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MITIGATING GROUND-BORNE VIBRATIONS WITH A BOX-IN-BOX SOLUTION: FEASIBILITY AND CHALLENGES IN A REAL CASE STUDY

Iñigo Arana Goenaga[1], Pere Vicenç Rodríguez Sorribes[2], Albert Isnardo Iglesias[2], Sérgio Fernando Frasson Quaresma[1], Hamid Masoumi[1]*

[1] CDM Stravitec, Overijse, Belgium

[2] ICR, Barcelona, Spain

ABSTRACT

When addressing ground-borne vibration issues, such as those caused by railways, the state-of-the-art for new building projects typically includes various Building Base Isolation (BBI) solutions. However, some projects face constraints that complicate the implementation of such systems. Specifically, when isolation measures are introduced late in the planning phase, a Box-in-Box (BiB) isolation system can be a practical alternative to achieve the required vibration reduction. This paper discusses the mitigation of ground-borne vibrations in a building near a metro line using a BiB system. It emphasizes the importance of detailed design and rigorous quality control during construction to ensure the system's success. The case study also demonstrates the feasibility of BiB systems as a practical alternative to BBI in constrained situations, while offering recommendations on decoupling details to achieve promised performance in vibration isolation projects. This study highlights challenges posed by the acoustic bridges, which led to performance deficiencies in some areas. In contrast, sections where decoupling measures were carefully followed achieved the expected performance, as verified through in-situ measurements.

Keywords: *Ground-borne noise and vibration, Building Base (vibration) isolation, Box-In-Box*

**Corresponding author*: *h.masoumi@cdm-stravitec.com.*

1. INTRODUCTION

Buildings located near railway infrastructure are often subjected to ground-borne vibration (GBV), which is generated by passing trains and transmitted through the soil to the building structure. Train-induced vibrations can cause discomfort for habitant due to both floor vibrations and re-radiated (structural) noise inside the rooms. This requires a decoupling and mitigation strategy either between the surrounding ground and the building foundation, or inside the building between the building's main structural element and the sensitive spaces. Such an approach demands a multi-disciplinary effort, involving a comprehensive understanding of the railway infrastructure and the train types and speeds (as the source of vibration), on the dynamic characteristics of the ground (as the vibration propagation path), the building structural dynamics (for vibration response), and acoustics of the sensitive spaces (as the receivers), [1].

Two primary strategies used for ground-borne vibrations mitigation in buildings are:

- Building Base Isolation (BBI): This method involves isolating the entire building by decoupling it from the ground at the foundation level or at least at one storey below the sensitive spaces. BBI effectively mitigates low-frequency ground-borne vibrations using elastomeric bearings or structural coil springs. Once BBI is implemented at a certain level, the entire structure above the vibration cut remains decoupled from the incoming ground-borne vibrations.
- Box-in-Box (BiB) Solutions: This technique in-

Table 1. Comparison between BBI and BiB solutions for building vibration isolation.

	BBI (Building Base Isolation)	**BiB (Box-in-Box)**
Primary Function	Reduces vibration transmission through the entire building (superstructure) above the vibration cut.	Creates an acoustically isolated space within the building by decoupling its floors, walls, and ceilings.
Efficiency Range	Highly effective in mitigating low-frequency ground-borne vibrations (e.g., from railway traffic).	Optimized for controlling high-frequency vibrations, including both airborne and structure-borne noise within the building.
Structural Adaptation & Design Challenges	The serviceability of the building, must be carefully checked under all load conditions; performance improves with increased stiffness of both the superstructure and substructure.	Effectiveness is enhanced by incorporating an independent “floating” space within the building, requires a detailed design for decoupling the floor, walls, and ceiling.
Installation challenges	Easy installation on a flat, clean surface in a protected area against water inundation, with possible fire protection requirements, for placing BBI bearings.	Precise execution is required to prevent conflicts between new elements and the existing non-isolated structure, ensuring the avoidance of acoustic bridges.
Suitability	Ideal for isolating the entire buildings with a high number of vibration-sensitive spaces, especially those in close proximity to railway infrastructure.	Best suited for buildings with a limited number of sensitive spaces, where both internal and environmental (external) noise and vibration sources need to be controlled between different areas.
Impact on Occupants	Significantly reduces both ground-borne noise and perceptible vibrations for occupants.	Effectively minimizes both vibration and noise transmission into and out of sensitive environments.

volves creating an independent, locally isolated space within the building by incorporating isolated floors, walls, and ceilings. A conventional BiB is effective particularly in controlling high-frequency noise and vibration in specific sensitive areas, such as recording studios, rehearsal rooms, cinemas, or laboratories. However, achieving higher performance against low-frequency ground-borne vibrations (GBV) may require a low-frequency isolation system combined with heavy floating floors, walls and suspended ceilings.

Table 1 presents a comparison of key characteristics and critical aspects of BBI (Building Base Isolation) and BiB (Box-in-Box) solutions for building vibration isolation:

Although Building Base Isolation (BBI) is often considered a more practical solution for mitigating train- induced vibrations, as it provides a one-time payment system to isolate the entire building at once, some projects face constraints that complicate its implementation. These challenges include the retrofitting and restoration of existing (older) buildings or cases where isolation systems are introduced late in the planning phase. In such situations, the Box-in-Box (BiB) system can serve as an effective alterna-

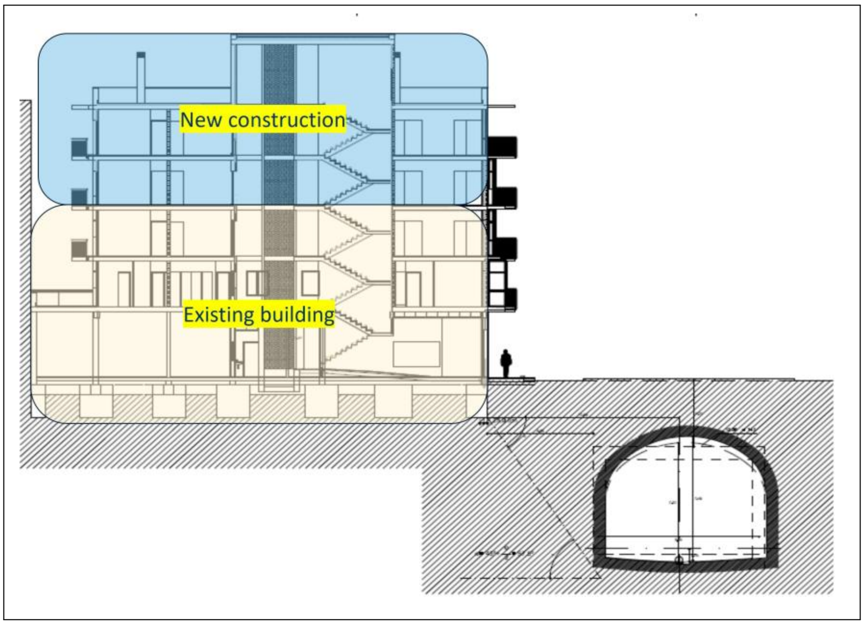

Figure 1. General overview of the building and the metro tunnel.

tive to achieve the required noise and vibration reduction.

While BiB is a viable solution, its effectiveness depends largely on high-quality installation and precise execution during construction. This case study highlights challenges which resulted in performance deficiencies in certain areas, emphasizing the critical role of execution accuracy. This paper explores the mitigation of ground-borne vibrations in a building located near a metro line through the application of a BiB system. It presents both pre- and post-construction vibration measurements, analyses the system's overall performance, and examines the key installation challenges encountered during the process.

For the evaluation of vibrations inside a building in Spain, the vibration measurement is processed according to Decree 176/2009, Annex 7 “Immission of vibrations into the interiors of buildings.” The limit levels of immission established in this Annex are shown in Tab. 2, based on the building's use. The vibration levels are presented in terms of weighted acceleration level according to ISO 2631, [2].

2. CASE STUDY: ISOLATION OF NEW STORIES ON AN EXISTING BUILDING

The case study involves a residential building with a ground floor and two upper floors. The project aims to add two additional floors on top of the existing structure, resulting in a building with a ground floor and four upper floors.

Table 2. Vibration Limit Values.

Building Use	L_{aw} [dB]
Dwelling and Residential	75
Healthcare	72
Educational or Cultural	72

The building is located adjacent to a metro tunnel, which is very close to the surface (at a depth of 4 meters) and situated 6 meters away from the building's edge.

Following the vibration study and on-site measurements, the maximum recorded vibration levels on the second floor ranged between 70 and 73 dB. Although these levels are below the legal limit of 75 dB for residential buildings, as stipulated by law, the vibrations are perceptible and could cause discomfort to future occupants.

Given that structural modifications and the addition of floors could amplify vibrations due to floor resonance, potentially exceeding the limit on the upper floors. To prevent these potential risks, based on the results of the vibration study, the acoustic consultant has proposed implementing a vibration isolation system from the third floor

Figure 2. Box-in-Box solution .

upwards. The system involves using Stravitec SEB elastomeric bearings at 12 Hz on top of the third floor to isolate the new structure from the existing one.

However, in practice, the proposed BBI isolation system was introduced late in the construction planning, and instead, a Box-in-Box (BiB) isolation system was proposed to achieve the required vibration reduction.

Figure 2 illustrates a general overview of the proposed Box-in-Box system, where the base slabs are decoupled using a concrete floating floor, 80 mm thick, on elastomeric bearings at 12 Hz (Fig. 3). Additionally, the structural walls are decoupled using elastomeric strips and double gypsum with an intermediate mineral wool layer.

3. VALIDATION OF VIBRATION LEVEL

Vibration level validation was conducted in the building at the completion of construction, following the addition of two floors, to assess compliance with current regulations on vibrations from the nearby metro line L1. The objective of the study was to determine whether the renovated building, now consisting of a ground floor and four upper floors (following the addition of two floors on top of the existing structure), meets the vibration standards set by Decreto 176/2009 due to the passage of passenger trains on the adjacent metro line L1.

Since the apartments are in their final construction

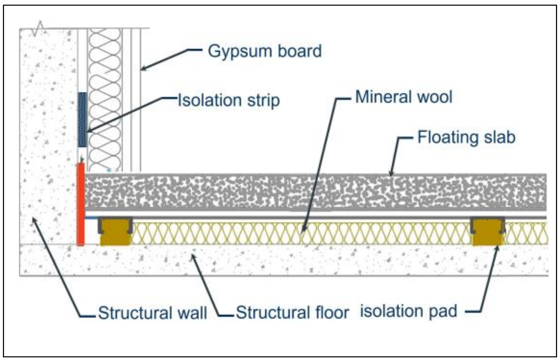

Figure 3. Section of the floating floor and the structural wall decoupling.

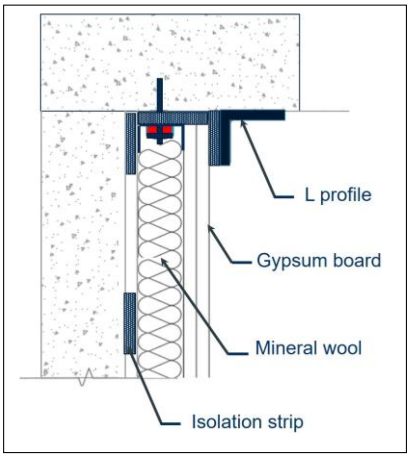

Figure 4. Section of the floating floor and the structural wall decoupling.

stage, with finished walls, floors, doors, and windows, vibration measurements have been carried out at four control points: three in the bedroom and two in the living room of the apartment closest to the metro line. These measurements were taken on each of the three floors with residential units (PL2, PL3, and PL4, as shown in Fig. 5).

A summary of the vibration measurement results is presented in Tab. 3. While the majority of measurement points across different floors of the building show compliance with current vibration regulations, one critical location— a bedroom on the third floor closest to the metro line—exhibits vibration levels exceeding the permissible limit. This non-compliance raised concerns regarding potential discomfort for occupants and regulatory adherence,

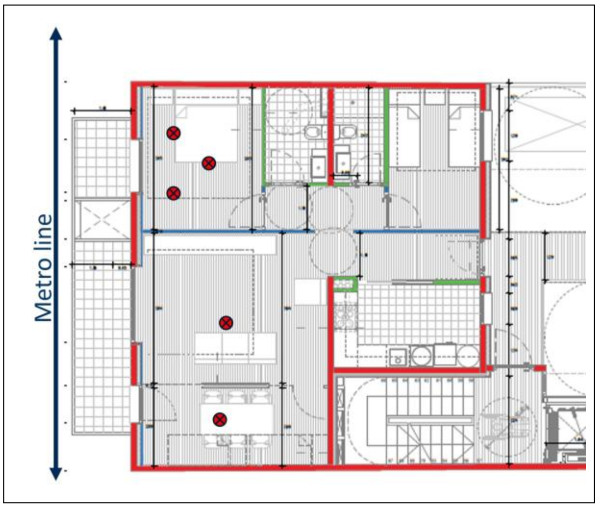

Figure 5. Measurement points in the apartment closest to the metro line.

Table 3. Vibration levels at different floor levels.

Measurement Point	Background L_{aw} [dB]	Maximum L_{aw} [dB]
PL2 Bedroom	44.6	71.1
PL3 Bedroom	49.2	76.3
PL4 Bedroom	51.7	71.1
PL2 Living Room	44.7	73.4

necessitating a more detailed investigation.

To further assess the issue, a follow-up measurement campaign was conducted within the affected bedroom, with vibration levels recorded at four distinct points, as illustrated in Fig. 6. The results of this secondary assessment, presented in Tab. 4, indicate that while three of the measured positions remained within acceptable limits, one location continued to exceed the regulatory threshold of 75 dB.

Following this assessment, a technical inspection of the building's structural elements was carried out to identify possible causes of the elevated vibration levels. The investigation revealed the presence of a mortar bridge beneath the balcony door frame, which was likely facilitating the transmission of vibrations from the structural floor (non-isolated part) to the bedroom floating floor (see Fig. 7). This rigid connection was suspected to be a significant contributing factor to the non-compliant vibration levels in the affected area.

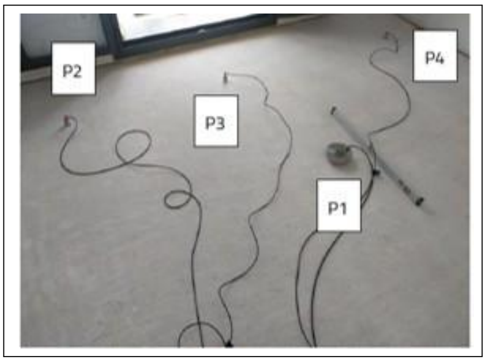

Figure 6. Measurement points in critical bedroom.

Figure 7. Acoustic bridges in critical room.

To address the identified issue, a series of corrective measures were implemented to eliminate the acoustic bridges beneath the balcony door frame. These measures involved removing the rigid connections and ensuring that no direct pathways remained for vibration transmission. Special attention was given to the interface between the door frame and the floating floor to prevent any residual mechanical coupling that could compromise the effectiveness of the isolation.

Figure 8 provides a detailed illustration of the corrective measures undertaken. Following the modifications, a repeat measurement campaign was conducted at the same four positions within the affected bedroom to verify the effectiveness of the intervention. The updated results, presented in Tab. 5, confirm that vibration levels at all measurement points now fall below the legal limit of 75 dB, ensuring compliance with current regulations.

These findings indicate that the applied mitigation measures successfully addressed the excessive vibration issue, restoring the acoustic performance of the space and minimizing potential discomfort for future occupants.

Figure 8. Removing the acoustic bridges before the final assessment.

Table 4. Vibration levels at different points in the critical bedroom.

Measurement Point	Background L_{aw} [dB]	Maximum L_{aw} [dB]
P1 Bedroom	46.2	76.4
P2 Bedroom	42.9	69.8
P3 Bedroom	43.9	72.1
P4 Bedroom	41.2	63.5

Table 5. Vibration levels at the critical bedroom after removing the acoustic bridges.

Measurement Point	Background L_{aw} [dB]	Maximum L_{aw} [dB]
P1 Bedroom	51.4	74.7
P2 Bedroom	46.5	69.1
P3 Bedroom	47.8	68.8
P4 Bedroom	45.0	63.2

4. GUIDANCE AND RECOMMENDATION

The successful implementation of a Box-in-Box (BiB) system for vibration mitigation requires careful planning, precise execution, and thorough quality control at every stage of construction. Based on the findings of this study, the following key recommendations should be considered for future projects involving BiB systems in vibration-sensitive environments:

- Isolation Efficiency at low frequency: While BiB systems are generally effective for high-frequency isolation, their performance at lower frequencies—such as those typically generated by railway traffic—can be highly sensitive to the flexibility of both the floating floor and the substructure, which exhibit multiple vibration modes within the 25-30 Hz range.

  In predicting isolation performance, it is essential to consider the mobility of both the base slab and the floating floor, as their dynamic interaction can lead to practical performance deviations from those predicted by a single-degree-of-freedom (SDOF) model. This effect can result in lower vibration reduction in spaces with larger spans compared to those with shorter spans, where structural flexibility of the structural floor plays a more significant role.

- Quality Control and Inspection During Construction: Proper execution is critical to achieving the expected vibration reduction. Special attention should be given to junctions between walls, floors, and ceilings to prevent rigid connections that could bypass the isolation system.

  Frequent inspections should be conducted at key milestones, such as after the installation of the floating floor and before closing walls, to identify and rectify potential acoustic bridges before they compromise system performance.

- Effective Communication Between Architects and Contractors: Successful BiB implementation requires clear coordination and communication between the architects, acousticians, and contractors throughout the project. The architect should provide detailed construction drawings and specifications highlighting vibration isolation requirements, verified by acoustical consultant of the project. The Contractor must be fully informed of BiB system sensitivities, especially regarding structural decoupling and the avoidance of rigid connections. Regular coordination meetings should be held to review and address potential challenges, and ensure compliance with the intended design.

5. REFERENCES

[1] J. P. Talbot, "Base Isolation of buildings for control of ground-borne vibration," *Handbook of Noise and Vibration Control*, John Wiley & Sons, Hoboken, p. 1470-1478, 2007.

[2] ISO 2631-2:2003 "Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration. Part 2: Vibration in buildings (1 Hz to 80 Hz)".