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In-situ investigation of building base isolation performance: construction details and bridging elements

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ABSTRACT

This paper describes the experimental evaluation of the performance of an isolation system installed in a building constructed near a light train line in Madrid (ES). The building has been isolated using pre-compressed spring boxes installed on the column heads. In addition, the stairs and side walls have been decoupled from the non-isolated part using springs and strip elastomers. During construction, a set of inspections has been performed on the static deflection of each spring box and the quality of the structural joints (between isolated and non-isolated parts). When the construction was finished, again, the spring box deflections and the joints have been controlled. Furthermore, a measurement campaign was undertaken to evaluate the performance of the isolation system by means of hammer impacts and train induced vibrations. Although, the static deflection of spring boxes confirmed the acoustic design parameters, the isolation efficiency obtained by in-situ measurement revealed bridging between the non-isolated and isolated part of the building. The measurement results clearly showed that the fire protection panels installed around each spring box have resulted in an acoustic bridge between the top and bottom part of isolation system. Other rigid points have been found in the staircase cores where the side walls have been rigidly connected to the isolated floors.

Keywords: Building base isolation, acoustic bridging, structure-borne noise
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1. INTRODUCTION AND THE STATE-OF-THE-ART

Building Base Isolation (BBI) is today a well-known technique to control structural borne noise in buildings generated by external vibration sources, mainly railway induced vibration.

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Since the first known application in 1964 [1], where the Royal Conservatory in Antwerpen was decoupled from its surroundings by so called resilient “elephant feet” bearings (Figure 1), the technology has evolved dramatically. Several authors [2, 3] have provided an overview of the different evolutive steps over the last decades and latest state-of-the-art. In recent years, new calculation models, hardware solutions and improved measurement techniques in Building Base Isolation (BBI) have been implemented in the frame of European and National research programs such as DIAVIBAT [4], MOTIV [5] and recently, BIOVIB [6].

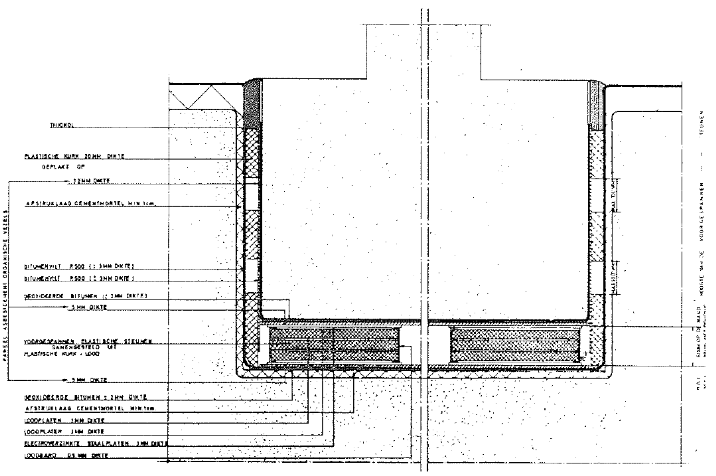


Figure 1: Sketch of the base isolation system "elephant-feet” in the Royal Conservatory in Antwerpen.

Today building design teams, confronted with the building in vicinity of railway traffic (underground or on the surface) and more stringent acoustic comfort requirements, will consider BBI as a reliable solution to control the transmission of ground-borne vibration in the building.

Prediction of real performance of BBI systems has been the subject of several research projects in recent years, [6–8]. In principal, the performance of an isolated building is defined in terms of the resonance frequency of a SDOF system of a rigid mass on a spring in which the rigid mass represents the building mass and the spring refers to the dynamic stiffness of the isolation bearing. However, in practice, this simple SDOF model is too far from the real dynamic behavior of the building with its flexible substructures. In fact, the total building mass above the vibration cut is not fully participating in the vibration transmission mechanism and the resonance frequency of the system could be even higher than the one predicted by a simple SDOF model. The effect of participating building mass on the building performance has been experimentally studied for several isolated buildings by P. Carels, [2].

Furthermore, it has been shown that the real insertion gain is influenced not only by the dynamic characteristics of the isolation bearings, but also by the mobilities of the dynamic soil-foundation system as well as the mobility of the super-structure including the vibration transmission within the building and the flexibility of structure members, [8]. In the frame of BIOVIB project, “Building Insulation against Outdoor Vibrations”, considering the aforementioned effects, a new isolation performance indicator has been introduced [6]. Based on Power Flow Insertion Gain (PFIG) [7], this new indicator has been defined in terms of the transmission loss “TL” (can be

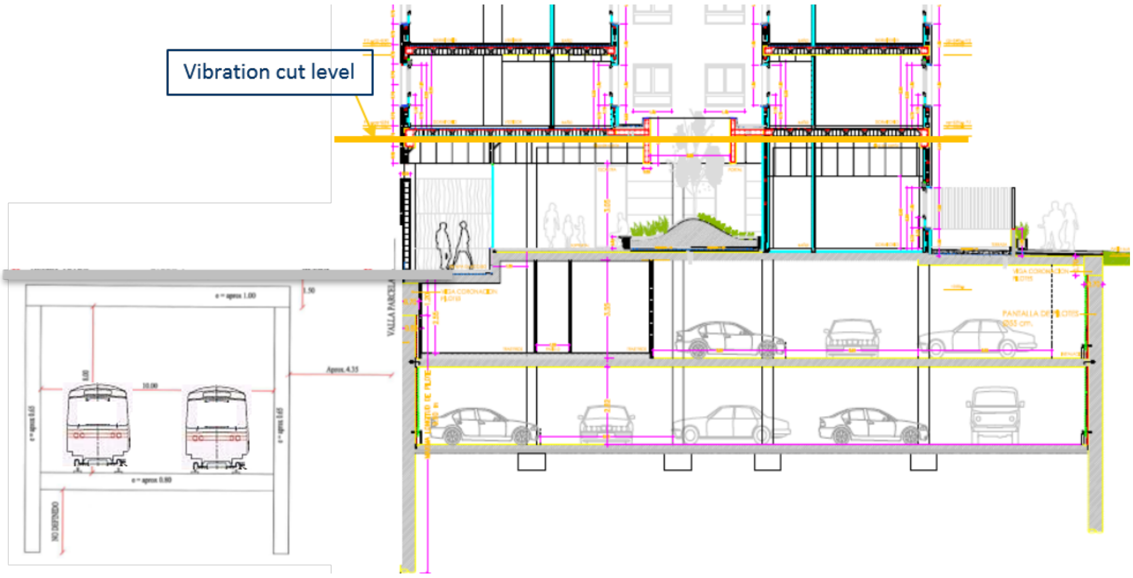


Figure 2: The section of the building and metro tunnel.

measured in an isolated building) and the sub-structure “Y_f “(soil-foundation) and the super-structure (the structure above the vibration cut) “Y_b” mobilities :

$$\text{Indicator}[\text{dB}] = \text{TL}[\text{dB}] + 20\log_{10}\left(\frac{\|Y_f\| + \|Y_b\|}{\|Y_b\|}\right) \tag{1}$$

In the above expression, the first term (TL) implies on the resonance frequency of the system and is mostly influenced by the dynamic stiffness of the isolation bearing and the participating mass. The second term $(20\log_{10}(\|Y_f\| + \|Y_b\|)/\|Y_b\|)$ acts as a modification factor and shows the effect of soil-structure interaction as well as the resonance frequencies of super-structure members.

Figure 3: BBI project in Madrid using pre-compressed spring boxes type CDM-CHR-Box installed on top of the concrete column.

Although selecting a relevant isolation bearing is important to meet the isolation requirements of a BBI project, one of major risks on the performance of the building would be due to the acoustic bridge connections between the isolated and non-isolated part. Therefore, a major attention must be paid during the construction to prevent any rigid connection or acoustic bridge at the vibration cut.

In this work, the performance of a BBI project in Madrid (ES) has been discussed and the risk of isolation bridging from the staircases, the facade and wall connections, and the fire protection will be examined by means of an in-situ measurement.

2. PROJECT DESCRIPTION

The building is located close to a metro line where regional RENFE trains pass in a tunnel at about 8 m in depth at a few meters from the front side of the building (Figure 2). After an extensive vibration measurement campaign and vibro-acoustic analysis, to meet the acoustic requirements of the project, an isolation system with pre-compressed spring boxes type CDM-CHR-Box was designed with a stiffness and load bearing capacity to cope with 3.5 Hz resonance frequency under 100% active acoustic design load (ADL). The spring boxes were installed on the column heads of the first floor.

(a) (b)

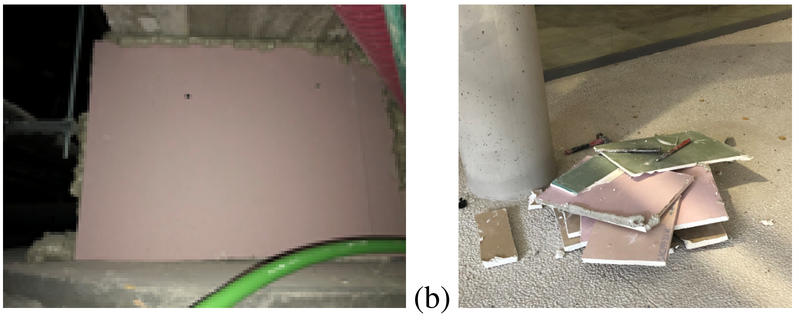
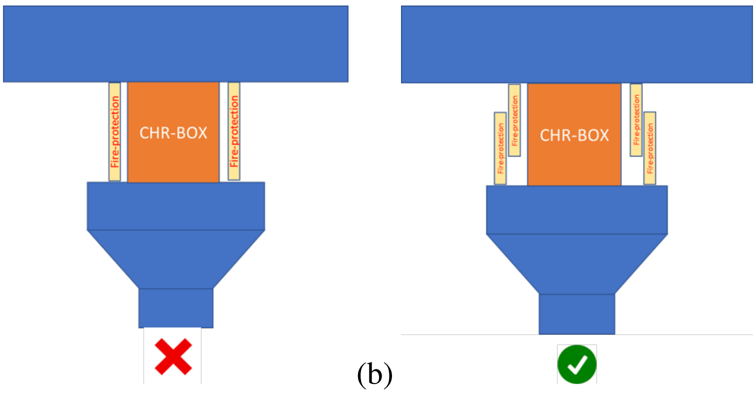


Figure 4: (a) CHR-BOX covered by fire protection boards and (b) samples of the MEGAPLAC boards after removing from the spring box.



(a) (b)

Figure 5: The fire protection of the spring boxes on top of the column (a) the incorrect way and (b) the correct way.

In addition, the stairs and side walls have been decoupled from the non-isolated part using springs and strip elastomers. During the construction, a set of inspections has been performed on the quality of the structural joints (between isolated and non-isolated parts). In addition, the static deflection of each spring box during the construction as well as at the end of the construction were measured. Results show agreement between the spring box deflections predicted at the design phase and those measured at the end of construction that confirms the load distribution as predicted in the design phase.

Figure 6: The acoustic bridging at the staircase and side walls.

Figure 7: Some examples of the acoustic bridging in the facade and the walls between the isolated and non-isolated floors.

Since the static and dynamic stiffness of a spring are the same, the same dynamic behavior as predicated in design phase, was expected. However, the results of the measurements inside the building show higher structural borne-noise level compared to that was predicted in the design phase.

During the site visit after the completion of the construction, it was found that the fire protection boards (2× MEGAPLAC PPF 25 mm) have been rigidly installed whole around of each spring box, Figure 4. Unfortunately, the way the fire protection boards have been installed, has resulted in an acoustic bridge between the isolated and non-isolated part of the building. In a correct way, we should avoid to rigidly contact the isolation part. Figure 5 displays the correct way for the installation of fire protection boards around an isolation bearings such as the spring boxes.

Figure 8: The measurement setup to asses the influence of the fire protection boards on the vibration transmission.

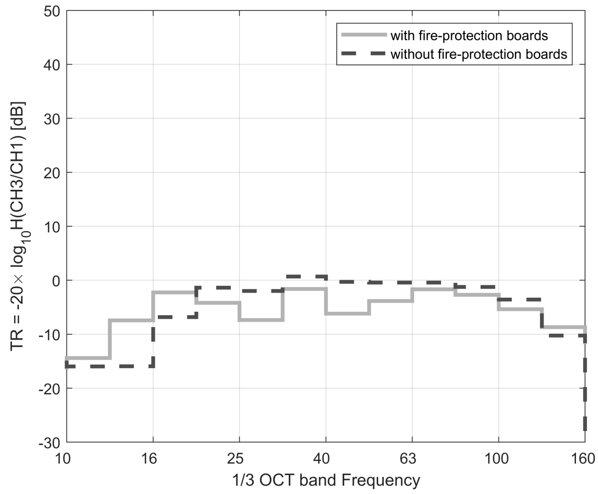
In addition, the site visit during the construction has revealed other acoustic bridging points in the staircases. As mentioned above, the staircase which is extending from the basement level (non-isolated part) through the upper floors above the vibration cut has been also isolated by means of springs. Figure 6 shows some evidence of the rigid connections between the isolated and non-isolated parts around the staircase.

Some more examples of acoustic bridging have been found in this building in the facade and the walls between the isolated and non-isolated floors, Figure 7.

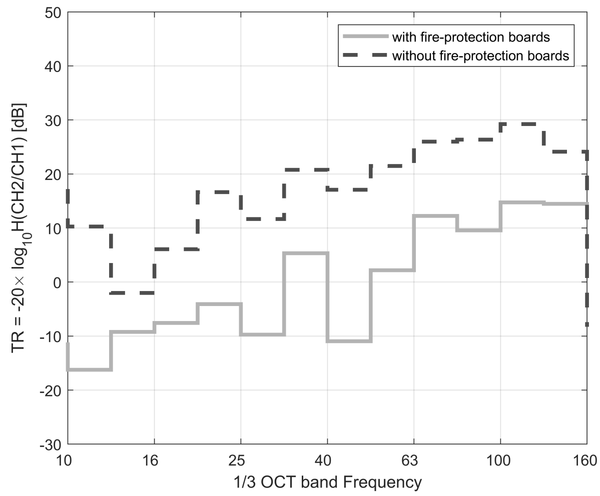
To show how these acoustic bridging points may influence the performance of the building, an in-situ measurement campaign was undertaken by means of hammer impacts.

3. MEASUREMENT CONFIGURATIONS

The first measurement setup (Figure 8) examined the effect of fire-protection boards. The measurement has been performed for two cases: (1) the spring box was covered by the fire protection boards and (2) after removing the fire protection boards. In both cases, a point on the slab at level 0 and close to the column was excited by a heavy hammer and the vibration level were measured at the reference slab at level 0 (CH1) , the column head below the vibration cut (CH3), and the slab (level +1) just above the vibration cut (CH2) by three accelerators (with the sensitivity of 1 v/g).



(a)



(b)

Figure 9: Spectrum of transfer function between the reference point on the floor slab and (a) the measurement point at the column head below vibration cut, (b) the measurement point above the vibration cut obtained in both cases: with fire protection boards (solid line) and after removing the fire protection boards (dashed line).

Figures 9 displays the vibration level at different points in the setup 1. Results were presented in terms of transfer function in one-third Octave band frequency between the reference measurement point (CH1) close to excitation point and the measurement points CH2 and CH3 above and below the spring box (the vibration cut). It can be seen that the transmissibility between two measurement points on top and bottom of the column (both in non-isolated zone), as expected, is almost zero. However, a significant improvement (almost 10 dB) was obtained after being removed the rigid fire protection boards.

Figure 10: The measurement setup in staircase to asses the influence of rigid connection points in staircase on the vibration transmission.

The second measurement has been performed in the staircase. Note that in this project, the staircase has been decoupled from the floor level 0 using a set of springs under the first steps as well as under the first stair landing. Figure 10 shows the measurement setup in which the vibration level were measured at three measurement points: on the floor slab (CH1) in non-isolated zone, on the first step , and on the first stair landing.

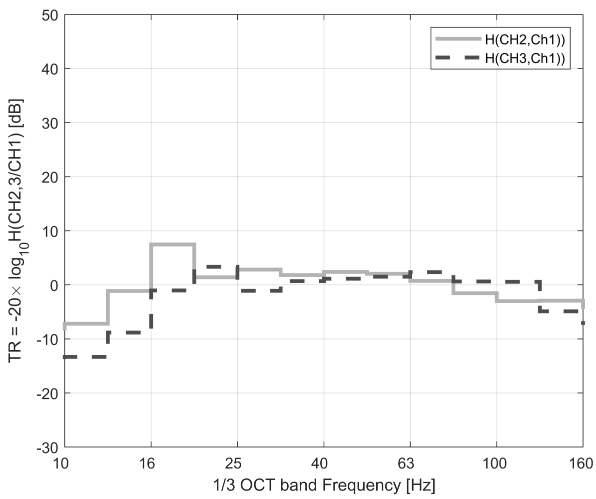


Figure 11: Spectrum of transfer function between the reference point on the floor slab and those located above the vibration cut at the first step (solid line) and at the first stair landing (dashed line).

Figure 11 displays the transfer function in one-third octave band frequency between the reference point on the floor slab and those located above the vibration cut at the first step and at the first stair landing. A transmissibility of almost zero obtained at both points confirms the rigid connections shown in Figure 6.

4. CONCLUSIONS

An experimental investigation has been carried out to show the influence of acoustic bridging in an isolated building. The study has been performed in a building close to a metro line in Madrid (ES). The main focus was on the acoustic bridge connection between the isolated and non-isolated part. Results of the in-situ measurements display that despite of selecting a relevant isolation bearing to overcome the ground-borne vibrations, one of major risk on the performance of the building would be due to the acoustic bridge connection between the isolated and non-isolated part.

The measurement results clearly showed that by removing the fire protection panels installed around each spring box, a significant improvement can be obtained on the acoustic performance of the isolation system. Other rigid points have been also found in the staircase cores where the side walls have been rigidly connected to the isolated floors.

The conclusions of this study have been sent to the client to remove the rigid connections, and to modify the fire protection details around the spring boxes.

5. ACKNOWLEDGMENTS

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