Noise and vibration assessment from a go-kart track inside a mall

Francisco Irarrazabal[1], Drew Gibson, Samuel Hord, Bethany Wu, Mike Dickerson, Thad Trubakoff, Jordan Trubakoff
MD Acoustics, LLC
170 S William Dillard Dr, Suite 105, Gilbert, AZ 85233

ABSTRACT

A proposed multi-level indoor go-kart track on the third floor of a commercial mall presented a risk of structure-borne vibration affecting a retail tenant below. Modal testing was performed on the existing floor slab to characterize its dynamic response and calibrate a vibration model of the structure. Additionally, vibration measurements were conducted at a comparable operational facility to quantify excitation forces generated by kart operation and collision events. A simulation model calibrated with the field measurements was used to predict vibration transmission and evaluate mitigation strategies. Results demonstrated that without isolation, vibration levels could exceed acceptable thresholds, while properly designed isolation systems significantly reduced transmitted vibration to below ambient levels.

1. INTRODUCTION

A racetrack system for go-kart racing was proposed to be constructed on a vacant space inside a commercial center with multiple tenants. The go-kart track is a multi-level structure typically constructed of a steel frame, attached to the floor via bolted joints through columns. The noise and vibration from a go-kart track come from the vehicle's tires, vehicle bumps in the structure, vehicle collisions, crowd noise, PA and music amplification, etc.

The entertainment companies that operate this type of racetrack system normally have a building completely occupied by the same operator, with no other tenants, and with the structure attached to the main or ground level of the building. In this case, the challenge is double, since the proposed racetrack system is planned to be installed on a third floor, with tenants below, inside a mall. The noise and vibration levels transmitted to the other tenants shall comply with the internal Codes, Covenants and Restrictions (CC&R's).

A combined experimental and analytical approach was used, including modal testing of the proposed structure, operational vibration measurements at a comparable facility, frequency-response analysis, and evaluation of vibration-isolation strategies.

2. MEASUREMENT AND ANALYSIS METHODOLOGY

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[1] francisco@mdacoustics.com

The approach consisted of two measurement campaigns and a finite element model analysis. The measurements and analysis informed the vibration reductions needed and allowed the specification of a suitable vibration isolation system.

2.1. Modal Testing at Proposed Site

Impact testing was performed at multiple locations along a north-to-south transect of the slab within the proposed track footprint on the third-floor slab to characterize structural dynamics. The acceleration signals were integrated to velocity to facilitate mobility analysis. Test setup included:

- Instrumented impact hammer.
- Three accelerometers placed in close proximity
- Vertical (out-of-plane) response measurements
- Signal analyzer for frequency response functions
- Impact test performed at 37 locations across the floor

The objective was to identify:

- Natural frequencies
- Structural damping
- Dynamic compliance of the slab

This data was used to calibrate a vibration model of the building. Figure 1 below shows the vibration measurement setup for the slab of the proposed project site.

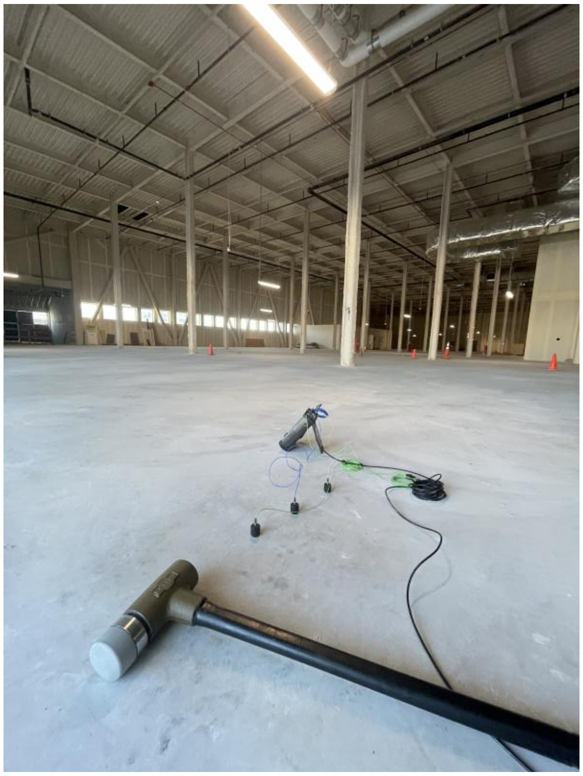

Figure 1: Measured mobility frequency response function and coherence of the proposed slab derived

2.1.1. Frequency Response Function Estimation

Frequency response functions (FRFs) were computed using the following equation:

$$H(f) = \frac{G_{VF}(f)}{G_{FF}(f)} \qquad (1)$$

where the G_{VF} is the cross-spectrum between velocity and force, and G_{FF} is the auto-spectrum of the force input.

Velocity signals from multiple sensors were averaged to improve robustness. Windowing and spectral averaging were applied across multiple impacts.

2.1.2. Coherence Evaluation

The coherence functions between the impact hammer input and sensor responses were computed using:

$$\gamma^2(f) = \frac{|G_{VF}(f)|^2}{G_{VV}(f)G_{FF}(f)} \tag{2}$$

where the G_{VF} is the cross-spectrum between velocity and force, and G_{VV} is the auto-spectrum of the velocity response, and G_{FF} is the auto-spectrum of the force input.

Coherence values exceeding 0.9 across the primary frequency range confirmed high data quality and reliable FRF estimation.

2.2. Operational Measurements at Reference Facility

Vibration measurements were conducted at an existing multi-level go-kart facility with similar track design and vehicles. See Figure 2 below for the measurement setup picture. Instrumentation included:

- Six accelerometers connected to a multi-channel analyzer
- Three accelerometers mounted on steel supports (x,y,z)
- Three accelerometers mounted on the concrete slab (vertical direction)
- Measurements taken at five locations including the track structure and the supporting building floor

Measurement scenarios included:

- Ambient conditions
- Kart pass-by events (elevated level)
- Kart collision events

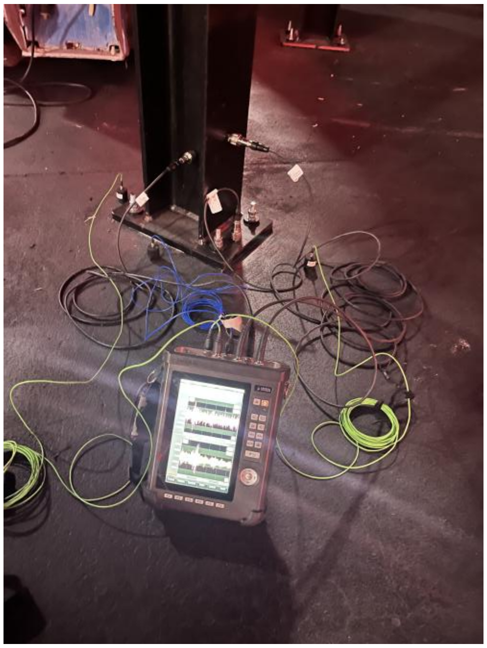

Figure 2: Vibration measurement setup at an operational equivalent facility

3. RESULTS AND DISCUSSION

3.1. Mobility functions

Mobility functions (velocity-to-force ratios) were computed to characterize the modal response of the slab. Figure 3 shows the spatial-average mobility FRF for the entire floor space, with the marked frequencies corresponding to structural resonances governing the vibration response.

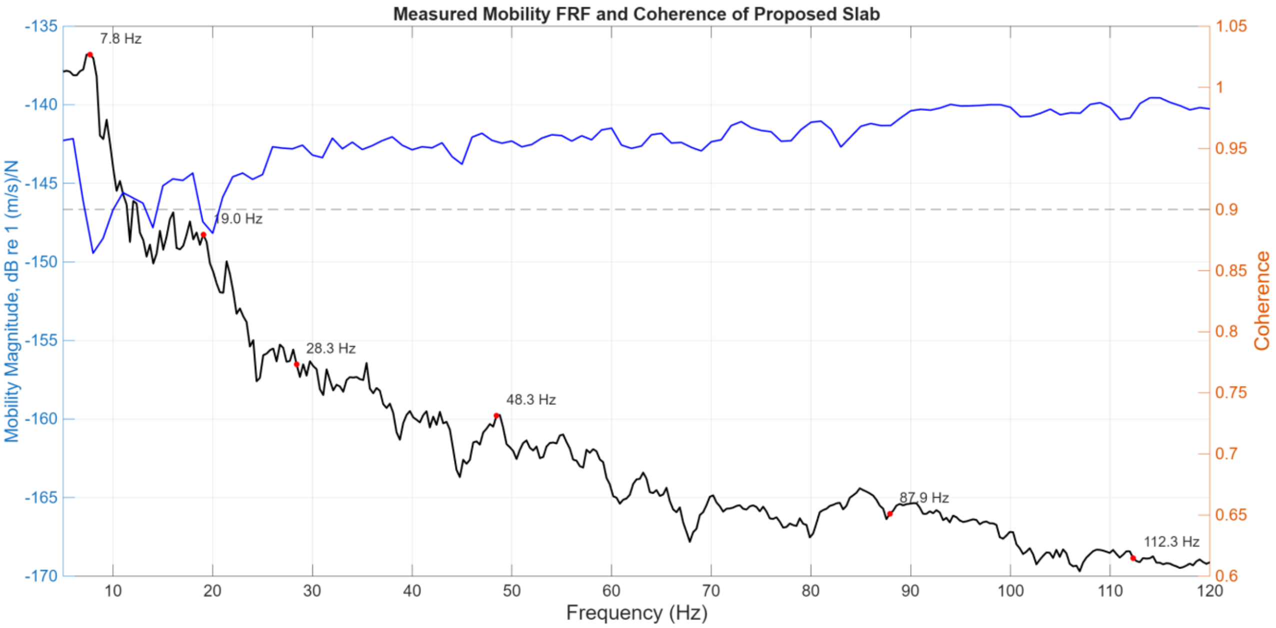

Figure 3: Measured mobility frequency response function and coherence of the proposed slab derived from impact testing.

Some of the identified resonant frequencies are not clear peaks compared to the surrounding frequency bins. This is mainly due to the large concrete slab nature and the heavily damped, field-tested conditions. Also, during the one-by-one location analysis, the peaks appeared slightly clearer but still showed broad resonant behavior, which is characteristic of large concrete floor systems. The values shown next to the markers are the same as those presented in Table 1 (See Section 3.3) and represent the average resonant frequencies across the floor. Coherence values indicate reliable FRF estimation across the primary frequency range of interest. Minor reductions in coherence were observed near certain resonant regions, likely due to spatial variability and mode overlap associated with the large-span slab system.

3.2. Spatial variation of structure response

A spatial mobility map (Figure 4) illustrates variation in vibration response across the slab. The results indicate non-uniform structural behavior, with reduced response in regions of increased mass and stiffness.

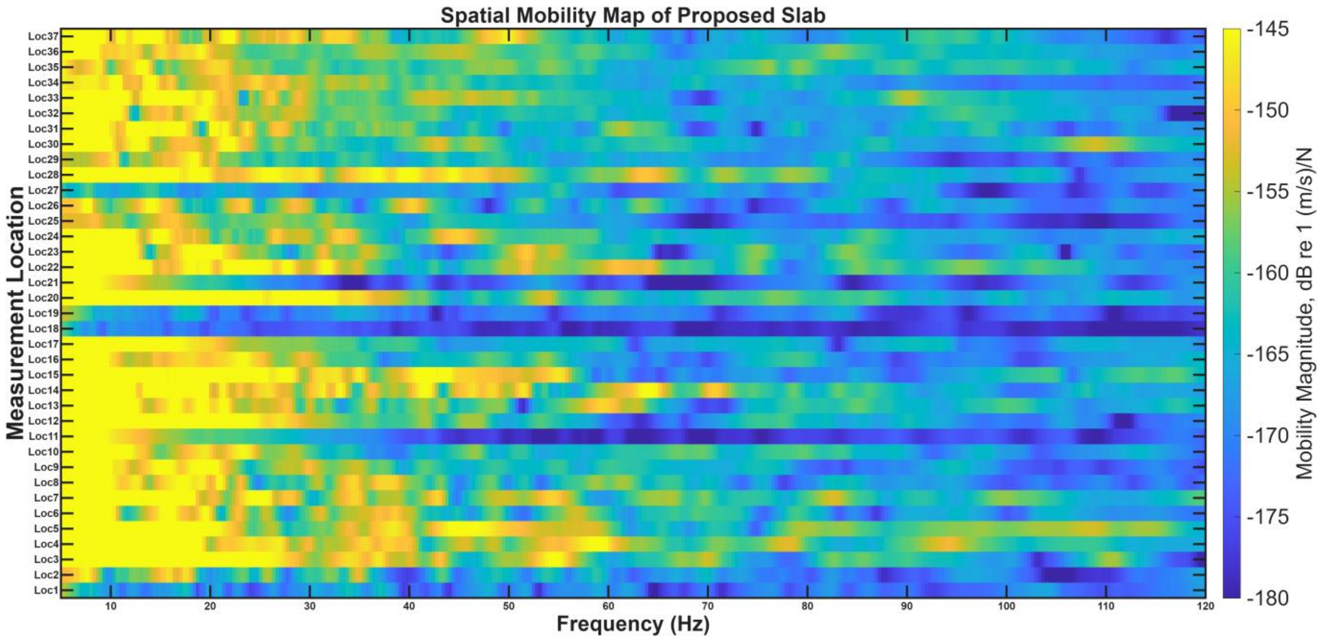

Figure 4: Spatial distribution of mobility magnitude across the proposed slab.

Variations in response indicate non-uniform dynamic behavior and distributed modal participation across the floor system. Broad, resonant regions extending across multiple measurement locations suggest globally coupled slab modes. The stronger modal response was for frequencies below 30 Hz at most of the floor locations tested. This is the expected behavior for large slab systems. At locations 18 and 19, the mobility magnitude is at its lowest level on the floor. These locations are probably on the largest stiffness portion of the floor.

3.3. Modal frequencies

The following modal frequencies were identified:

Table 1. Spatially averaged modal frequencies

Mode	Frequency (Hz)
1	7.8
2	19.0
3	28.3
4	48.3
5	87.9
6	112.3

These modes fall within the frequency range most relevant for structure-borne vibration transmission. The values presented in Table 1 are also shown in Figure 3, which shows the mobility FRF of the modal testing.

3.4. Operational vibration characteristics

Operational vibration measurements were conducted at a comparable indoor go-kart facility to characterize excitation mechanisms and structure-borne vibration transmission paths. Acceleration measurements were obtained simultaneously on the track structure and supporting slab using tri-axial accelerometers mounted on structural elements and vertical accelerometers mounted on the slab. Figure 5 below compares the operational vibration spectra measured on the track structure and supporting floor.

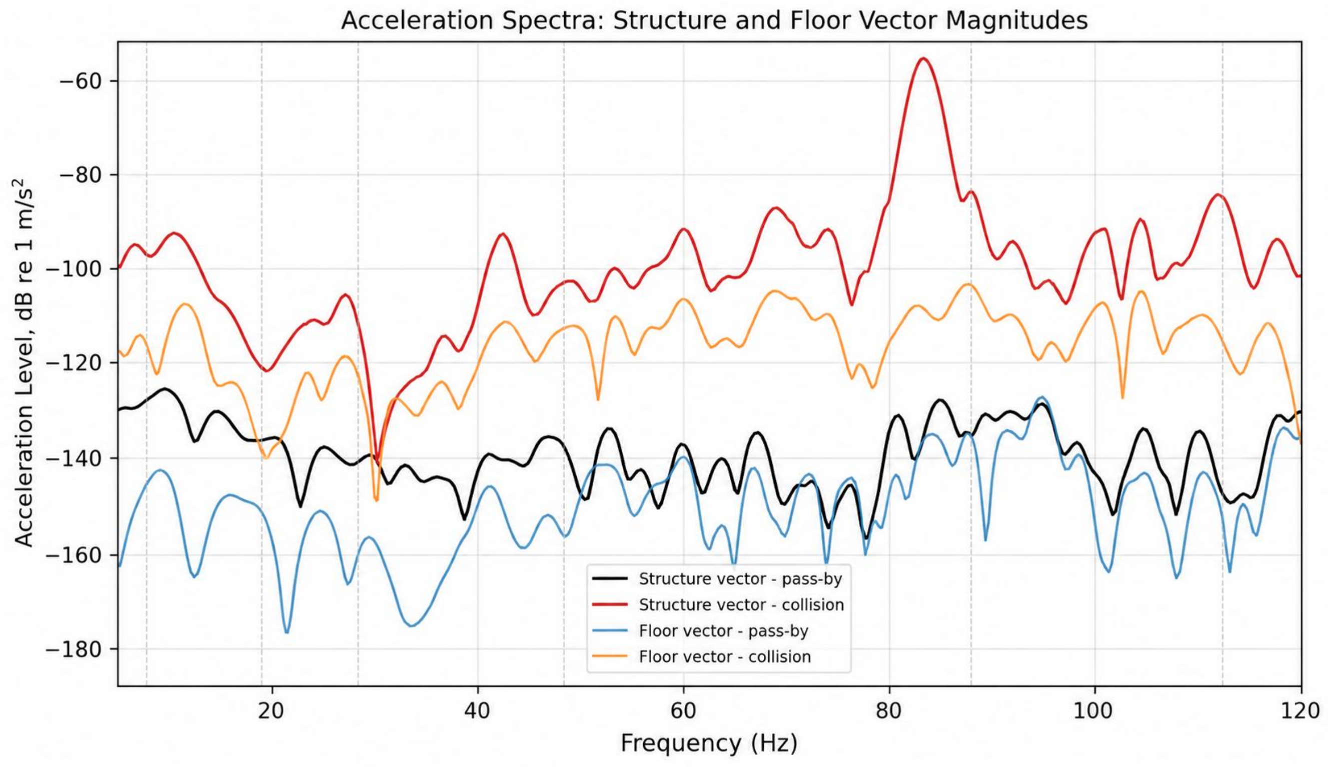

Figure 5: Spatial distribution of mobility magnitude across the proposed slab.

The measured spectra confirm that vibration transmission is dominated by direct mechanical coupling between the track support system and the slab structure. Although attenuation occurs between the structure and the slab, substantial broadband energy remains within the frequency range governing structure-borne vibration response. Also, collision events produced the highest transient vibration amplitudes and represent the governing operational condition for vibration mitigation design.

3.5. Peak particle velocity (PPV) analysis

Peak particle velocity (PPV) was evaluated to quantify vibration severity throughout the structure and the supporting slab. Figure 6 below shows the peak particle velocity vibration measured at four different locations on the operational equivalent facility. As mentioned previously, there were six channels and they were grouped in two systems; channels 1 to 3 were attached to the racetrack structure, and channels 4 to 6 were attached to the floor slab. The equivalent level for the two sensor groups was calculated using the vector norm of the three sensors. Also, the transmission ratio (TR) is shown in Figure 6. TR is computed as the ratio of the floor slab group to the racetrack structure group. Finally, the vibration measurements were taken at four locations during the testing.

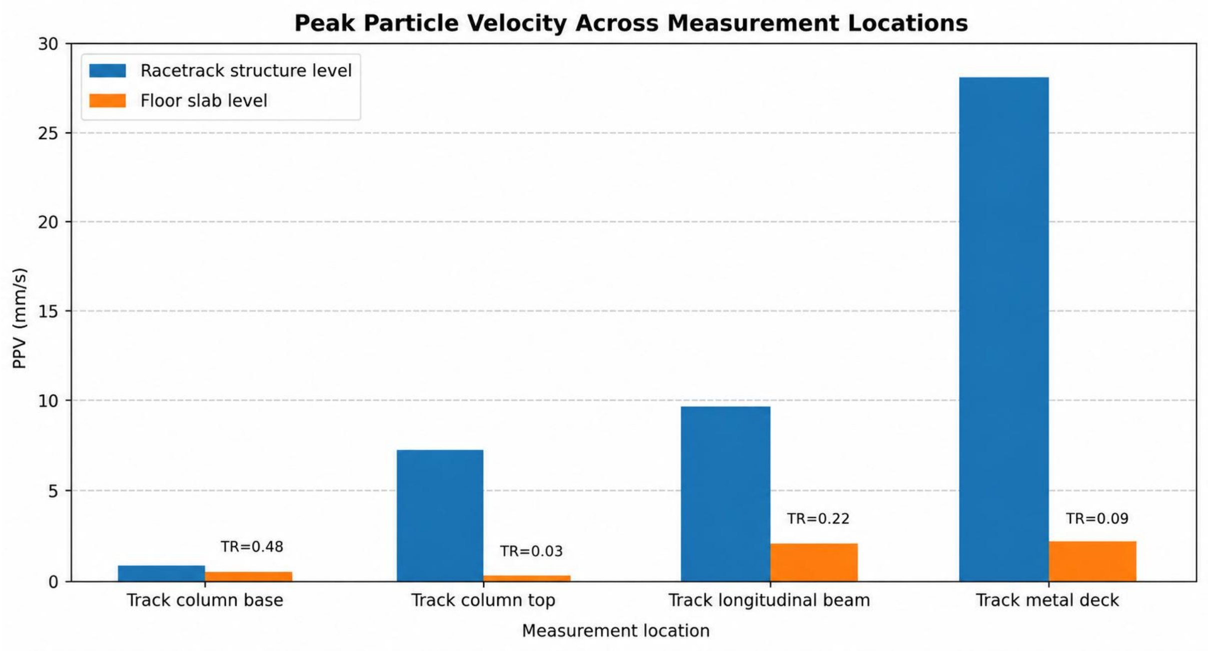

Figure 6: Peak particle velocity (PPV) measured at structural and slab locations throughout the reference facility. The measured PPV levels confirm that transient impact events govern vibration transmission severity and represent the controlling operational condition for vibration mitigation design.

Figure 6 shows that structural elements exhibit higher vibration levels than the slab. Also, as shown in Figure 5, collision events produce the highest amplitudes, and the slab response's overall PPV level is attenuated but remains significant, with TR values spanning 0.03 to 0.48 across the measured locations.

The reduction in vibration levels between the track structure and the slab demonstrates partial attenuation through the supporting system; however, sufficient broadband energy remains to excite low-frequency slab modes. These observations reinforce the need for vibration isolation measures to reduce structure-borne transmission.

3.6. Vibration transmission mechanisms

Measurements indicate that vibration transmission is dominated by direct mechanical coupling between the track structure and the slab. Structural elements physically connected to the track system exhibited significantly higher vibration levels than the nearby building floor, not connected directly to the track, as shown in Figure 2. The behavior confirms that the structure-borne transmission is governed by vibration propagation.

Collision events represent the governing condition for vibration design, as they introduce high-energy broadband excitation directly into the structure

4. ENGINEERING IMPLICATIONS

The results demonstrate that vibration transmission is governed by the interaction between structural dynamics and operational excitation. Low-frequency modes combined with low damping increase susceptibility to resonance amplification.

Spatial variability further indicates that local structural conditions significantly influence vibration response. The use of elastomeric isolation elements reduces force transmission into the slab, mitigating resonance effects and limiting vibration propagation.

The proposed raceway includes an engineered rubber isolation layer to reduce vibration transmitted from the tracks and bumper supports into the concrete slab. The proposed isolation layer is to be located below the track and bumper supports and is expected to provide 10-30 dB of vibration isolation from 30 to 100 Hz, with higher levels of isolation at higher frequencies. It is important to specify the isolation to be tuned to the excitation loads and conditions. This means that the isolation material is designed to reduce vibration from pass-by events and collisions to below the ambient vibration level, down to 80 Hz.

5. CONCLUSIONS

A combined experimental and analytical approach was used to evaluate vibration transmission from a proposed indoor go-kart facility. The key findings include the following: (1) structural resonances fall within the excitation range of kart operation, (2) collision events generate the highest vibration levels and govern design, (3) spatial variation in slab response influences vibration transmission, (4) vibration transmission is dominated by direct structural coupling, and (5) isolation systems significantly reduce transmitted vibration

The combined use of experimental modal analysis, operational vibration measurements, and calibrated modeling provided a technically robust basis for evaluating vibration transmission risk and the performance of vibration isolation systems. The proposed isolation design is effective in mitigating structure-borne vibration and ensuring compliance with project requirements.

ACKNOWLEDGEMENTS

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