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Gymnasium vibration isolation within a sensitive medical research building

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ABSTRACT

This paper presents the design, installation and outcomes of a bespoke weightlifting platform within a university-based Exercise Physiology Laboratory. The Exercise Physiology laboratory is located within a medical research building which houses vibration sensitive research functions including microscopes. The Exercise Physiology Laboratory has a requirement for elite level athletes to conduct heavy weightlifting movements including deadlifts and overhead presses. Weight placement on the floor without appropriate treatment demonstrated that adjacent spaces would be adversely impacted by these activities. A targeted vibration isolation platform was designed to mitigate these potential impacts.

1 INTRODUCTION

This paper describes the assessment, design and outcomes of a vibration isolation platform within a medical research building at the University of NSW (UNSW). Specifically, in relation to the potential structure-borne vibration levels from heavy weight drops on two weight lifting stations that were proposed to be located within a new Exercise Physiology facility within the building. The weight lifting stations (Olympic Platforms) include iron cages on which weight plates and bars are stored, and a raised weight drop platform in front of each cage. A combination of empirical, measurement based calculations and a numerical finite element model was used to predict structure-borne vibration levels. For context, the weight lifting platforms were located on Level 1 of a four storey building.

2 VIBRATION TARGETS

Structure-borne vibration targets were developed considering the adjacent sensitive uses within the building including teaching spaces on the level below and office areas and laboratory spaces housing vibration sensitive equipment such as microscopes and biological resources located on the levels above.

2.1 Human Comfort Targets

Table 1 presents the assessment criteria for continuous, intermittent and impulsive vibration at sensitive land uses from NSW EPA's Assessing Vibration: A Technical Guideline. The criteria are presented here as root-mean-square (rms) vibration levels for continuous and impulsive vibration, and a Vibration Dose Value (VDV) for intermittent vibration. The NSW Vibration Guideline specifies "Preferred" and "Maximum" vibration levels as shown in Table 1. The maximum values for impulsive vibration in critical working areas were adopted. It was noted that these values may not be achievable for all scenarios relating to the use of the weight lifting platforms considering the variety of weights and skill levels for users.

Table 1: NSW Vibration Guideline recommended vibration levels

(based on natural frequency of floors in question in the range of 10 Hz – 12 Hz)

Receiver	Continuous vibration: rms velocity, mm/s		Intermittent vibration: VDV, $m/s^{1.75}$		Impulsive vibration: rms velocity, mm/s	
	Preferred	Maximum	Preferred	Maximum	Preferred	Maximum
Critical working area such as operating theatres	0.07	0.14	0.1	0.2	0.07	0.14
Offices and schools	0.28	0.6	0.4	0.8	9.0	18.0

2.2 Bio-Resources Areas (Lower Ground and Level 3)

The *Code of Practice for the Housing and Care of Laboratory, Mice and Rats – Department of Primary Industries, Victoria, 2004* advises that "noise and vibration should be controlled in a bio-resources facility" but does not provide specific criteria for vibration levels. From previous experience, vibration targets were set at 100 to 200 µm/s (0.1 to 0.2 mm/s).

2.3 Sensitive Equipment (Level 3 and Level 4)

General vibration criteria (VC) curves (Gordon et al., 2005) are commonly used criteria for sensitive equipment. The VC criteria are defined as velocity spectra in one-third octave frequency bands, arriving at a 'curve' of allowable levels for each one-third octave band. VC criteria are described as curves, named alphabetically and sequentially from VC-A to VC-G in order of increasing sensitivity. In the absence of equipment specific criteria, the following values were adopted as targets for a mass spectrometer and optical microscope:

- VC-A (50 µm/s) as a maximum 1-second rms level in any one third octave band

3 VIBRATION MEASUREMENTS

3.1 Methodology

Vibration measurements were conducted on lower ground, ground level, Level 1, Level 2, Level 3 and Level 4 to measure the effects of variety of weight-drop activities occurring on ground level. The following tests were conducted:

- A weight of 55kg (consisting of two 20kg weight plates and a 15 kg bar) was lifted over-head and dropped onto a 50 mm thick rubber floor pad. This action was repeated while simultaneous vibration measurements were taken within the selected receiver locations within the building.
- A modal hammer was utilised to excite the Level 1 floor slab to determine its dynamic characteristics in combination with an accelerometer.

3.2 Measurement Results

The maximum measured 1 second rms vibration level in any one-third-octave band between 1 Hz and 80 Hz is provided in Table 2 together with a comparison of the established targets.

Table 2: Measurement results

Measurement Location	Measured Vibration Level (1 second rms µm/s highest in any 1/3 octave band)	Vibration Target (1 second rms µm/s highest in any 1/3 octave band)
Lower Ground Level Bio-resources	12.5	150
Lower Ground Level Lecture Theatre	12.5	140
Ground Level Teaching Room / Computer Room	97	140
Level 1 Exercise Physiology	800	140
Level 2 Offices / Open Plan	183	140
Level 3 Microscope Laboratory / Bio-resources	64	50
Level 4 Mass Spectrometer	30	50

A peak hold one third octave band spectrum for the Level 1 floor slab in response to an impact hammer excitation is presented in Figure 1. The following observations were made:

- The fundamental floor slab resonant frequencies were centred around 12.5 Hz.
- The floor response at 5 Hz and below was consistently very low.
- The damping ratio was determined using the log decrement method and was consistently in the range of 5-10% depending on location. The minimum damping ratio of 5% was assumed for the subsequent numerical analyses.

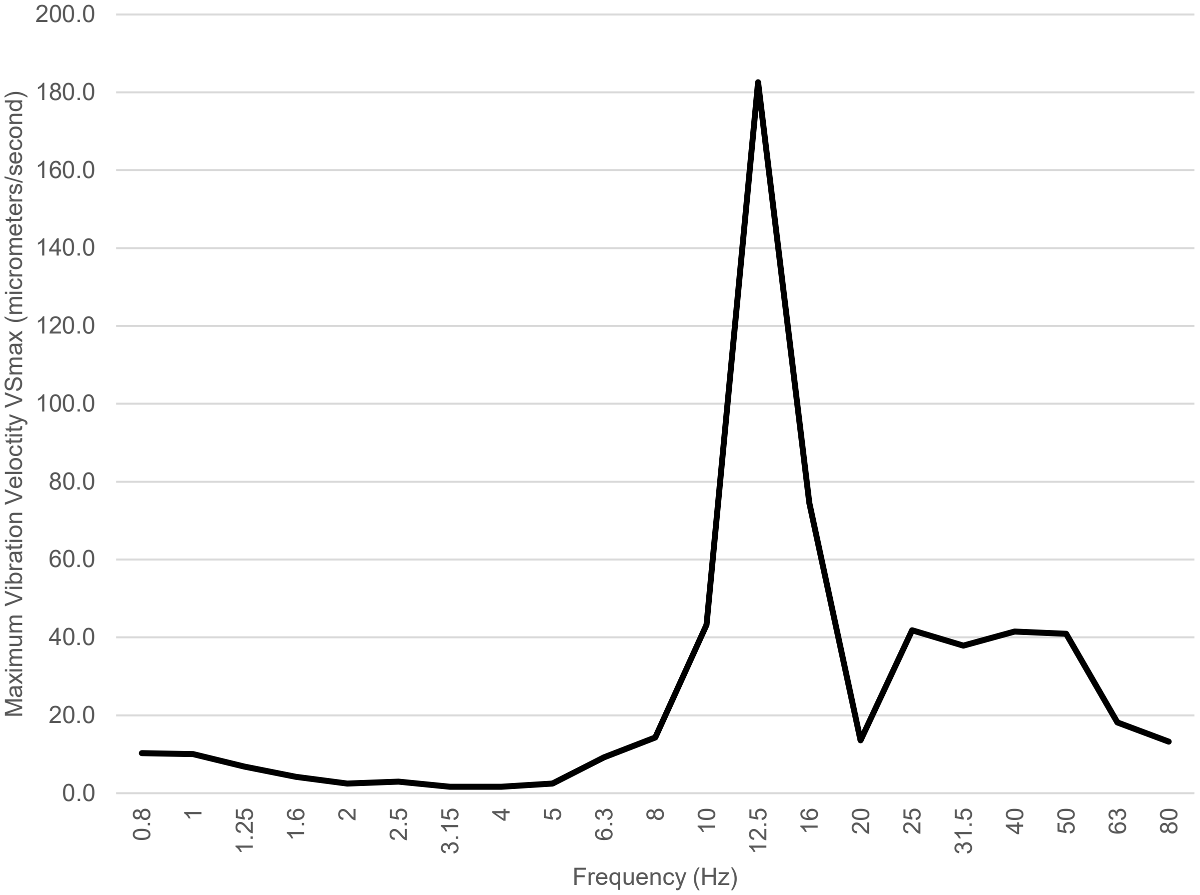

Figure 1: Measured floor slab fundamental frequency - 1/3 octave bands

3.2.1 Discussion

The baseline vibration measurement results demonstrated that the target vibration levels would be exceeded for activities associated with the use of the weight lifting platforms for activities such as deadlifts and overhead presses if additional structure-borne vibration control measures were not considered. For design purposes it was necessary to consider weight ranges for the critical activities as follows:

- Deadlift: 100 kg to 150 kg (dropped from knee height)
- Overhead press: 70 kg to 100 kg (dropped from overhead)

Increasing the thickness of a potential rubber floor covering would not provide sufficient additional attenuation. Therefore, an investigation into the potential benefits of a concrete floating floor covering the ‘impact zone’ in the weight-lifting area was conducted. The objective was to maximise the flexibility of the space whilst minimising potential impacts to adjacent spaces.

4 OLYMPIC PLATFORM FLOATING FLOOR DESIGN

The underlying structural floor had constraints with respect to load bearing capacity. As such the mass of the of the floating floor was limited by a maximum thickness of 200 mm within an area of 1500 mm by 4840 mm.

4.1 Finite Element Analysis

A beam and shell Finite Element (FE) model of the first floor of the building was developed on the basis of as-built structural drawings. An isolation frequency (natural frequency of floating concrete mass on springs) was set at 4.5 Hz. This was the frequency at which the structural floor did not have a notable response to impulsive vibration excitation and was also remote from footfall frequencies (in the range of 1.5 Hz to 3 Hz). In summary, it was necessary to set an isolation frequency that does not result in an unstable floor and that is as far removed from the structural floor natural frequencies as possible.

- It was determined that the upper bound of the natural frequency for the isolation system should not exceed 4.5 Hz under the following static loading condition:
- Dead load of floating concrete floor with dimensions (1500 mm x 4840 mm x 200 mm) with Olympic Platform and one person weighing approximately 70 kg.

4.1.1 Finite Element Methodology

The assumed material properties are described in Table 3.

Table 3: Material properties

Material	Young's Modulus (GPa)	Poisson's Ratio	Density (kg/m^3)
40 MPa Concrete (Concrete columns, walls and slabs)	34.5	0.2	2,400

4.1.2 Boundary conditions

All the base nodes of the supporting columns and walls were modelled as being fully constrained.

4.1.3 Damping

A structural damping value of 5% was assumed in the analyses and this aligned with the values measured on site. This is also in line with the lower bounds of the expected range for reinforced concrete structures.

4.1.4 Modal analysis and linear transient analysis

The natural frequency solver was used, in conjunction with the results from the on-site vibration measurements, to validate the FE model. The natural frequencies and mode shapes aligned with those measured on site. The predominant response across the floor plate occured at approximately 12.5 Hz. Furthermore, the response of the structural floor to a unit force aligned well with the values measured on site. An isometric view of the FE model geometry (including floating floor) is shown in Figure 2.

A linear transient analysis solver was used to predict the response of the Level 1 floor to an impulsive load. Two scenarios were modelled, one scenario included the existing building and the second scenario included the existing building with a floating floor as specified.

A comparison of the floor vibration levels for each scenario at a common assessment point was used to determine an insertion loss curve (frequency dependant vibration reduction factor). The predicted insertion loss curve is presented in Figure 3. Amplification was predicted at 4.5 Hz which is expected as this aligned with the proposed natural frequency of theisolation system. The insertion loss multiplier at 8 Hz and above is less than 1 which indicates the isolation system is predicted to reduce vibration levels at 8 Hz and above.

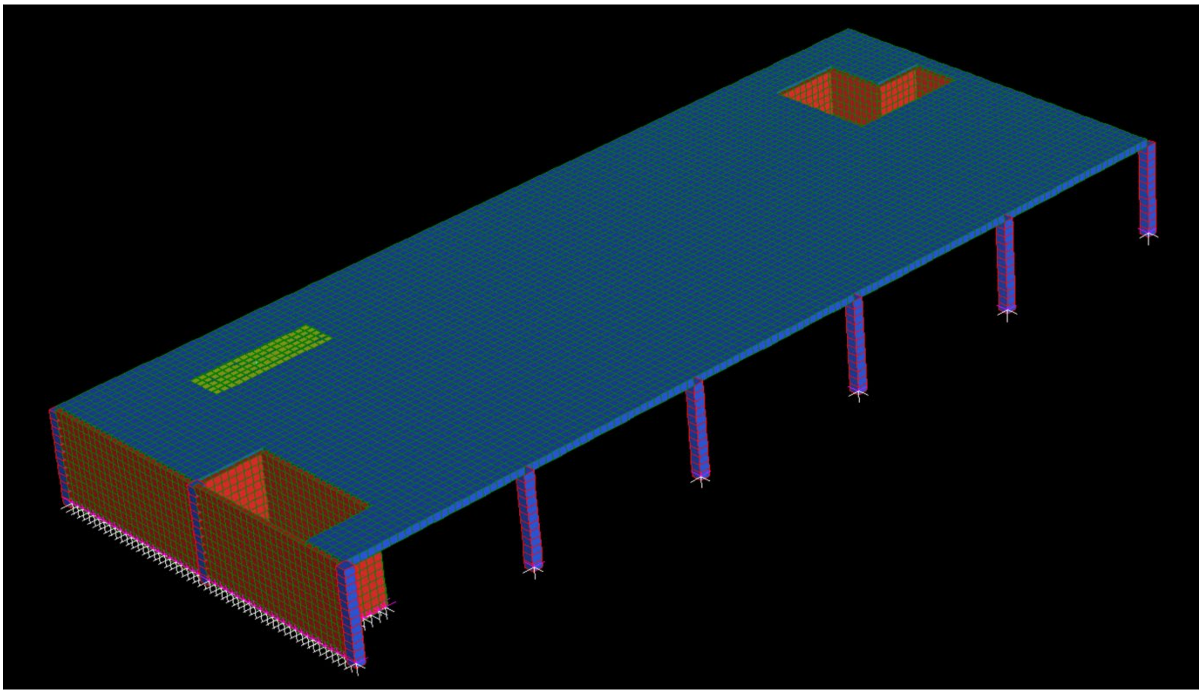

Figure 2: Finite element model geometry

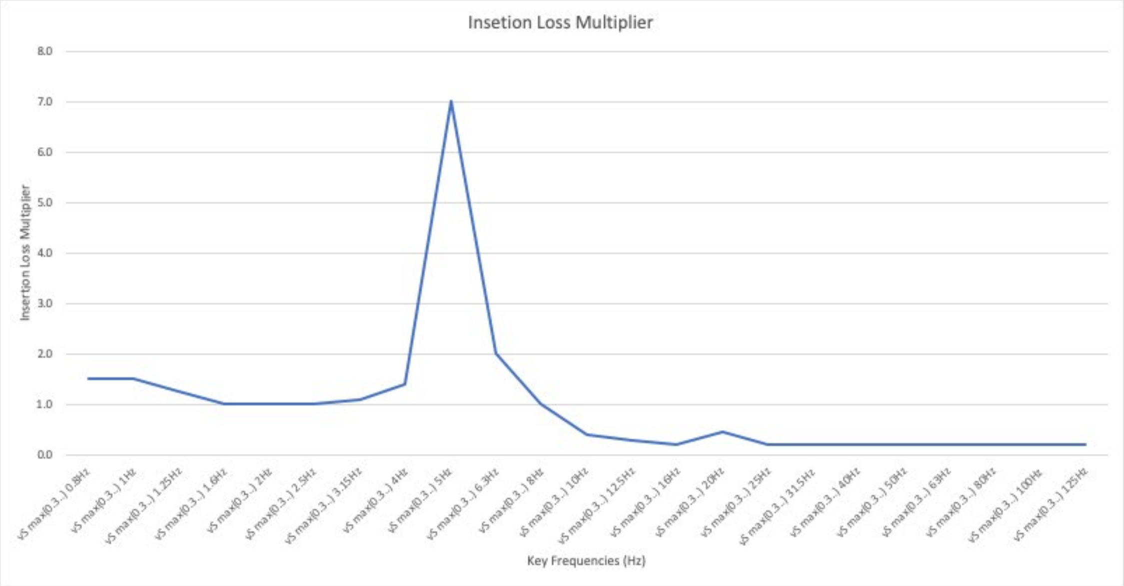

Figure 3: Predicted insertion loss curve

4.2 Predicted Vibration Levels

Predicted vibration levels incorporating the proposed floating floor are presented in Table 4. The predictions for the Olympic Platform include the predicted insertion loss of the floating floor and a factor for the design weight and drop heights as indicated. The Clean and Jerk activity sets the upper range of the predictions while the Deadlifts set the lower range of the predictions.

The predicted vibration levels demonstrated compliance with the proposed targets at all locations for the most conservative design scenarios with the exception of the Exercise Physiology space where potential exceedances were predicted. Under these circumstances operational controls was deemed to be an acceptable measure.

Table 4: Predicted noise and vibration levels

Activity	Room	Target	Prediction
		Vibration 1 second rms μm/s highest in any 1/3 octave band	Vibration 1 second rms μm/s highest in any 1/3 octave band
Clean and Jerk (100kg) at a height of 2.4m Deadlift (controlled, 150 kg) at a height of 1m	Lower Ground Level Bio-resources	150	12.5-7
	Lower Ground Level Lecture Theatre	140	17-30
	Ground Level Teaching Room/ Computer Room	140	60-88
	Level 1 Exercise Physiology	140	300-436
	Level 2 Offices/ Open Plan	140	68 - 100
	Level 3 Microscope Laboratory/ Bio-resources	50	24-34
	Level 4 Mass Spectrometer	50	17-30

5 POST INSTALLATION OUTCOMES

The isolated concrete lifting platform took the form of a 200 mm thick concrete slab sprung with an array of damped coil springs tuned to a natural frequency of 4.5 Hz. Lateral restraint was provided by a concrete hob surrounding the sprung slab, with elastomeric mounts providing a coupling between the slab and hob. A commissioning test was conducted as part of the construction process. The findings of the test were as follows:

- An impact test was conducted on the sprung concrete floor. The measured natural frequency varied between 4.5 Hz and 5 Hz depending on the additional static loads from weights and personnel. This aligned with the target natural frequency of 4.5 Hz.
- At the time of writing an extensive vibration measurement assessment has not been conducted. However a subjective test of performance was conducted. Floor vibration levels were not perceptible at a point approximately 3 m to 4 m from the sprung slab when a 55 kg overhead press was dropped onto the platform from above head height. BS6472-1992 indicates that 0.1 mm/s rms is an approximate threshold of perception for humans in the frequency range of interest. This is below the predicted level of 436 um/s, however it is noted that the design case considered a 100 kg overhead press which would result in higher levels.

6 CONCLUSIONS

This paper has presented the methodology, predictions and outcomes for a sprung concrete floor that was designed to control structure-borne vibration levels from heavy weight drops. A combination of empirical data relating to vibration transfer though the subject building and finite element modelling was used to predict the insertion loss performance of the system. The implementation of the sprung floor system allowed for acceptable levels of vibration in adjacent spaces to be achieved.

7 ACKNOWLEDGEMENTS

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