PERFORMANCE OF BUILDING BASE ISOLATION: THE TWO-LEVEL APPROACH

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RESUMEN

Es habitual observar niveles importantes de ruido estructural dentro de edificios adyacentes a nudos de transporte. Para construcciones nuevas, el uso de sistemas de Aislamiento Estructural/Basal de Edificios (*BBI*, de sus siglas en inglés) es una solución con una buena relación costo-eficacia para mitigar la propagación de vibraciones provenientes del terreno.
En la práctica, la elección del sistema BBI depende principalmente del requerimiento acústico prescrito por el consultor vibroacústico. Se prescribe la frecuencia de resonancia a alcanzar, según las mediciones in situ y los modelos numéricos de predicción que permiten estimar el nivel de ruido estructural esperado dentro del edificio. De todos modos, la decisión se toma muchas veces con base en el pico de frecuencia observado. Una ved designada la frecuencia de resonancia, se realiza el diseño del sistema de aislamiento en función de los mapas de cargas.
En este artículo se analiza tal metodología tradicional y, basándose en un caso real, se analiza críticamente el rendimiento global de aislamiento, no solamente a la frecuencia de pico sino considerando el comportamiento real del edificio y la posibilidad de resonancias tras la implementación del aislamiento estructural.

Palabras clave: Building Base Isolation, vibraciones, ruido estructural, aislamiento.

ABSTRACT

In buildings close to transit hubs, it is common to observe important levels of structure borne noise inside the buildings. For new constructions, the use of a Building Base Isolation (BBI) is a relatively cost effective solution to mitigate the ground-borne vibrations propagating in the building.

In practice, the choice of the BBI system depends principally on the acoustic requirements proposed by the acoustic consultant. The resonance frequency to be achieved is prescribed following different in-situ measurements and a numerical modelling which allows an estimation of the level of structure-borne noise expected in the building. However, the main decision is very often based on the peak frequency observed. Once the resonance frequency is set, a design of the isolators is then proposed based on the load scheme.
This paper discusses the traditional approach and based on a real case study, the overall performance of the isolation is critically analyzed not only at peak frequency, but also taking into account the real building behavior and the possibility of resonances after the BBI implementation.

1. INTRODUCCIÓN

Buildings, especially near railway or subway networks, can be subjected to ground-borne vibrations resulting in unacceptable level of structure-borne noise and vibration for the occupants of the building. In order to protect a building from important ground-borne noise and vibrations, it is necessary to decouple the building from the surrounding noise and vibration sources, by introducing a building base (vibration) isolation solution [1].
In 2017, the owner of a residential building project, located in Gran Vía Street in Barcelona, has contracted an acoustic consultant to investigate whether the heavy railway infrastructure of the Generalitat of Catalonia (FGC), passing

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close to the building, could generate important levels of noise and vibrations in his building. Figure 1 shows the location of the building and its distance from the FGC railway tunnel.

This paper will make use of this case study to describe the procedure adopted to investigate the need for a BBI system but also to discuss the performance of the isolation used based on the results of a measurement campaign carried out at the end of the construction.

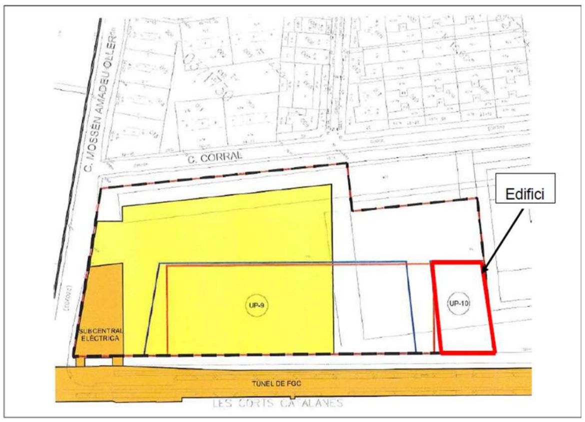

Figure 1. Location of the building and its distance from the railways**.**

In Spain, in this case of study, in Catalonia in particular, all buildings need to comply with the regulation 16/2002 on the protection against noise pollution and appendices modified according to *Decree 176/2009*, which specifically approves the regulations of the law regarding vibrations generated *by* ***the passage of passenger trains.***
This regulation provides the Law immission limit levels depending on the intended use of the building as follows:

Table 1. Law imposed limits by the Law 16/2002.

Intended use of the building	L_{aw} [dB]
Residential	75
Hospitals	72
Educational/Cultural buildings	72

The building being a residential building, the maximum allowable L_{aw} was set to 75dB.

2. DESCRIPTION OF THE CASE STUDY

The residential tower building, used as a case study in this paper, consists of a multi-storey residential building (Figure 2). It is located in GRAN VIA Street, in Barcelona close to tunnel Lines L8, R5 and R6, among others of the railways of the Generalitat of Catalonia (FGC) at the height of the Magoria La campana stop.

Figure 2 below provides a cross section of the building at the height of the tower and a cross section of the different floor types.

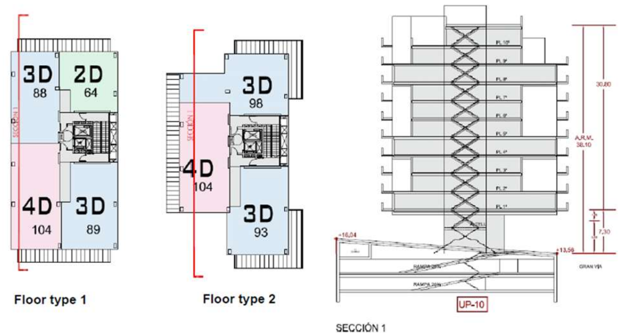

Figure 2. Cross section of the Building and Floor types.

3. NOISE AND VIBRATION STUDY

The objective of the noise and vibration study was to investigate whether despite the heavy railways passing close by, the building could comply with the limits imposed with the law 16/2002, according to *Decree 176/2009*.
In this respect, the acoustic consultant has initiated a measurement campaign at the construction lot determine the level of vibrations which will be received by the building.

3.1. Measurement campaign :

The measurements have been carried out at different points of the construction land in order to take into account possible differences in ground vibration. Differences which could be linked to different parameters, such as differences in the distance relative to the railway tunnel, or differences in the soil composition all along the vibration propagation path, the speed of the trains, irregularities present in the tunnel, etc.

Figure 3 shows the location of the different measurement points vis à vis the railway. Five points were located along the surface area occupied by the building, to control the vibration reduction. These five points were considered enough to cover all the analyzed area, locating the P1 the closest to the tunnel, considering it the worst case.

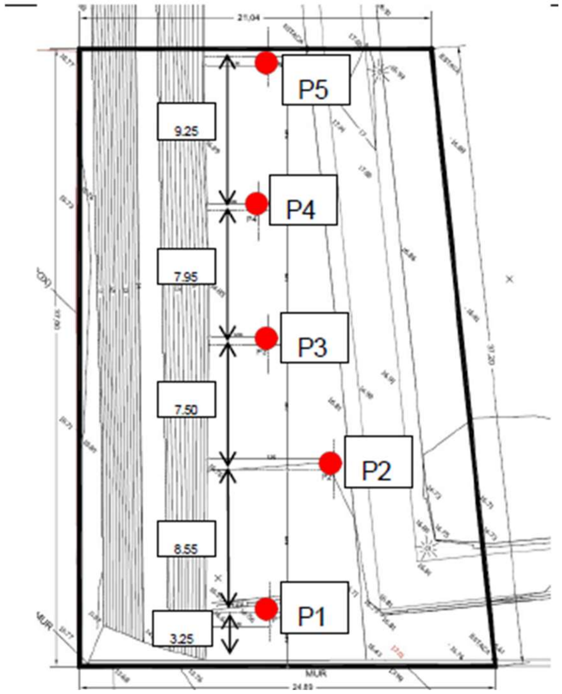

Figure 3: Location of vibration measurement points

All the measurements have been carried out on December 31, 2015 between 9 am and 1pm. This period was chosen because it corresponds to the peak period for train passings by. A train passing by is detected approximately every 3-5 minutes.

3.2. Measurement equipment

The equipment installed in the different vibration locations is detailed as follows:

Table 2. Measurement equipment

Equipment	Model
5 x Integrating third octave sound meter. Class 1. CESVA	SC310
5 x Accelerometer CESVA. Sensitivity 1000 mV/g	AC 006

The CESVA SC310 is a Class 1 equipment that acquire acceleration time-signals and contain internally the post-process of the Maximum Transient Vibration Value, MTVV, according to ISO 2631-2 standard as well as the average spectra. After that, an additional post process was carried out to obtain the MTVV modulus of the three axes (XYZ).

3.3. Measurement results :

In different measurement locations, a time evolution of the vibration level has been collected and processed to evaluate the evolution of L_{aw} .

Figure 4. Measurement equipment installed

As an example, Figure 5. Shows the time evolution of L_{aw} in the P1 location (the worst case). Where we can clearly identify that the maximum L_{aw} level due to the passing train at point P1 is 81.8 dB, identified with a yellow mark.

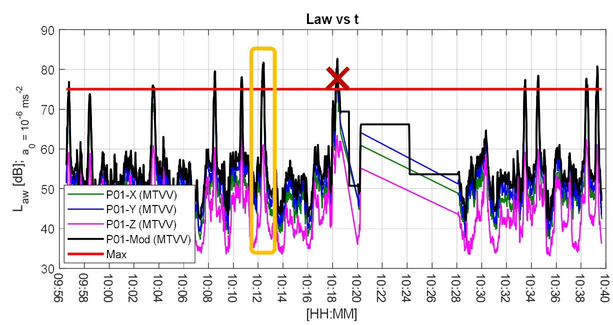

Figure 5. Measurements at P1. Note: between 10:20 and 10:30, the hollow refers to an event not related to the train passage – here a crane movement onsite.

Table 3. L_{aw} measured and estimated in each measurement point.

Measurement point	L_{aw} measured [dB]	L_{aw} [1] [dB]	L_{aw} [2] [dB]
P1	81.8	73.2	79.2
P2	77.6	69.4	75.4
P3	74.6	64.8	70.8
P4	70.7	62.9	68.9
P5	65.4	56.4	62.4

[1] Estimation including only the attenuation due to soil/building coupling.
[2] Estimation including the soil/building coupling loss and the penalty due to the slab resonance.

As expected, we can notice that different levels have been obtained in the different measurement points, as indicated in the 2nd column of Table 3.

At this point, a correction need to be applied to estimate the vibration inside the building as follows :

1. Attenuation due to the coupling soil/building :

In order to estimate the attenuation due to the soil/building coupling, it is necessary to know the spectrum of the ground vibration due to the passage of the trains and the type of foundations which will be used. In this specific case, the client indicated that the foundations were concrete piles.

The Figure 6 below, shows the attention applied for each frequency band according to FTA [2].

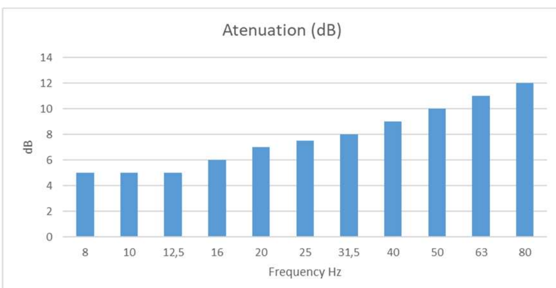

Figure 6. Attenuation due to the soil/building coupling.

After applying the attenuation for each of the frequency bands and for the typical spectrum obtained at each measurement point, the estimated levels of L_{aw} are indicated in the 3rd column of Table 3.

2. A penalty for the resonance of the slab, wall or support:

Once the attenuation due to the soil/building coupling has been considered, it is now necessary to take into account the possibility of resonance of a slab, wall or supports in one of the upper floors, which may result in higher vibration levels. According to FTA [2] and the return of experience of the acoustic consultant, the amplification due to a resonance can reach 6 dB in most critical cases. By assuming this worst case scenario, the estimation of L_{aw} in different measurement points is indicated in Table 3, column 4.

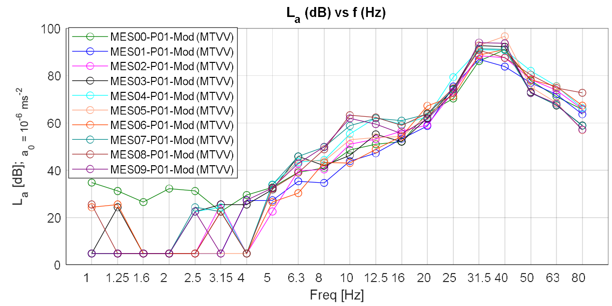

Figure 7. MTVV spectrum (XYZ) at the time of maximum level of train passing by.

3.4. Conclusions:

It is not possible to measure directly L_{aw} inside the different apartments, therefore an estimation is made based on vibration measurements conducted on the construction site.

Following the test campaign carried out and the post processing of the information obtained, it has been noticed that the expected vibration values, at some of the measurement points, were above the limit values established by the regulations (see table 3), which is in this case 75dB. In this respect, the acoustic consultant proposed to integrate an anti-vibration solution to reduce the level of vibrations.

4. INTEGRATION OF A BUILDING BASE ISOLATION

In a building base isolation strategy, it is important to consider all the connection points to the building, whether it's the soil on where the building stands (vertically and horizontally) or any existing construction which will be connected to the building. In the specific case of the presented building, the vibrations were transmitted via the soil only, as no adjacent buildings were to report.

Based on the measurement campaign results, the vibration index L_{aw} was compared in each measurement point to the limit imposed by the regulation (75 dB). It appeared that the limitation was not respected in some of the measurement points and a vibration isolation strategy was required to reduce the vibrations levels by 10 dB.

Following numerous exchange with the BBI supplier and the structural engineer, it has been decided to isolate the building at different levels because of the adopted structural design.

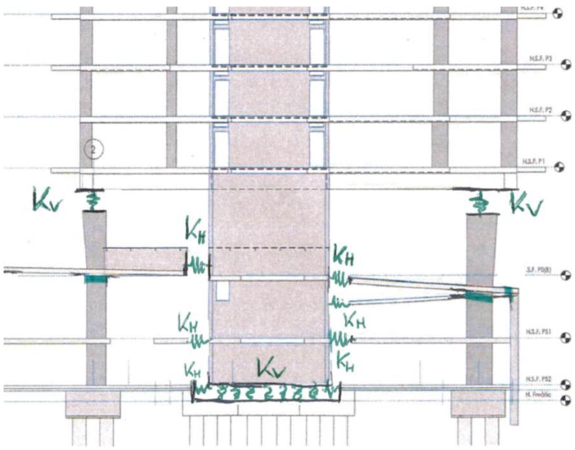

Figure 8. Isolation strategy.

Figure 8 shows where the isolation will be integrated, specifically :

1. Adding isolators on top of pillars below the 1st floor.
2. Adding isolators vertically and horizontally at the core walls in the basement (level -2). See Figure 9.
3. At slab level: cut the slabs and Insert corbels to support the slab. The corbels will then be decoupled from the slab using an isolator. See Figure 10.

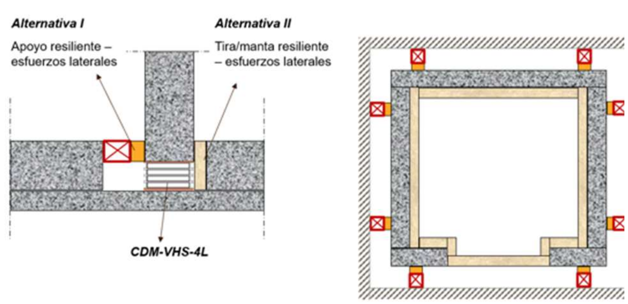

Figure 9. Proposed isolation for the core walls.

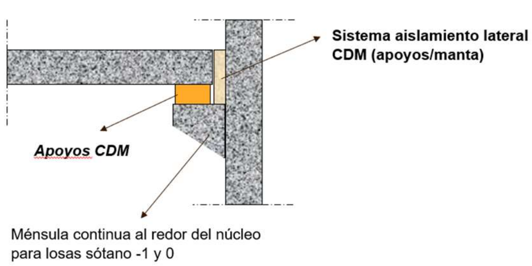

Figure 10. Proposed isolation for the slab connections.

2 *These VHS sandwich bearings refer to* ***Very High Stress*** *bearings and consist of an alternance of steel plates and elastomeric sheets which allow to sustain higher loads than traditional elastomeric bearings, in a limited footprint area.*

4.1. Choice of Isolators :

The choice of the isolators will depend on the dynamic response of the isolators to the disturbance. With an understanding of its properties, the type of isolator is then chosen for the load it will support and the dynamic conditions under which it will operate.

The ratio of vibrations transmitted after the isolation is described as transmissibility and the maximum transmissibility of an isolator occurs at resonance.

In this specific case, the estimated L_{aw} was at 80dB and the peak frequency at 31.5Hz. Therefore, using the transmission loss formula, it has been estimated that an elastomeric vibration isolation system of 10Hz would easily allow the attenuation needed of 10 dB.

Based on the level of the vertical loads and the limited footprint area, the Very High Stress - VHS sandwich bearings[2] have been proposed to isolate the core walls and the column heads. Moreover, the client has requested his design team to include failsafes (additional safety measures) in the event of major accidents (such as fires, explosions, etc).

In this regards, after numerous discussion with the design team, the manufacturer of vibration isolation has recommended the use of bearings with integrated failsafes, as shown in Figure 11. The steel failsafe does not engage unless that bearing stability is compromised.

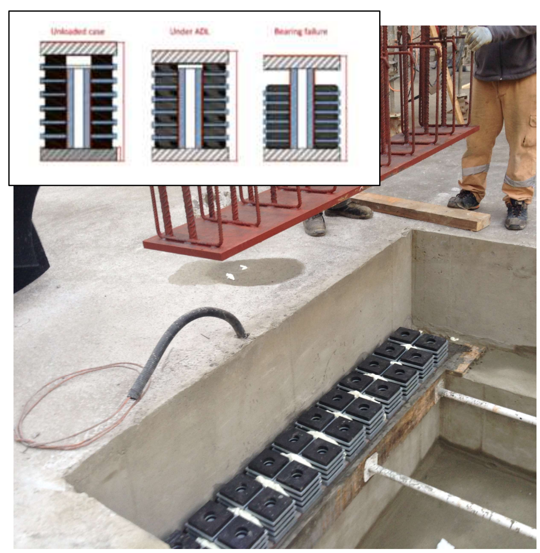

Figure 11. Installation of the VHS (very high stress) bearings with integrated failsafes.

4.2. Performance of the vibration isolation :

Following the completion of the project, the acoustic consultant went back to the construction site to evaluate the performance of the vibration isolation. A measurement campaign has been carried out and different measurement points have been selected in the building in the floors 1, 3 and 5 respectively. (Figure 12)

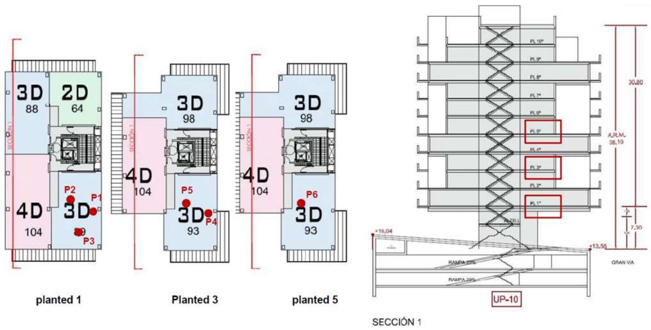

Figure 12. Location of the vibration measurement points in the building.

Figure 13. below shows the time evolution of the vibration levels at the different measurement points. The vibration spectrum of the maximum peak detected at all the measurement points of floor 1 and 3, is shown in the Figure 13 below.

In Figure 13, we can clearly notice how the vibration levels measured around this range have been reduced considerably; from 16Hz the levels oscillate between 50 and 60 dB.

The measurements results show that the isolation was effective and achieved the expected performance. Table 4. below shows the measured L_{aw} in the different measurement locations. All measurements confirmed that the limits imposed by the regulation are respected.

<u>Note</u> : The peak at around 10 Hz reflects the isolation frequency of the isolation system.

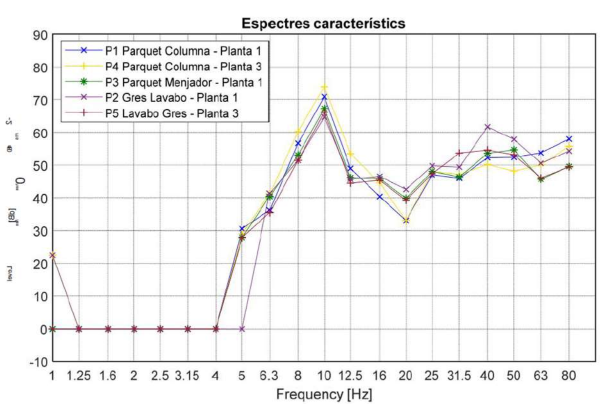

Figure 13. Spectrum of the averaged vibration inside the building above of the vibration isolation system.

Table 4. Measurement of L_{aw} after integrating the Building Base Isolation solutions.

Measurement point	L_{aw} [dB]
Internal - P1	64.3
Internal - P2	58.5
Internal - P3	60.6
Internal - P4	66.9
Internal - P5	60.4

5.CONCLUSION

The choice of the Building Base Isolation system strongly depends on the acoustic performance required by the acoustic consultant, but has also primarily to comply with all structural requirements.

This paper presented a real case study highlighting that complying to both acoustic requirements and structural requirements is not contradictory. The vibration isolation proposed in this case study integrated an additional failsafe inside the solution to avoid any disproportional collapse in the event of explosions, fires, or any other accidental event. At the end of construction measurements have confirmed that the integrated failsafe does not compromise in any manner the expected performance and provides an additional safety measure.

12. REFERENCES

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[2] Transit Noise and Vibration Impact Assessment. Federal Trannsit Administration (FTA), USA. 2006.