

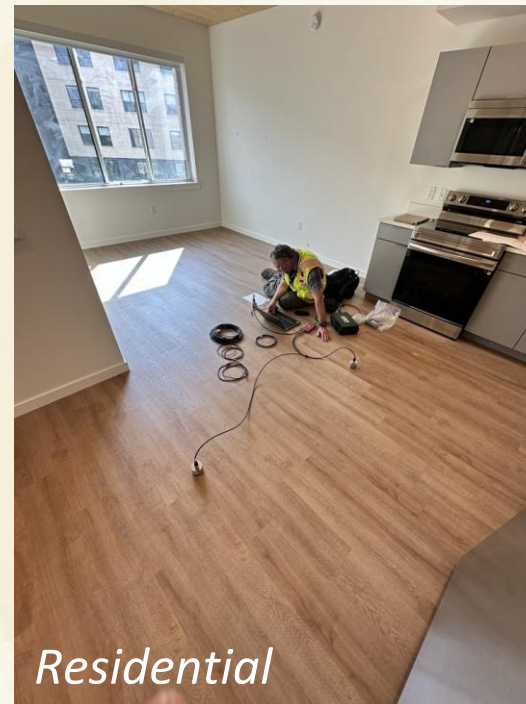
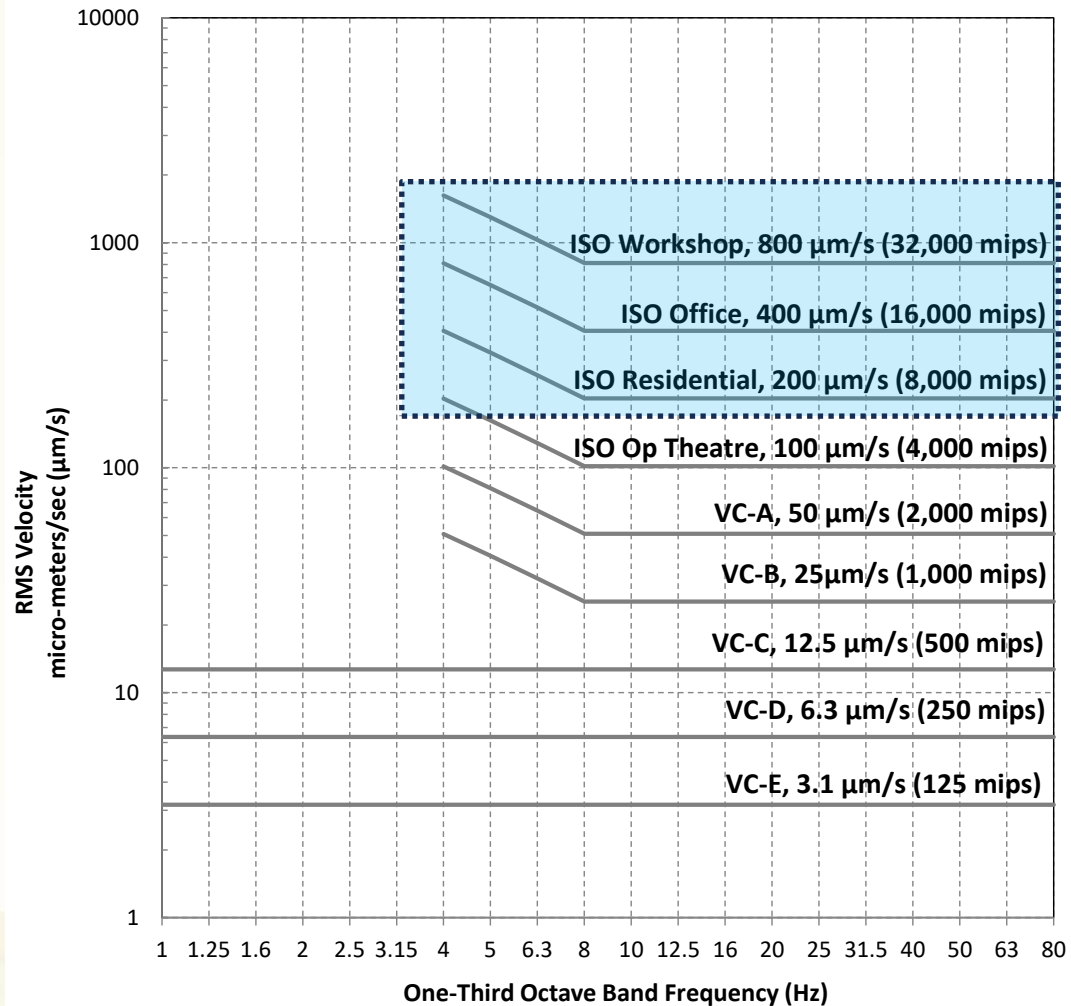


Mass Timber Floor Vibration: Trends and Insights From an Extensive Collection of Real-World Measurement Data

Presenter: **Steven Lank**
Vice President
Colin Gordon Associates

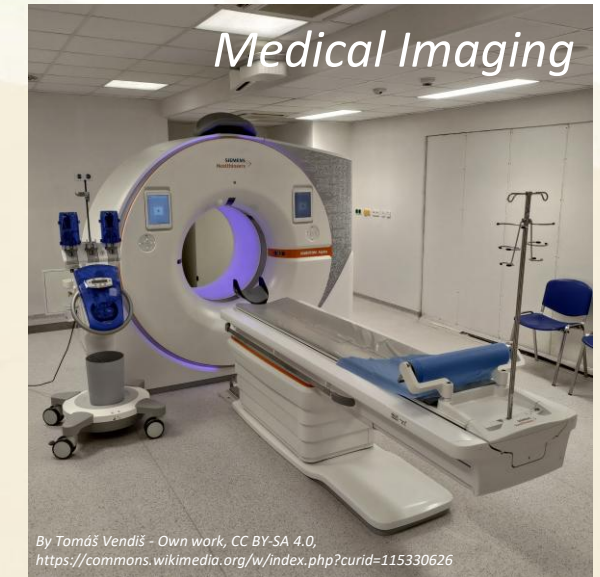
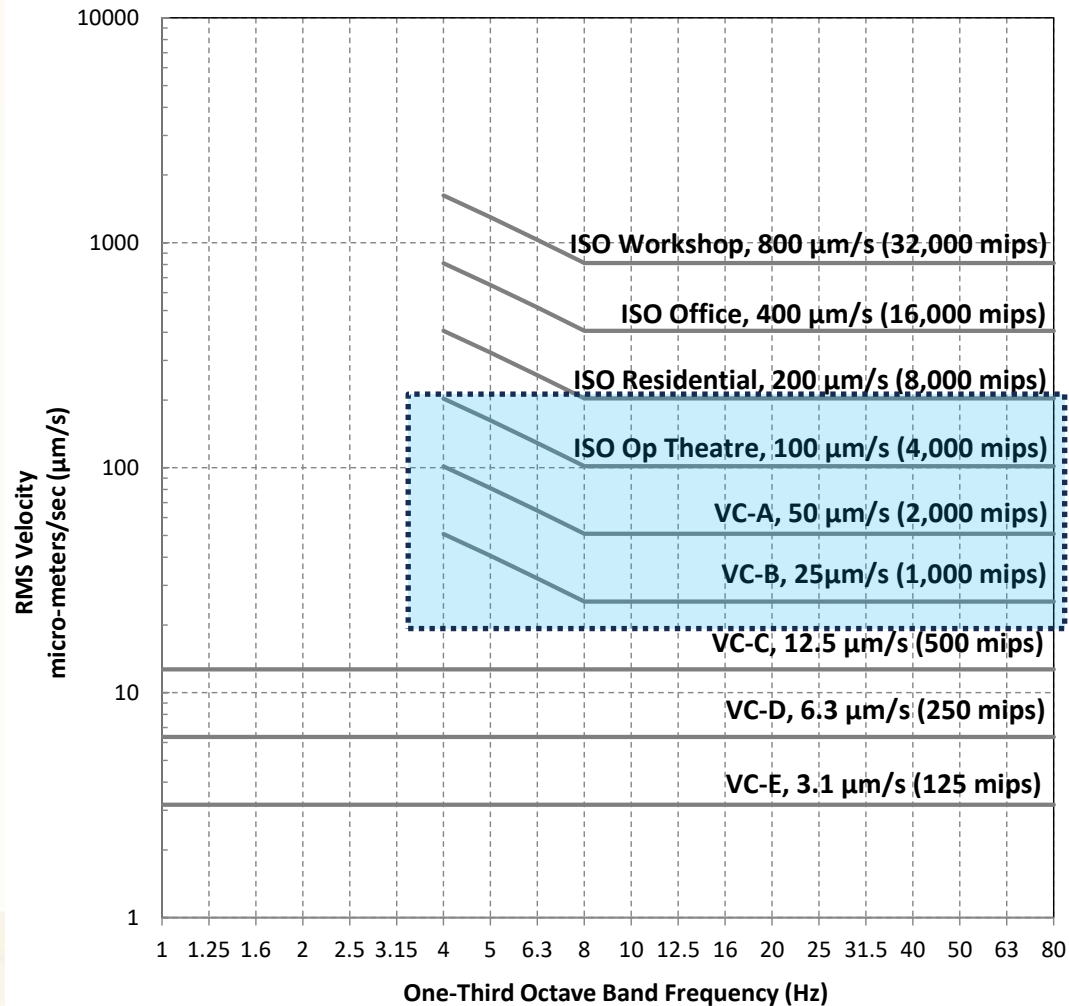


GENERIC VIBRATION CRITERIA



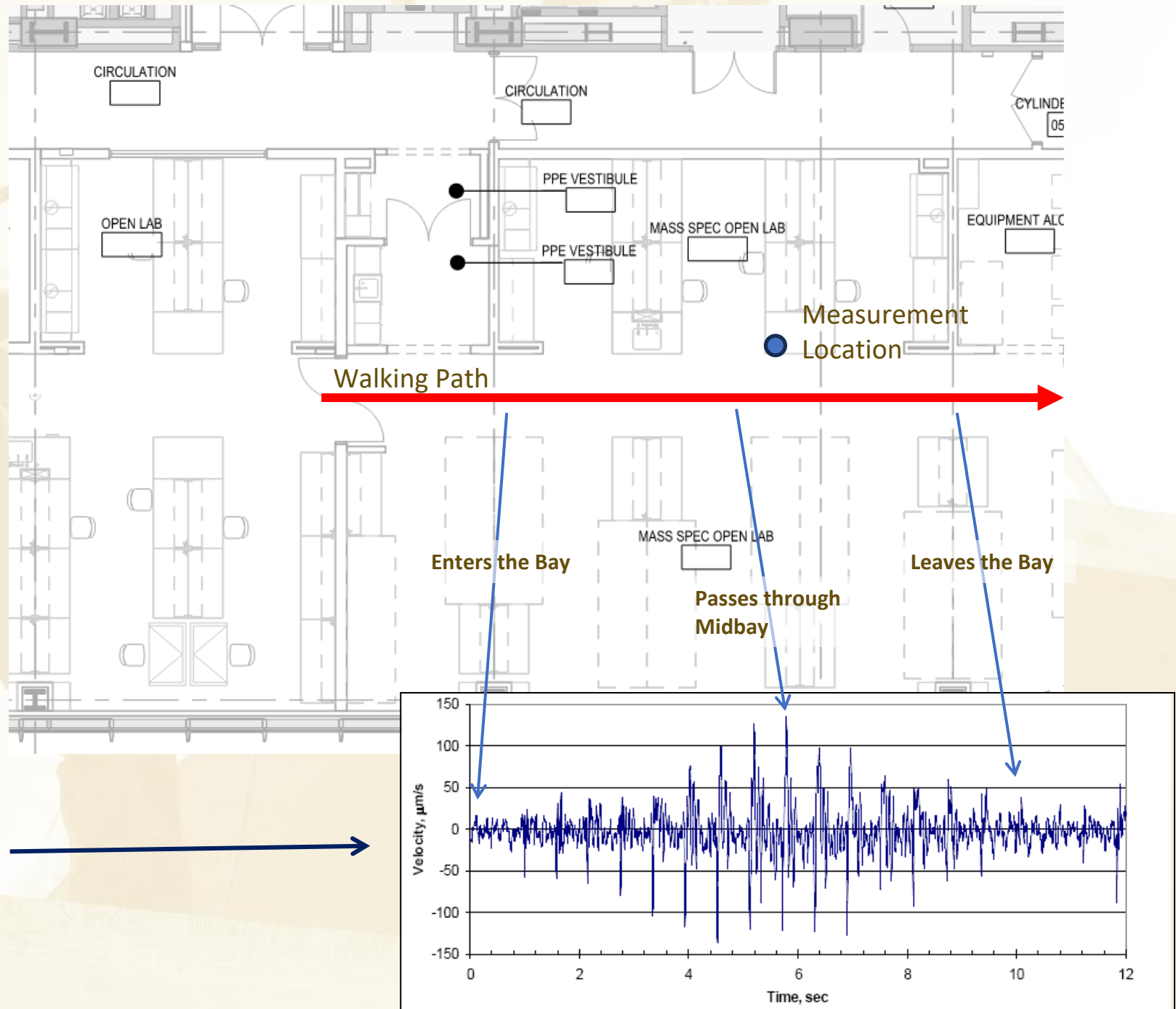
Expand into more sensitive uses?

GENERIC VIBRATION CRITERIA

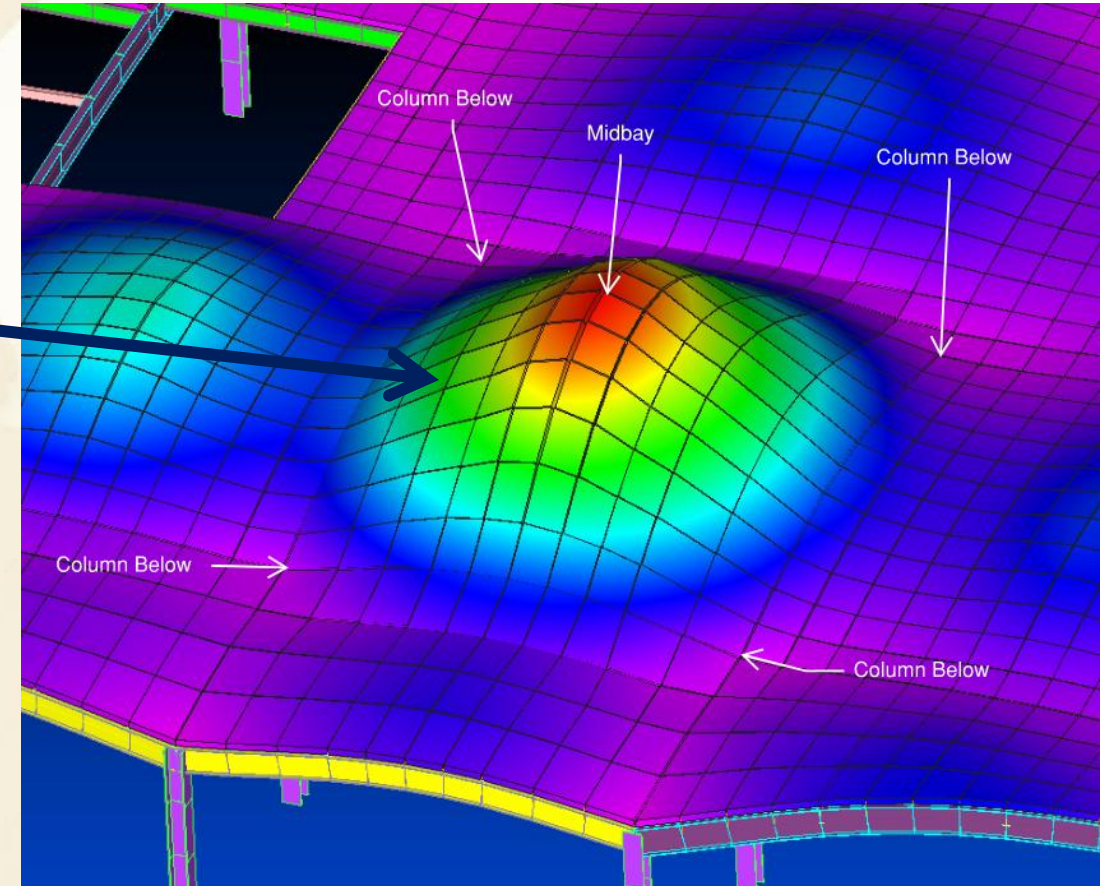
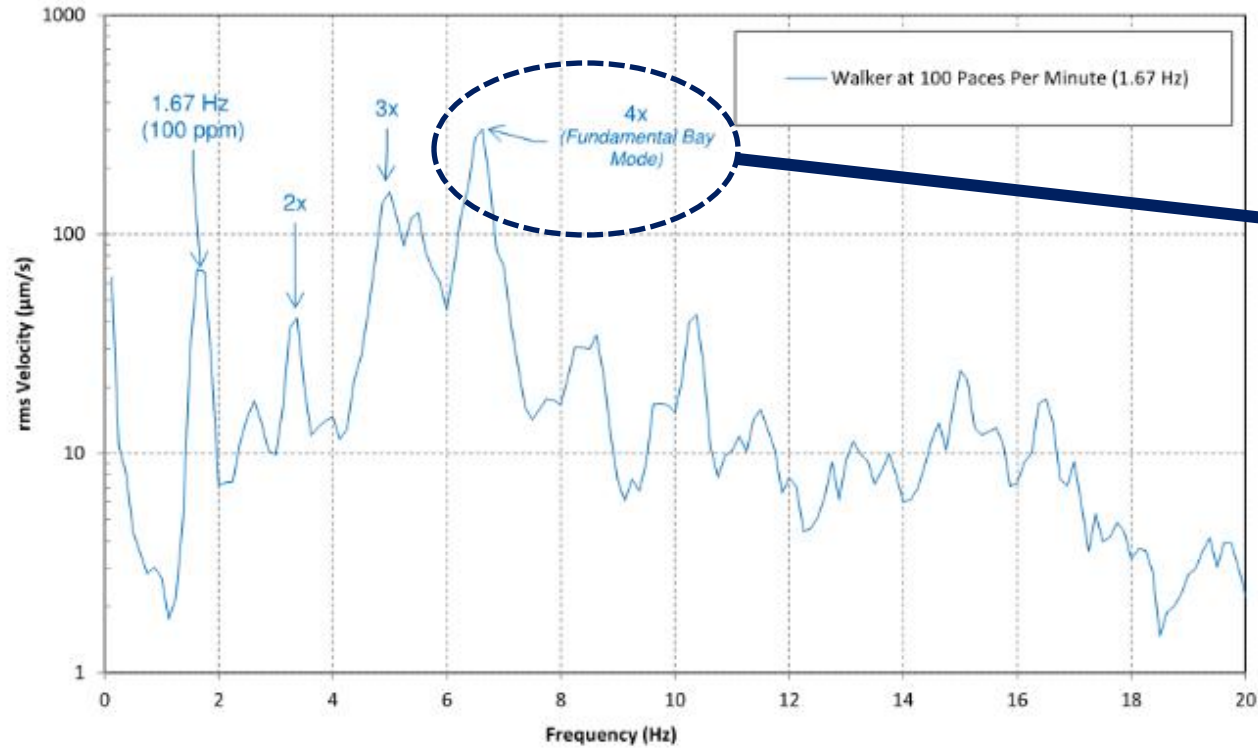


The Main Concern: Vibration due to people walking

Typical vibration time
history of a person walking



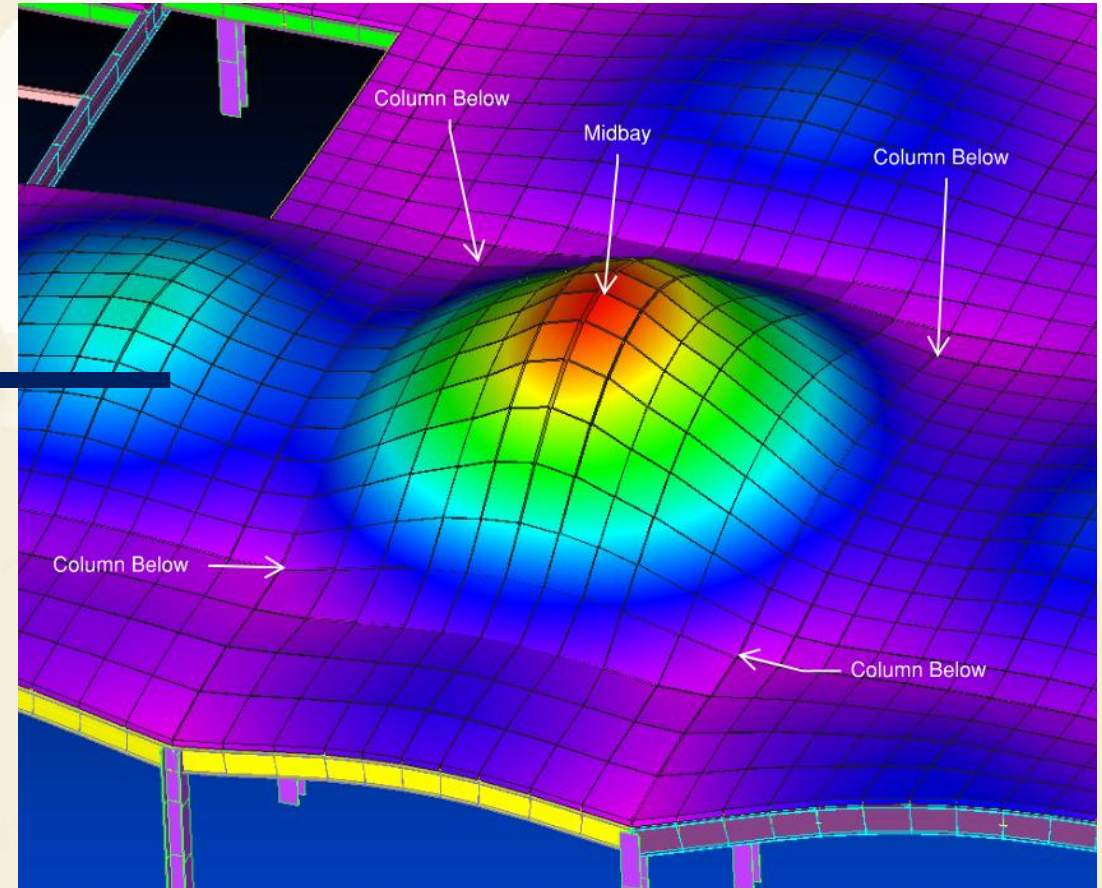
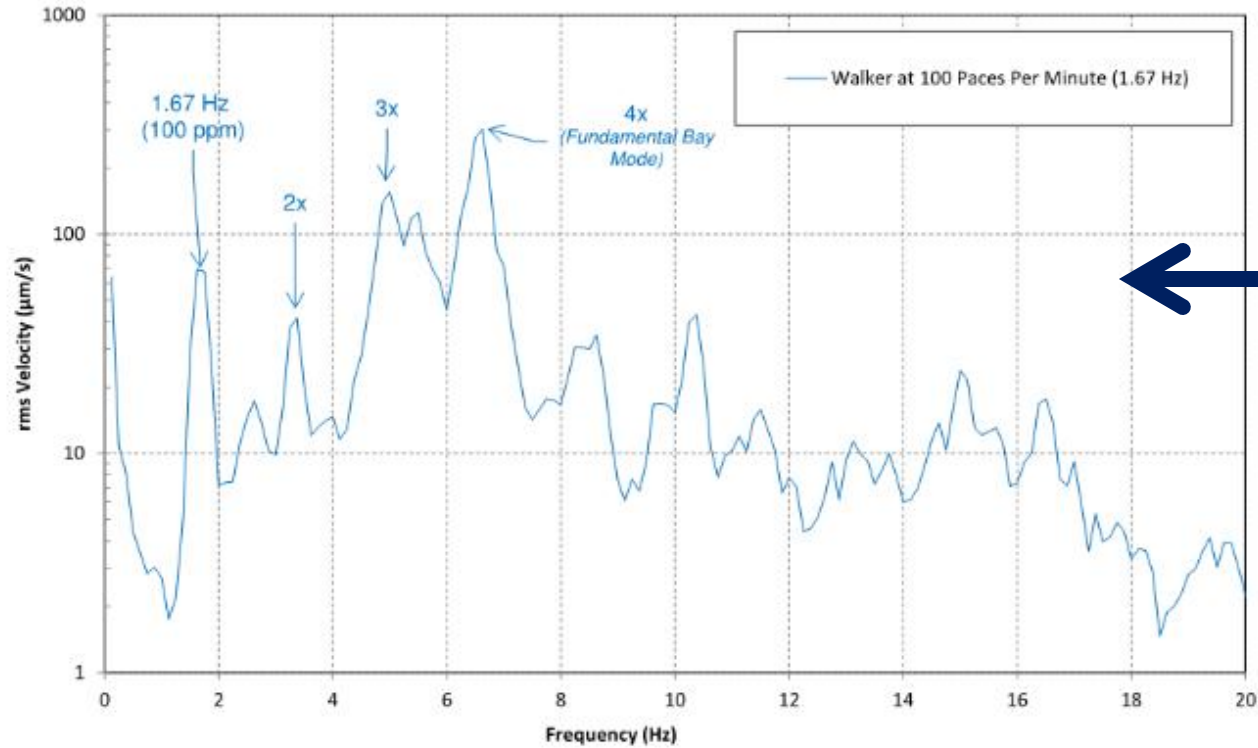
a) Narrowband Velocity ($\Delta f = 0.125$ Hz, Hann)



Walker Vibration - Measured Frequency Response

FEA Model – Response at Resonance

a) Narrowband Velocity ($\Delta f = 0.125$ Hz, Hann)



Walker Vibration - Measured Frequency Response

FEA Model – Response at Resonance

The Challenge:

Vibration due to people walking is highly variable!

Variations of 3.5 dB (50%) or more can be expected, even when controlling for pace rate, weight, etc.

Walker vibration prediction is necessarily probabilistic.

We need a large data set.

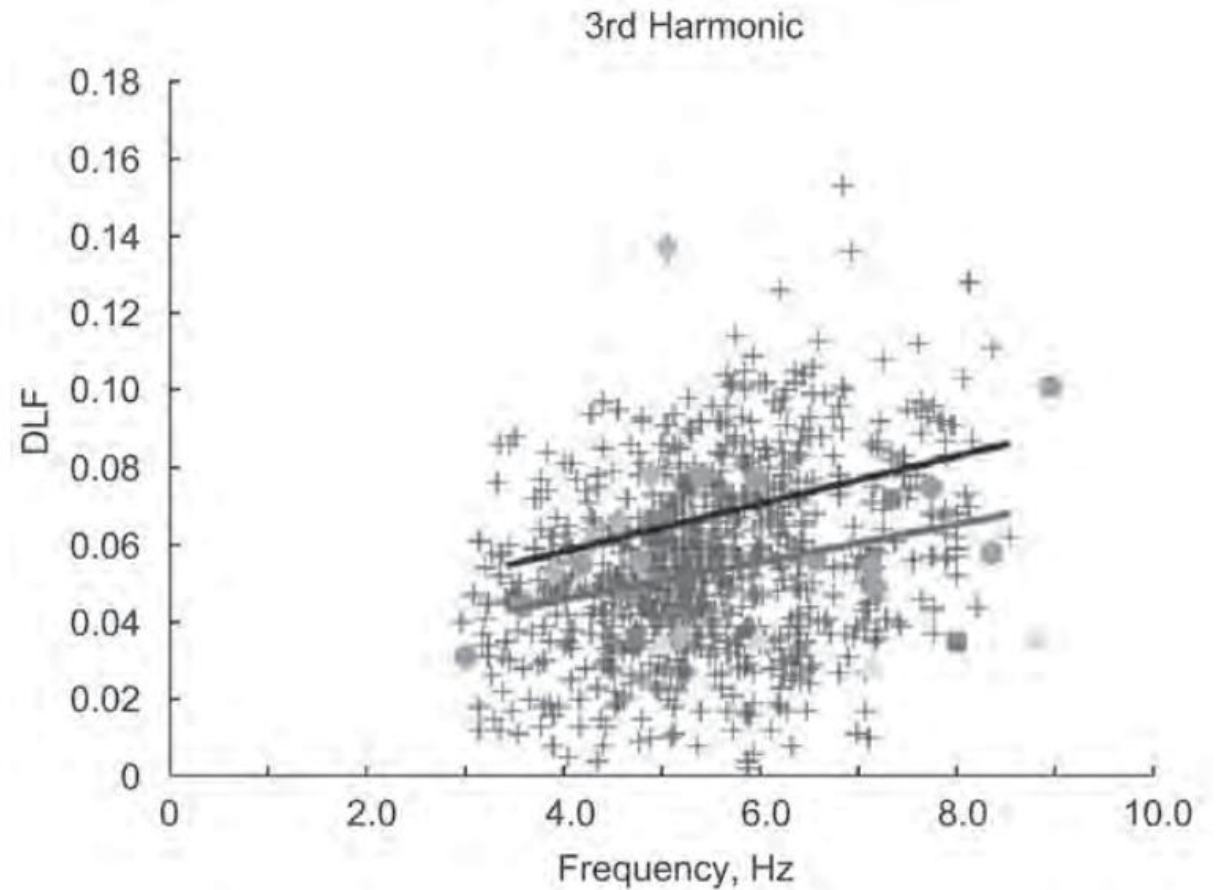


Fig. 3-4. Variation of third harmonic dynamic coefficients (Willford et al., 2007).

64 Measurement Locations Across 11 Buildings (CA, OR, CO)

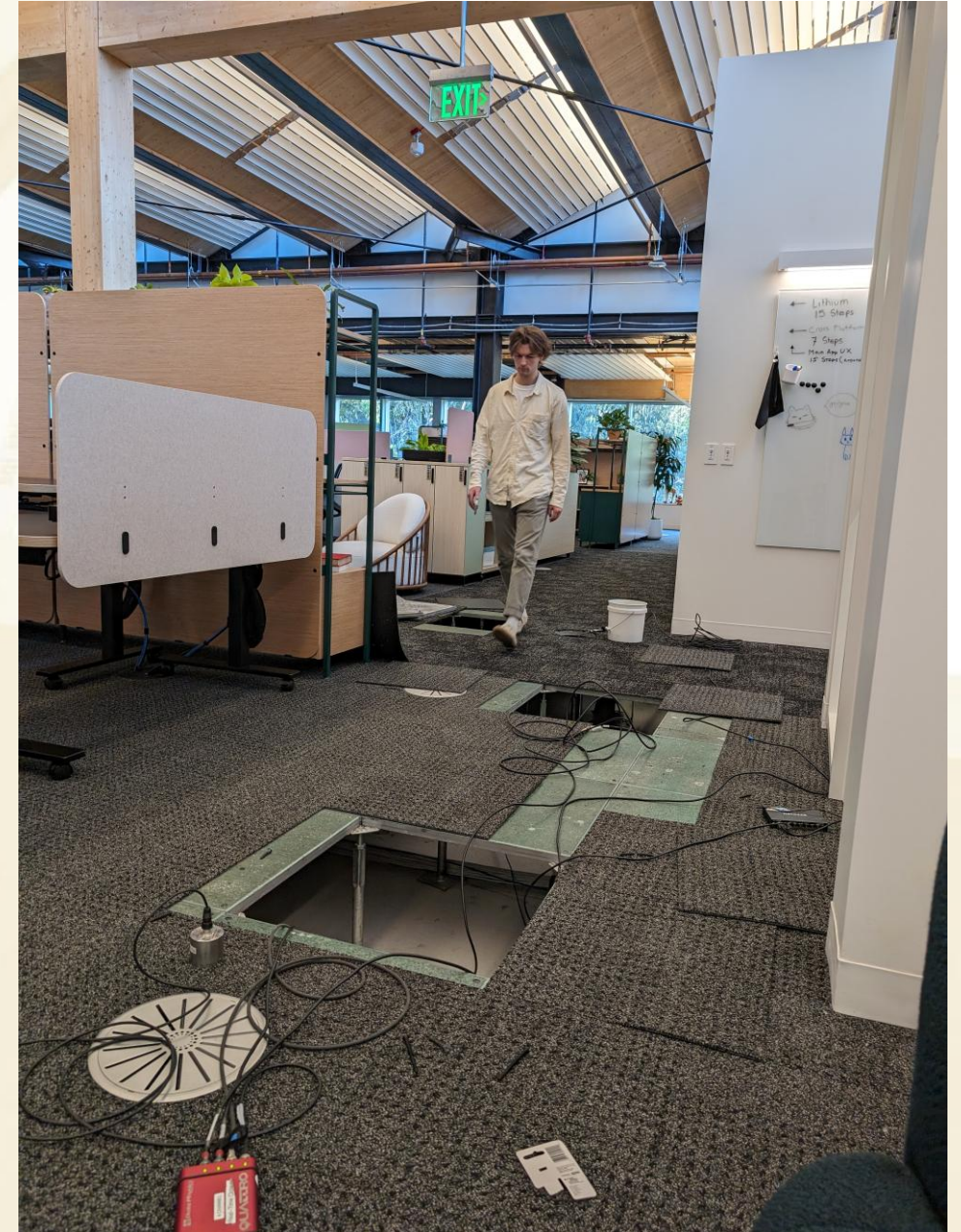
Bldg #	Building Type	Measurement Conditions	# Locations	Criterion	Numerical Criterion
1	Office	Occupied	5	ISO Office	400 $\mu\text{m/s}$ (16,000 mips)
2	Office	Occupied	3	ISO Office	400 $\mu\text{m/s}$ (16,000 mips)
3	Office	Occupied	4	ISO Office	400 $\mu\text{m/s}$ (16,000 mips)
4	Academic/Laboratory	Occupied	5	ISO Res Day & ISO Office	2-400 $\mu\text{m/s}$ (8-16,000 mips)
5	Academic	Core and Shell/As-Built	10	ISO Office	400 $\mu\text{m/s}$ (16,000 mips)
6	Recreation	Occupied	5	ISO Office	400 $\mu\text{m/s}$ (16,000 mips)
7	Housing	As-Built	2	ISO Res Day	200 $\mu\text{m/s}$ (8,000 mips)
8	Housing	As-Built	8	ISO Res Day	200 $\mu\text{m/s}$ (8,000 mips)
9	Office	Occupied	4	ISO Office	400 $\mu\text{m/s}$ (16,000 mips)
10	Office	Core and Shell/As-Built	5	ISO Office	400 $\mu\text{m/s}$ (16,000 mips)
11	Laboratory	Core and Shell	9	VC-A & ISO Operating Theatre	50-100 $\mu\text{m/s}$ (2-4,000 mips)

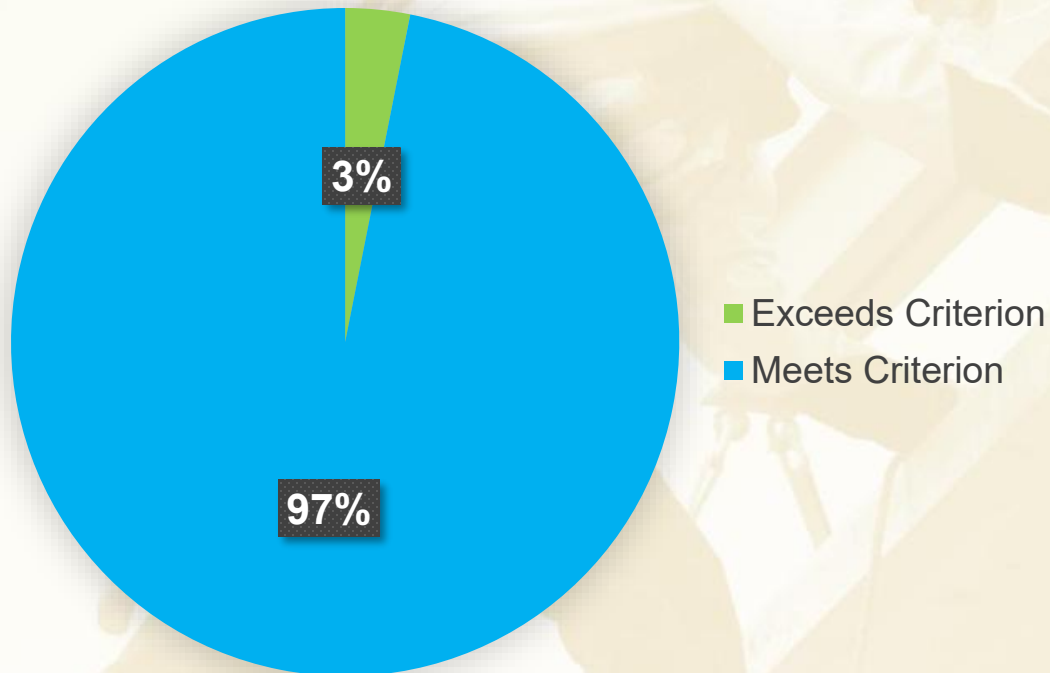
Floor Framing Summary

Bldg #	Floor Assembly	Floor Framing	Topping	Underlayment	Raised Floor
1	3-PLY CLT	Glulam	3" Concrete	None	Y
2	5-PLY CLT	Glulam	1.5" Levelrock	1 1/8" Acoustic	Y
3	5-PLY CLT	Glulam	3.5" Concrete	None	N
4	5 & 7-PLY CLT	Glulam	3.5" Concrete	1" Rigid Insulation	N
5	5-PLY CLT	Glulam	2" Gypcrete	3/8" or 1" Acoustic	N
6	3-PLY CLT	Steel	None	None	N
7	4" MPP	Stud Wall/Glulam	2" Levelrock	3/8" Acoustic	N
8	5-PLY CLT	Stud Wall/Glulam	1.25" Gypcrete	3/4" Acoustic	N
9	3-PLY CLT	Glulam	3" Concrete	1/2" Acoustic	N
10	3-PLY CLT	Steel	2.5" Concrete	None	N
11	3-PLY CLT	MPP/Glulam	5.5" Concrete	None	N

Measurement Methodologies

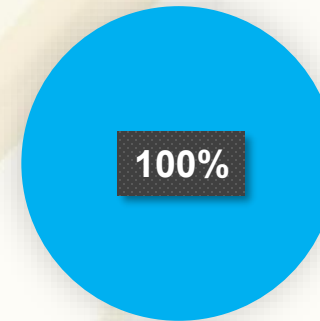
- 1 to 3 walkers at each location
- 7 different walkers across 11 buildings
- Typical structural bays with typical fit-out
- Walk in a straight line through the bay at various normal pace rates
- Measure vibration response at various locations within the bay – focus on midbay for this study
- ***Also measured stiffness, resonance, and damping***





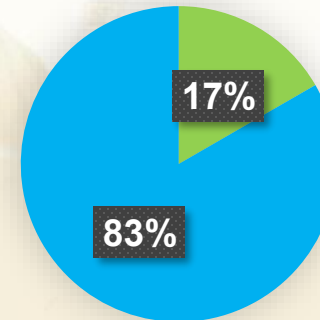
Full Data Set

62 of 64 Locations Meet Criterion
Avg **5.4 dB below criterion**



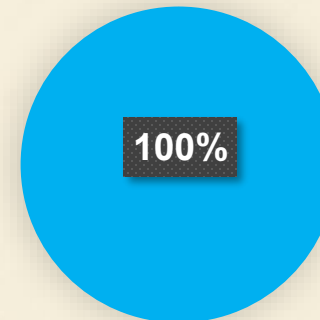
ISO Office

43 of 43 Locations (8 Buildings) Meet Criterion
Avg 7.6 dB below criterion



ISO Residential Day

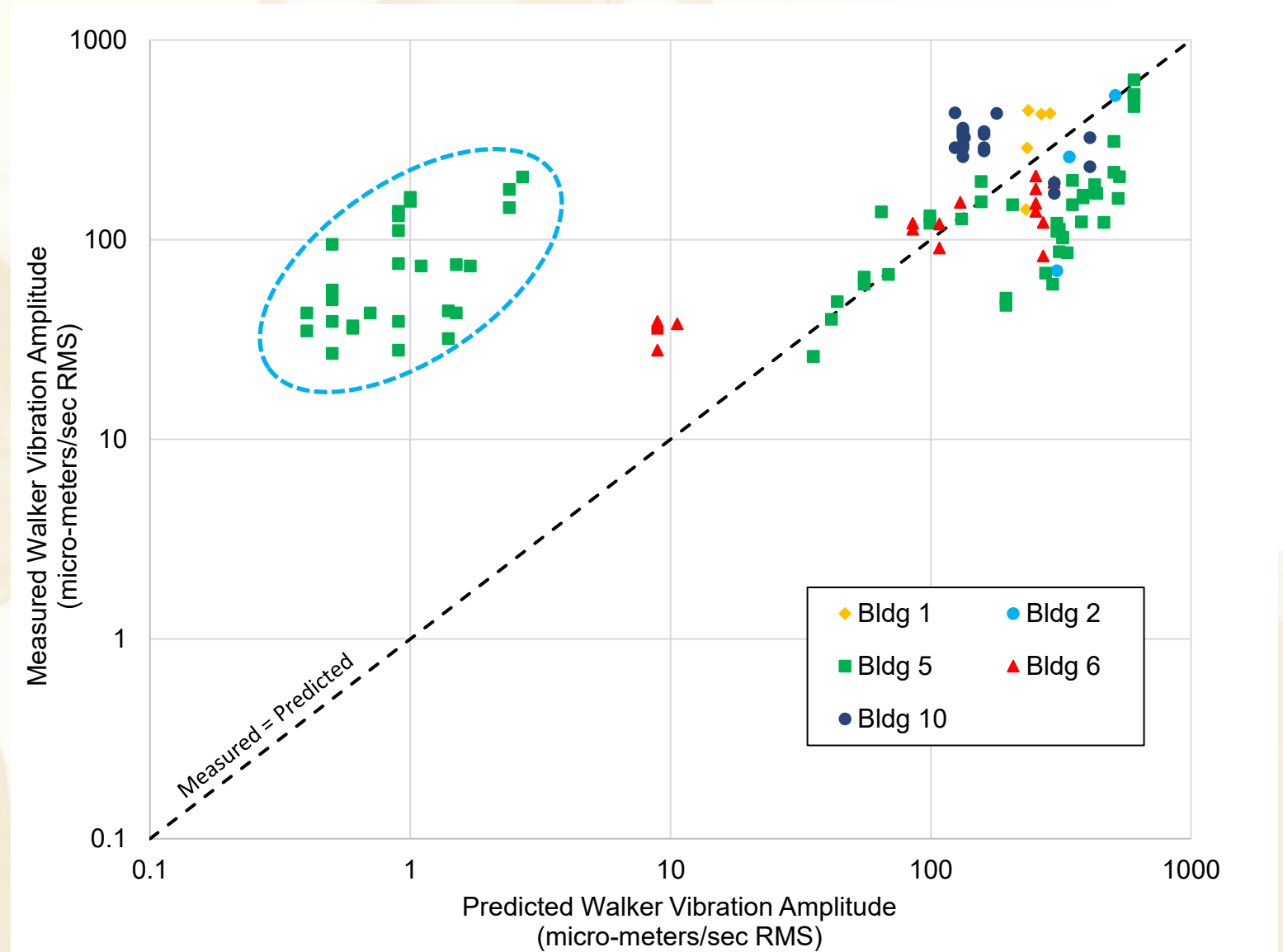
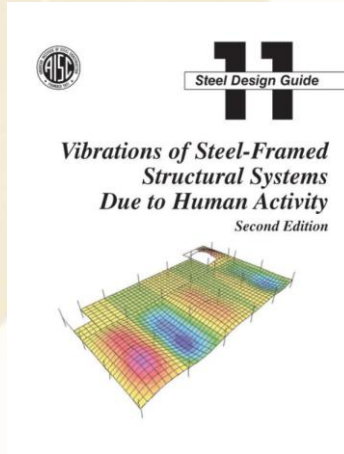
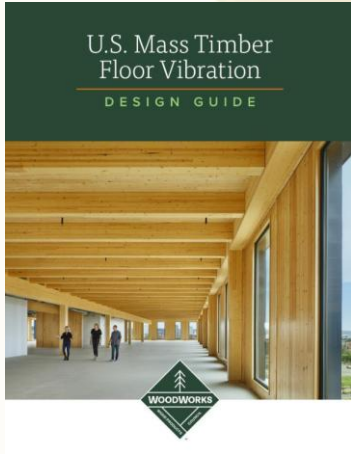
10 of 12 Locations (3 Buildings) Meet Criterion
Avg 1.8 dB below criterion



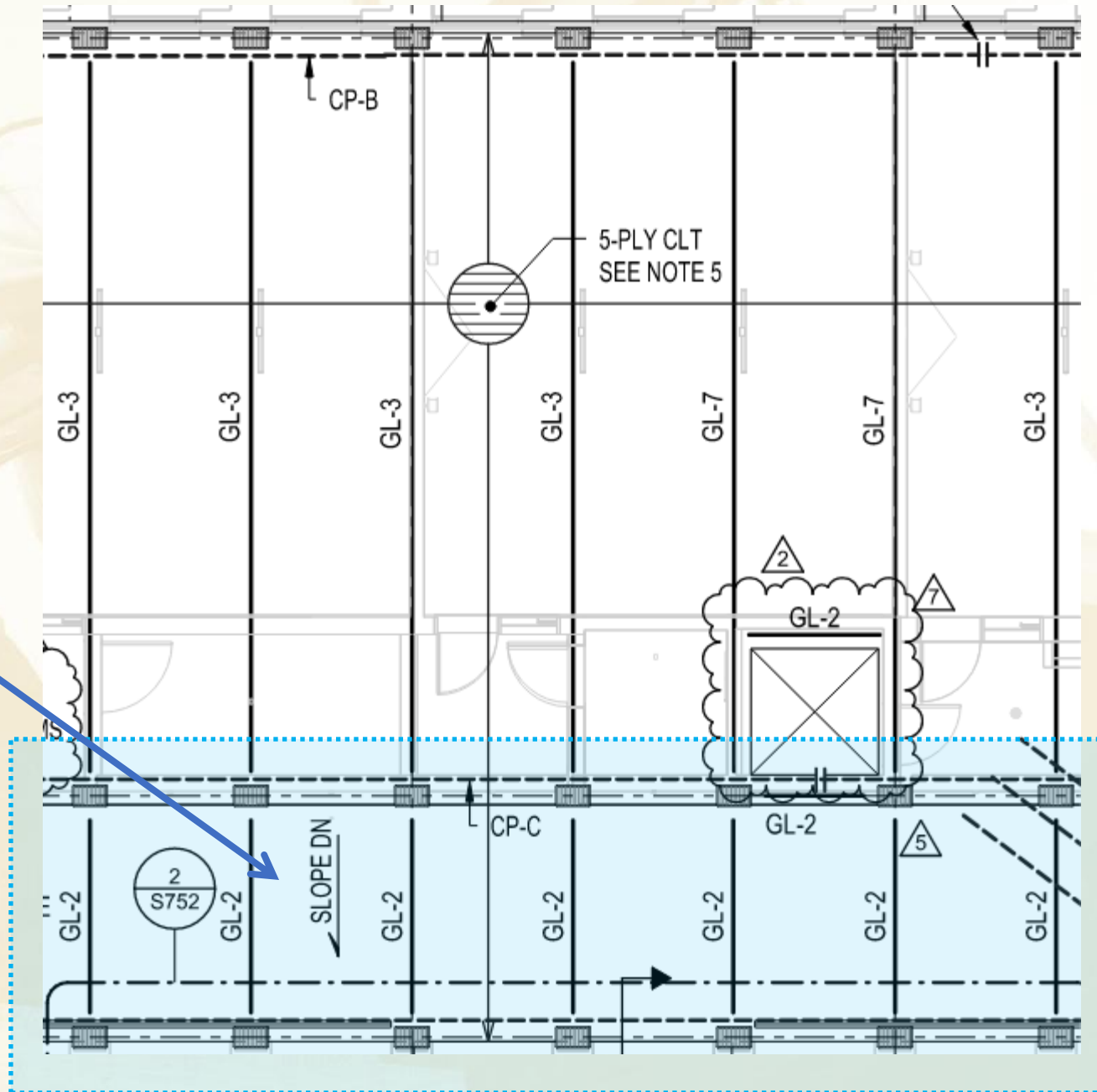
VC-A and ISO Operating Theatre

9 of 9 Locations (1 Building) Meet Criterion
Avg 0.3 dB *above* criterion

Compare Measured Response to Typical Prediction Methodologies



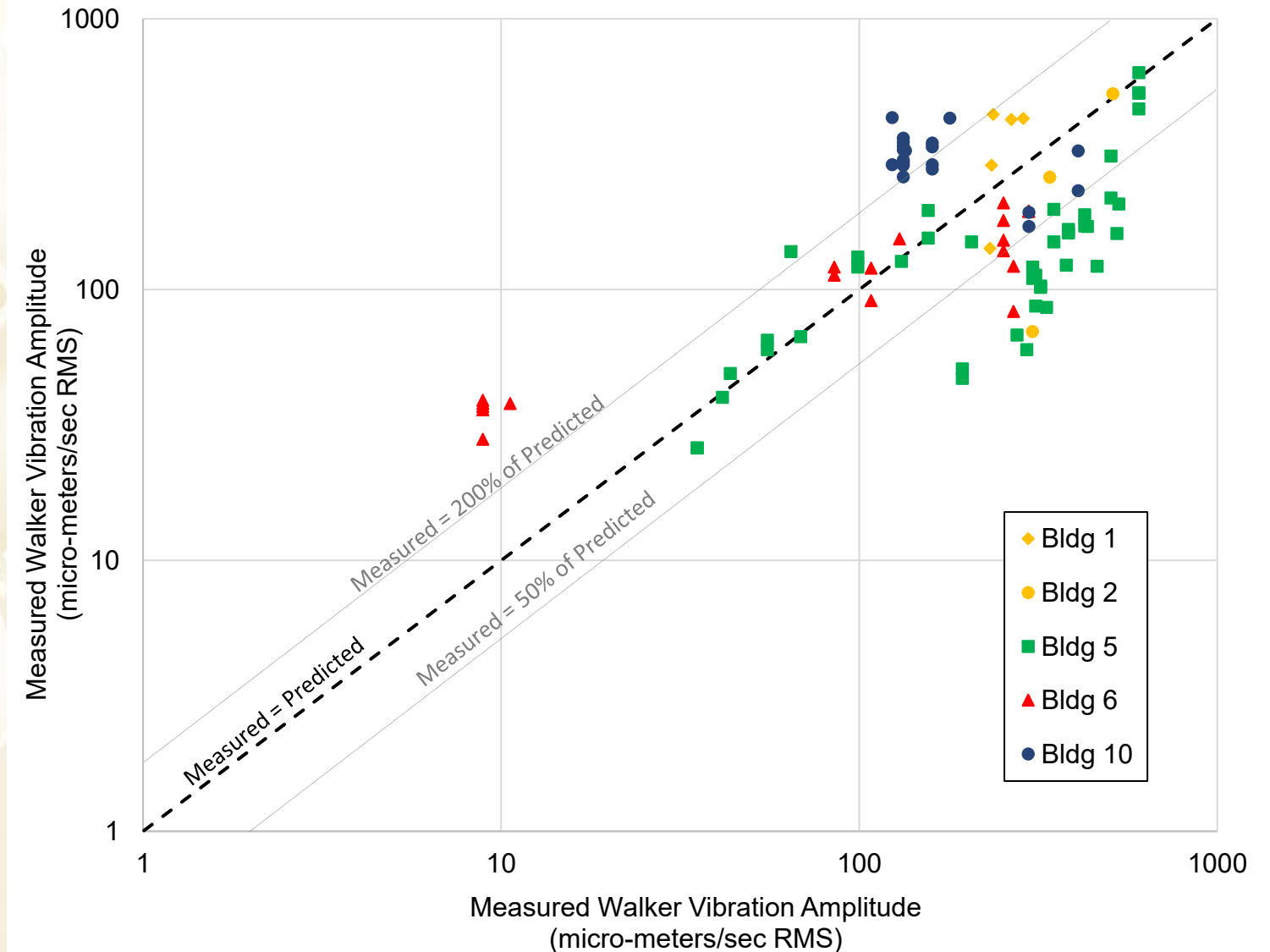
Typical Outlier Structural Bays from Building 5



Remove Apparent Building 5 Outliers

*Model Prediction deviates by
6.1 dB (2x) on Average –
Difference of one criterion class*

*Model Overpredicts
(Conservative) in **60%** of cases*



Mass Timber Data Set

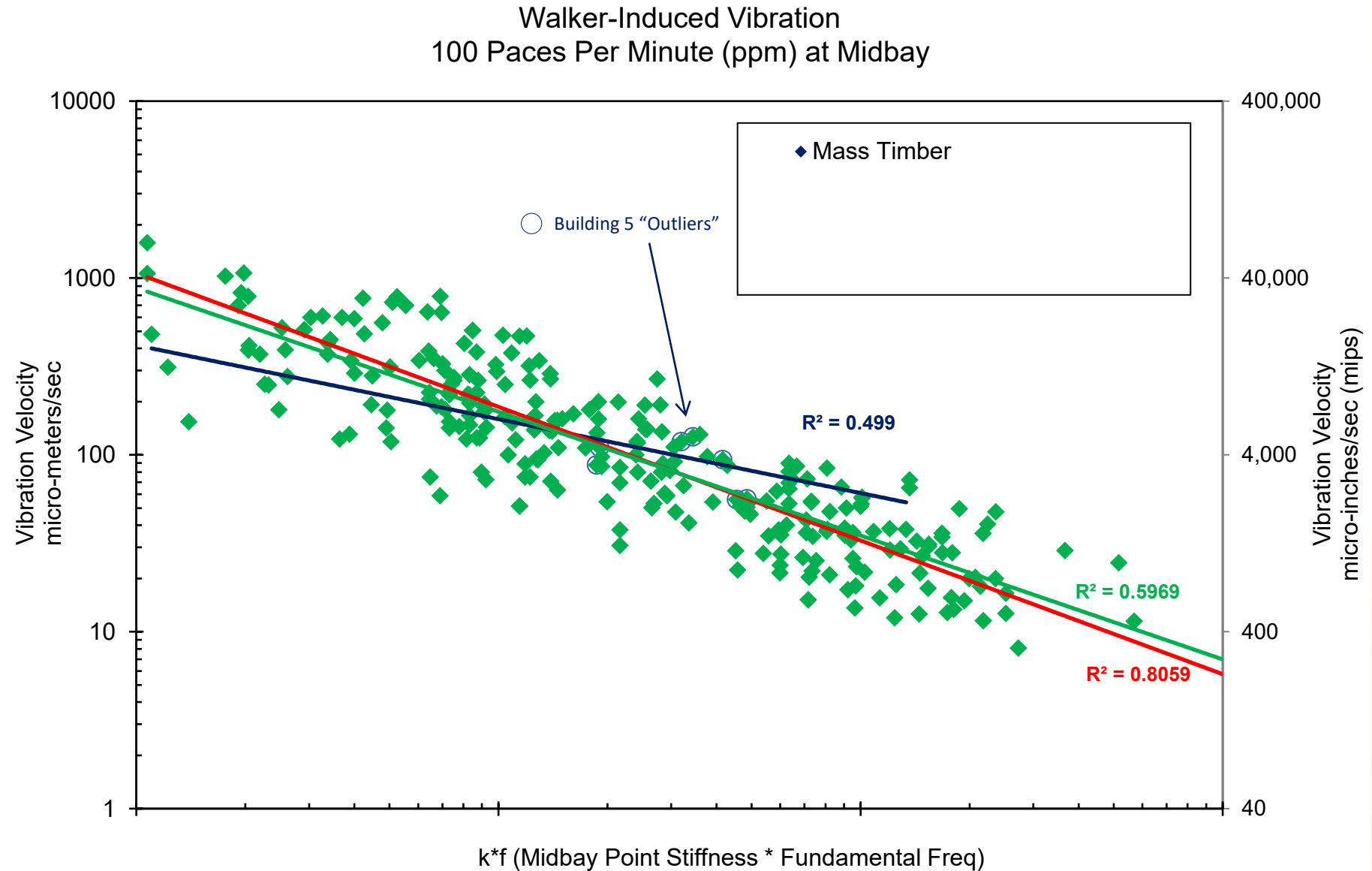
Standard Dev = 4.3 dB

Steel Data Set

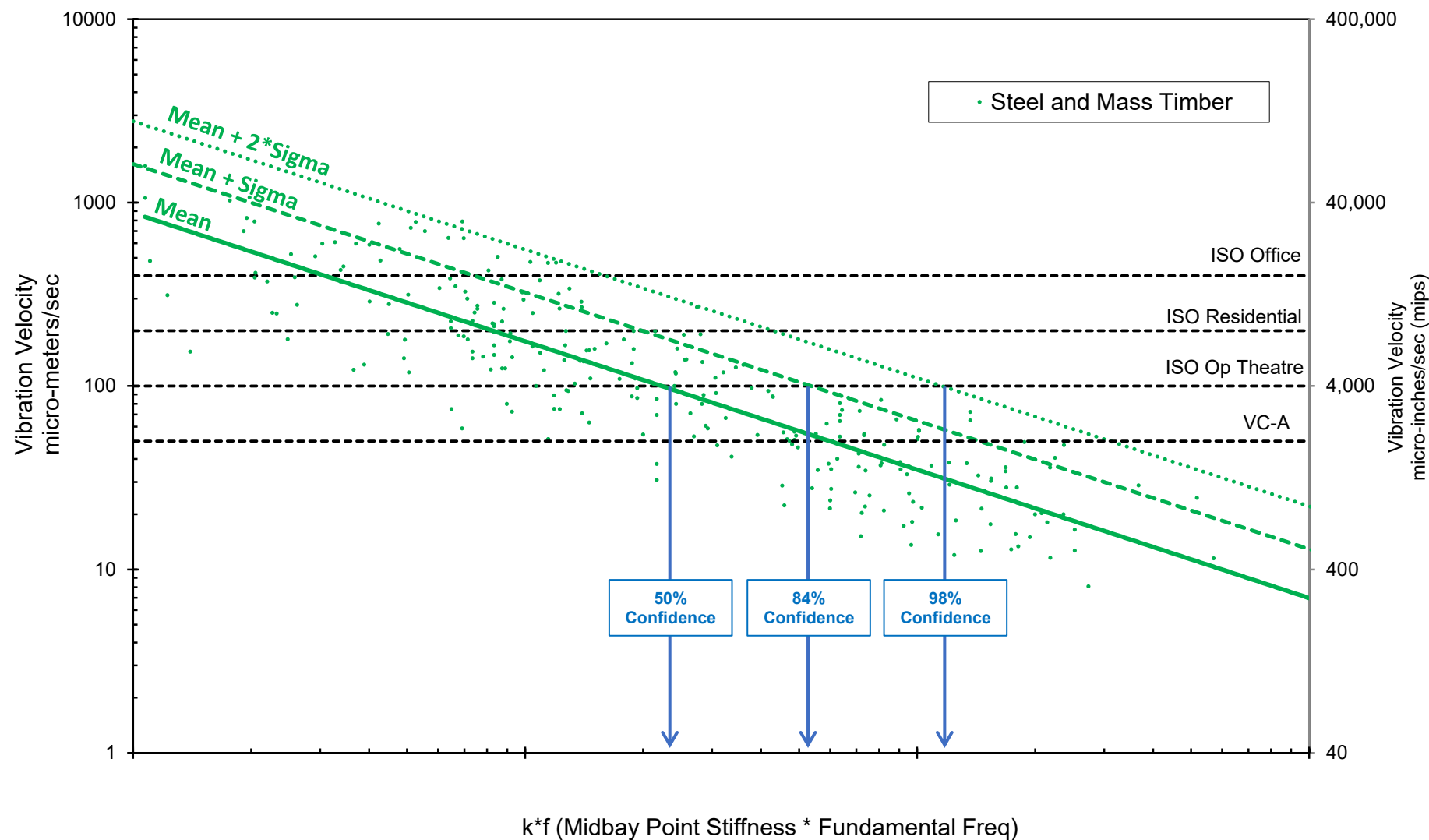
Standard Dev = 4.5 dB

Combined Data Set

Standard Dev = 4.7 dB



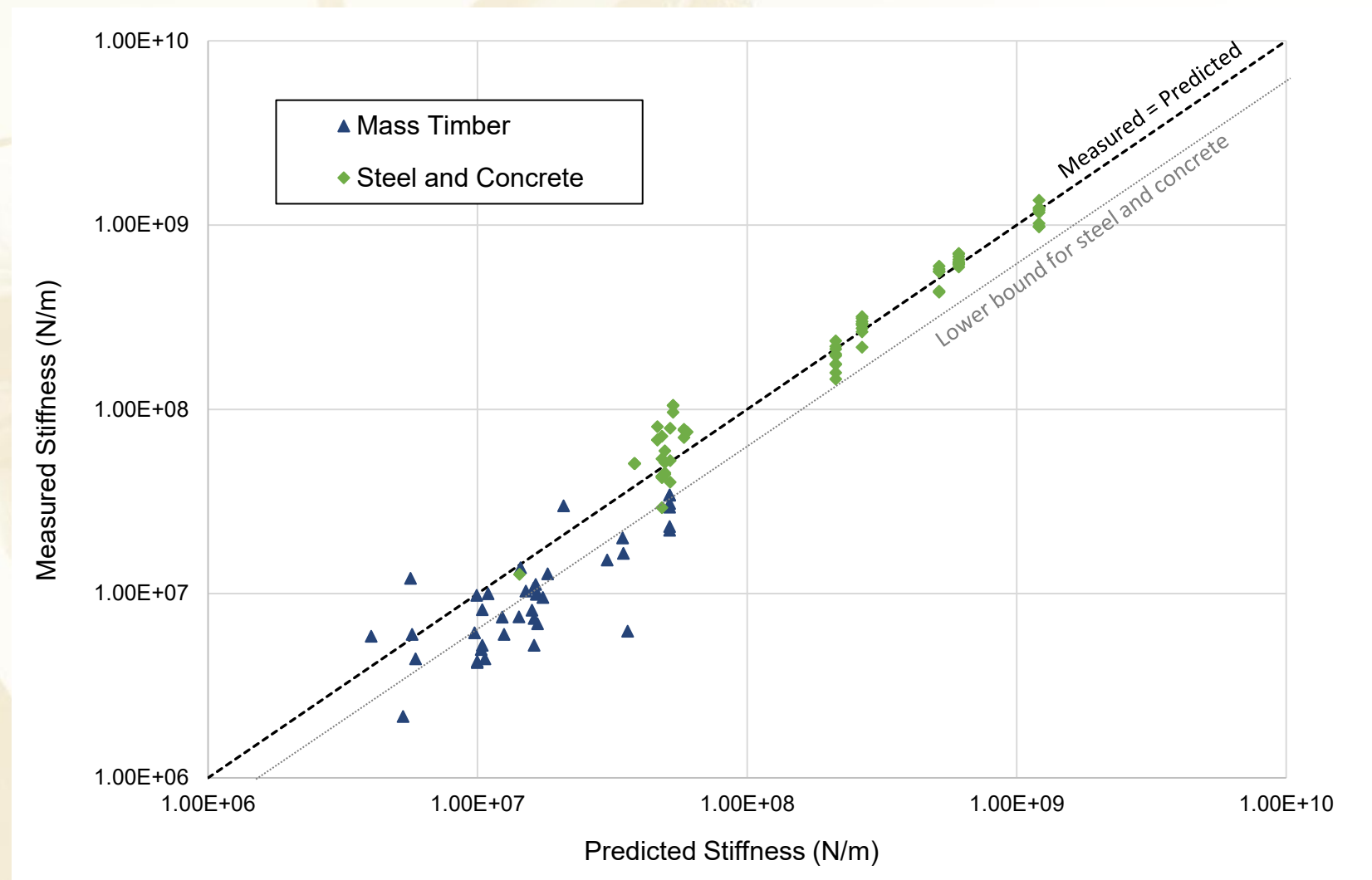
Confidence Levels Facilitate Engineering Judgement



Static Point Stiffness

Measured vs. Predicted

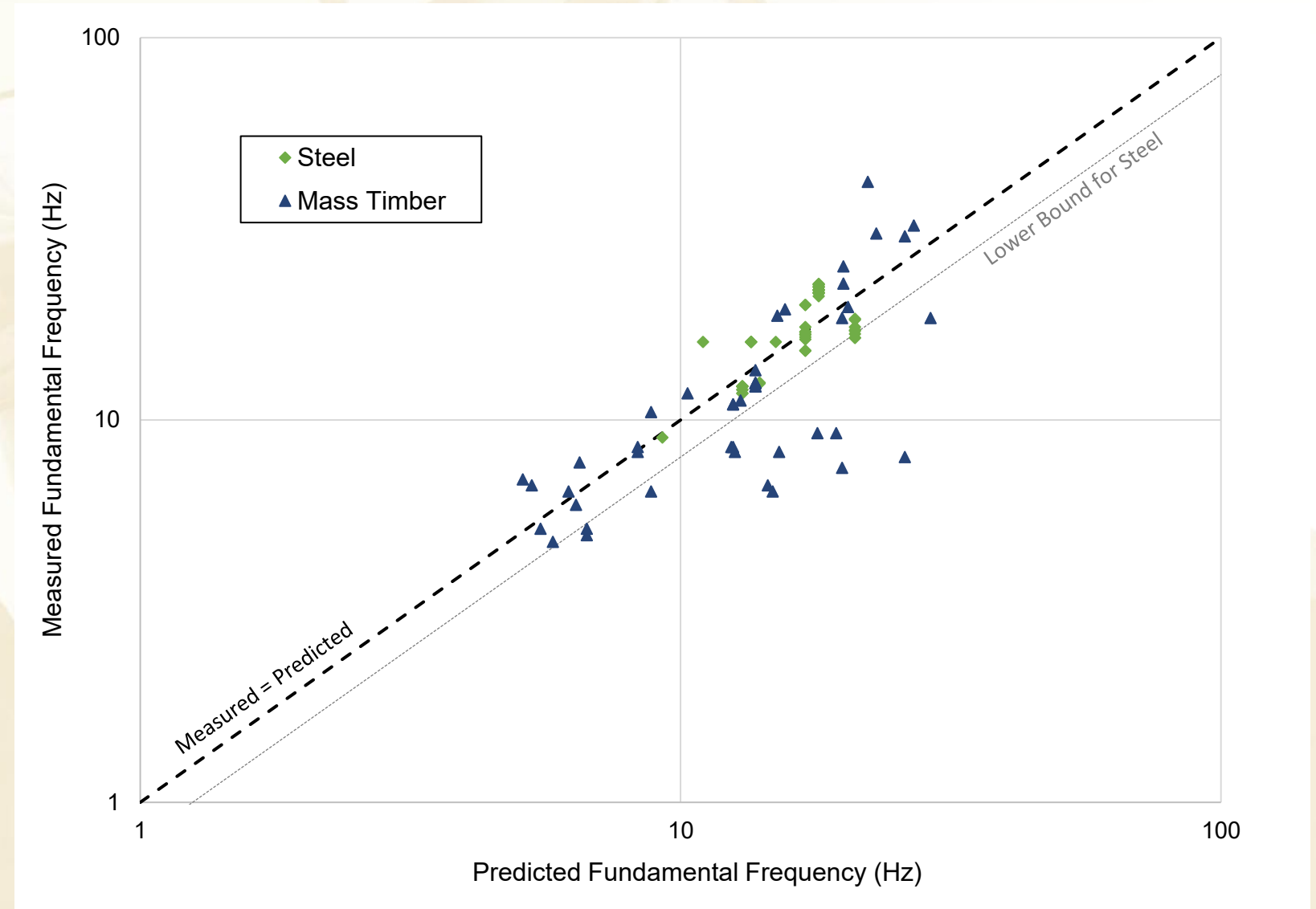
On Average:
Measured = **60% of Predicted**



Floor Type	Meas/Model (dB)	
	Avg.	Standard Dev
Mass Timber	-4.4	3.8
Steel and Concrete	+0.5	2.0

Fundamental Resonance

Measured vs. Predicted

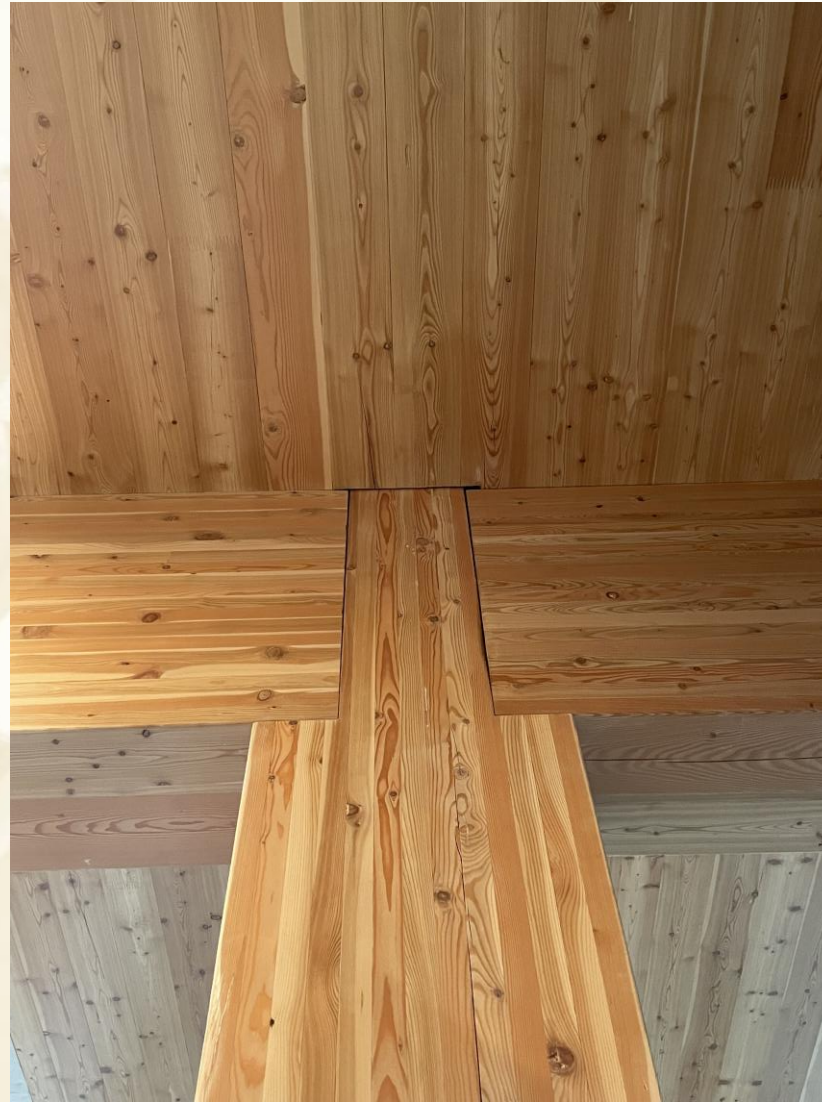


Why do the models over-predict stiffness in mass timber buildings?

Softer floors = more variability?

Connections and composite action?

Material property variability?



Conclusions

- Buildings consistently met vibration targets
- Clear divergence from steel and concrete methods
- Sensitive buildings are viable, but **conservatism is advisable**
- Probabilistic prediction methodologies help facilitate engineering judgment
- Additional data and detailed studies needed - ***Improve prediction accuracy, reduce conservatism, and increase cost competitiveness***



Additional Studies

Further quantify unique aspects of mass timber walker response and improve stiffness prediction accuracy through studies of:

- Add Additional Buildings to the Data Set
- Individual Bay Studies
- Parametric Studies of Components, Connections, Environmental Factors, etc.
- Subsets within “Mass Timber” Category

Leverage Broader Industry Experience and Data



Study Team



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Questions?

Additional Support From

Degenkolb

Martin/Martin

*The Building Owners, Site Superintendents, and Engineers who provided access
(and company!) during our testing*