

# MOTION CONTROL FOR BRIDGES AND FLOORS

Optimizing occupant experience and structural performance by mitigating motion and vibration



motioneer

The Motioneer team has over 25 years of experience solving complex issues in the field of applied structural dynamics on bridges, floors, grandstands, buildings, spires, antenna, and other types of dynamically sensitive structures.

With over 300 projects completed worldwide, our design and construction team provides practical and cost-effective motion control solutions from concept to completion. Performance, quality, constructability, and a client-first attitude are always at the forefront of our approach.

## CLIENT FIRST APPROACH

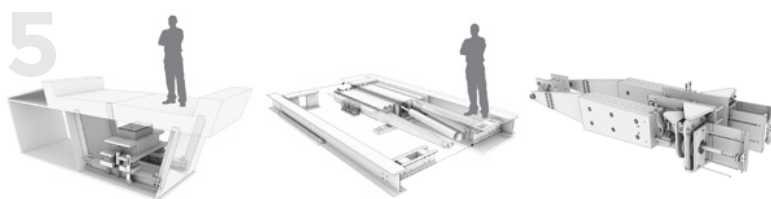
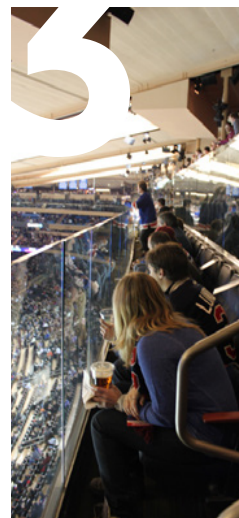
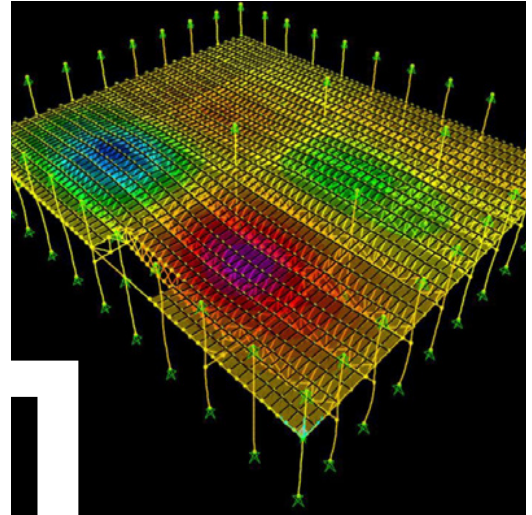
We believe in proactive collaboration. We listen. We engage. And together we develop a strategy that will suit your needs.

## ADVANCED, PROVEN TECHNIQUES

We assess the dynamic response of bridge and floor systems using advanced modeling techniques developed and calibrated from as-built measurements in the real world. We can accurately assess the motions of dynamically sensitive structures and help you to establish practical & achievable performance targets.

## RISK MANAGEMENT SOLUTIONS

We have developed a range of modular, prefabricated, and compact damper solutions for bridges and floor systems. Constructability, cost efficiency, quality, and performance are at the core of our approach. Our construction services offering can be customized to serve the specific risk management and performance needs of the project.



1. Floor motion simulation
2. Grand Canyon Skywalk
3. Madison Square Garden suspended bridges
4. Wichita Pedestrian Bridge
5. Bridge and floor damper designs

# RELEVANT EXPERIENCE

## SENSITIVE SPACES - HOSPITALS



Project	Location
Fort Bliss Replacement Hospital <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> <li>• Ground-borne vibration measurements.</li> </ul>	El Paso, TX USA
New York University (NYU) Lagone Medical Center <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> </ul>	New York, NY USA
Centre hospitalier de l'Université de Montréal <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> <li>• Ground-borne vibration measurements.</li> </ul>	Montreal, QC CAN
Reading Hospital + Medical Center <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> </ul>	West Reading, PA USA
Florida Hospital Women's Pavilion <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> </ul>	Orlando, FL USA
Rutgers University, School of Dental Medicine <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> </ul>	Newark, NJ USA
Calgary Cancer Centre <ul style="list-style-type: none"> <li>• Footfall-induced vibration.</li> <li>• Vehicle-induced vibration.</li> <li>• Vibration from gym activities.</li> <li>• MEP-induced vibration near sensitive equipment.</li> <li>• Vibration measurements.</li> </ul>	Calgary, AB CAN
Joe DiMaggio Children's Hospital <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> <li>• Footfall-induced vibration measurements.</li> </ul>	Hollywood, FL USA
Sport Medicine Center at Cypress Creek <ul style="list-style-type: none"> <li>• Modelling of floor vibration from gym activities.</li> </ul>	Ft. Lauderdale, FL USA
CHUS Fleurimont Centre Mére-Enfant <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> </ul>	Sherbrooke, QC CAN
Hôpital Lachine expansion <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> <li>• Footfall-induced vibration measurements.</li> </ul>	Lachine, QC CAN
Cowichan District Hospital <ul style="list-style-type: none"> <li>• Footfall-induced vibration modelling.</li> </ul>	N. Cowichan, BC CAN
Children's Health Medical Center Plano <ul style="list-style-type: none"> <li>• Footfall-induced vibration modelling.</li> </ul>	Plano, TX USA

Terra Hill Ambulatory Surgical and Medical Centre <ul style="list-style-type: none"> <li>• Footfall-induced vibration modelling.</li> <li>• Modeling of vibration on slab supported on micro-piles.</li> <li>• Footfall-induced vibration measurements.</li> <li>• Ground-borne vibration measurements.</li> </ul>	Richmond Hill, ON CAN
Almoosa Specialist Hospital <ul style="list-style-type: none"> <li>• Footfall-induced vibration modelling.</li> </ul>	Al Khobar, KSA
Hopital de Vaudreuil-Soulanges <ul style="list-style-type: none"> <li>• Footfall-induced vibration modelling.</li> </ul>	Montreal, QC CAN
Prince Albert Victoria Hospital Redevelopment Project <ul style="list-style-type: none"> <li>• Footfall-induced vibration modelling.</li> </ul>	Prince Albert, SK CAN

# RELEVANT EXPERIENCE

## SENSITIVE SPACES - LABORATORIES



Project	Location
The University of North Carolina (UNC) Marsico Hall <ul style="list-style-type: none"> <li>• Footfall-induced floor vibration modelling.</li> <li>• Ground-borne vibration measurements.</li> <li>• Footfall-induced vibration measurements.</li> <li>• Measurements to identify problematic vibration source.</li> </ul>	Chapel Hill, NC USA
Clinical & Translational Research Institute UC San Diego <ul style="list-style-type: none"> <li>• Ground-borne vibration</li> </ul>	San Diego, CA USA
Argonne National Laboratory Advance Protein Crystallization Facility <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements.</li> </ul>	Chicago, IL USA
University of Massachusetts Physical Science Building <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements.</li> </ul>	Amherst, MA USA
Binghamton University Smart Energy Building <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements.</li> <li>• Footfall-induced vibration measurements.</li> </ul>	Binghamton, NY USA
The University of British Columbia Quantum Matter Institute + Advanced Materials and Process Engineering Laboratory <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements</li> <li>• Footfall-induced vibration measurements.</li> </ul>	Vancouver, BC CAN
The University of Ottawa Advanced Research Centre <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements.</li> <li>• Footfall-induced vibration measurements.</li> </ul>	Ottawa, ON CAN
The University of Waterloo Institute for Quantum Computing <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements.</li> </ul>	Waterloo, ON CAN
The University of Michigan Kraus Building Addition + Renovation <ul style="list-style-type: none"> <li>• Footfall-induced vibration measurements.</li> </ul>	Ann Arbor, MI USA
Wexford Science + Technology, Academic Tower - Drexel University <ul style="list-style-type: none"> <li>• Dancing- and running-induced vibration modelling.</li> </ul>	Philadelphia, PA USA
National Research Council of Canada <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements.</li> <li>• Footfall-induced vibration measurements.</li> </ul>	Ottawa, ON, CAN
University of Ottawa Science, Technology Engineering + Mathematics Complex <ul style="list-style-type: none"> <li>• Ground-borne vibration measurements.</li> <li>• Footfall-induced vibration measurements.</li> </ul>	Ottawa, ON, CAN
University of Wisconsin Milwaukee – Chemistry Building <ul style="list-style-type: none"> <li>• Footfall-induced vibration measurements.</li> </ul>	Milwaukee, WI USA

Cambridge Crossing • Ground-borne vibration measurements.	Cambridge, MA USA
University of Maryland Chemistry Building – Wing 1 • Ground-borne vibration measurements. • Footfall-induced vibration modelling.	Norfolk, VA USA
University of Ottawa – STEM building • Ground-borne induced vibration measurements • Footfall-induced vibration measurement.	Ottawa, ON CAN

# RECENT CASE STUDIES

## FLOOR VIBRATION 1



Floor vibration analysis required where an office building is to be converted to a life science/laboratory facility.

Motioneering was retained to provide floor vibration analysis, measurements, and damping options for a conventionally framed office building located in Pennsylvania, USA. The building was to be retrofitted to life science and laboratory use and as such, more stringent floor vibration criteria would need to be targeted.

As a first step, we created a finite element method model (FEM model) to determine the dynamic properties of the subject floor inside the building.

The dynamic properties were then exported to Motioneering's proprietary Unified Solver program – a program that employs time-domain analysis to apply footfall forces at the expected locations of excitation to a structural model then extract the resulting vibrations.

Dynamic forces for slow to moderate pace rates were applied to the floor at conservative locations (near the centres of the structural bays).

Our study found that the existing structure will experience floor vibrations that exceed the target criteria over much of the floor area.

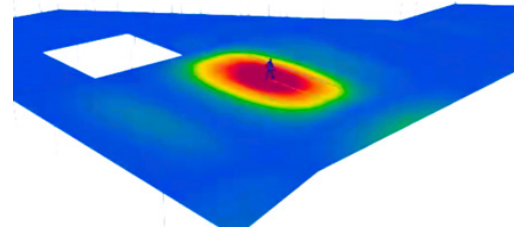


Illustration: Dynamic forces applied to floor.

The following mitigation options were investigated:

1. Mitigation with tuned mass dampers designed for floors (floor TMDs).
2. Mitigation with stiffening plates welded beneath structural beams and girders.

Motioneering's analyses found that the mitigations are expected to reduce the floor vibrations but that the criteria will still be exceeded in some areas. Mitigation by stiffening only the structural girders was not found to offer meaningful improvement.

Our client will now determine the preferred mitigation to achieve the vibration criteria. It is possible that a combination of stiffening and floor TMDs will provide them with a preferred outcome.

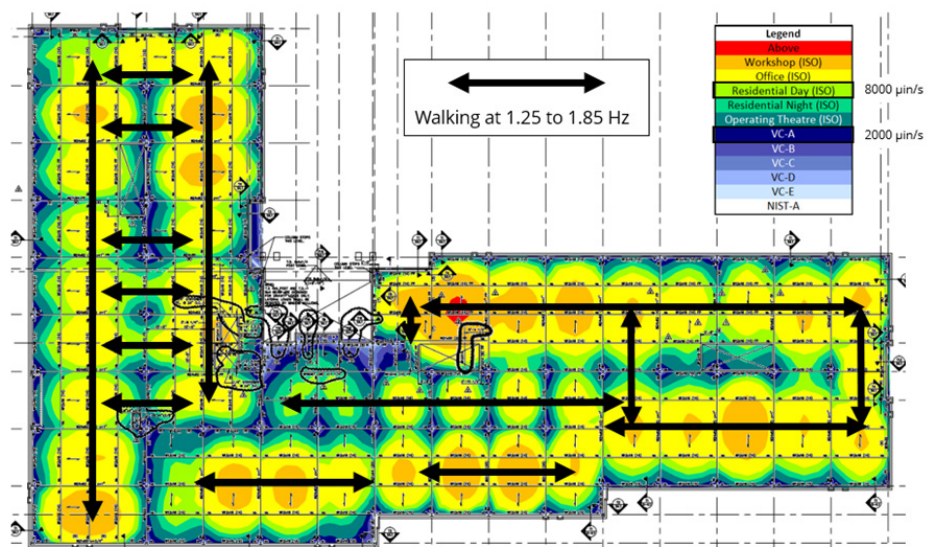


Illustration: Unified Solver predicted vibration criteria due to slow to moderate walking.

# RECENT CASE STUDIES

## FLOOR VIBRATION 2



Floor vibration modelling study required where vibration-sensitive equipment is to be installed in a new laboratory facility.

Motiveering was retained to complete a vibration modeling study to evaluate potential vibration solutions for a new laboratory in Maryland, USA, where a prospective tenant is planning to install vibration-sensitive equipment (3D bio- printers).

The bio-printers in question are a new technology and the vibration criterion is not fully understood. To make this new vibration-sensitive technology function as well as practically possible, the stakeholders wanted to target a vibration criterion of VC-C (e.g., the appropriate standard for optical microscopes to 1000x). It was also understood that the bioprinters may operate over extended periods, up to 30 days consecutively, thus it was desired that the vibration target be sustained over a period of up to 30 days.

RWDI and Motiveering had conducted an earlier study at the site which found that the target vibration criterion would be exceeded in some loading scenarios.

The objective of this new study was to use Finite Element Method (FEM) structural analysis to compare the expected vibration levels of the original structure to those of two mitigated structures and to provide recommendations on the preferred mitigation solution.

Predictions of single-person-footfall vibrations were computed using Motiveering's Unified Solver program.

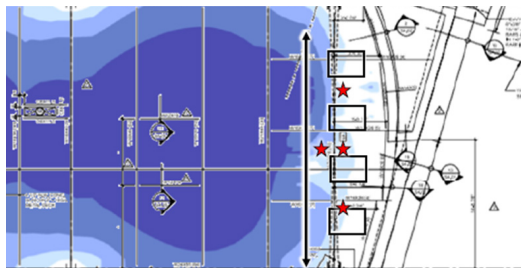


Illustration: Unified Solver predicted vibration criteria results mitigated with four posts.

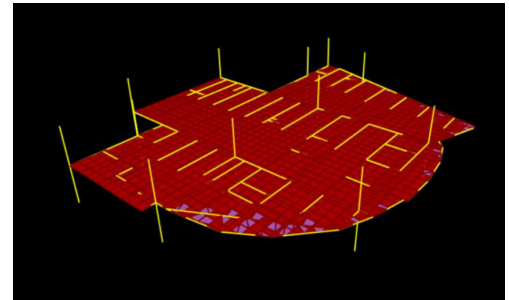


Illustration: FEM Model of unmitigated structure..

The Unified Solver program employs time-domain analysis to apply footfall forces at the expected locations of excitation to the structural model then extract the resulting vibrations.

Footfall forces due to an individual walking on a floor depend primarily on the weight of the person and on his or her walking speed (measured in steps/minute). A single individual is assumed to weigh 76kg (167lb). Walking speeds typically employed by Motiveering are 102-132 steps/minute in open spaces, such as corridors, and 75-108 steps/min in enclosed spaces where furniture or other obstructions typically cause people to walk at slower speeds. For this analysis, walking speeds of 108-132 steps/minute were used to represent expected worst-case scenarios and to agree with the measurement test data.

FEM models representing the building level in question facility were developed. Three models were developed to represent the original, unmitigated structure, the structure mitigated with a single post, and the structure mitigated with four posts.

The models were used to estimate the dynamic properties of the floors, which were then used to predict the footfall-induced vibrations.>>>

# RECENT CASE STUDIES

## FLOOR VIBRATION 2

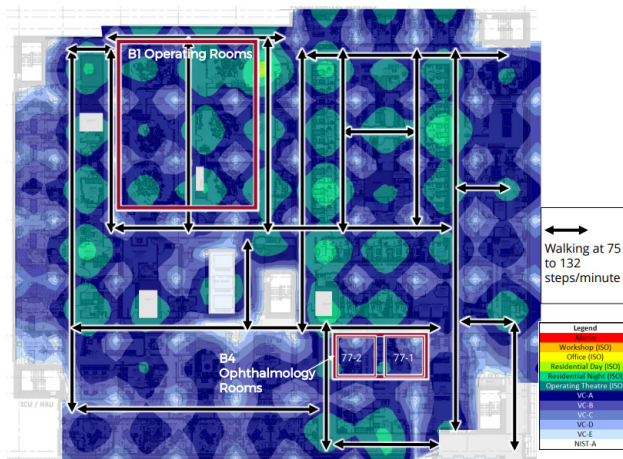


Floor vibration modelling study required where vibration-sensitive equipment is to be installed (continued)

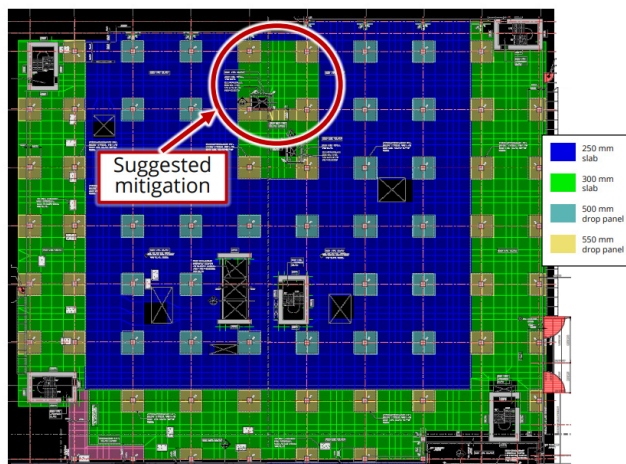
Motioneering's modeling found that both vibration mitigation solutions are expected to result in achievement of the target criterion under the modeled loading scenarios. However, due to the risk associated with vibration exceedances in this project, we recommended that mitigation proceed with the 4-post solution. Tuned mass dampers for floors (floor TMDs) were deemed to not be a cost-effective mitigation option in this case.

## APPENDICES

Figures from a recent RWDI and Motioneering vibration consulting project for multiple levels in a proposed hospital building.



Illustrative example showing Unified Solver predicted vibration criteria results due to slow and fast walking.



Illustrative example showing recommended mitigation for example shown above..