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EFFECT OF MEASUREMENT POSITIONS ON STRUCTURE-BORNE NOISE LEVELS IN BUILDINGS SUBJECT TO RAILWAY VIBRATIONS

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ABSTRACT

In the objective of improving the comfort and even the health of occupants of buildings close to railway lines, it is appropriate to predict and measure vibration levels and ground-borne noise levels in order to limit them, particularly in housing.
In this work, the effect of tabulated transfer functions generally used for the vibration impact assessment investigations, measurement positions for both vibration levels and structure -borne noise is studied on the basis of numerical modeling. Concerning vibrations, a measurement at mid-span of the floor is generally considered; however, this position can be difficult to determine or access, especially when the floor supports several rooms, so a measurement in the center of a room is often carried out. The vibration levels can then be used to predict ground-borne sound levels. To set an acceptable threshold for occupants, it is necessary to specify one or more easily identifiable and accessible measurement positions and to adapt the limit threshold to this measurement configuration. The same problem exists for ground-borne noise measurements. Based on the results obtained, proposals concerning impact assessment investigations, measurement and prediction positions for vibrations and ground-borne noise in buildings are formulated.

Keywords: ground-borne noise, railway vibrations, building acoustics, measurement positions.

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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 railway lines will impact existing buildings. In both cases, vibration, and noise levels especially in lodgings might be severely impacted by the proximity of underground and surface railway traffic. In France, there is still no mandatory requirement regarding limitation of vibration and ground-borne noise levels from railways, even though discussions on the subject have started a few years back. However, developers and city planners are now aware of the necessity to consider these aspects.
Prediction methods are required for designing buildings to protect inhabitants against ground-borne (structure-borne) noise from railway lines or other ground vibration sources, a European task group (CEN/TC126/WG2/TG1) is doing preliminary work on this subject.
The effect of using tabulated transfer function (ground to building foundations and building foundation to building floor) for vibration impact assessment investigations is questioned with respect to a security margin. Furthermore, it is also quite important to be able to verify the vibration and ground-borne noise levels after either a building or a new railway line construction. In this work, the effect of the measurement positions for both vibration levels and ground-borne noise is studied based on numerical modeling. Concerning vibrations, a measurement at mid-span of the floor is generally considered; however, this position can be difficult to determine or access, especially when the floor supports several rooms, so a measurement in the center of a room is often carried out. The vibration levels can then be used to predict ground-borne sound levels. To set an acceptable threshold for occupants, it is necessary to specify one or more easily identifiable and accessible measurement positions and to adapt the limit threshold to this measurement configuration. The same problem exists for ground-borne noise measurements.

2. INVESTIGATED CONFIGURATIONS

Simulations are conducted based on a 2.5D FEM/BEM model (infinite constant geometry in one-direction) implemented in CSTB MEFISSTO software [1]. The ground-borne noise levels are evaluated following the 2.75D approach proposed in [2] also implemented in CSTB MEFISSTO software.

The base configuration is shown in Figure 1: it consists in a concrete based building with an underground level and 3 stories above ground. The underground slab and walls are 40 cm in thickness; the other slabs are 20 cm in thickness, and the façade is 18 cm in thickness. The height between slabs is 2.5 m. The type and thickness of the central wall at the first and second stories are varied; the reference case corresponds to a concrete wall 18 cm in thickness. The ground is either a simple half-space (soft, medium, or hard type), or made of 2 layers (surface layer on a semi-infinite layer). The railway line platform has a height of 50 cm and a width of 6 m; for simplicity, it is assumed to be concrete. The center of railway line is located at 10 m from the building façade. The excitation in the center of the railway platform (red dot in Figure 1) is assumed to be a line of uncorrelated forces applied over the considered train length L_T (geometry infinite in the direction of the train line).

Tables 1 and 2 give the characteristics of different elements used for the prediction.

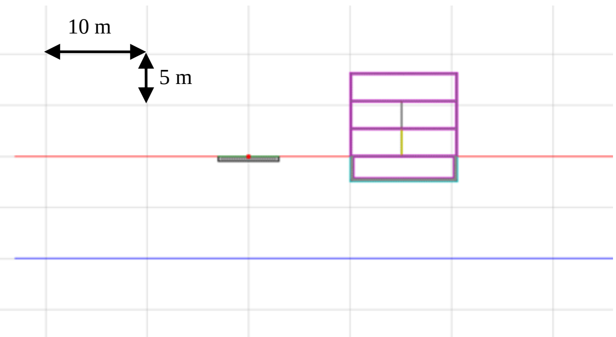

Figure 1. Investigated base configuration.

Table 1. Building component characteristics.

	E (MPa)	ν (-)	ρ (kg/m³)	η (%)
Concrete	25000	0.3	2500	1
Bricks	20	0.1	1000	1
Equivalent lightweight partition	40	0.1	476.6	2

Table 2. Ground characteristics.

	C_p (m/s)	C_s (m/s)	ρ (kg/m³)	η (%)
Surface layer	300	150	1800	5
Semi-infinite layer	800	300	1800	5
Soft soil	208	120	1400	5
Medium soil	388	224	1600	5
Hard soil	731	422	1800	5

Figure 2 shows the force density spectrum applied to platform by the train.

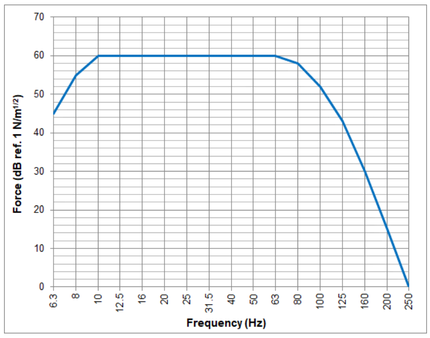

Figure 2. Force spectrum applied to platform by the train.

3. EFFECT OF TABULATED BUILDING TRANSFER FONCTION

In most vibrations impact assessment studies, the building floor velocity needs to be estimated in neighboring buildings of railway tracks. A typical configuration for such estimation is shown in Figure 3.

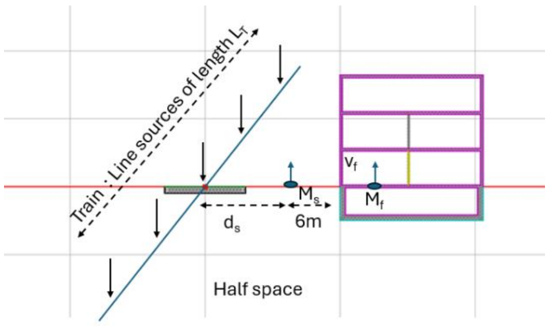

Figure 3. Typical configuration with used notation

In this case, the floor velocity v_f can be computed using a combination [3] of (i) the excitation terms as a force density spectrum (*FDS*, unit N/m$^{1/2}$), (ii) the propagation between the track center and near the building at point M_s given by a line source transfer mobility (*LSTM*, unit m/s/N/m$^{1/2}$) [3] and finally (iii) the dynamic of behavior represented by a correction factor C_b [4] :

$$v_f = FDS \times LSTM \times C_b \quad (1)$$

The correction factor C_b can be estimated by the ratio between the "global transfer function" Y_G (defined by the velocity at the receiver point M_f (floor center) for a "unit" line force applied on the track) and the *LSTM*. Nevertheless, it is not possible to measure Y_G when either the track or the building, does not exist. In practice, the *LSTM* is defined using numerical method and C_b is replaced by measured or tabulated transfer function between points M_s and M_f. Note that C_b includes C_{b2} and C_{b3} in [4] that replace TF2 representing the transfer function from free field ground (at building distance) to building foundations and TF3 representing the transfer function from building foundations to floor, in [3]. In this case, the global transfer function can be misestimated. In general, this error depends on the type of the building, the soil profile, the distance between the track and the building and the train length. Considering the same building and the same soil, the error can be expressed with the sum over the frequency band [8-250] Hz as:

$$Error(d_s, L_T) = 10 \log_{10} [\Sigma Y_G^2 / (LSTM \times C_b)^2] \quad (2)$$

In the following, the error given by Equation (2) is computed for three simple cases of homogenous half space soil (soft, medium, and hard soil type defined in Table 2); the building corresponds to the one described in Section 2. The building correction factor is taken from [4] for medium size building. The error is observed as a function of distance d_s from 7 to 40 m, and train length L_T from 1 to 100 m.

As seen in Figures 4 to 6, the use of the transfer function in place of correction factor does not have an impact on results when the train length L_T is very small. When L_T increases, for building near the track (d_s < 10 m), the transfer function is underestimated, meaning that the floor velocity is underestimated as well. On the contrary, for large distances between building and track, the transfer function and the floor velocity are overestimated. For intermediary distances, a zone for which the global transfer function is correctly estimated, exists (zone in green). The position and the size of this zone depend on soil characteristics. The results show that the zone is larger for stiffer soil; this can be explained by the fact that the transfer function from soil to building foundations (TF2 or C_{b2}) is smoother when the soil stiffness is higher. On the contrary, the transfer function FT2 or C_{b2} for lower soil stiffness has a deeper and large minimum, leading to more impact on the global transfer.

Due to these observations, tabulated transfer function must be used with caution, particularly when issued from measured point to point transfer function. It is more accurate to use a building correction factor C_b measured in situ. If impossible, a security margin of 6 dB should be considered when using tabulated transfer functions in the case of buildings located near the railway track.

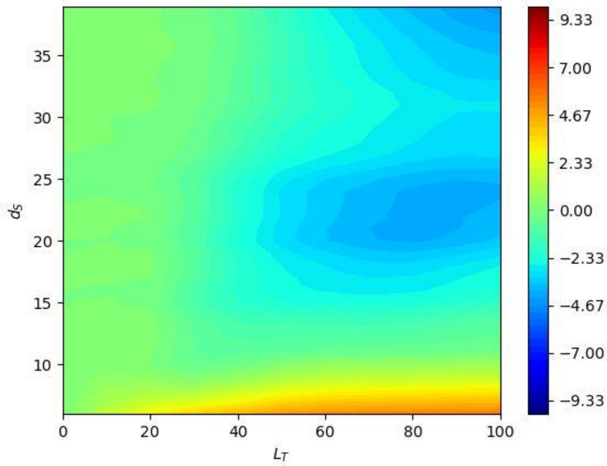

Figure 4. Maps of the error function for a 3-storey building on a soft soil half space

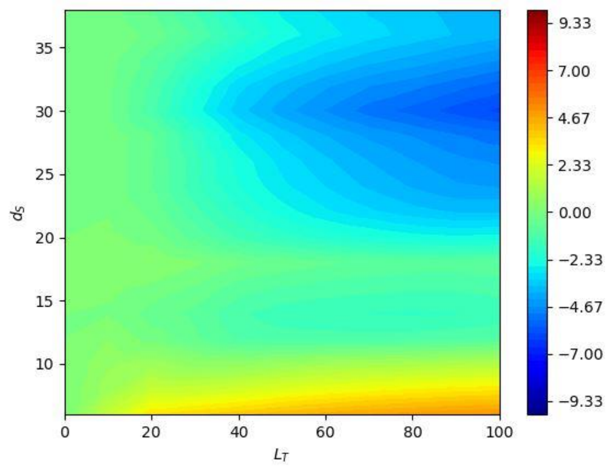

Figure 5. Maps of the error function for a 3-storey building on a medium soil half space

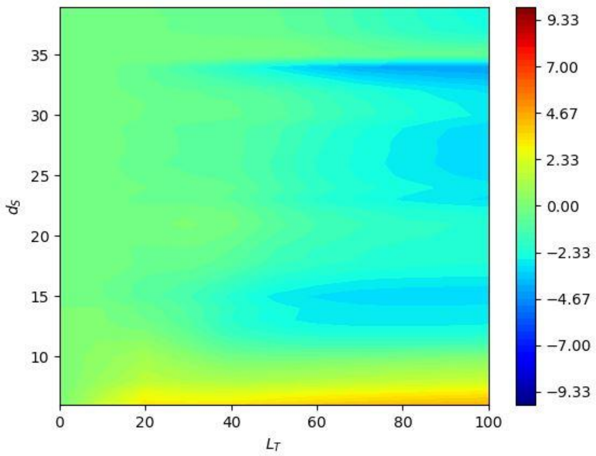

Figure 6. Maps of the error function for a 3-storey building on a hard soil half space

4. EFFECT OF EVALUATION POSITIONS IN BUILDING

In this section, the effect of the middle wall in the first and second building stories is investigated on the floor vibration level as well as on the ground-borne sound pressure level. The train is assumed to be 20, 40 or 100 m in length and the uncorrelated force are applied at 10 m from the building façade at the center of the railway platform. The ground is composed of two layers.

Indeed, it is quite important when fixing a limit for either vibration or ground-borne sound level to verify by the measurements that it is respected. In [5], measurements in the vertical direction at the floor mid-span is mentioned regarding vibration, due relevance in terms of human perception of the train passage event and possible annoyance. Following [5], ground-borne noise measurement is performed using one microphone at the one third point of a room's plan dimension (four options possible) and at a height of 1.2 to 1.5 m.

Since the prediction model is based on 2.5D approach, the vibration levels and the ground-borne sound levels are evaluated is a plane situated at the center of the train.

The middle wall in the first and second building stories can be made of either concrete (18 cm in thickness), lightweight bricks (7 cm in thickness) or an equivalent lightweight partition wall (like plasterboards on metallic frame, 10 cm in thickness). The case of no middle wall on all building stories is also considered.

4.1 Floor vibration levels

The vibration levels are evaluated along the floor slab across the building for the different situations considered. Figure 7 presents the velocity level on the concrete slab for the different investigated configurations in the case of a 100 m long train. It can be seen that the general pattern of the velocity level across the slab is rather similar for the different configurations. The presence of the wall, even for the concrete wall case, on the 1st and 2nd floors does not appear in an obvious way.

Figure 8 shows the one-third octave spectra of the concrete slab velocity for a position at one-quarter, half and three-quarter of slab length (on the left hand-side) and the global level over the frequency range (on the right side). Note that to simplify the spectra graphics the case of the equivalent lightweight partition is not shown; the behavior being close to the one for the brick type wall.

It is interesting to note that the velocity level in the 1st floor slab is pretty much the same regardless of the type of wall and the three selected positions along the slab.

For the 2nd floor slab due to the presence of a wall below and above the slab, the effect of the wall is well observed. At one-quarter of the floor length, the levels are slightly increased (except at 6.3 Hz), and the maxima slightly shifted in frequency for the concrete wall, while it is mostly increased for the other considered wall types (more lightweight). At the half length of the slab (under the wall if present), the velocity levels are lower in the presence of the concrete wall above 25 Hz, while they are higher for the other wall types (more lightweight). At three-quarter of the concrete slab, the velocity levels are generally increased compared to the case without wall.

For the 3rd floor slab and for the concrete wall, the velocity levels are increased above 20 Hz for the positions at one-quarter and three-quarter of the slab length and mostly increased below 25 Hz at the center of the slab (at the wall position). For the other wall types, the levels are increased.

For the top slab, the velocity levels are larger when the lightweight walls (brick wall or equivalent partition) are considered in the building and for the various locations considered (one-quarter, middle, and three-quarter of the slab length).

For lightweight wall, it appears of interest to evaluate the velocity level at the centre of the room (in the present case at one-quarter of the slab length) but to also investigate the center of the slab and if not taking a margin into account (margin of about 3 dB).

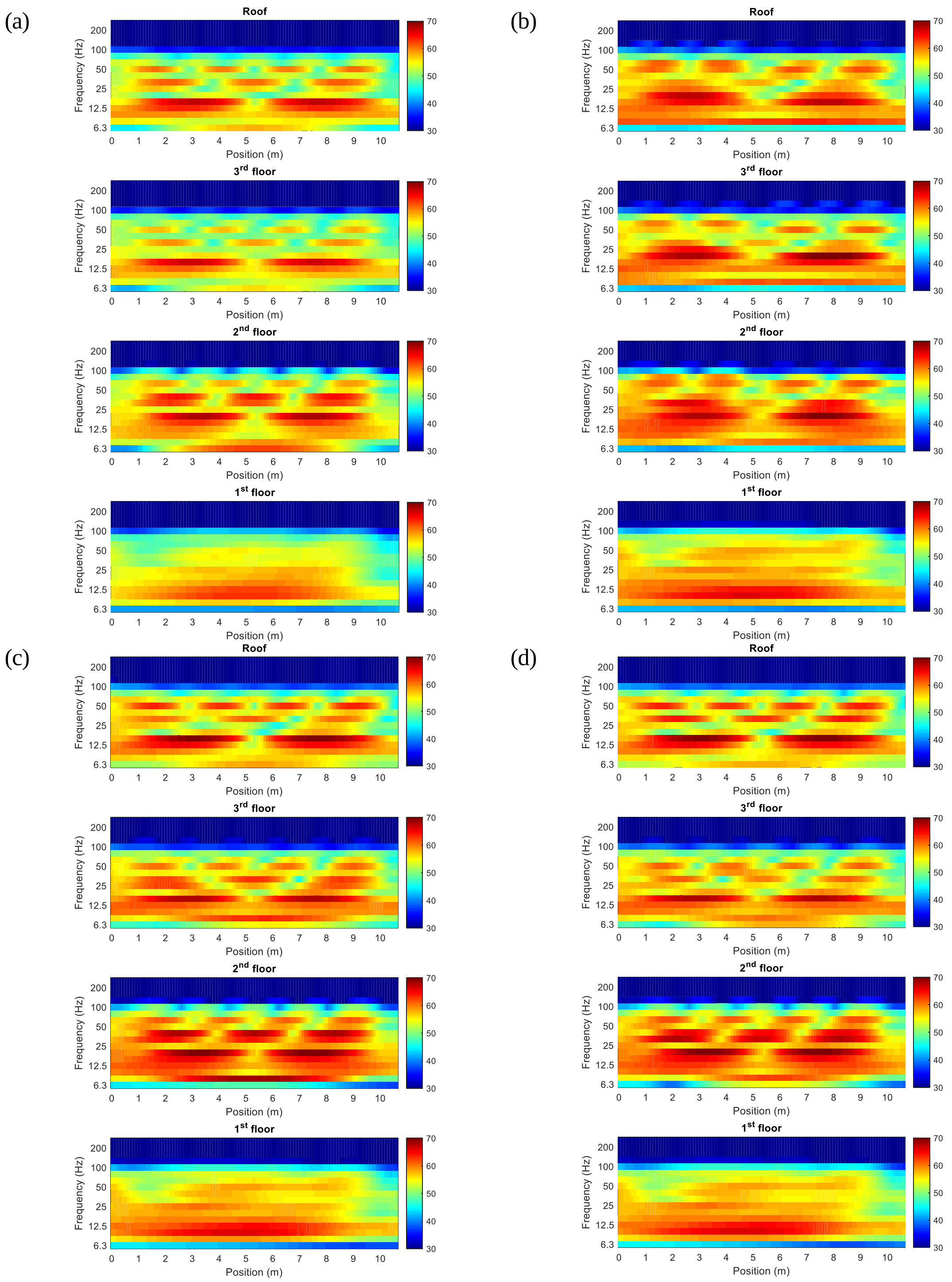

Figure 7. Slab velocity level (dB ref. 50 nm/s) for 100 m long train; (a) without wall, (b) concrete wall, (c) brick wall and (d) equivalent lightweight partition.

Figure 8. Velocity level (dB ref. 50 nm/s) for 100 m long train; at (a) one-quarter, (b) middle, (c) three-quarter, of the slab length and (d) space averaged, (left) Spectrum and (right) global value over the frequency range.

4.2 Ground-borne noise levels

Preliminary results were obtained in terms of ground-borne noise levels. Figure 9 presents the ground-borne noise levels in dB(A) over the investigated frequency range (one-third octave bands from 6.3 to 250 Hz) at a height of 1.3 m in the different rooms and for the different cases considered. Depending on the frequency, the pressure distribution across the room differs. Figure 10 shows the pressure distribution in the building rooms for the case without wall and for the case with a concrete wall at the one-third octave band of 50 Hz. These preliminary results need more in-depth analysis in order to reach any guidance with respect to measurements. A corner position could be an interesting option since it is easily identifiable and usably available for measurement in furnished room, and is expected to be an overestimate of the space average ground-borne noise level.

5. CONCLUSION

In the first part of this work, the effect of using tabulated transfer function to evaluate building floor vibration velocity was investigated. Due to these observations, tabulated transfer function must be used with caution, particularly when issued from measured point to point transfer function. It is more accurate to use a building correction factor C_b measured in situ. If impossible, a security margin of 6 dB should be considered when using tabulated transfer functions in the case of buildings located near the railway track (about 10 m).

In a second part of this paper, vibration velocity of building floors was investigated without and with several types of walls. For lightweight wall, it appears of interest to evaluate the velocity level at the centre of the room (in the present case at one-quarter of the slab length) but to also investigate the center of the slab and if not taking a margin into account (margin of about 3 dB). For heavyweight wall, the evaluation of the velocity level at the centre of the room appears appropriate.

Finally, concerning ground-borne noise inside building, the analysis of the preliminary results requires more work in order to determine general guidelines for preferable measurement positions.

Measurements are planned before the summer in a building to investigate in-situ the floor vibration velocity level distribution as well as the ground-borne noise level distribution.

6. ACKNOWLEDGMENTS

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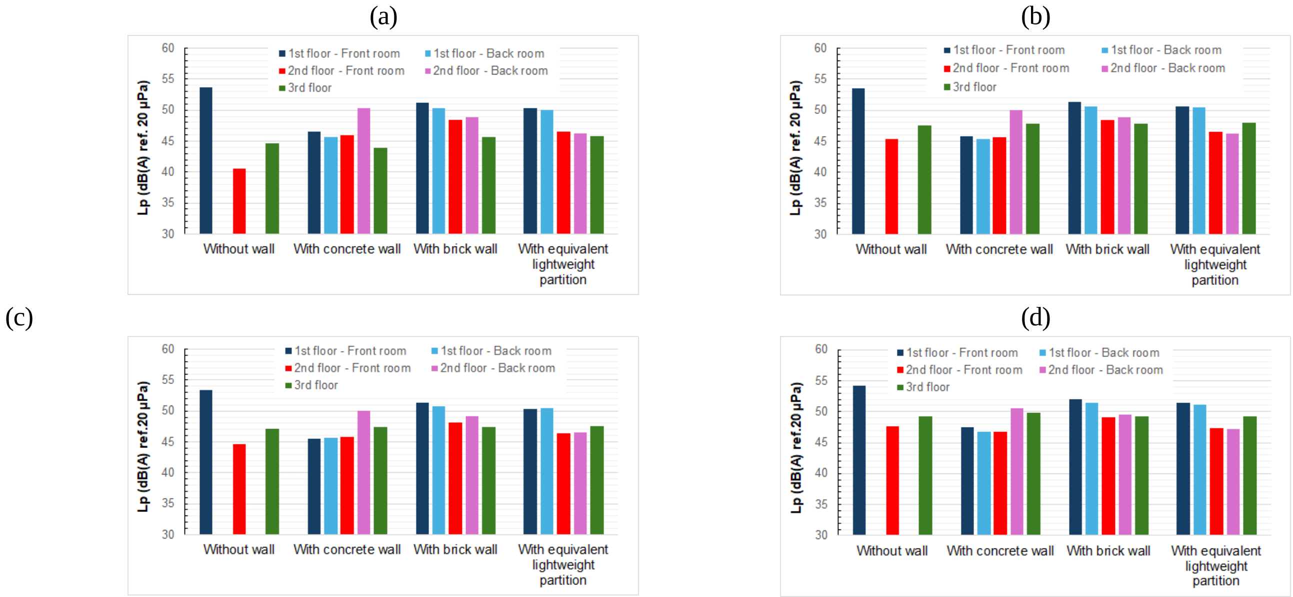

Figure 9. Ground-borne noise level (dB(A) ref. 20µPa) for 100 m long train; at (a) middle, (b) one-third, (c) two-third, of the different rooms at a height of 1.3 m and (d) space averaged.

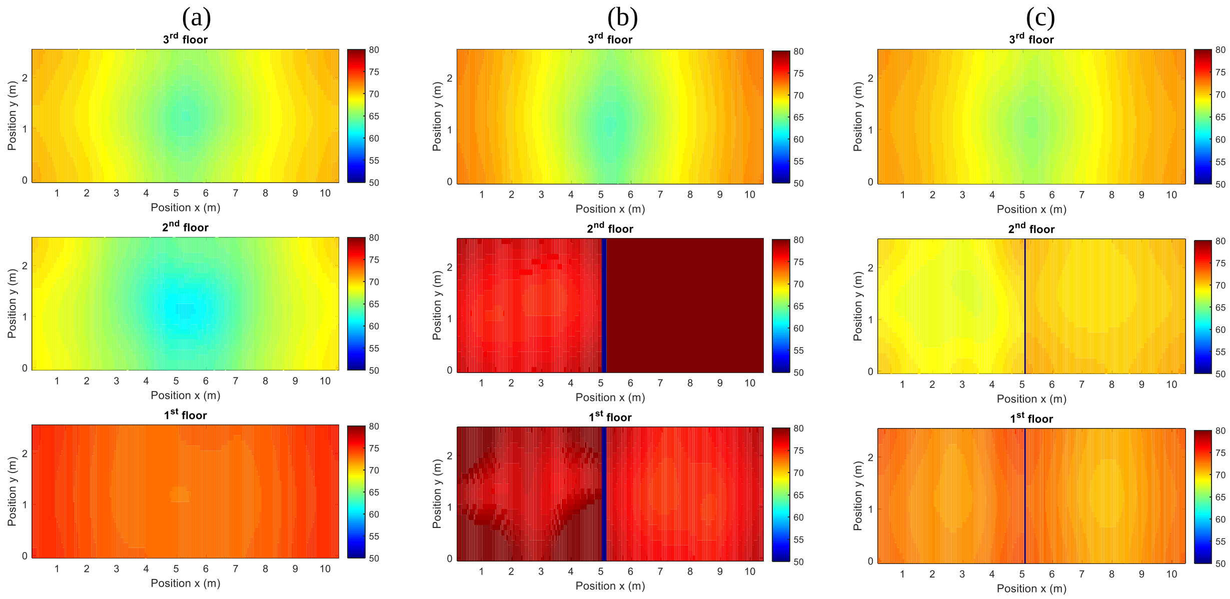

Figure 10. Ground-borne noise level (dB ref. 20µPa) distribution in the rooms for 100 m long train at the one-third octave band of 50 Hz; (a) without wall, (b) with concrete wall, and (c) with brick wall.