



# Novel prototype testing methods for shock impacts to vibration sensitive locations

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**Abstract** - As medical and scientific equipment grows more precise, so too does its need for vibration isolation. A specific project provided a case for providing vibration isolation to vibration impacts associated with a loading dock activity to sensitive laboratories located on upper floors. This paper presents testing results from prototype slab impact testing undertaken onsite to assess various methods of vibration isolation and their effects on vibration propagation throughout a structure. The testing focused on shock impact tests from the dropping of heavy masses onto the prototype slab. By utilising a prototype slab the response with different forms of mitigation could be measured and assessed to project specific criteria that adopted VC curves.

## 1 INTRODUCTION

As densification grows increasingly more pertinent throughout modern and developing nations, the choice of a suitability appropriate site for vibration sensitive spaces becomes harder as time passes. Densification has brought buildings in closer proximity to more sources of vibration such as public transport systems both at ground level and underground. Scientific and education are becoming more prominent in such locations. These sites, to be profitable, will have to be located highly centrally to allow for both talent retention and industry collaboration, further increasing the proximity to modern public transport systems.

Further to the challenges of transport sources of vibration, large-scale high-rise buildings will also have to consider geotechnical, traffic, wind and many other factors that contribute to the vibration response of the building.

The project site analysed in this paper, was to provide a facility that included a loading dock which had operational functional requirements that introduced sources of vibration. These activities included truck movements, goods handling equipment (walkie stacker), the potential movement of chemical Intermediate Bulk Containers [IBC] (with a maximum load of 1580kg) as well as movement of goods of general goods and waste for the typical operations. The loading dock had three separate areas, the upper level for goods in, the traversing ramp section for vehicle movement and the lower dock for goods and waste out.

## 2 AIM

The aim of this research paper provides a summary of testing undertaken on a prototype concrete slab to provide prediction to the effectiveness of vibration isolation selection in relation to the vibrational response of the structure. This paper aims to provide a summary of the assessments undertaken on a smaller scale prototype of an isolated acoustic slab. A unique feature of this testing was the ability to change the type of isolation in the slab. The results of the tests were to be used to inform further design and final selections of the proposed isolation system for the Loading Dock.

## 3 CRITERIA

The Vibration Curves (VC) were introduced by Gordon in 1991 in his publication by SPIE (Gordon, 1991) and by IEST in 1993 (IEST, 1993) and adopted in ASHRAE as widely accepted criteria for design of facilities accommodating vibration sensitive equipment (ASHRAE, 2023). The ASHRAE curves include workshop, office, residential, operating room and VC curves for sensitive equipment.

VC-A is often used for Research Laboratories and is adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity and projection aligners, etc. The project included vibration sensitive spaces located two floors above a loading dock. The client has provided a project specific requirement for the vibration response of the slab to be no greater than VC-A at any point of the slab in sensitive spaces located on levels two to level ten.

Furthermore, due to office spaces being located on the same level as the loading dock, the 'Office' VC curve was required for compliance, meaning no greater than 400µm/s vibration was allowed to be observed on the ground floor at the office locations.

#### 4 PROTOTYPE DESIGN

The prototype acoustic floor consisted of twelve (12) cast in Mason Type FS jack up floor housings at a nominal 1220mm x 1220mm spacing as shown in Figure 4.1. The cast in housings were customisable to allow for springs (shown Figure 4.1) or natural rubber bearings (shown Figure 4.2) to support the acoustic slab. This allowed for the ability to change the type of isolation in the testing procedure. The design allowed for the ability to install additional dampers if required. The airspace between the structural slab and the acoustic floor could be adjusted up to 100mm. However due to design constraints limited this to 50mm.

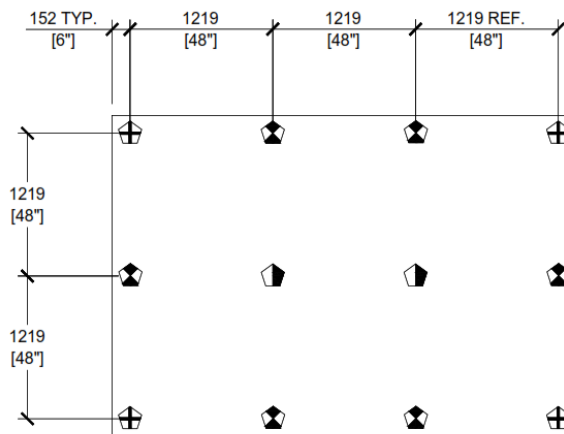


Figure 4.1 - Prototype Floor Layout

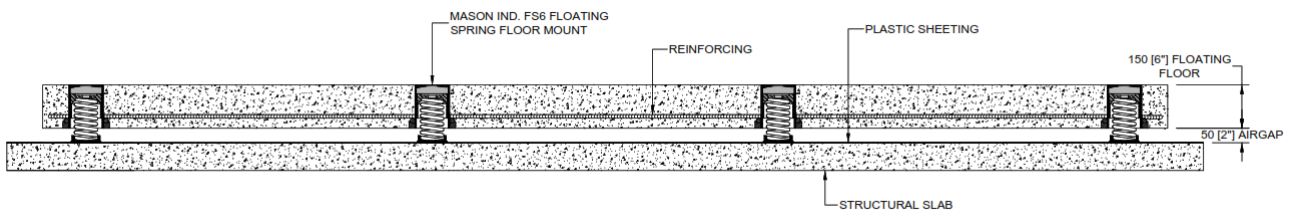


Figure 4.2 - Prototype Floor Layout Section – Springs

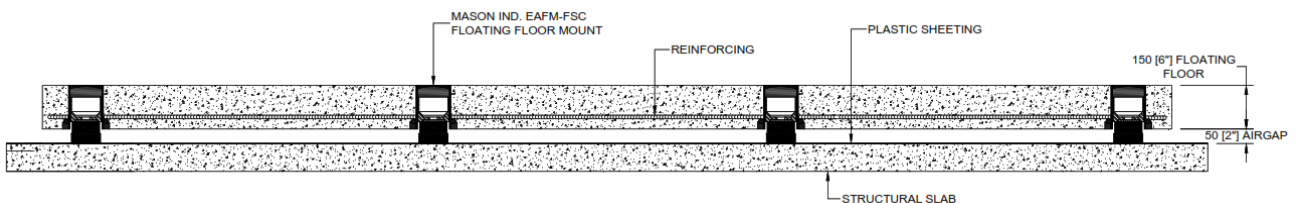


Figure 4.3 – Prototype Floor Layout Section – Natural Rubber Bearings

### 5 VIBRATION ISOLATION SELECTION

Given the design constraints of the acoustic floor buildup, helical springs would provide the highest levels of isolation for isolation of shock. In areas where the structural slab spans were considerably lower and activities less, the client looked to investigate a lower performance isolation system. Options for Natural Rubber bearings were included in the prototype floor. The four key types of isolation system investigated included:

- Low deflection rubber mount
- High deflection rubber mount
- 25mm deflection restrained steel housed spring
- 50mm deflection restrained steel housed spring

Selection of spring and natural rubber bearing type was adjusted to allow for the reduced test floor area and adjusted dead load and live load so the isolator deflection could be matched for the full-scale floor installation.

### 6 TESTING METHODOLOGY

The testing installed an array of accelerometers to provide data analysis of vibration propagation in line with the above aims. The locations where the vibration levels were tested were as follows;

- Position M1: An accelerometer located on the Prototype slab. This was measuring only in Z axis direction (vertical movement). The location was approximately 300mm from the drop zone of the IBC.
- Position M2: A triaxial accelerometer located approximately 1m from the Prototype slab on the Primary Structural Slab on Ground Floor. Triaxial accelerometer measured acceleration in three axis (X and Y axis – horizontal and Z axis – vertical). This location was reasonably representative of mid-span position between structural beams.
- Position M3: A triaxial accelerometer located approximately 1m from the nearest column on the Primary Structural Slab on ground floor.
- Position M4: A triaxial accelerometer located approximately mid-span on level 2 directly above the Prototype test location.

The proposed locations are indicated on Figure 6.1.

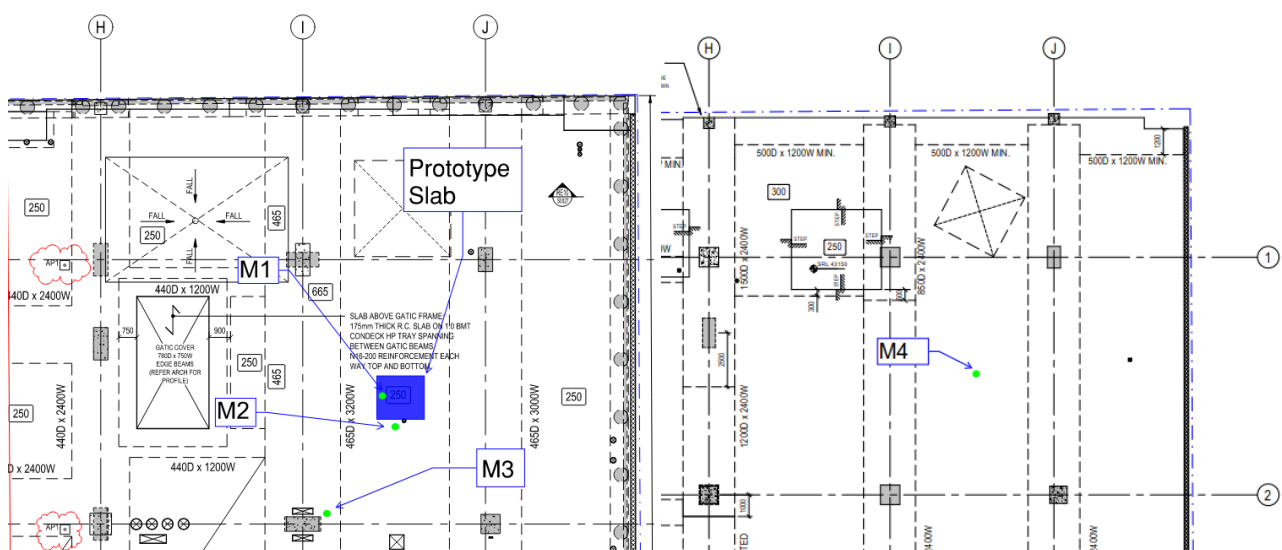


Figure 6.1 – Measurement locations on the ground floor (left) Measurement locations on the 2<sup>nd</sup> floor (right).

The shock loading tests of the fully laden IBC measured the vibration from the following scenarios;

1. The acoustic slab with a 50mm static deflection spring isolation. No damper present.
2. The acoustic slab with a 50mm static deflection spring isolation and dampers.
3. The acoustic slab with a 25mm static deflection spring isolation and dampers.
4. The acoustic slab with a 25mm static deflection spring isolation. No damper present.
5. The acoustic slab with a high deflection rubber mount isolation.
6. The acoustic slab with a low deflection rubber mount isolation.
7. The acoustic slab located on top of the structural slab.

The IBC was filled with water and additional mass provided to ensure that the load met the understood design load of 1580kg.

The IBC was located on a wooden pallet and lifted using a forklift. The height at the time was measured to be approximately 50mm from the top of the prototype slab as shown in Figure 6.2. The forks would then be released to provide a controlled free release drop on to the Prototype slab. The forklift would pick up the IBC after the movement of the prototype slab had settled (approximately 30s after each drop). The process was then repeated 5-7 times per testing scenario.

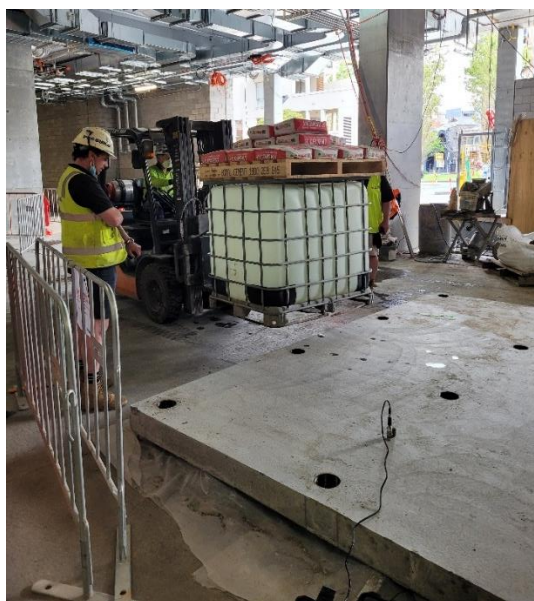


Figure 6.2 – Prototype slab used during testing with Wilcoxon 799M fixed to slab

At the time of testing no construction works on the site were being conducted.

## 7 EQUIPMENT DETAILS

Vibration levels were measured using the equipment detailed in Table 1, using tri-axial vibration analysers with high sensor sensitivity (noise floor less than  $2 \mu\text{m/s}$ ), capable of measuring levels at 1 Hz and above. At each measurement location, vibration levels for the overall broadband and 1/3 octave-band data were logged at one-second intervals at each location.

The Wilcoxon accelerometer was mounted to a steel bracket base plate that was securely bonded by a structural epoxy resin. All triaxial accelerometers were fixed to the primary structure via beeswax.

*Table 1 - Table Heading example positioned above the table and in italics*

Equipment	Make	Model	Serial Number	Accelerometers	Position
Vibration transducer	Wilcoxon	799M	16599	Single channel (Vertical direction)	M1
Vibration analyser	SVAN	958A	36693	Triaxial	M2
Vibration analyser	SVAN	958A	45591	Triaxial	M3
Vibration analyser	SVAN	958A	45586	Triaxial	M4

### 8 PROTOTYPE TESTING RESULTS

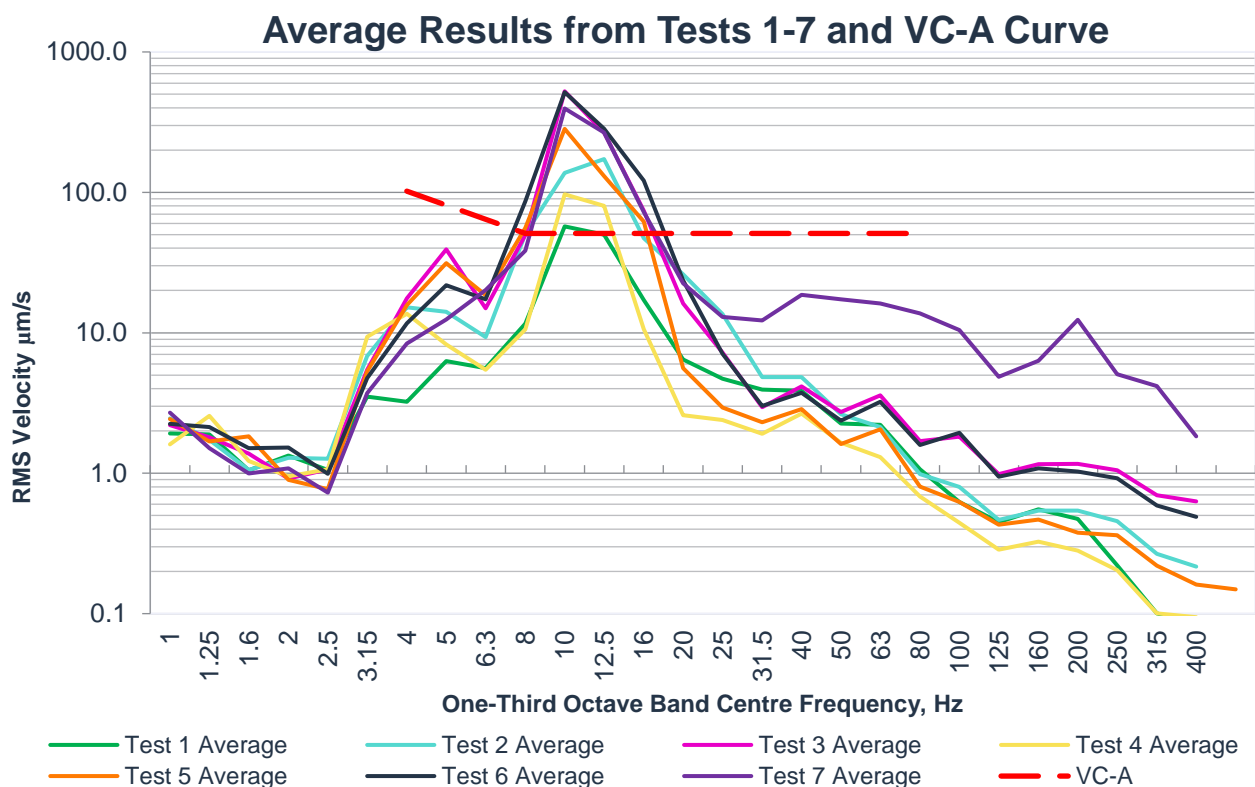


Figure 8.1 – Average test results from all Vibration Isolation situations

### 9 FINDINGS

All vibration mitigation methods did provide some reduction in response from the slab in comparison with the unmitigated scenario, but all had different levels of effectiveness. Both rubber mount solutions provided minimal impact control with the High-Density providing greater mitigation. In both spring cases, the spring without the damper provided greater control than their alternative with the damper, which is hypothesised to have been due to such a large weight being placed on the slab, that the damper was compressed to a point of rigidity, which then coupled the slab with the structure increasing the vibrational response throughout the slab. And finally, the larger spring had a greater vertical deflection allowing for greater reduction of excitation throughout the slab and thus the 50mm spring was selected as it was in general compliance with VC-A.

### 10 IMPLEMENTATION

The upper loading dock area where the prototype slab was tested utilised a 50mm spring system. The lower loading dock structural floor slab provided a stiffer substrate for the floating slab and subsequent to a vibration analysis it was determined that a rubber bearing system could be adopted to achieve project criteria.

The springs and Natural Rubber bearings were installed as shown in Figure 10.1, 10.2, 10.3 and 10.4.

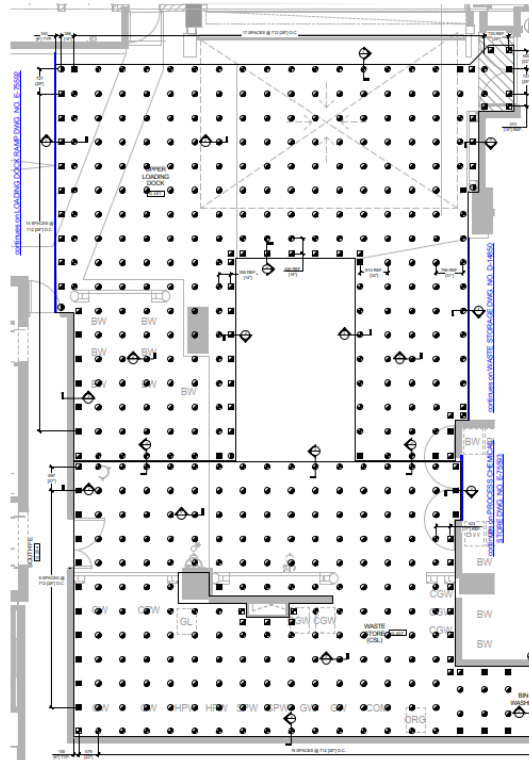


Figure 10.1 – Spring layout of Jack up Floating Floor

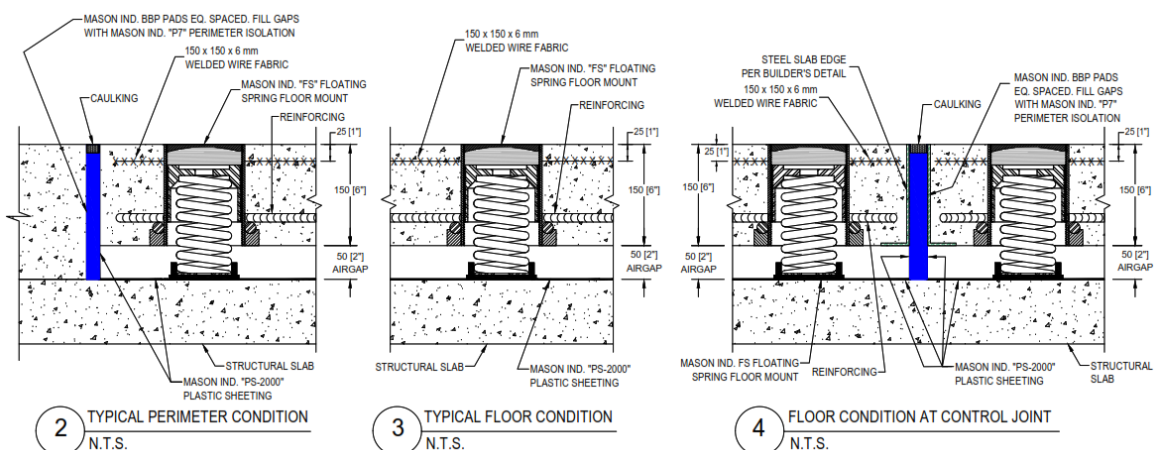


Figure 10.2 – Spring section specification

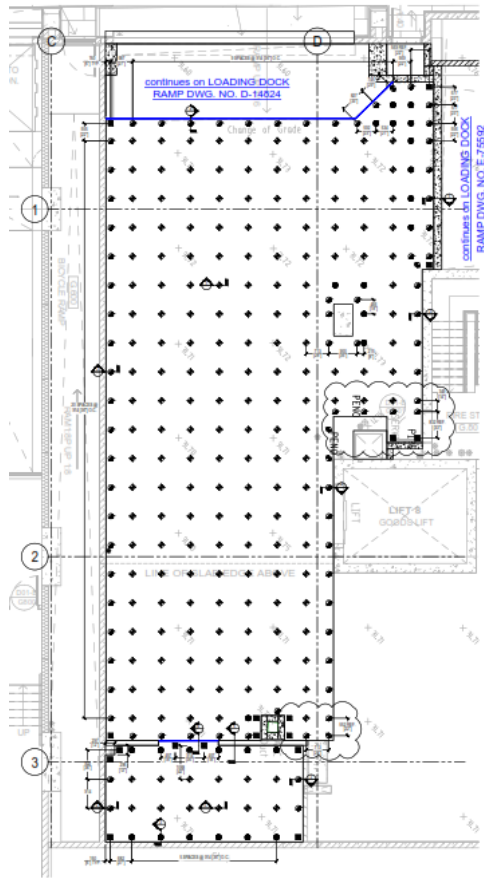


Figure 10.3 – Natural Rubber Bearing layout of Jack up Floating Floor

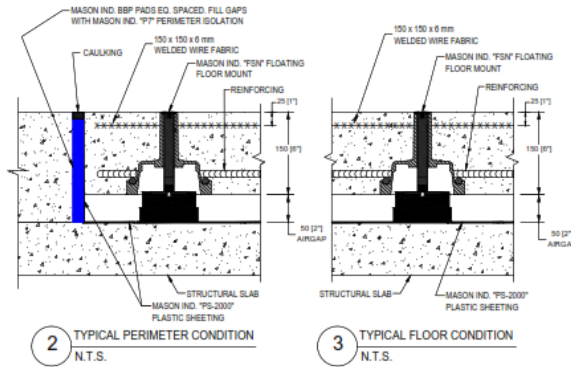


Figure 10.4 – Natural Rubber section specification

The primary difference between the prototype slab and the final design was mass of the ground floor slab as a forklift was used during prototype testing, this would have increased the stiffness of the slab resulting in marginally greater vibration mitigation.

The other notable difference between the final installed design and the Prototype was that the testing conditions meant there was no potential bridging of the acoustic slab and the primary structure from the forklift or walkie stacker dropping the load.

## 11 POST CONSTRUCTION VALIDATION MEASUREMENTS

Once construction had been completed post construction measurements were required to assess VC-A compliance in the nominated spaces. Testing methods from the initial prototype tests were replicated on the finished structure, utilising a walkie-stacker loaded with 1580kg to be dropped at the same height of 50mm. Vibration measurements were taken in the midspan of nearest VC-A sensitive space two floors above the loading dock. Results from the post construction testing is shown below in Figure 11.1.

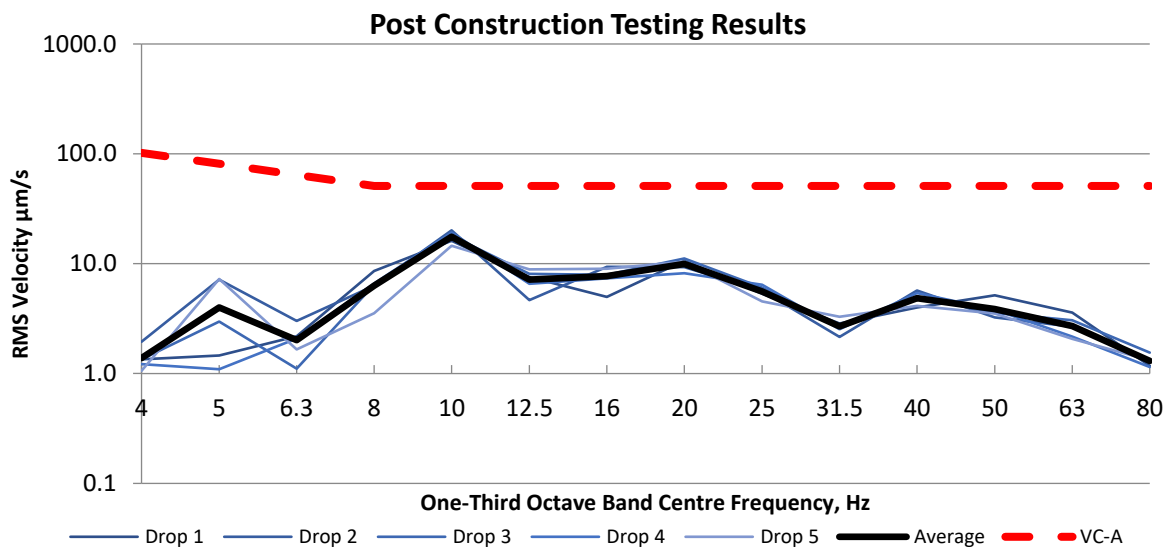


Figure 11.1 – Post Construction Testing Results

As shown through the figures the response of the slab remained consistent between the prototype and the final testing with resonance occurring depending on measured location between 10-12Hz frequency band. Due to the prototype testing a VC-A compliant result was achieved.

## 12 CONCLUSION

The results indicate that the closest system to compliance with the VC-A criteria for the IBC shock impact was the 50mm static deflection spring system with no damper. This test scenario had three impacts that provided vibration levels within the VC-A requirements and three impacts that resulted in exceedance over the VC-A requirement.

Test scenario 4 with the 25mm static deflection spring was the only system to provide a result for one impact drop that resulted in vibration levels below the VC-A requirements.

All other scenarios exceeded the VC-A requirement on level two. In general, the spring systems provided the greatest level of vibration mitigation to the shock impact load of the IBC drop. The low deflection rubber mount is providing minimal improvement to mitigation in comparison with the baseline at the fundamental natural frequency.

Post construction testing confirmed the initial compliant results displayed from the prototype testing for both VC-A and 400µm/s criteria.

## 13 REFERENCES

ASHRAE. (2023). ASHRAE Handbook—HVAC Applications. 49.1-49.58.

Gordon, C. G. (1991). Generic Criteria for Vibration-Sensitive Equipment. *SPIE Proceedings Volume 1619*.

IEST. (1993). Considerations in Cleanroom Design. *RR-CC012.1*.