CASE STUDY: COMPARING MEASURED AND FINITE ELEMENT MODELLED FOOTFALL VIBRATION LEVELS IN A NEW RESEARCH BUILDING

Briét L. Coetzer. *[1], **Julia M. Graham.** †[2] **and Steve P. Meszaros.** ‡[1]
[1]Rowan Williams Davies & Irwin Inc, Vancouver, British Columbia, Canada.
[2]Rowan Williams Davies & Irwin Inc., Guelph, Ontario, Canada.

1 Introduction

Occupant footfalls are often the most critical source of floor vibration on the elevated floors of buildings. In research facilities employing high resolution electron microscopes, this issue can be critical. Vibration impacts on sensitive equipment are best addressed during the design stage, relying on prediction methodologies to determine the building's response to footfall vibration.

This paper presents a case study of the measured vs. predicted footfall vibration levels on elevated, bare concrete floors, prior to completion of the extension of the Brimacombe Building which is associated with the Stewart Blusson Quantum Materials Institute at the University of British Columbia (UBC). The facility requires a low vibration environment to support world-leading quantum materials research. The building is entirely concrete; the most vibration-sensitive equipment is housed in the basement which has been isolated from the surrounding soil by engineered sub-soils and a 50 mm thick layer of Regupol Vibration 450 isolation material [1]. Level 1 (L1) consists of a 450 mm slab supported on shear walls spaced at 6.4 m. Levels 2-4 (L2-L4) consist of a 350 mm thick slab with 6.4 m x 9.8 m bays.

2 Methodology

Both the prediction methodology and the measurement methodology used the following loading conditions:

- Walking at 108 steps per minute (slow) within same bay as measurement.
- Walking at 132 steps per minute (fast) within bay adjacent to measurement location.

Pedestrian weight was normalised in both cases to 746 N by multiplying the measured levels by 746 divided by the walker's weight. One test location on each of the four elevated levels (L1-L4) was measured.

2.1 Prediction methodology

The concrete centre (CCIP-016)

The CCIP-016 methodology predicts vertical vibration induced by pedestrians crossing structures such as floors and bridges. It uses a Finite Element (FE) approach based on principles of modal analysis, and is considered a robust approach for the assessment of any type of structure of any construction material [2].

The CCIP considers the resonant and impulsive response of a floor to footfall forces. The modal responses at the locations of the footfall force and the receiver point are used to determine the response of the floor, at any point, based on a footfall force applied at any point. The method uses modal superposition to determine the combined effect of many modes. The response can be determined in the time domain or converted to a frequency-domain format. In this paper the data has been processed using one-third octave frequency spectra. A damping ratio of 3% was chosen to suit the building design in accordance with Table A2 in CCIP-016.

2.2 Measurement methodology

Field measurements, using the same receiver and loading locations used for the CCIP predictions, were performed. Site conditions dictated that the receiver locations were slightly different between each floor with reference to the centre of the structural bay. The site was unoccupied during the measurements and construction was incomplete and varied by floor from inclusion of ducts and framing (L1) to no ducts or framing (L4). Construction equipment and building supplies loaded the floors. Three single-axis accelerometers were mounted on the bare concrete floor in a tri-axial configuration for each receiver location. Two subjects performed walking tests along a path not closer than 1.2 m from the sensors. The pedestrians were prompted to maintain a constant pace rate by a metronome.

3 Vibration criteria

The vibration criteria (VC) curves described by Amick et al [3] are expressed as the root mean square (RMS) values of each one-third octave band from 1 Hz to 80 Hz and range from VC-A (least stringent) to VC-G (most stringent). The target criteria for the UBC project was VC-C at L1 and VC-A at L2, L3, and L4.

4 Predicted vs. measured floor vibrations

The following metrics were compared between the CCIP-016 predictions and the field measurements:

- Natural Floor Resonance
- Damping Ratio
- Vibration Class – Fast Walking Speed
- Vibration Class – Slow Walking Speed

* Brizi.Coetzer@rwdi.com
† Julia.Graham@rwdi.com
‡ Steve.Meszaros@rwdi.com

4.1 Natural floor resonance and damping ratio

Natural floor resonance

The natural frequencies of the modelled floor were extracted from the FE model. The natural frequencies of the measured floors were determined by measuring the responses of the floors to a series of heel drop impulses at the receiver locations. These responses were converted to the frequency domain and the predominant response frequency was taken to be the natural frequency of the floor.

Damping ratio

The CCIP-016 predictions assumed a 3% damping ratio (fixed across all frequencies) on the basis of the site conditions described above. Actual damping ratios in the field are difficult to estimate accurately due to frequency-dependent and non-linear behaviour. However, they were estimated at the receiver locations by applying a bandpass filter to the measured heel drop responses at the predominant response frequency and fitting a logarithmic decrement curve to the data points. A comparison of the measured vs. predicted metrics are shown in Table 1 below.

Table 1: Measured vs. predicted floor properties

Level	Predicted		Measured	
	Frequency (Hz)	Damping Ratio(%)	Frequency (Hz)	*Damping Ratio(%)
L1	58.6	3.0	42	1.5
L2	10.9/19.2		11	2.8
L3	10.9/11.9		10.25/12	2.0
L4	9.8		8.5/11.25	4.7

* Damping ratio at measured natural frequency

Note: Although L2-L4 are structurally similar, the receiver locations varied by floor causing variation in the natural frequency and vibration levels.

4.2 Vibration class

The results of the CCIP-016 time series predictions as well as the measured vibration levels at each receiver location were spectrally analysed and plotted against the VC criterion. The measured data was analyzed using 1 s windows and the maximum response in each frequency band was returned. The resulting VC classes for each receiver location are presented for both walking speeds in Tables 2 and 3.

5 Discussion

The predicted results at L3 and the predicted slow results at L2 were accurate (within the same class).

At L1 the CCIP-016 method over-predicted the slow walking response and under-predicted the fast walking response. The exceedance of predicted results for the fast walking scenario could be partially explained by the very low levels of vibration on this floor which mean that the measured levels could easily be influenced by external vibration sources. Additionally, it is not unexpected that the CCIP-016 method had difficulty predicting the response in this location as it is unlikely the method has been validated for floors this stiff. The shear walls supporting this space were modelled as fixed connections and it is possible that more flexibility is present at these connections which could change the mode shapes and thus alter the results.

Table 2: Measured vs. predicted vibration class – Slow walking

Level	Predicted	Measured
L1	VC-C	VC-D
L2	VC-A	VC-A
L3	VC-B	VC-B
L4	VC-B	VC-A

Table 3: Measured vs. predicted vibration class – Fast walking

Level	Predicted	Measured
L1	VC-E	VC-D
L2	VC-B	VC-C
L3	VC-C	VC-C

Note: Fast walking test was not possible on L4 due to construction materials and equipment blocking the walkway.

At L2, the model predicted a natural frequency at 19.2 Hz which is what resulted in the maximum predicted result in the fast case. In the measured results, the 19.2 Hz mode was not dominant. This resulted in the model over-predicting the expected vibration.

At L4, the model under-predicted the vibration response. This is an unexpected and unusual outcome. This measurement was recorded closer to the support column than measurements L2 and L3, the structure was loaded significantly with construction materials, and the structure is the same on Levels 2-4; thus, it would be expected that the natural frequency would be lowered by the added mass but the proximity to the support column would provide a lower vibration level than those measured at L2 and L3. Without further measurements it is difficult to draw meaningful conclusions from this unexpected result.

6 Conclusion

The results of this study indicate that the CCIP methodology is robust and provides reasonable estimates of the floor vibration response. In all cases, the predicted and measured vibration levels meet the building design targets.

References

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