

# **BUILDING BASE ISOLATION: THE IMPORTANCE OF CORRECTLY CONSIDERING AND IMPLEMENTING CONSTRUCTION DETAILS. A REAL CASE STUDY**

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## **Abstract**

Buildings close to railways or subway networks can be subjected to important levels of ground borne-noise and vibration, and it is the responsibility of the acoustic consultant to investigate and assess those levels of structure borne noise, and propose mitigation measures if the noise levels inside the building exceed the acoustic comfort limits. However, their assessment often relies on simplified prediction models.

In construction, in general, both designers and developers try to minimize as much as possible the performance gap between design and reality, through strict control of the contractors' work. This is even more important in vibration isolation.

This paper presents a real case study where both the design and execution were done consistently taking into account all details linked to the vibration cut. The developer and contractor were very careful and reviewed with the acoustic consultant the full scope of details, whether it was the decoupling of the stairs, façades, elevator rails or even fire safety measures. The results of the measurement campaign carried out after building completion corresponded to the acoustic consultant's predictions, proving that good design and implementation of details avoid performance deviation in Building Base Isolation applications.

**Keywords:** Building Base Isolation (BBI), Vibration Isolation, Railway-induced vibration, Structure-borne Noise, Acoustic comfort.

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# 1 Introduction

In an urban area, the noise and vibration challenges generated by railway transport involve both air-borne and structure-borne noise. Although the air-borne noise can be controlled by the façade insulation, but the control of the ground-borne noise inside the building is more complex.

Once the levels of ground-borne noise and vibration inside the building exceed the acoustic (comfort) requirements, it is necessary to decouple the building from the surrounding sources at the foundation level or the columns and walls in an upper level by introducing a Building Base (vibration) Isolation (BBI) solution. Today, BBI solutions are widely employed to mitigate ground-borne vibration and noise generated by railway networks.

The real assessment of the isolation performance requires a comparison between the noise/vibration levels inside the building with and without the isolation system. However, when a building is isolated, a non-isolated building does not exist, and the real insertion gain is not measurable. Therefore, in practice, in the isolated building, the transmission loss at each bearing position can be obtained by measuring the vibration level above ( $V_{s,iso}$ ) and below ( $V_{f,iso}$ ) the isolator:

$$TL [dB] = 10 \log_{10} \left( \frac{V_{s,iso}^2}{V_{f,iso}^2} \right) \quad (1)$$

In theory, assuming the isolated building as a simplified SDOF (mass-spring) system, equation (1) can be reformulated as a function of the resonance frequency,  $f_{res}$ , of the SDOF system:

$$TL [dB] = -20 \log_{10} \left( \sqrt{\frac{(1-\beta^2)^2 + (\eta\beta)^2}{1+(\eta\beta)^2}} \right) \quad (1)$$

where  $\beta = f_{exc}/f_{res}$  is the excitation frequency ratio and  $f_{res} = 1/2\pi\sqrt{K_{iso}/M_s}$  is the resonance frequency of the isolation system.  $M_s$  denotes to the superstructure mass,  $K_{iso}$  is the dynamic stiffness of the isolation bearing and  $\eta$  refers to the loss factor.

Note that the superstructure mass may not fully participate at the main vibration mode and would be practically equal to the building mass. Additionally, the dynamic stiffness and the loss factor of each bearing are determined by laboratory tests.

To achieve the expected dynamic mass, equivalent to the acoustic design load provided at the design stage, it is recommended to measure the transmission loss after the completion of the building once the final floor coverings, partitions, walls and facade have been already installed, [1].

## 1.1 Acoustic requirement

According to Annex III of Law 7/2010, on the protection against noise pollution in Aragón, the vibration thresholds in terms of the vibration index  $L_{aw}$  in [dB] inside the habitable spaces of buildings for different applications as housing, residential uses, hospitals, and educational or cultural purposes are presented in the Table 1.

Table 1 - Vibrations threshold in the buildings with different applications.

Building type	Index of vibration $L_{aw}$ [dB]
Residential	75
Health care, Hospital	72
Cultural and Educational	72

The vibration index is expressed in decibels (dB) and will be determined in a frequency range from 1 to 80 Hz by the following equation:



- d) Defining the specifications of the isolation system required to attenuate the transmission of ground-borne noise and vibrations.
- 2) Evaluation the isolation performance of the installed isolation system after the end of the building construction.

## 2 Vibration emission

The induced vibrations due to railway traffic were measured during midday hours, figure 2. The ground vibration was recorded using a 1 V/g three-axial accelerometer.



Figure 2 - Measuring the ground vibration in the site of the future building.

Table 3 – Comparison between ground vibration measured in the site and predicted vibration inside the rooms.

Nº superación	Hora	Nivel de vibración dB	Nivel de vibración dB	Valor límite dB	Superación dB
1	11:51:11	79,6	78,5	≤ 75	3,5
2	12:17:32	79,6	78,5	≤ 75	3,5
3	12:24:45	77,2	76,1	≤ 75	1,1
4	12:26:41	79,0	77,9	≤ 75	2,9
5	12:39:52	77,3	76,2	≤ 75	1,2
6	12:47:51	79,4	78,3	≤ 75	3,3
7	12:58:53	77,8	76,7	≤ 75	1,7
8	13:09:18	80,0	78,9	≤ 75	3,9
9	13:31:11	79,5	78,4	≤ 75	3,4
10	13:38:47	80,3	79,2	≤ 75	4,2
11	13:49:59	79,1	78,0	≤ 75	3,0
12	13:53:33	79,9	78,8	≤ 75	3,8
13	14:07:53	77,2	76,1	≤ 75	1,1
14	14:09:30	79,6	78,5	≤ 75	3,5
15	14:16:39	80,9	79,8	≤ 75	4,8
16	14:24:09	77,7	76,6	≤ 75	1,6
17	14:29:03	78,7	77,6	≤ 75	2,6
18	14:32:33	84,9	83,8	≤ 75	8,8
19	14:45:46	80,1	79,0	≤ 75	4,0
20	14:52:11	79,5	78,4	≤ 75	3,4
21	14:55:29	79,3	78,2	≤ 75	3,2
22	15:08:43	75,5	74,4	≤ 75	-0,6

An empirical methodology proposed by FTA and the European project RIVAS has been used to predict the vibration levels inside future buildings [3,4]. This method decouples the vibration transmission from the source (railway) to the building into:

1. Vibration propagation through the soil ( $C_g$ ) from the railway track to the site point in the absence of the building,

2. Vibration attenuation ( $C_{gb}$ ) due to soil-structure interaction, known as "coupling loss",
3. Vibration transmission from the foundation to the building floor slabs within the building structure ( $C_b$ ).

Therefore, the vibration level inside the future building,  $L_v$  (room), can be calculated based on the vibration level at the source,  $L_{v0}$  (track), and the aforementioned transfer functions:

$$L_a(Room) = L_a(Track) + C_g + C_{gb} + C_b \quad (3)$$

Since the ground vibration has been directly measured at the location of the future building, the terms of  $[L_a(Track) + C_g]$  in the equation (3) will be replaced by the measurement results given in Table 3. For the coupling loss  $C_{gb}$  and vibration transmission through the building structure  $C_b$ , the values given in the FTA and RIVAS guideline have been used.

Table 3 compares the predicted vibration levels inside the building using equation (3) with the ground vibration measured at the site. In the majority of measured instances, the results indicate excessive vibrations of approximately 2-5 dB beyond the limits specified in Table 1.

Once the vibration levels inside the building are predicted, corrective measures such as a Building Base Isolation (BBI) system are necessary to attenuate these excessive vibrations. Considering the comfort thresholds given in Table 2, a global vibration attenuation of at least 15 dB is recommended.

To achieve the required vibration attenuation, as per equation (1), an isolation system with a resonance frequency ( $f_{res}$ ) at 11 Hz would require.

To confirm the results of the preliminary study which was based on the ground vibration measurement in the site in the absence of the building, the ground-borne vibrations have been measured after the construction of the foundation at the pile heads, Figure 3.



Figure 3 – Ground-borne vibration measurement at the foundation (at the pile heads).

The vibration level inside the building can be recalculated using the new measurement results with equation 2. As the vibration has been measured at the foundation on pile heads, the first three terms  $[L_a(Track) + C_g + C_{gb}]$  in equation 2 can be replaced by the foundation vibration. The results of the secondary investigation presented in Table 4 largely confirm those obtained in the initial measurement campaign.

### 3 Vibration decoupling by Building Base Isolation systems

The building has been isolated using Stravibase VHS at 11 Hz on top of the ground floor columns, under the first-floor slab, Figure 4.

Table 4 – The predicted vibration inside the rooms in a secondary investigation.

Nº superación	Hora	Nivel de vibración dB	Nivel de vibración dB	Valor límite dB	Superación dB
1 (Pilar 48)	17:44:04	85,6	84,5	75	9,5
2 (Pilar 48)	18:12:44	76,7	75,6	75	0,6
3 (Pilar 48)	18:12:52	76,8	75,7	75	0,7
4 (Pilar 48)	18:19:48	76,6	75,5	75	0,5
5 (Pilar 48)	18:59:28	78,0	76,9	75	1,9
6 (Pilar 48)	19:22:32	78,4	77,3	75	2,3
7 (Pilar 48)	19:34:24	76,0	74,9	75	-0,1
8 (Pilar 7)	19:43:32	78,8	77,7	75	2,7
9 (Pilar 7)	19:50:35	77,0	75,9	75	0,9
10 (Pilar 7)	19:57:14	78,0	76,9	75	1,9
11 (Pilar 7)	19:58:47	78,7	77,6	75	2,6
12 (Pilar 7)	20:08:32	75,2	74,1	75	-0,9
13 (Pilar 7)	20:14:26	78,4	77,3	75	2,3
14 (Pilar 7)	20:18:47	78,8	77,7	75	2,7
15 (Pilar 7)	20:29:44	80,6	79,5	75	4,5
16 (Pilar 7)	20:35:26	76,7	75,6	75	0,6
17 (Pilar 7)	20:38:23	75,5	74,4	75	-0,6
18 (Pilar 7)	20:46:53	78,2	77,1	75	2,1
19 (Pilar 7)	21:14:02	75,8	74,7	75	-0,3



Figure 4 – Building decoupling using Stravibase VHS bearings.

#### 4 The acoustic decoupling between the isolated and non-isolated part

To ensure the optimal performance of the Building Base Isolation system, it is crucial to prevent acoustic bridges between the isolated and non-isolated sections, especially in the staircases, elevator shafts, partitions, and fire protection boards. Throughout the various stages of construction, the project's acoustic consultant has monitored the building process to verify the absence of any rigid connections. Figure 5 highlights the critical areas that need inspection.



Figure 5 – Acoustic decoupling in the staircase, top of ground floor brick walls, and fire protection boards.

## 5 Isolation performance validation

After the construction is completed, the performance of the Building Base Isolation solution has been investigated by means of in-situ measurements. Figure 5 provides an overview of the measurement points, where the ground-borne vibration has been measured once inside a room above the vibration cut, as well as inside a closed space on the ground floor, below the vibration cut.



Figure 6 – The vibration measurement inside a closed space (a) above and (b) below the vibration cut.

The vibration level in terms of  $L_{aw}$  measured above the isolation bearings are presented in Table 5 ranging from 60 to of about 65 dB which meet the vibration limits.

Table 5 – The level of vibration measured inside the room above the vibration cut.

CONTABILIZACIÓN DE LOS MAYORES NIVELES DE VIBRACIONES REGISTRADOS (SUPERIORES A 60 dBA)					
Nº	Hora	Nivel de vibración dB	Valor límite dB	Superación dB	Contabilización
1	12:53:50	65,2	≤ 75	0	0
2	13:08:21	61,6	≤ 75	0	0
3	13:17:14	61,2	≤ 75	0	0
4	13:25:54	60,4	≤ 75	0	0
5	13:43:10	62,3	≤ 75	0	0
6	13:51:28	61,7	≤ 75	0	0
7	14:07:30	64,5	≤ 75	0	0
8	14:23:45	60,7	≤ 75	0	0
9	14:41:31	65,0	≤ 75	0	0
10	14:58:38	61,5	≤ 75	0	0
11	15:45:00	63,0	≤ 75	0	0
12	16:27:41	60,6	≤ 75	0	0
13	16:33:45	63,9	≤ 75	0	0
14	16:43:04	60,0	≤ 75	0	0
15	17:13:50	65,2	≤ 75	0	0
16	17:29:26	63,0	≤ 75	0	0
17	17:32:15	62,9	≤ 75	0	0
18	17:53:03	61,9	≤ 75	0	0
19	17:59:20	61,0	≤ 75	0	0
20	18:01:56	64,8	≤ 75	0	0

Additionally, the ground-borne vibration level measured in a closed space below the vibration cut (in non-isolated part of the building) shows a ranging from  $L_{aw} = 75$  to 81 dB which does not meet the vibration limits. The overall transmission loss of the proposed isolation system, therefore, can be determined as the difference between the level of vibration below and above the vibration cut as  $75-60 \approx 15$  dB.

Table 6 – The level of vibration was measured inside a closed space on the ground floor.

CONTABILIZACIÓN DE LOS MAYORES NIVELES DE VIBRACIONES REGISTRADOS (SUPERIORES A 75 dBA)					
Nº	Hora	Nivel de vibración dB	Valor límite dB	Superación dB	Contabilización
1	13:08:39	76,3	≤ 75	1,3	1
2	17:05:41	75,1	≤ 75	0,1	1
3	17:05:54	81,0	≤ 75	6,0	3 (No se permiten superaciones mayores a 5 dB)
4	17:11:32	76,7	≤ 75	1,7	1
5	17:52:29	79,9	≤ 75	4,9	3
6	17:52:29	76,4	≤ 75	1,4	1

## 6 Conclusions

This paper presented a real case study of vibration emission and the design of a Building Base Isolation system for a residential building. Validation measurements performed after the building's completion confirm the proposed system's isolation performance, corresponding to the required vibration attenuation determined by the project's acoustic consultant. Significant attention from both the contractor and the acoustic consultant to every detail has ensured the effective decoupling of the stairs, façades, elevator rails, and even the fire protection boards.

## References

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