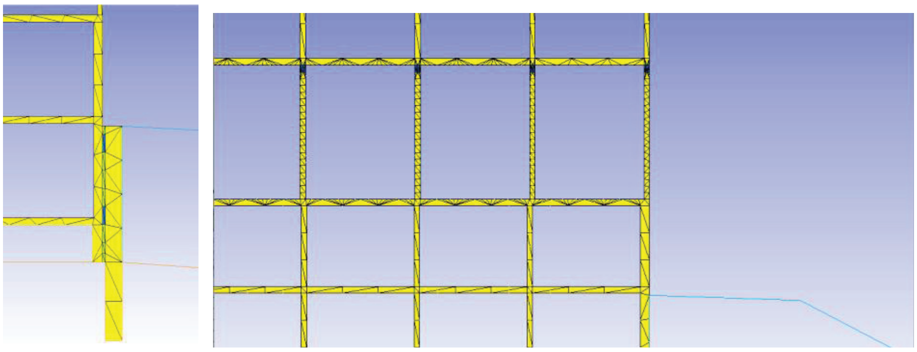

Figure 8 – a) Buildings with barriers: close-up b) Viscoelastic layers on top of ground floor walls

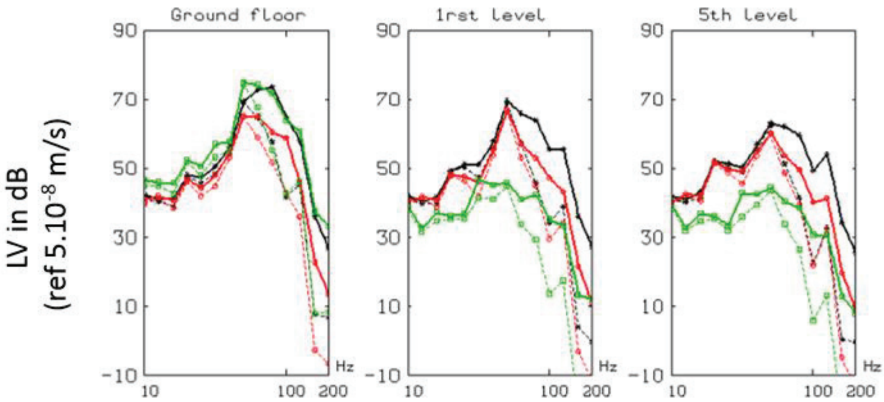

Figure 9 – LV spectra for 3 situations – dashed lines with vertical force only.
South building, section 3. (*) **Reference, (o) Barrier, (□) Spring**.

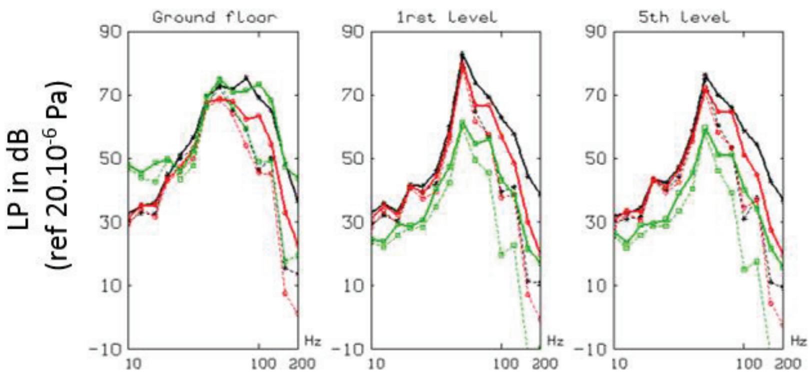

Figure 10 – SPL spectra for 3 situations – dashed lines with vertical force only.
South building, section 3. (*) **Reference, (o) Barrier, (□) Spring**.

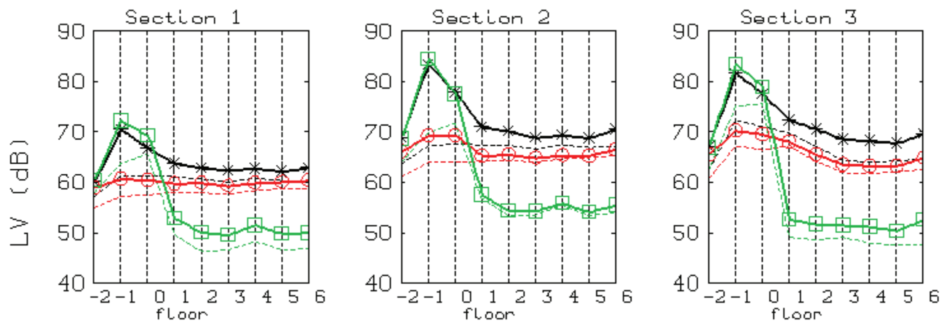

Figure 12 – Global Velocity levels for the 3 sections and both sides (3 buildings)
dashed lines with vertical force only- Target value of 67 dB.
(*) Reference, (o) Barrier (□) Springs

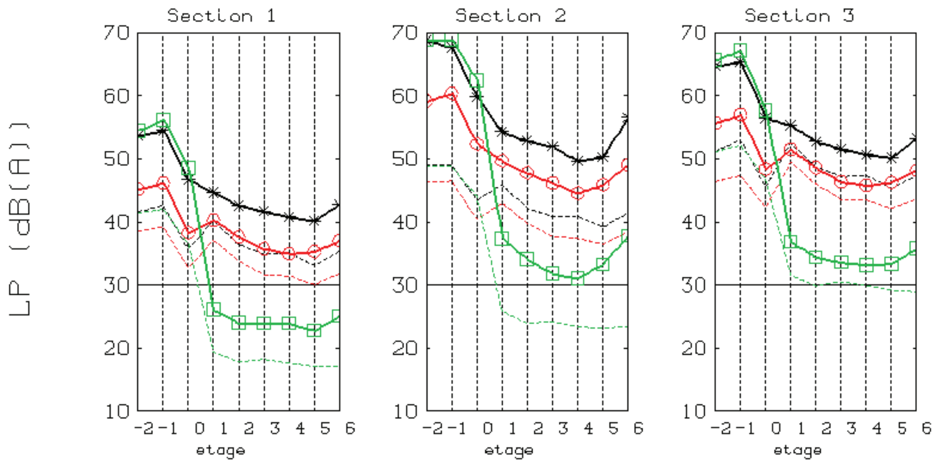

Figure 13 – Global dB(A) levels for the 3 sections and both sides (3 buildings)
dashed lines with vertical force only-Target value of 30 dBA.
(*) Reference, (o) Barrier (□) Springs

3D representations: we plot the vertical velocity in the buildings, top surface, interlayers and a central vertical plane at 100 Hz for a vertical unit force along y or z for 2 cases: reference (Figure 14), and "spring solution" (Figure 15). These snapshots visually demonstrate the efficiency of the "springs".

5. CONCLUSIONS

The construction of buildings close to railway lines may lead to high vibration and acoustic levels if no mitigation measure is taken. A real situation is here reported where a numerical analysis has been carried right from the design stage of the new project, east of Paris, close to a station where trains are either accelerating or decelerating. First, the existing problem (soil data and track excitation) has been assessed in (1). Here, mitigation measures have been considered with the main conclusion that a decoupling of upper floors is necessary by means of the insertion of resilient materials. Even then, the target of 30 dB(A) is exceeded in certain cases by a few dB's if one considers a full model where not only the vertical but also the tangential forces applied to the soil are considered. Little literature can be found for this problem and the authors feel that further work is needed; the assessment of both force components was done in a simple manner which needs be improved. Finally, one might note that another component must be added if the tracks are not straight.

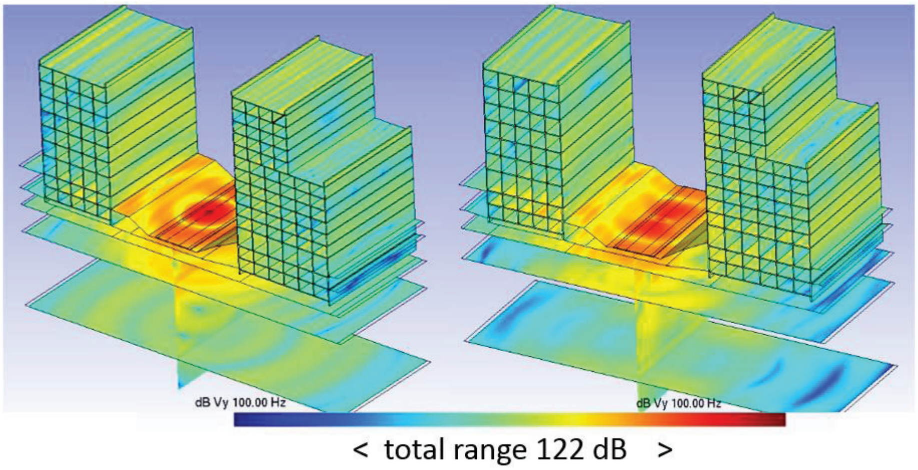

Figure 14 - 100 Hz, reference case Left/Right: Fy/Fz excitation (vert/tangent)

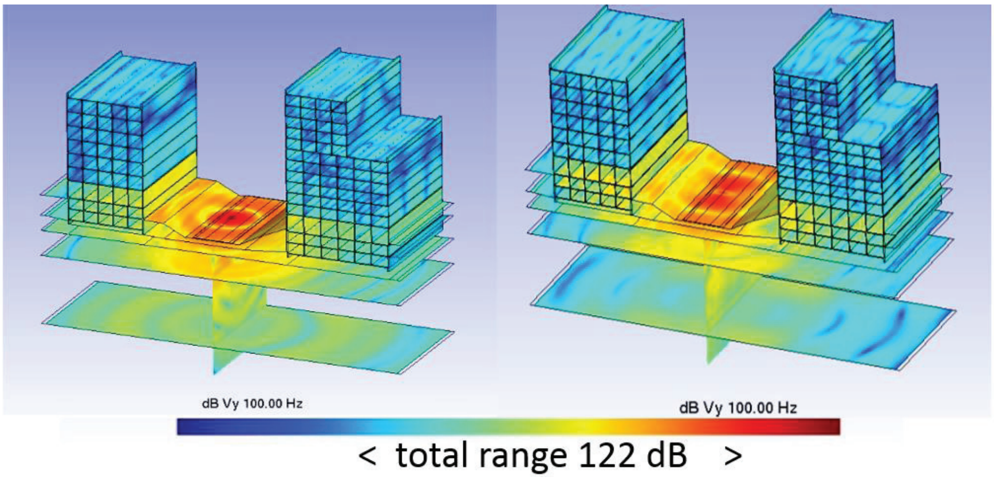

Figure 15- 100 Hz, spring case Left/Right: Fy/Fz excitation (vert/tangent)

ACKNOWLEDGEMENTS

The authors would like to thank LinkCity and Eparmarne, as well as the Caisse des Dépôts et Consignations (Deposit and Consignement Fund) for supporting this work through the “Ecocité 2 – Ville de Demain” program. This national French program involves public and private actors in a territory to develop disruptive projects to accelerate the energy and ecological transition of cities.

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