FEBRUARY 14, 2022

Construction Vibrations

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Senior Project Engineer

Thornton Tomasetti

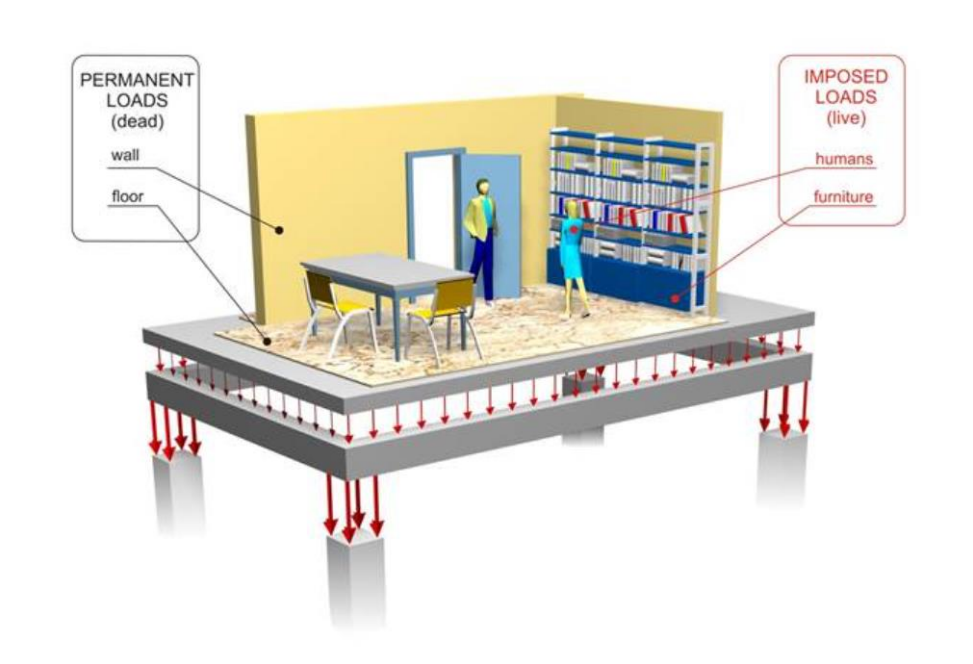
AGENDA

1. Introduction to Vibrations
2. How People Perceive Vibrations
3. How Structures Respond to Vibrations
4. Construction Vibrations
5. Vibration Monitoring
6. Conclusions

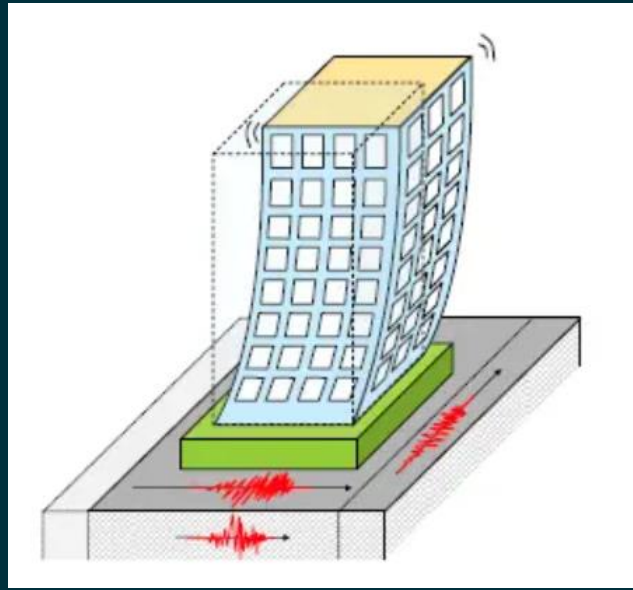
INTRODUCTION TO VIBRATIONS

INTRODUCTION TO VIBRATIONS

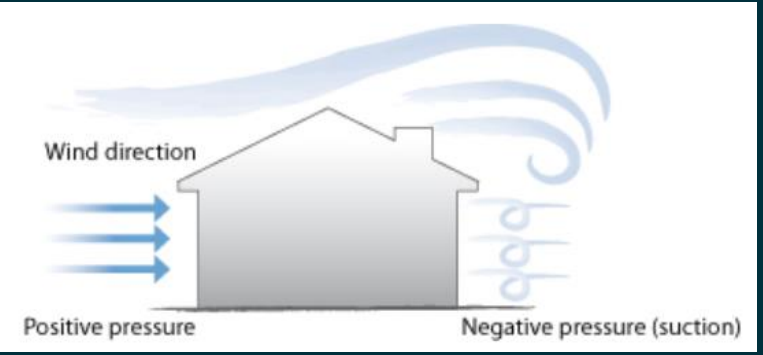
- Static vs dynamic actions:



https://www.buildinghow.com/en-us/Products/Books/Volume-A/The-structural-frame/Structural-frame-loading/Gravity-Loads



https://www.structuralguide.com/seismic-design/

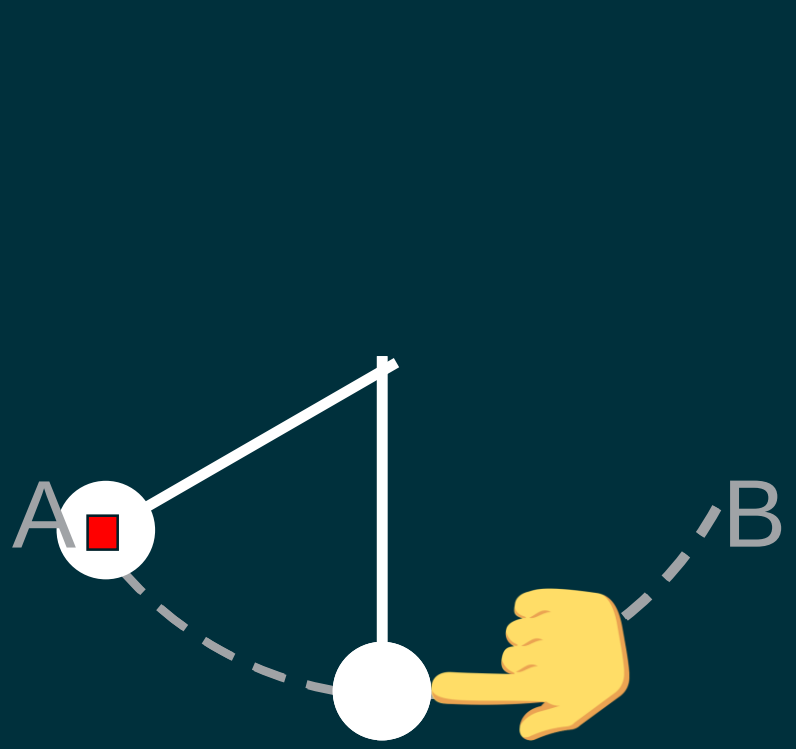


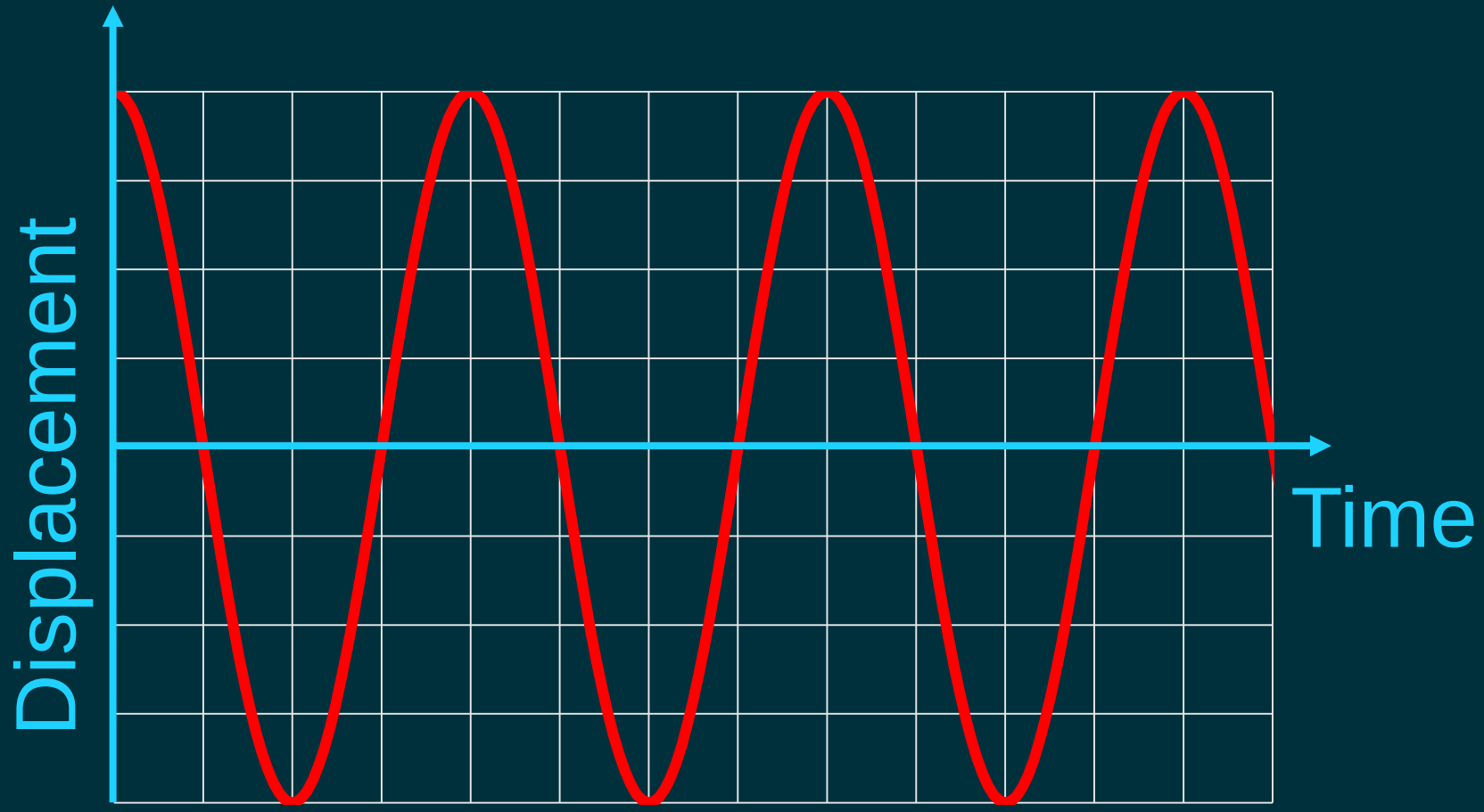
https://www.dlsweb.rmit.edu.au/Toolbox/buildright/content/bcgbc4010a/01_loads_loading/01_primary_loads/page_004.htm

INTRODUCTION TO VIBRATIONS

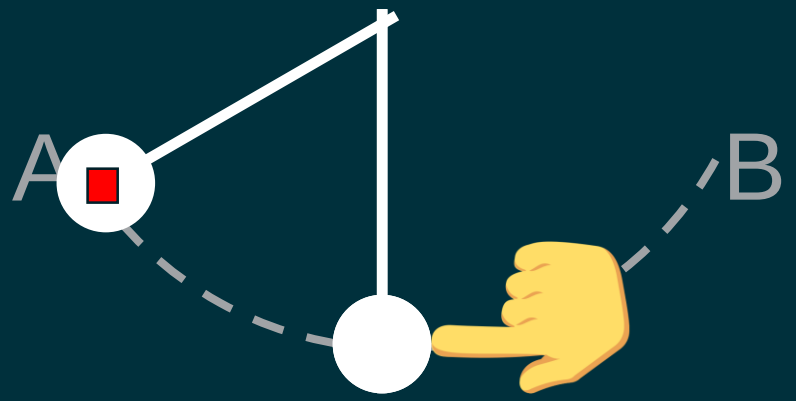
Sources of vibrations

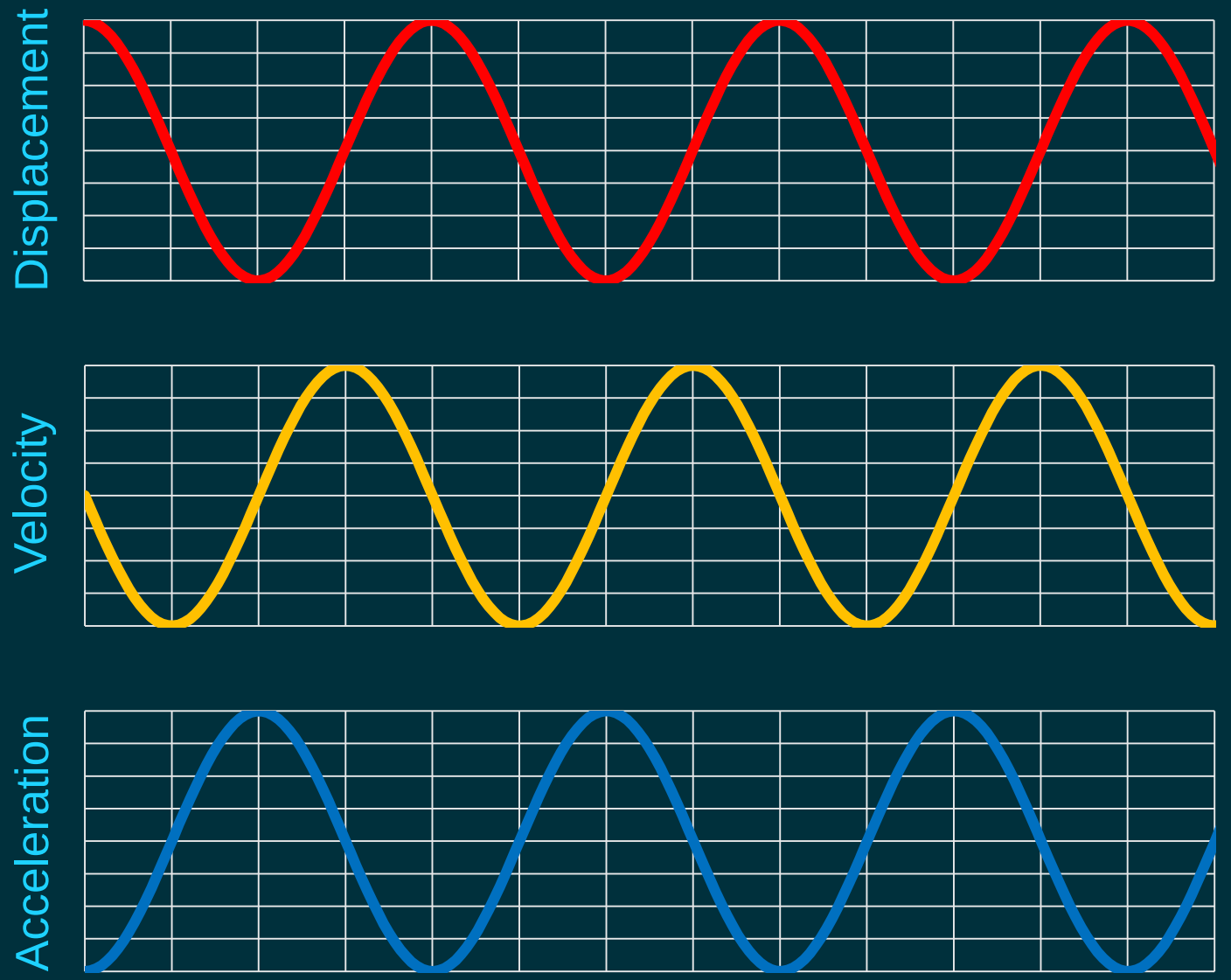
INTRODUCTION TO VIBRATIONS





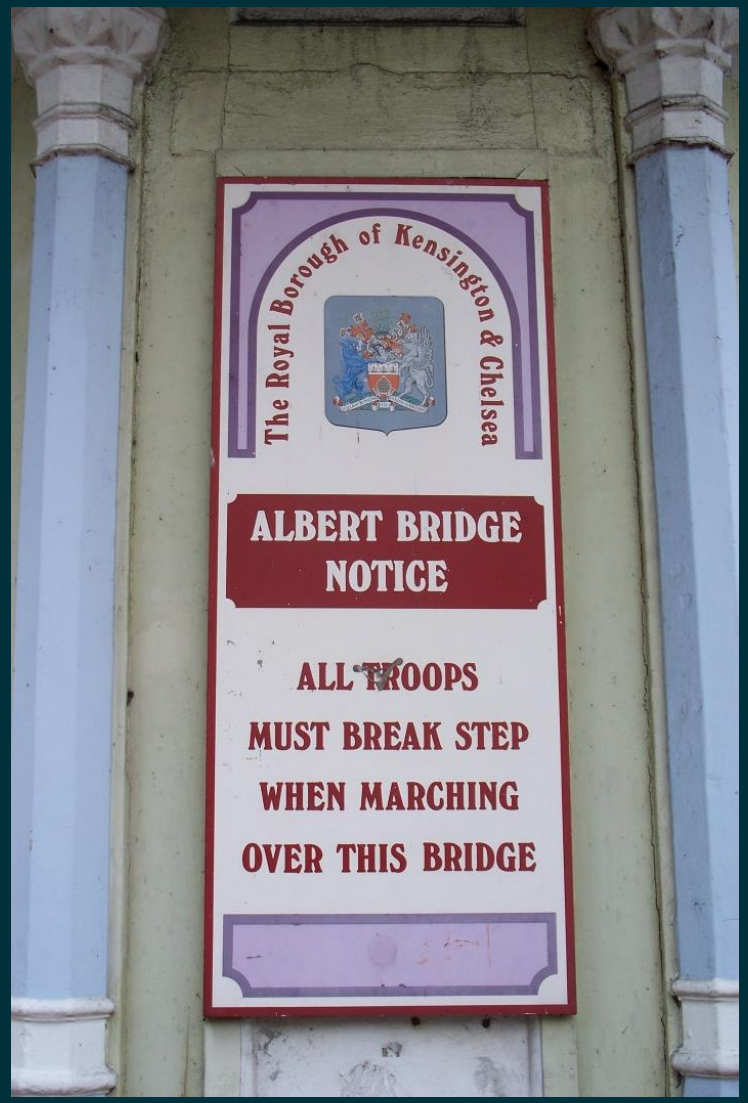
INTRODUCTION TO VIBRATIONS





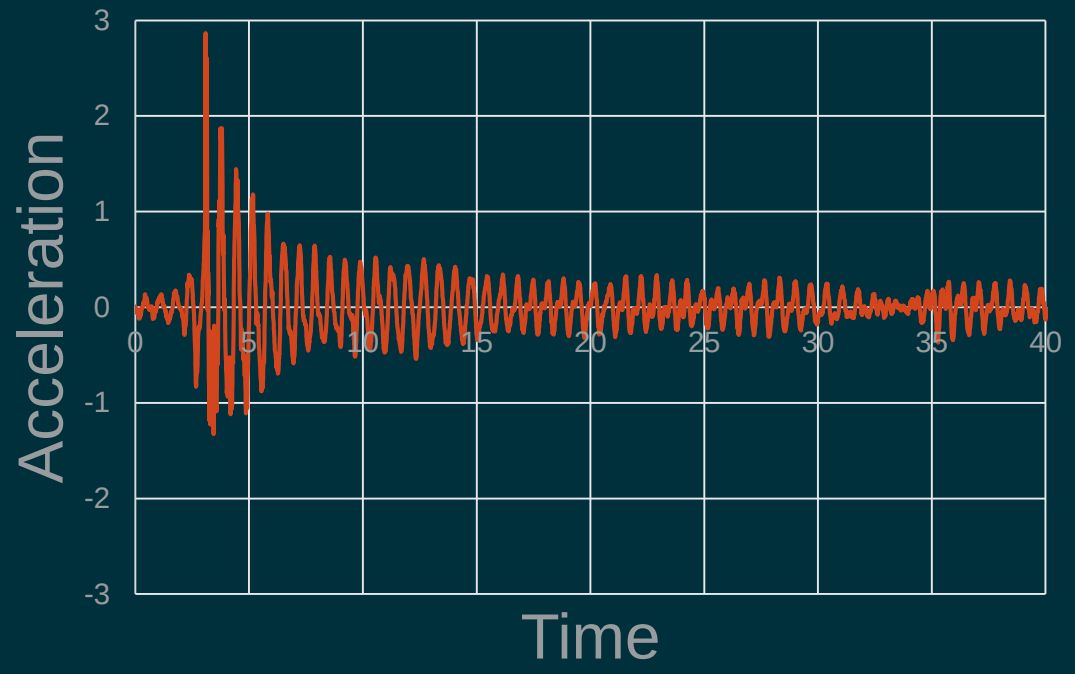
INTRODUCTION TO VIBRATIONS

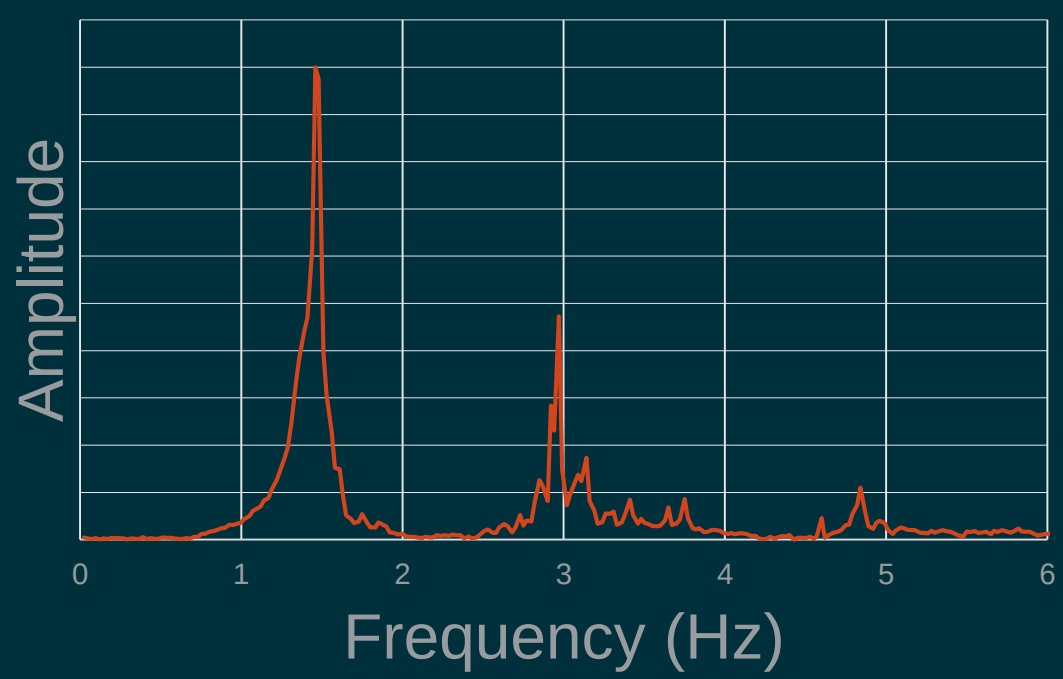
Resonance



INTRODUCTION TO VIBRATIONS

Time domain vs frequency domain

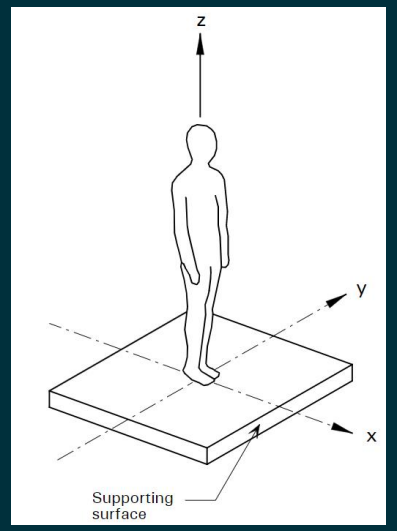


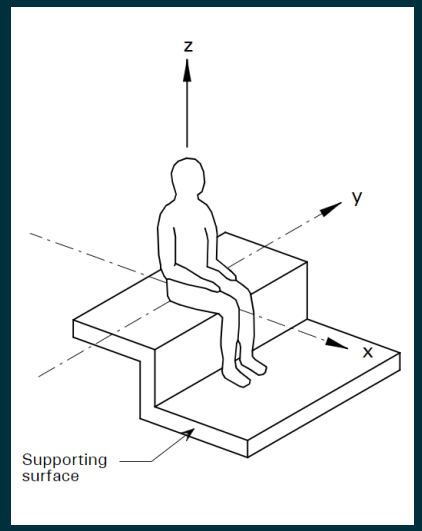


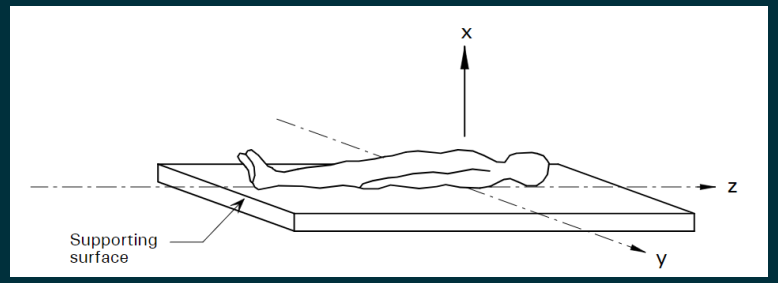
HOW PEOPLE PERCEIVE VIBRATIONS

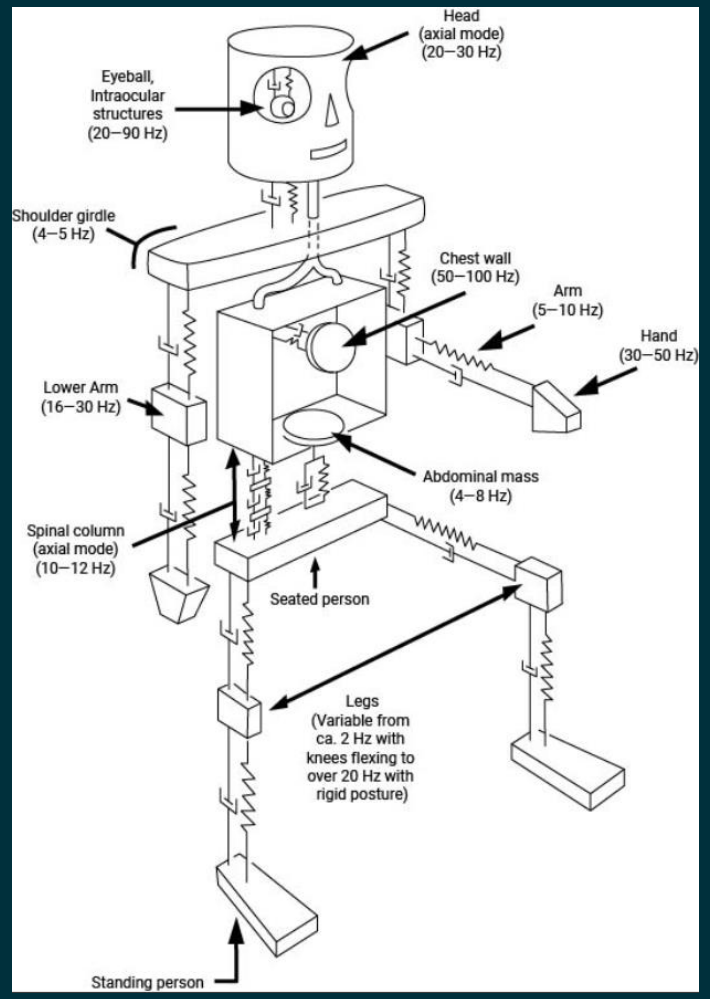
HOW PEOPLE PERCEIVE VIBRATIONS

The human body perceives vibrations differently whether it is in the standing, seated, or recumbent position, respectively.







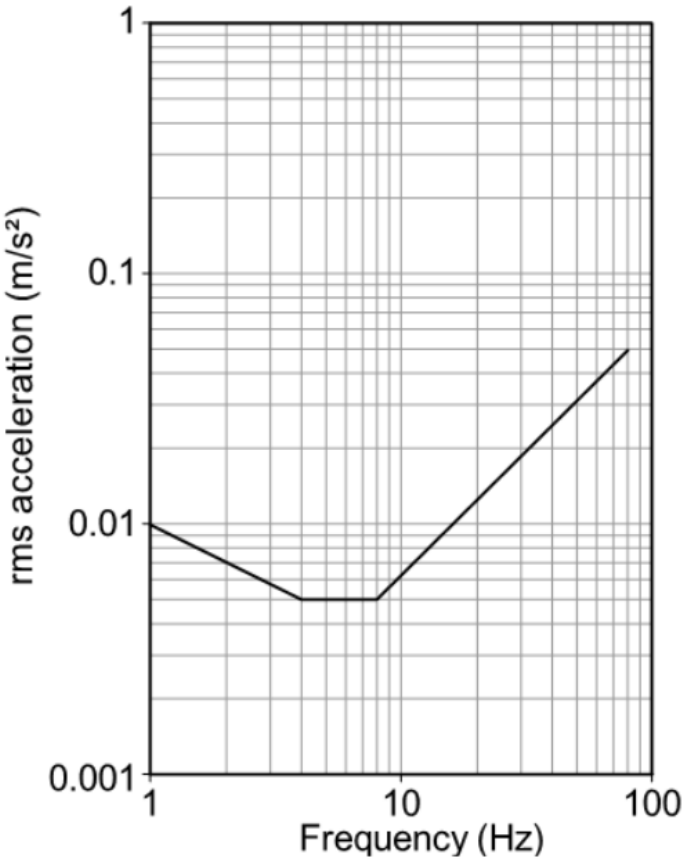


HOW PEOPLE PERCEIVE VIBRATIONS

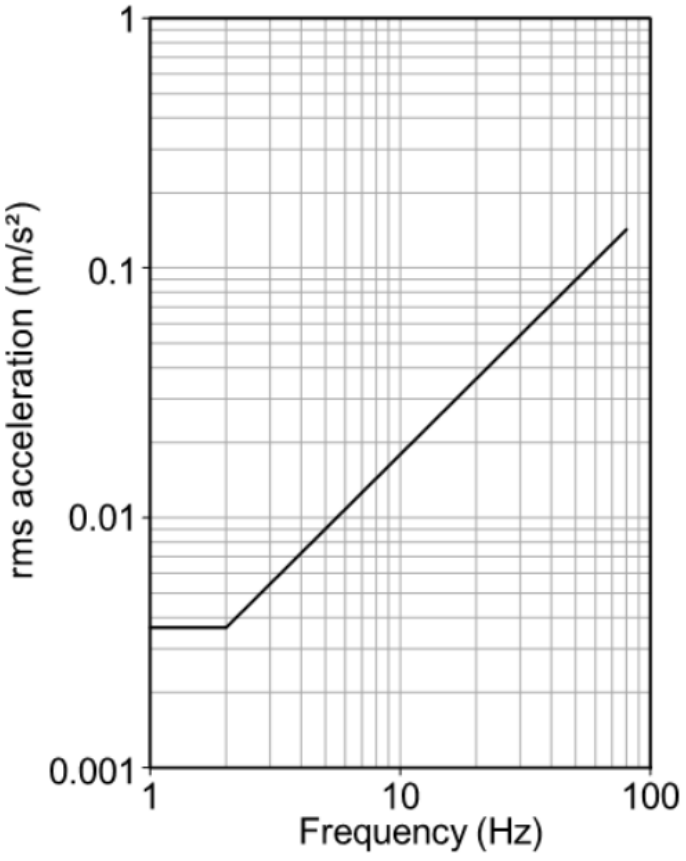
The human body's response to vibrations also varies with the excitation frequency.

[British Standards, BS 6472]

Vertical vibrations



Transverse vibrations



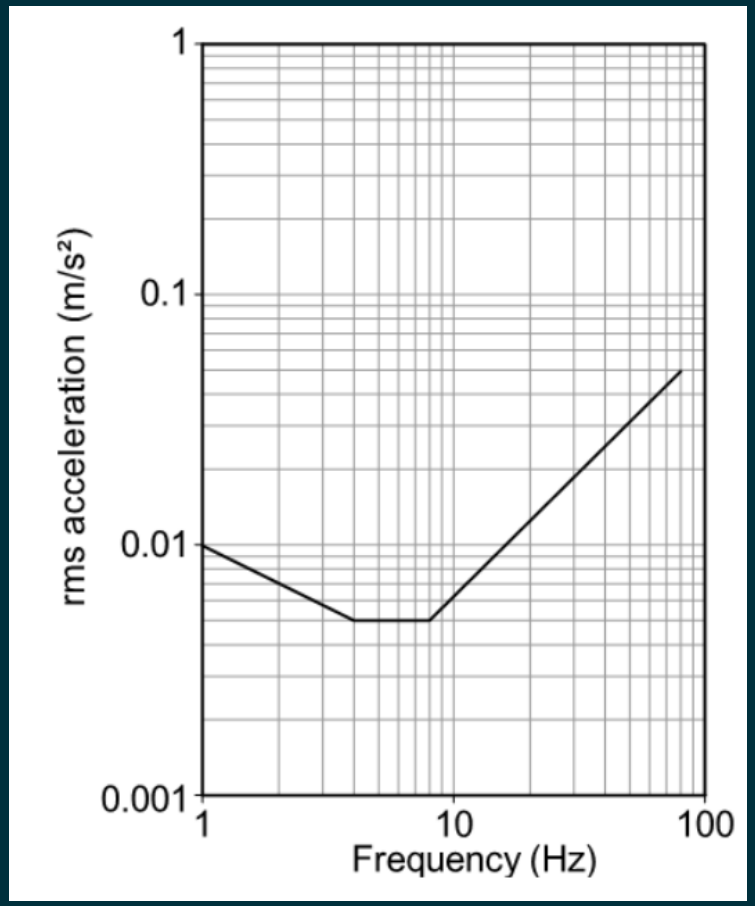
HOW PEOPLE PERCEIVE VIBRATIONS

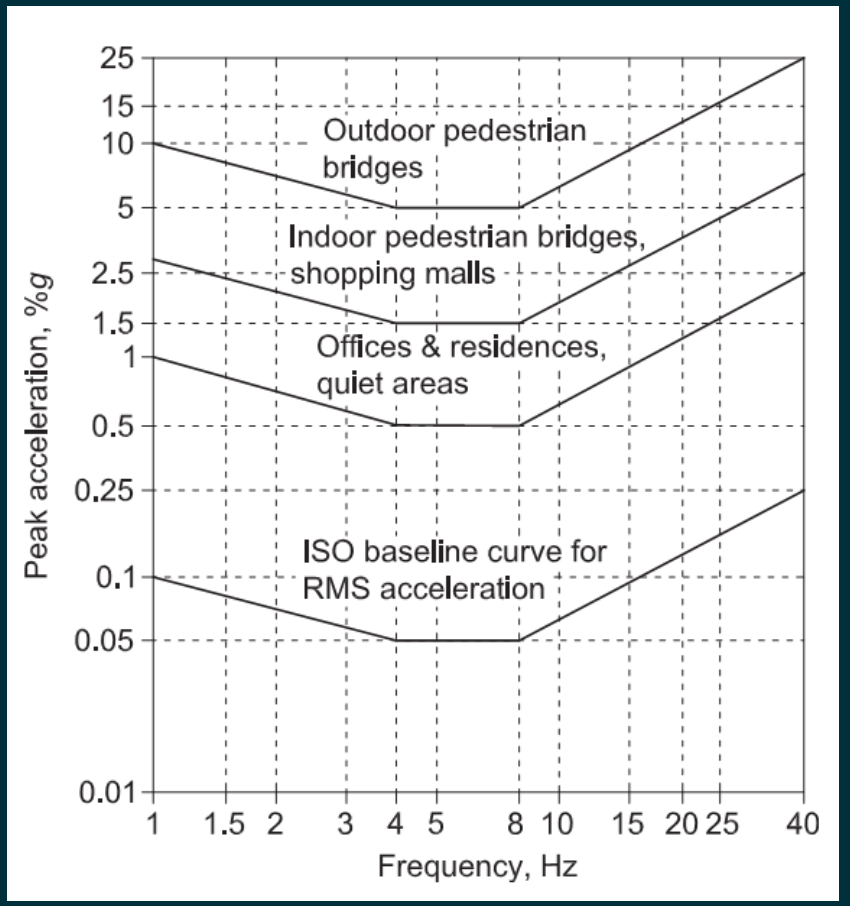
The human body's response to vibrations also varies with the excitation frequency.

[British Standards, BS 6472]

[American Institute of Steel Construction, AISC Design Guide 11]

Vertical vibrations





HOW STRUCTURES RESPOND TO VIBRATIONS

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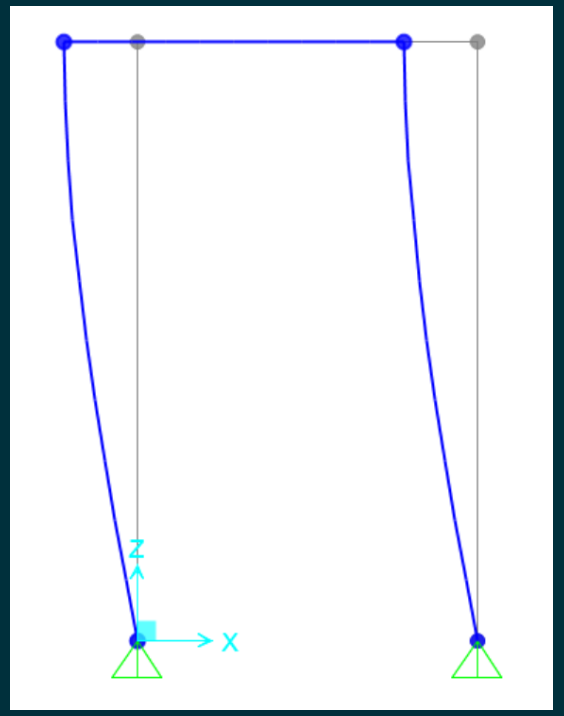

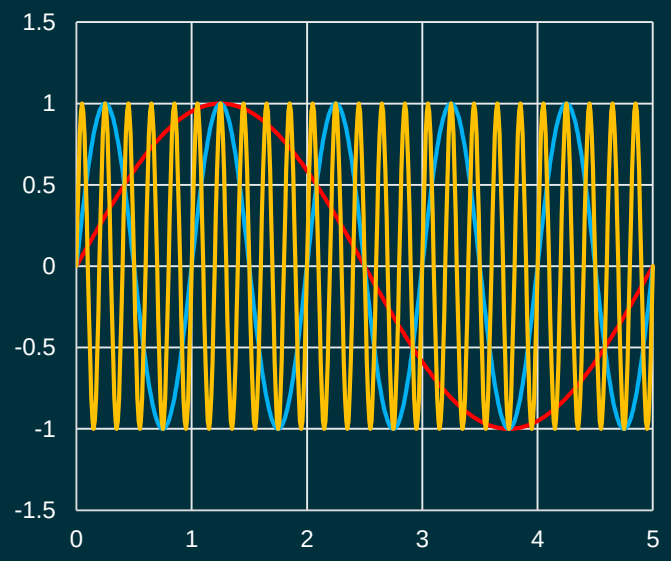

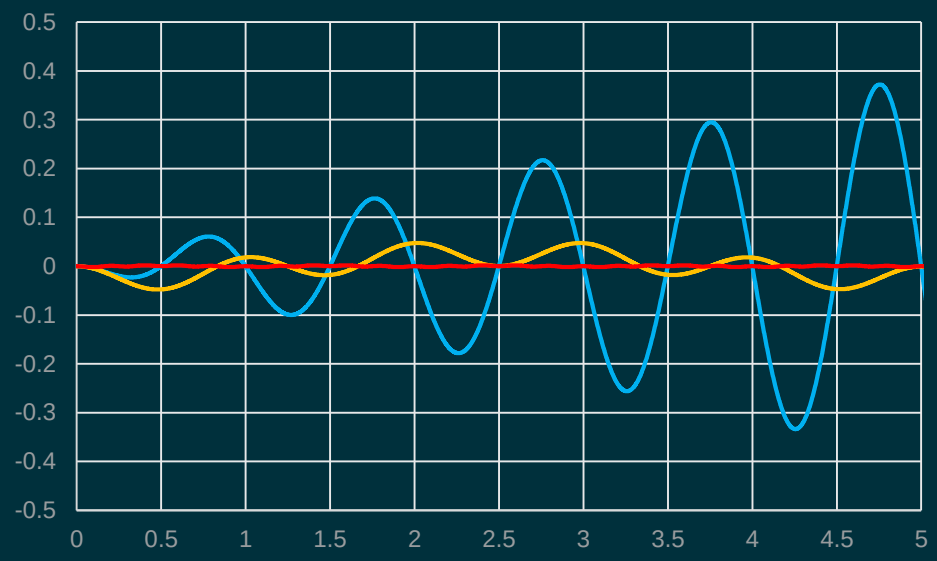

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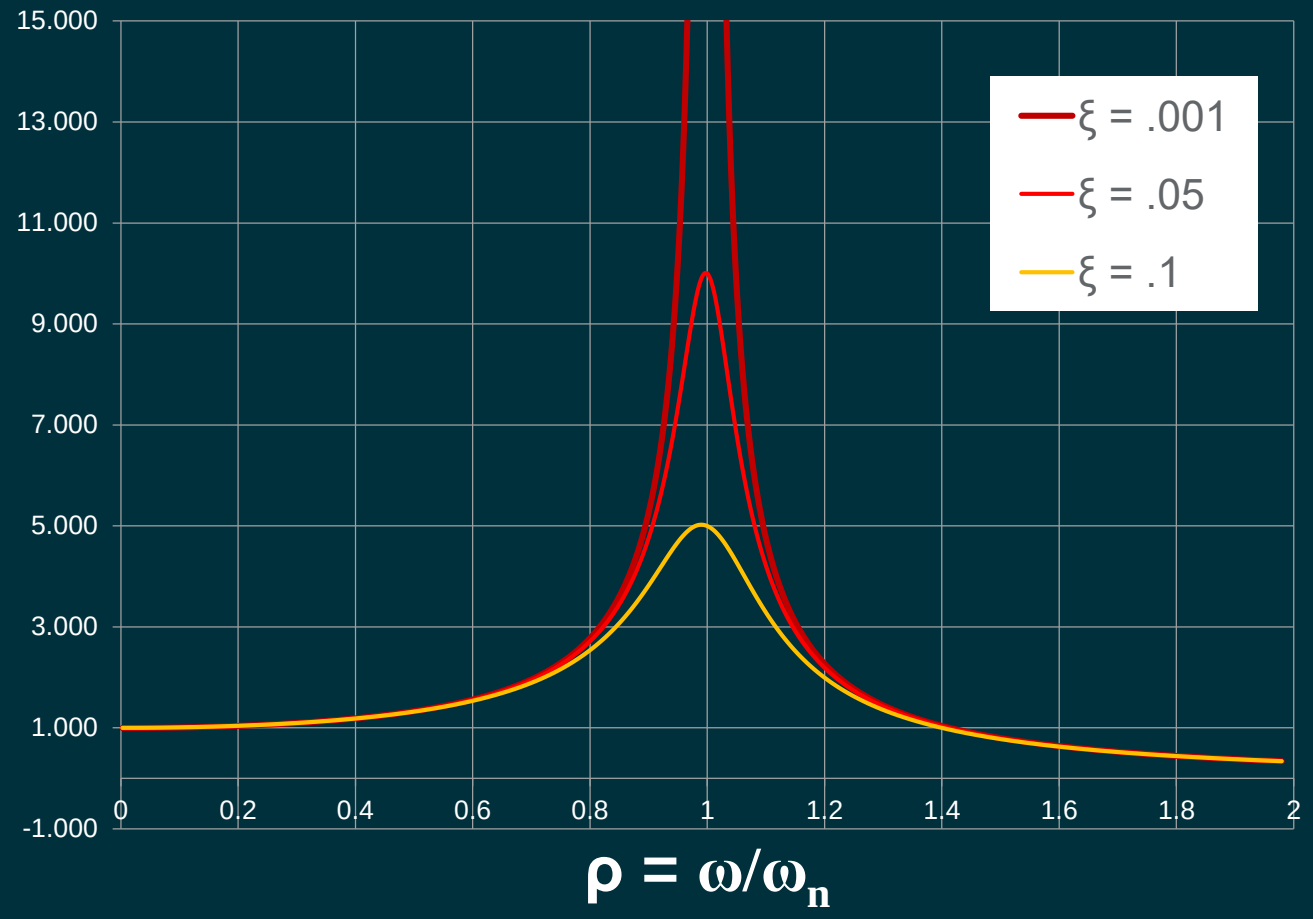

CONSTRUCTION VIBRATIONS

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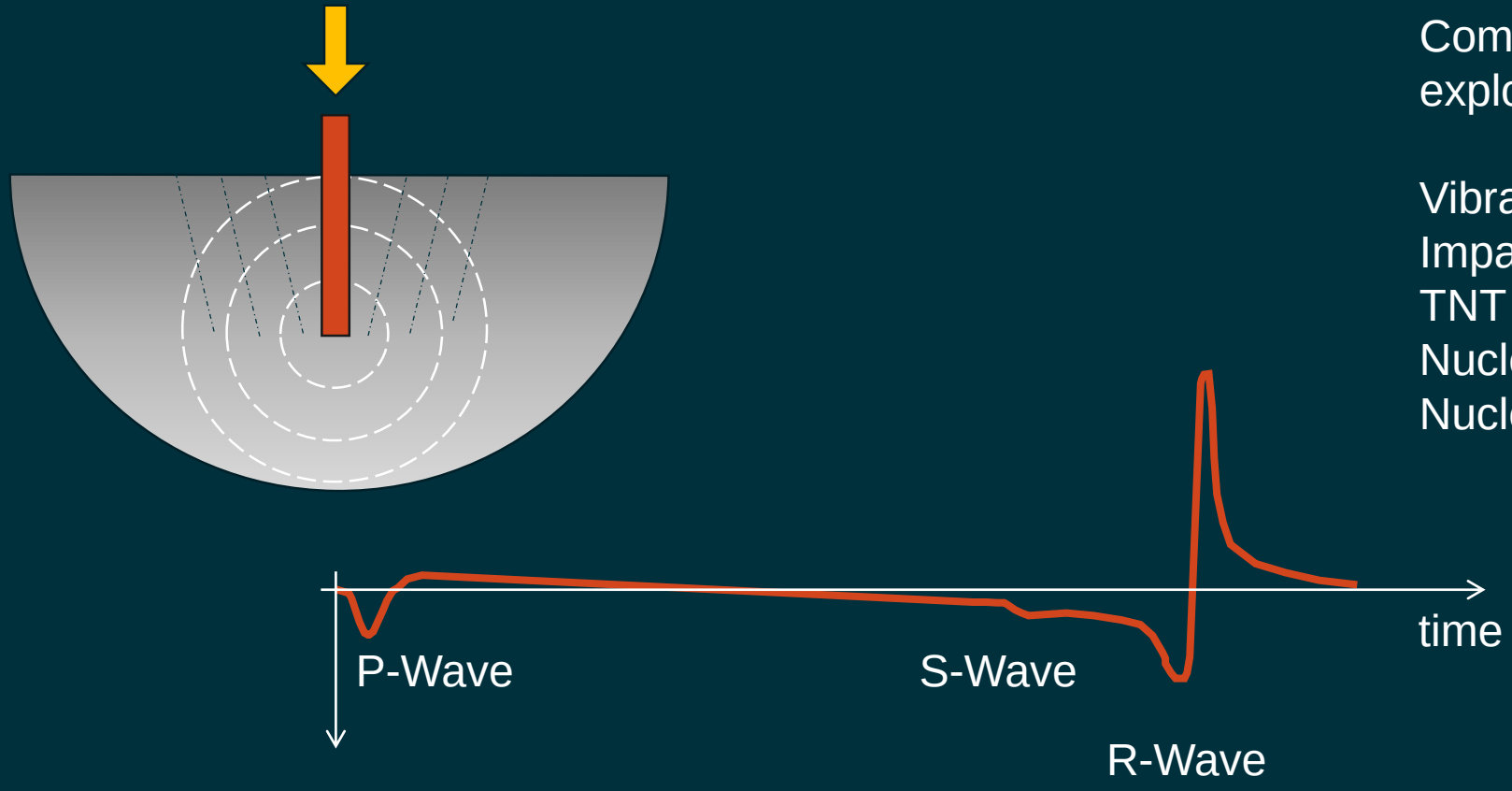
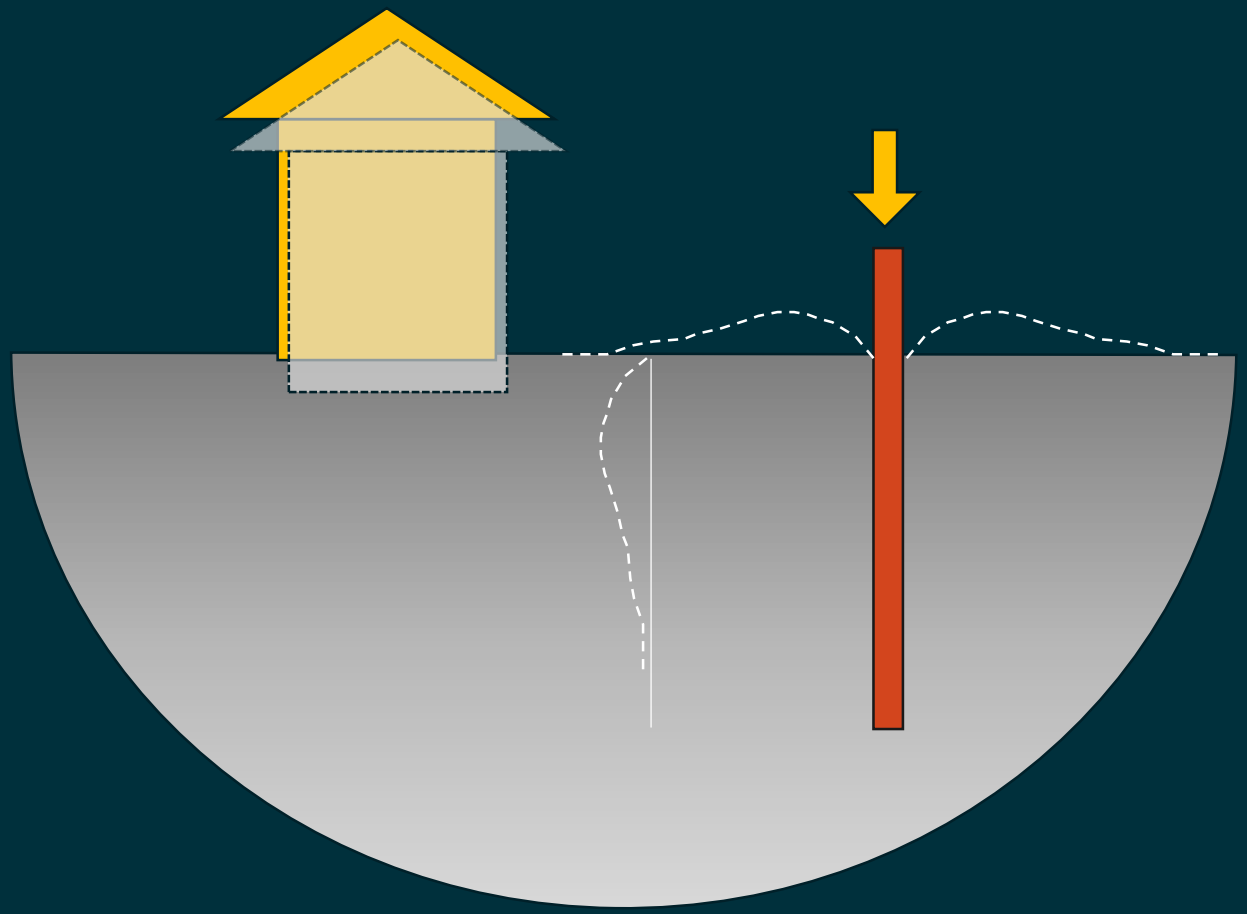


Comparison of pile driving and explosive energies:

Vibratory	1
Impact	2
TNT exp.	60
Nuclear exp.	$>10^6$
Nuclear exp.	$>10^9$

CONSTRUCTION VIBRATIONS



1. Ground vibrations
2. Vibratory settlements
3. Loss of support displacement

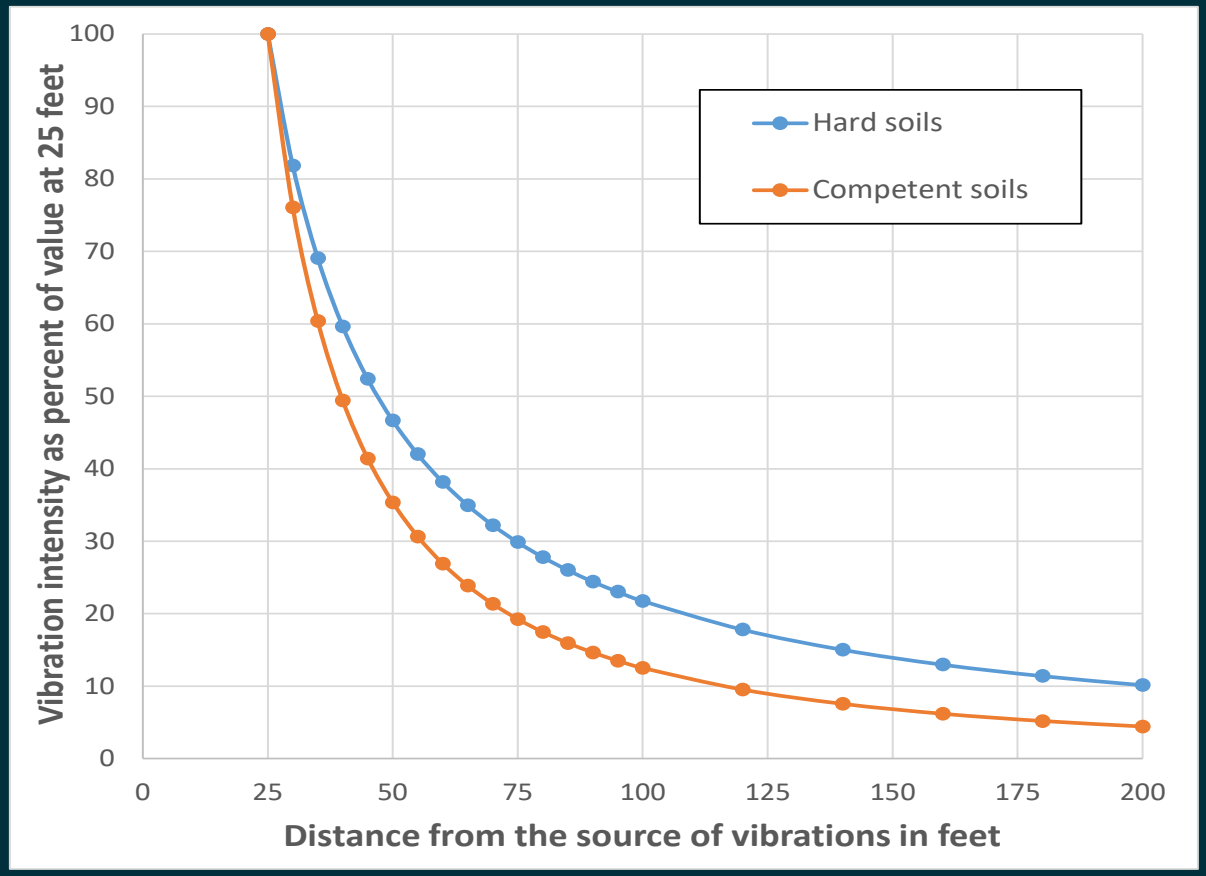
CONSTRUCTION VIBRATIONS

Predicting construction vibration levels

Equipment	PPV at 25 feet
Pile driver (impact)	0.644 to 1.518
Pile drive (sonic/vibratory)	0.170 to 0.734
Vibratory roller	0.210
Hoe ram	0.089
Large bulldozer	0.089
Caisson drilling	0.089
Loaded trucks	0.076
Jackhammer	0.035
Small bulldozer	0.003

Source: Federal Transit Administration 2006.

[NCHRP]



CONSTRUCTION VIBRATIONS

Definition of damage

Threshold damage: “loosening of paint; small plaster cracks at joints between construction elements; lengthening of old cracks.”

Minor damage: “loosening and falling of plaster; cracks in masonry around openings near partitions; hairline to 3-mm (0 to 1/8 in.) cracks; fall of loose mortar.”

Major damage: “cracks of several mm (1/8 in. and greater) in walls; rupture of opening vaults; structural weakening; fall of masonry; load support ability affected.”

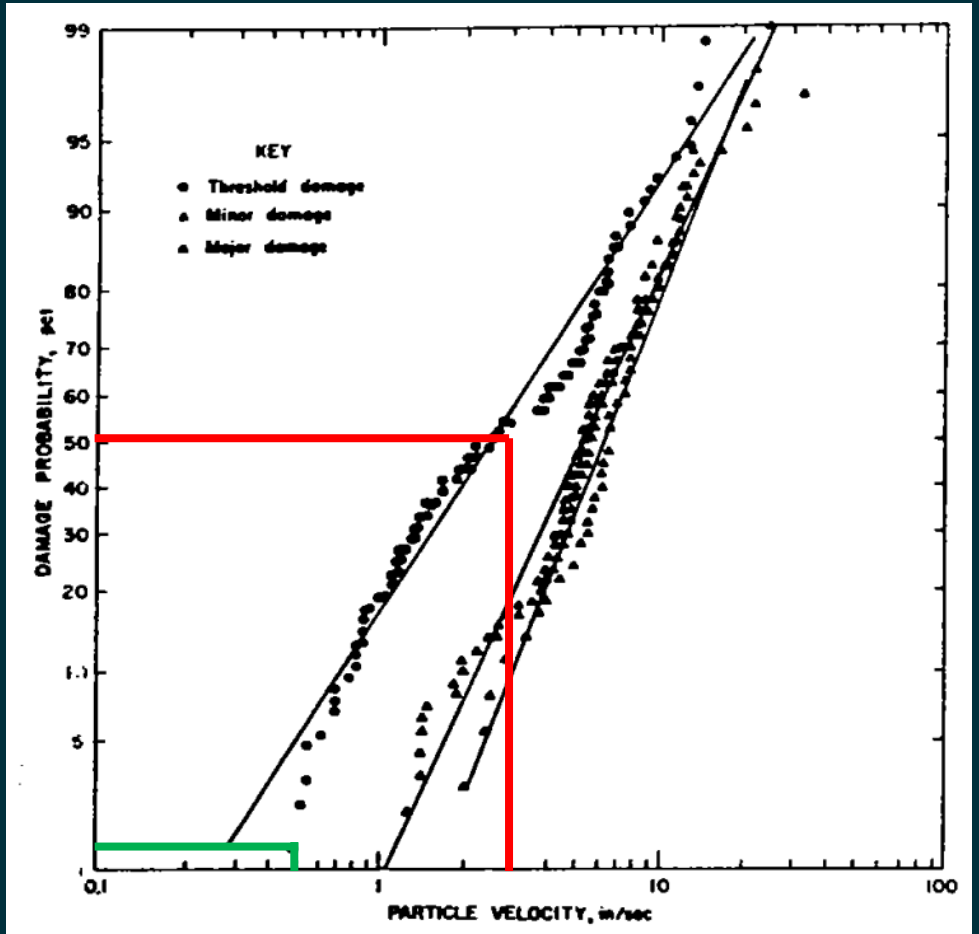
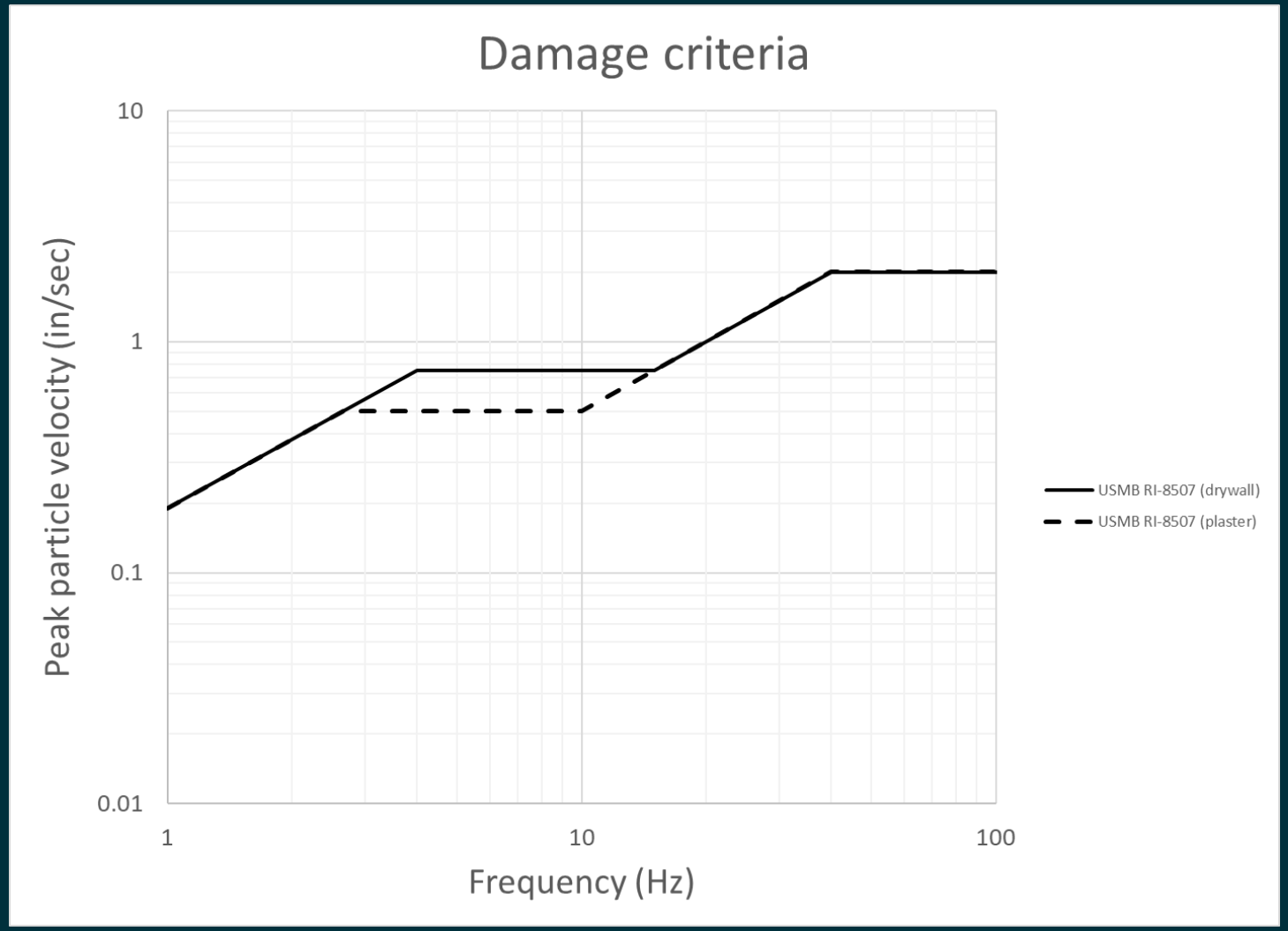


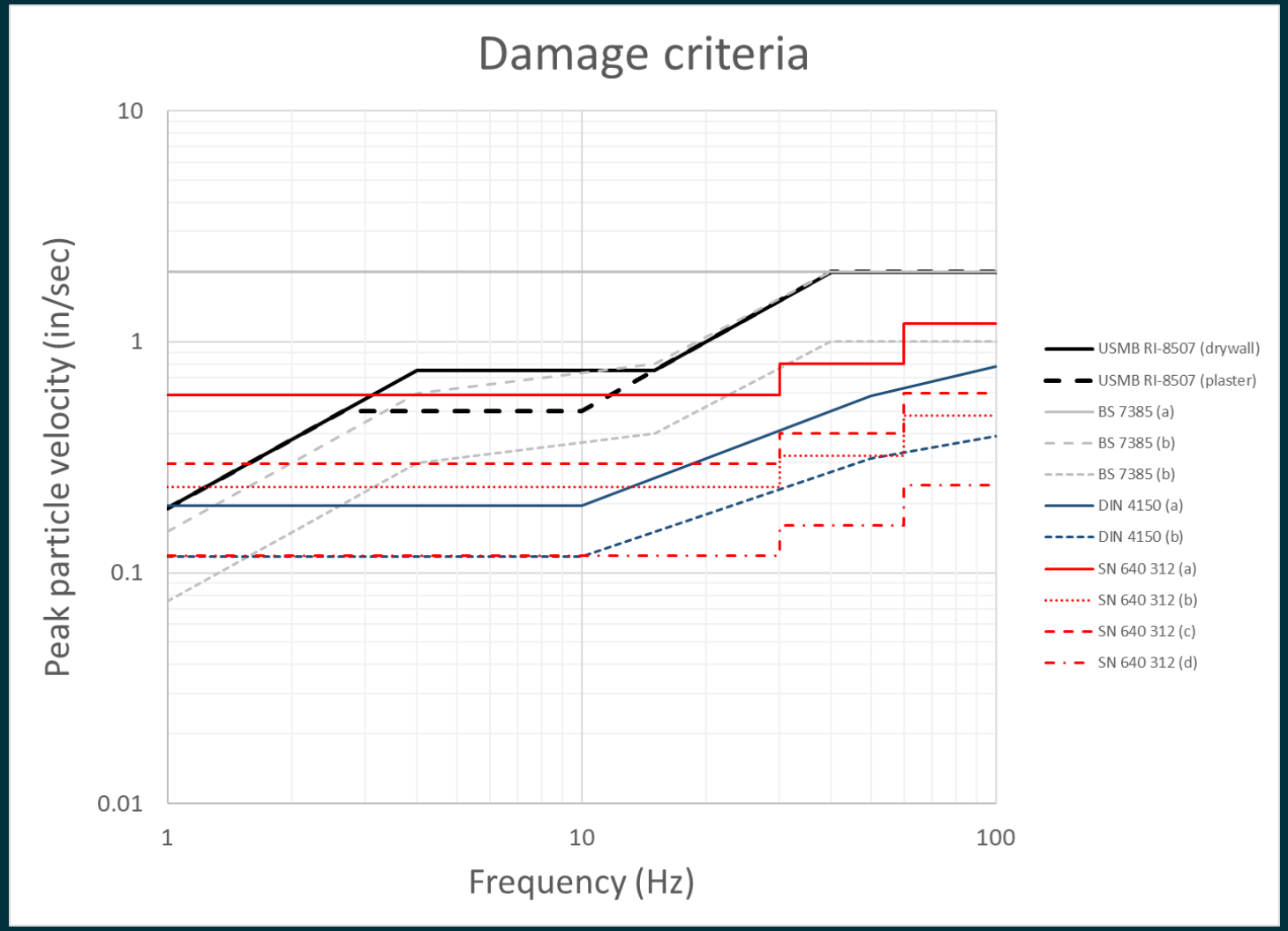
Figure 59.—Probability damage analysis summary, set 7.

[Siskind et al. in 1989]

CONSTRUCTION VIBRATIONS



CONSTRUCTION VIBRATIONS



CONSTRUCTION VIBRATIONS

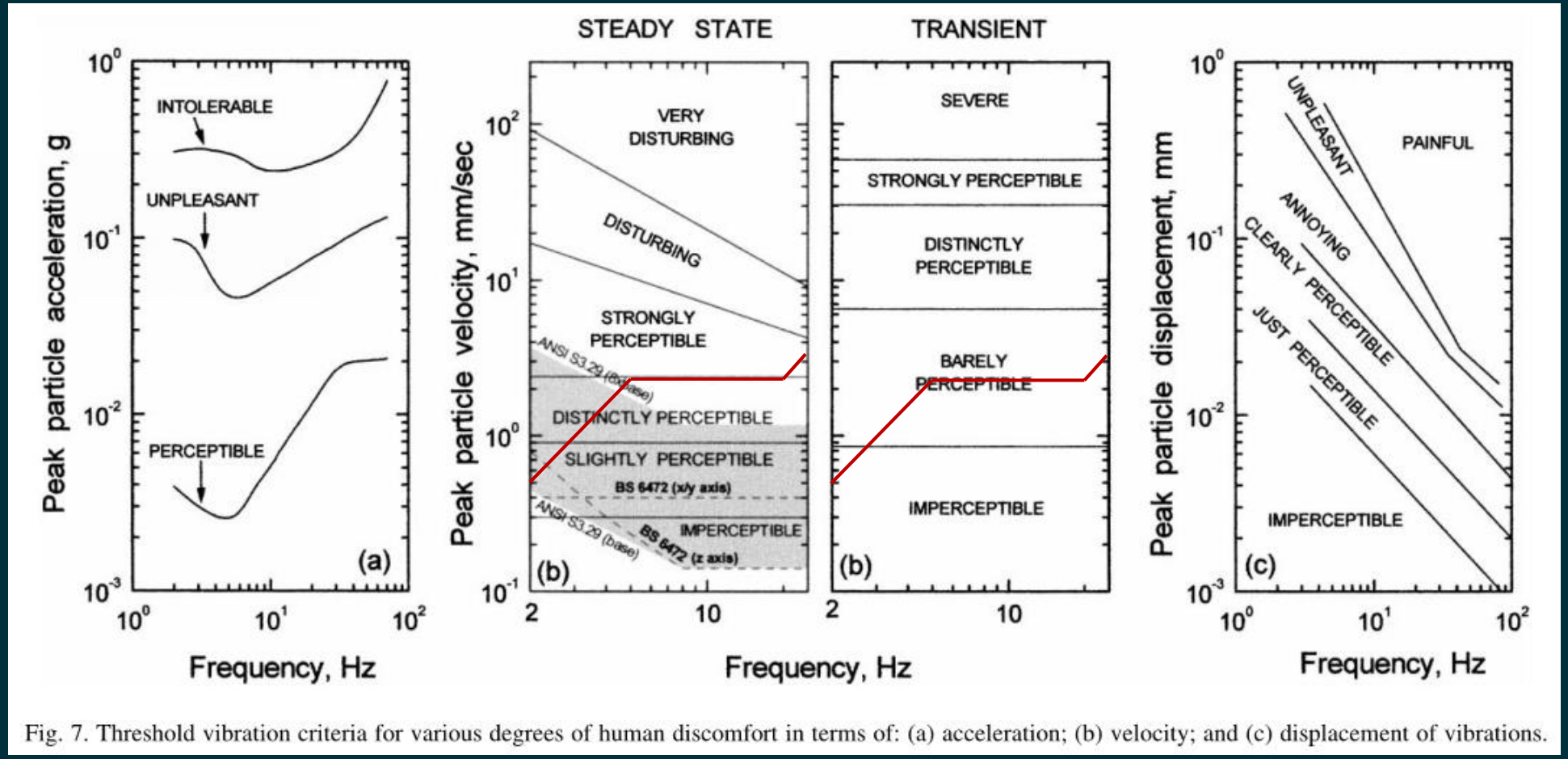


Fig. 7. Threshold vibration criteria for various degrees of human discomfort in terms of: (a) acceleration; (b) velocity; and (c) displacement of vibrations.

CONSTRUCTION VIBRATIONS

Comparison of settlement and particle velocities produced by pile-vibrations with typical settlements caused by braced excavations in sand (Dowding, 2000)

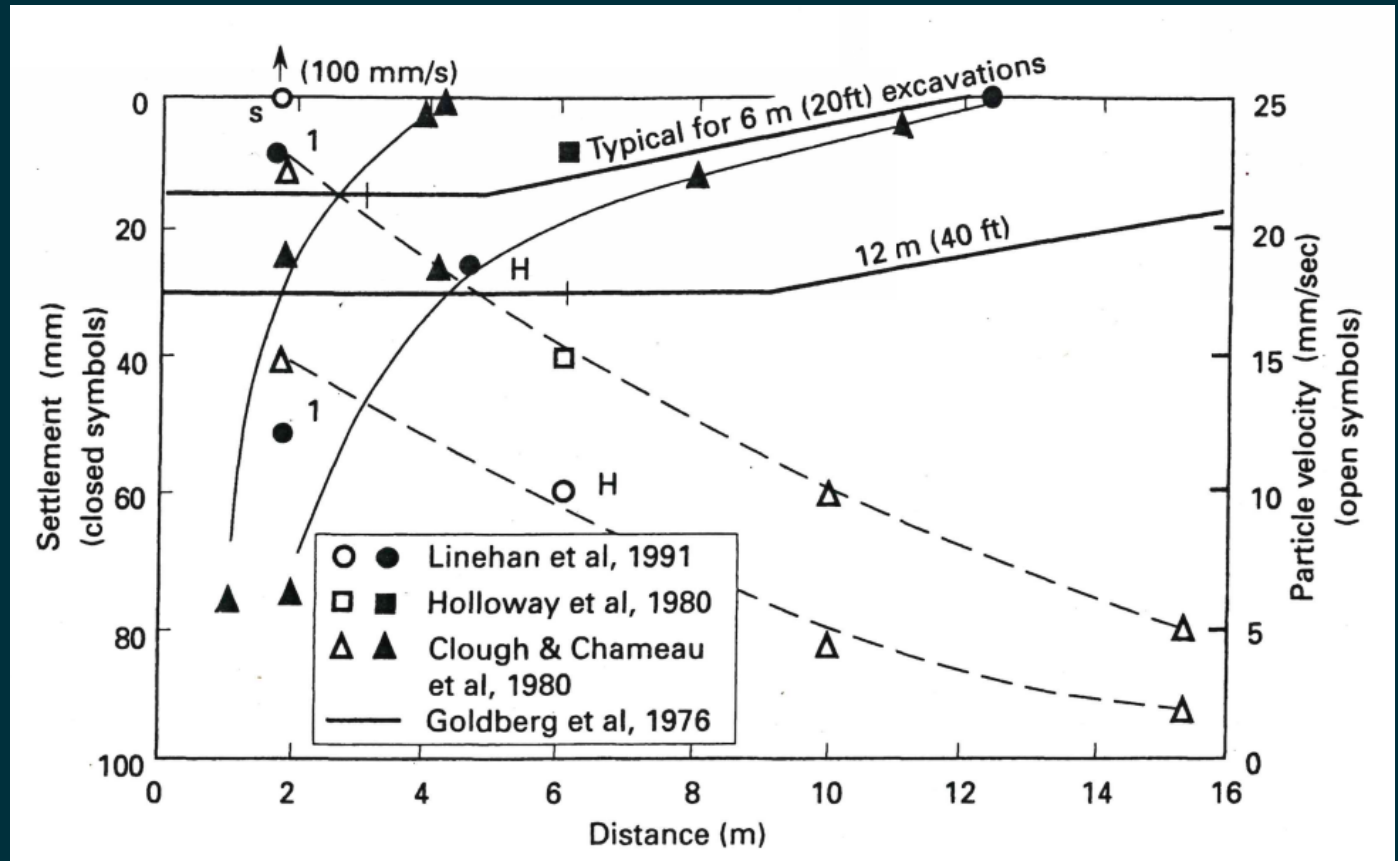


Figure 20-8 Comparison of settlement and particle velocities produced by pile-driving vibrations (thin, solid, and dashed lines, respectively) with typical settlements produced by braced excavation in sand (thick, solid lines).

CONSTRUCTION VIBRATIONS

Effects of environmental forces (Teasdale et al., 2006)

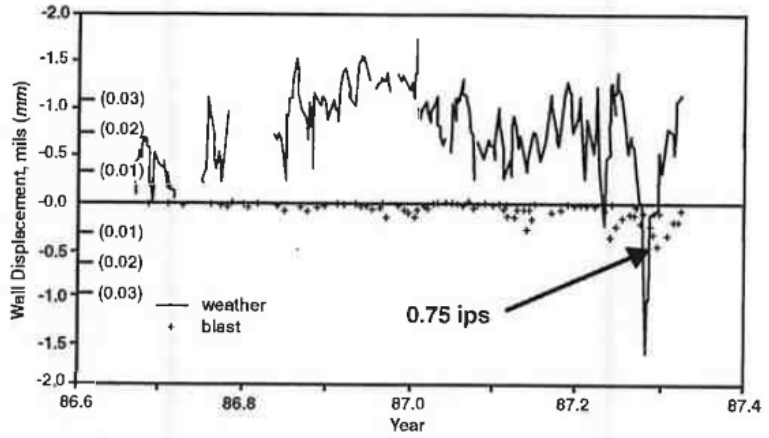


Figure 3. Comparison of crack displacements caused by weather changes (solid line) with those produced by surface coal mine vibrations (+) (Dowding, 1996).

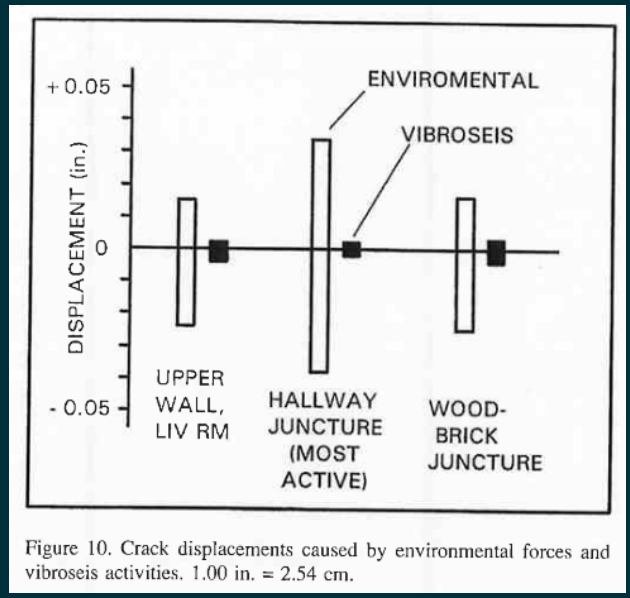


Figure 10. Crack displacements caused by environmental forces and vibroseis activities. 1.00 in. = 2.54 cm.

1. Hammering a 16d nail into the north wall of the living room: 0.860 in./second (2.18 cm/second).
2. Hammering a 16d nail into the south wall of the living room: 0.070 in./second (0.18 cm/second).
3. Hammering a 16d nail into the south wall of the north-east bedroom: 0.033 in./second (0.084 cm/second).
4. Back door slam: 0.560 in./second (1.42 cm/second).
5. Front door slam: 0.230 in./second (0.58 cm/second).

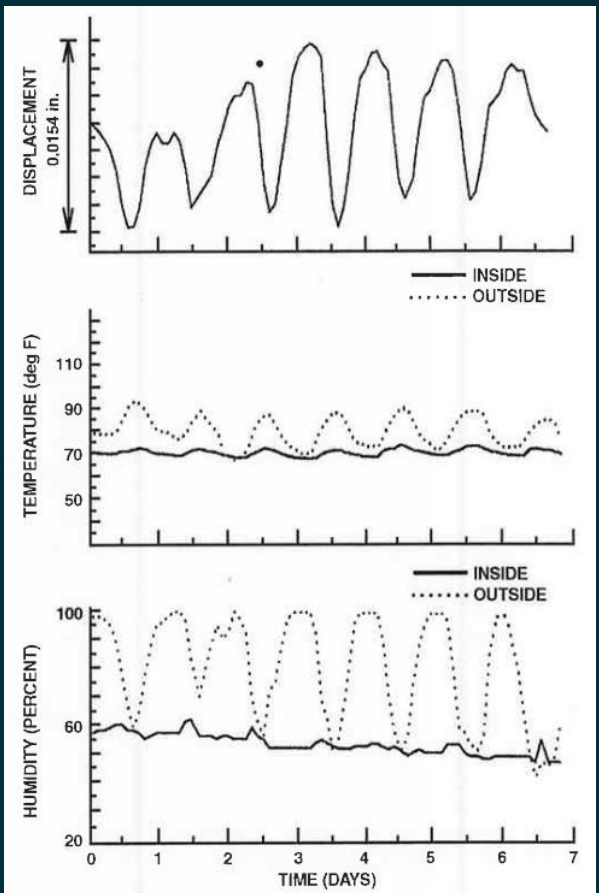


Figure 12. Weather effects on crack displacements. 1.00 in. = 2.54 cm; degrees F = (degrees C × 1.8) + 32.

CONSTRUCTION VIBRATIONS

2018 Florida Statutes

Title XXXIII REGULATION OF TRADE, COMMERCE, INVESTMENTS, AND SOLICITATIONS	Chapter 552 MANUFACTURE, DISTRIBUTION, AND USE OF EXPLOSIVES Entire Chapter	SECTION 30 **Construction materials mining activities.**

552.30 Construction materials mining activities.—

(1) Notwithstanding the provisions of s. 552.25, the State Fire Marshal shall have the sole and exclusive authority to promulgate standards, limits, and regulations regarding the use of explosives in conjunction with construction materials mining activities. Such authority to regulate use shall include, directly or indirectly, the operation, handling, licensure, or permitting of explosives and setting standards or limits, including, but not limited to, ground vibration, frequency, intensity, blast pattern, air blast and time, date, occurrence, and notice restrictions. As used in this section, "construction materials mining activities" means the extraction of limestone and sand suitable for production of construction aggregates, sand, cement, and road base materials for shipment offsite by any person or company primarily engaged in the commercial mining of any such natural resources.

(2) The State Fire Marshal shall establish statewide ground vibration limits for construction materials mining activities which conform to those limits established in the United States Bureau of Mines, Report of Investigations 8507, Appendix B - Alternative Blasting Level Criteria (Figure B-1). The State Fire Marshal may, at his or her sole discretion, by rule or formal agreement, delegate to the applicable municipality or county, the monitoring and enforcement components of regulations governing the use of explosives, as recognized in this section, by construction materials mining activities. Such delegation may include the assessment and collection of reasonable fees by the municipality or county for the purpose of carrying out the delegated activities.

(3) The State Fire Marshal is directed to conduct or contract for a study to review whether the established statewide ground vibration limits for construction materials mining activities are still appropriate and to review any legitimate claims paid for damages caused by such mining activities. The study must include a review of measured vibration amplitudes and frequencies, structure responses, theoretical analyses of material strength and strains, and assessments of home damages.

(a) The study shall be funded using the specified portion of revenues received from the water treatment plant upgrade fee pursuant to s. 373.41492.

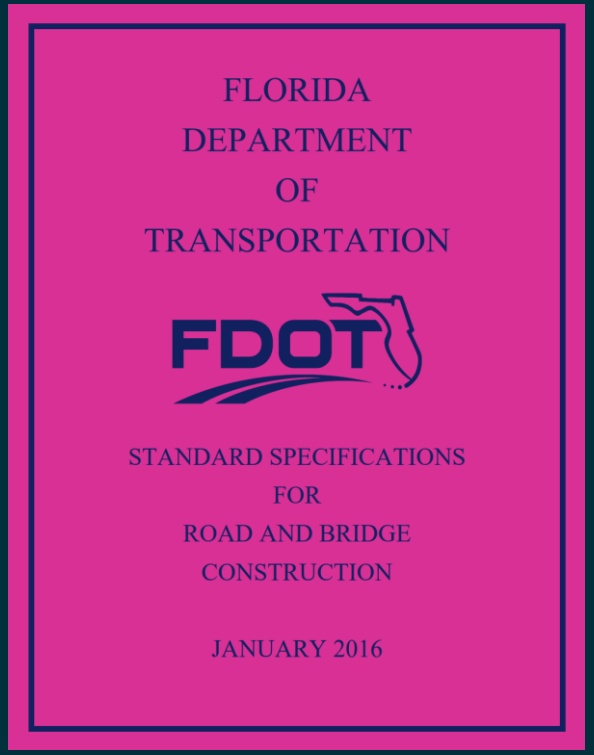
(b) The State Fire Marshal shall submit a report to the Governor, the President of the Senate, and the Speaker of the House of Representatives by December 1, 2016, which contains the findings of the study and any recommendations.

History.—s. 30, ch. 2000-266; s. 1, ch. 2003-62; s. 3, ch. 2015-141.

CONSTRUCTION VIBRATIONS

108-2.2 Vibration Monitoring: When shown in the Contract Documents, employ a qualified Specialty Engineer to continuously monitor and record vibration levels at the structures shown in the Plans during the operation of any equipment causing vibrations or during blasting operations. Furnish the vibration records to the Engineer within 24 hours of performing the monitoring activity. Provide vibration monitoring equipment capable of detecting velocities of 0.01 inches per second or less. Obtain the Engineer's approval of the number and locations of the monitoring points.

Upon either detecting vibration levels reaching 0.5 inches per second or damage to the structure, immediately stop the source of vibrations, backfill any open excavations, notify the Engineer and provide a corrective action plan for acceptance by the Engineer.



VIBRATION MONITORING

VIBRATION MONITORING

Preconstruction surveys

Pre-construction condition, 8/5/2013

Post-construction condition, 7/28/2016

VIBRATION MONITORING

Preconstruction surveys

Pre-construction condition, 8/5/2013

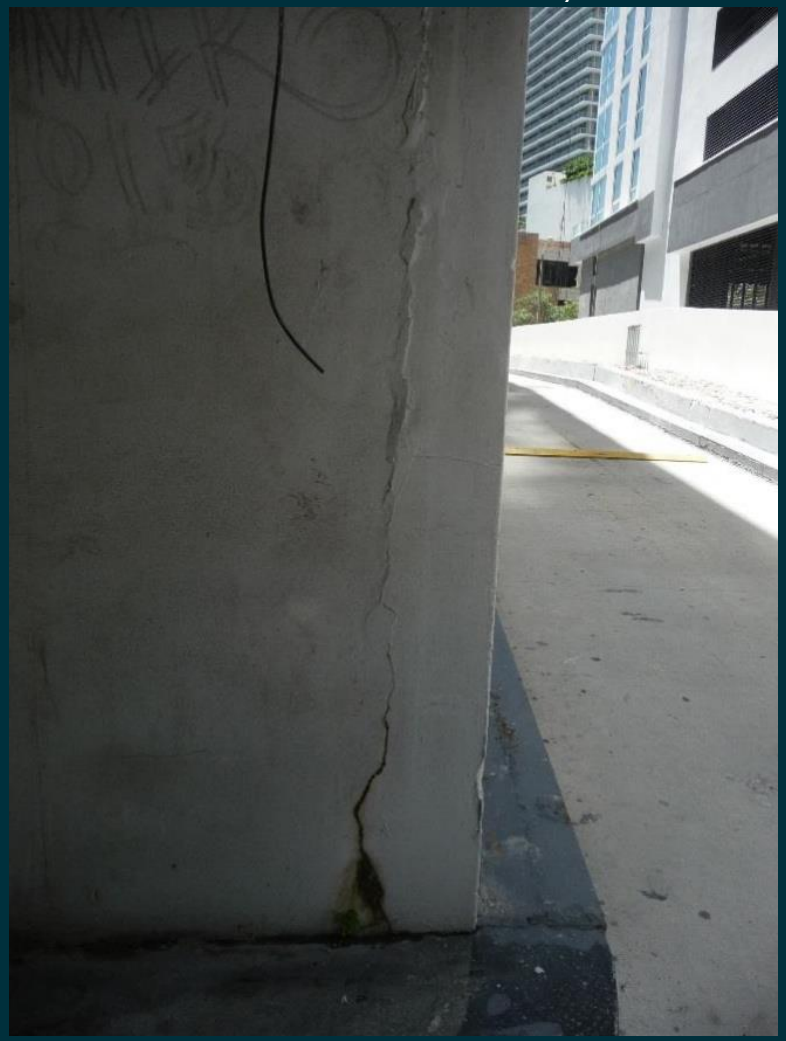
Post-construction condition, 7/28/2016

VIBRATION MONITORING

Preconstruction surveys

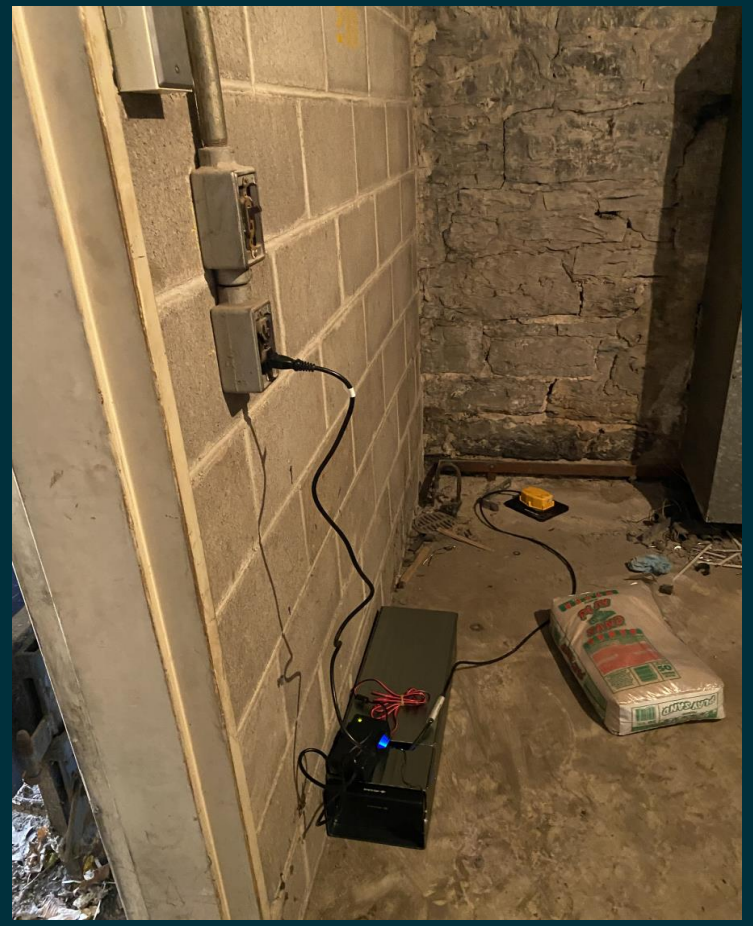
Pre-construction condition, 8/5/2013

Post-construction condition, 7/28/2016



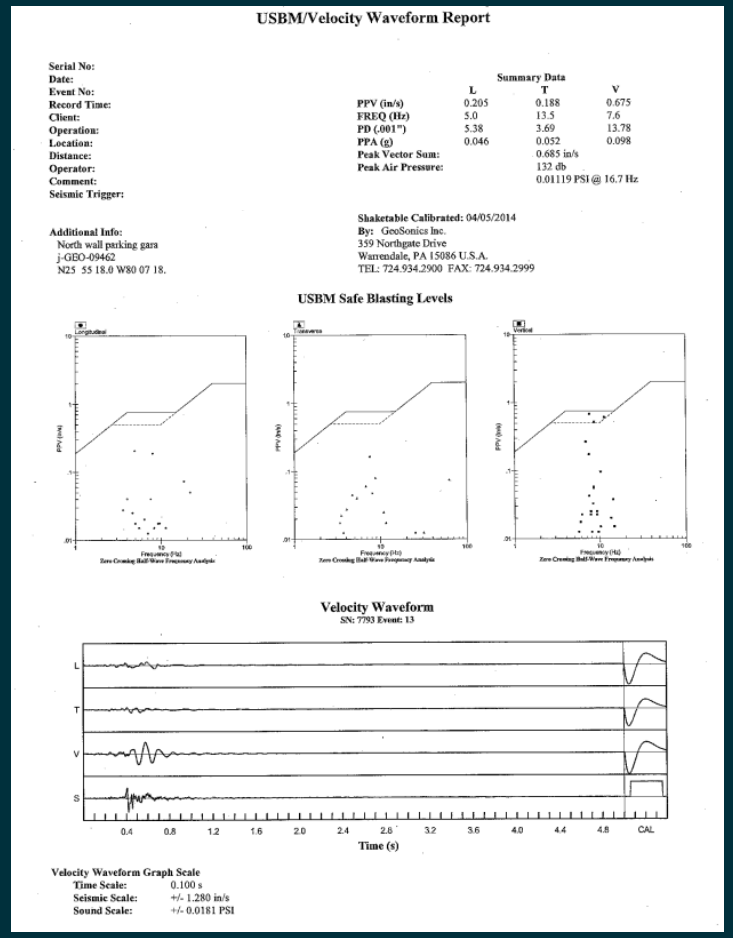
VIBRATION MONITORING

Vibration monitoring



VIBRATION MONITORING

Typical vibration report



USBM/Velocity Waveform Report

Serial No:
Date:
Event No:
Record Time:
Client:
Operation:
Location:
Distance:
Operator:
Comment:
Seismic Trigger:

Summary Data

	L	T	V
PPV (in/s)	0.205	0.188	0.675
FREQ (Hz)	5.0	13.5	7.6
PD (.001")	5.38	3.69	13.78
PPA (g)	0.046	0.052	0.098
Peak Vector Sum:		0.685 in/s	
Peak Air Pressure:		132 db	
		0.01119 PSI @ 16.7 Hz	

Additional Info:
North wall parking gara
j-GEO-09462
N25 55 18.0 W80 07 18.

Shaketable Calibrated: 04/05/2014
By: GeoSonics Inc.
359 Northgate Drive
Warrendale, PA 15086 U.S.A.
TEL: 724.934.2900 FAX: 724.934.2999

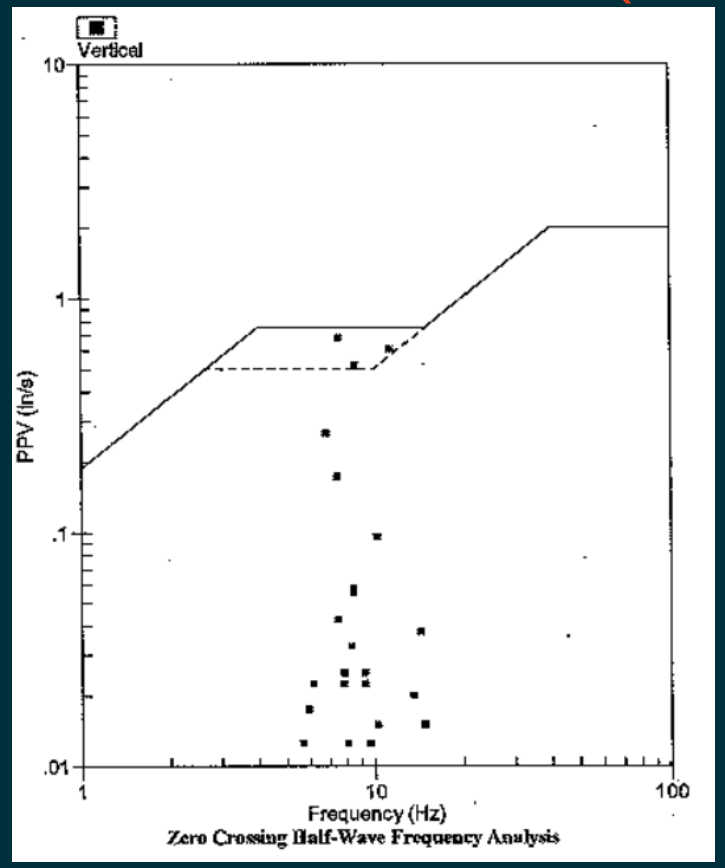
USBM Safe Blasting Levels

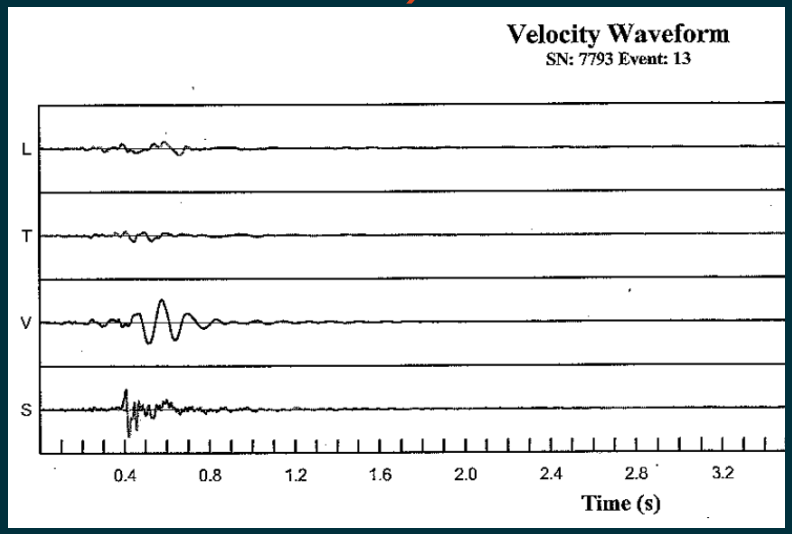
Velocity Waveform
SN: 7793 Event: 13

L
T
V
S
0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6 4.0 4.4 4.8 CAL
Time (s)

Velocity Waveform Graph Scale
Time Scale: 0.100 s
Seismic Scale: +/- 1.280 in/s
Sound Scale: +/- 0.0181 PSI

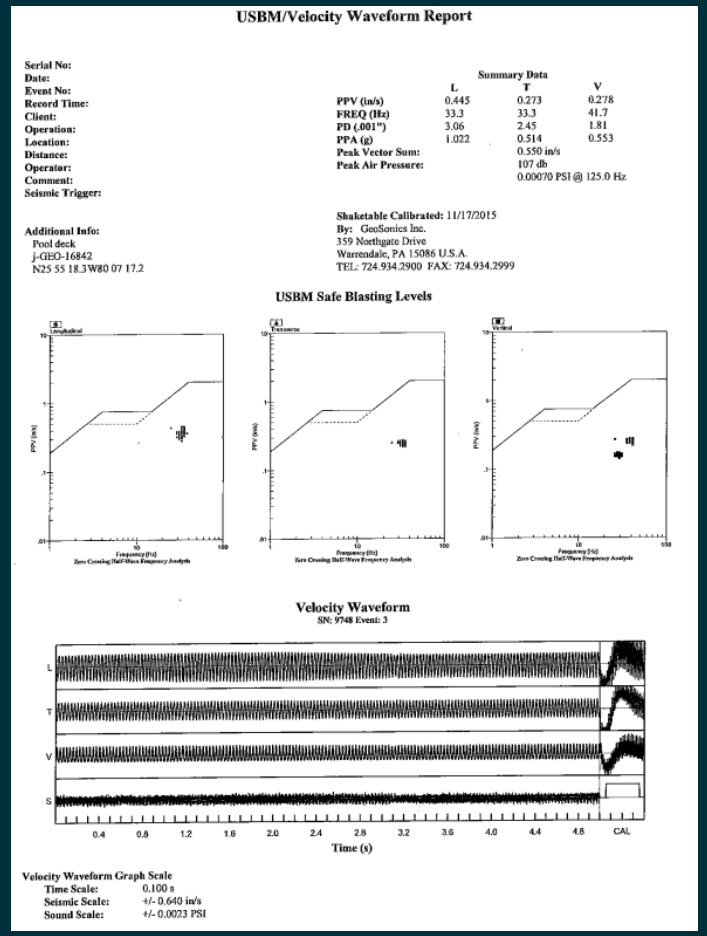
Demolition (transient vibrations)





VIBRATION MONITORING

Typical vibration report



USBM/Velocity Waveform Report

Serial No:
Date:
Event No:
Record Time:
Client:
Operation:
Location:
Distance:
Operator:
Comment:
Seismic Trigger:

Summary Data

	L	T	V
PPV (in/s)	0.445	0.273	0.278
FREQ (Hz)	33.3	33.3	41.7
PD (.001")	3.06	2.45	1.81
PPA (g)	1.022	0.514	0.553
Peak Vector Sum:		0.550 in/s	
Peak Air Pressure:		107 db	
		0.00070 PSI @ 125.0 Hz	

Additional Info:
Pool deck
j-GEO-16842
N25 55 18.3W80 07 17.2

Shaketable Calibrated: 11/17/2015
By: GeoSonics Inc.
359 Northgate Drive
Warrendale, PA 15086 U.S.A.
TEL: 724.934.2900 FAX: 724.934.2999

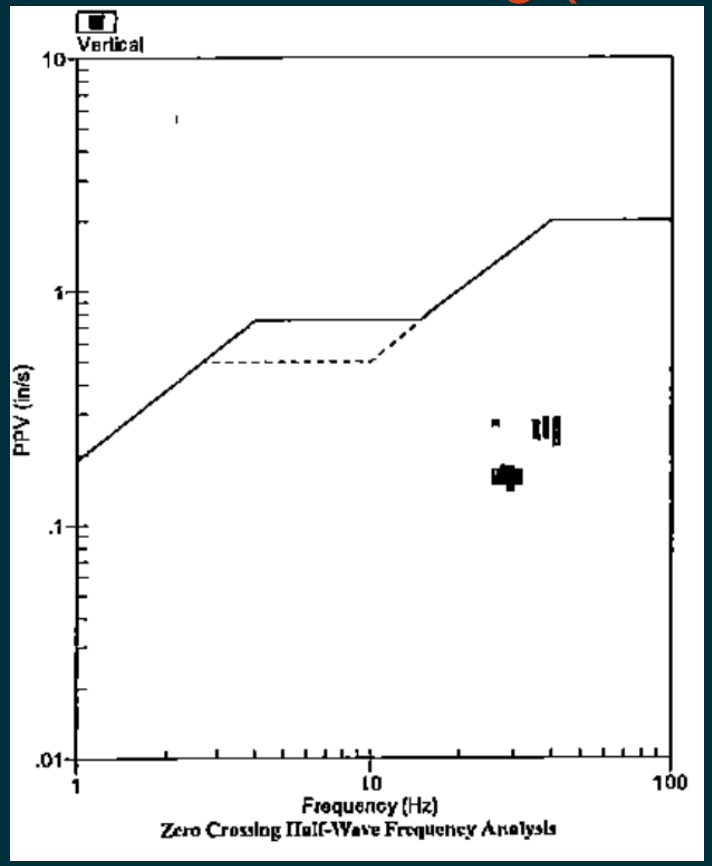
USBM Safe Blasting Levels

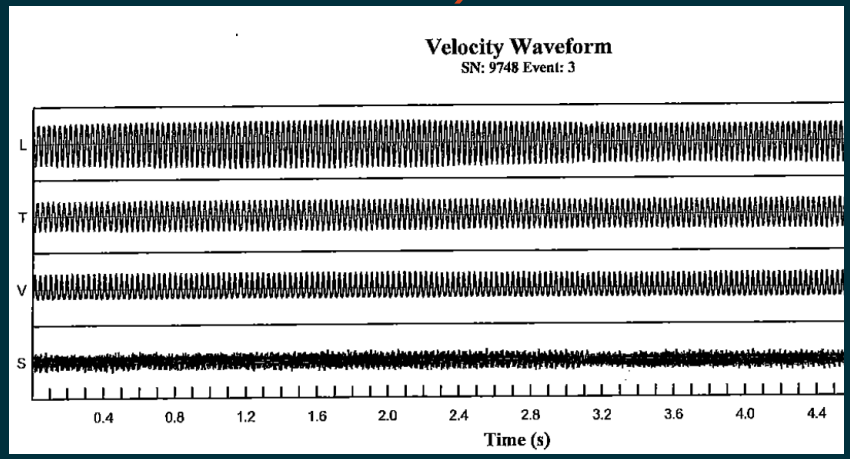
Velocity Waveform
SN: 9748 Event: 3

Time (s)

Velocity Waveform Graph Scale
Time Scale: 0.100 s
Seismic Scale: +/- 0.640 in/s
Sound Scale: +/- 0.0023 PSI

Pile-driving (continuous vibrations)





VIBRATION MONITORING

Preconstruction testing

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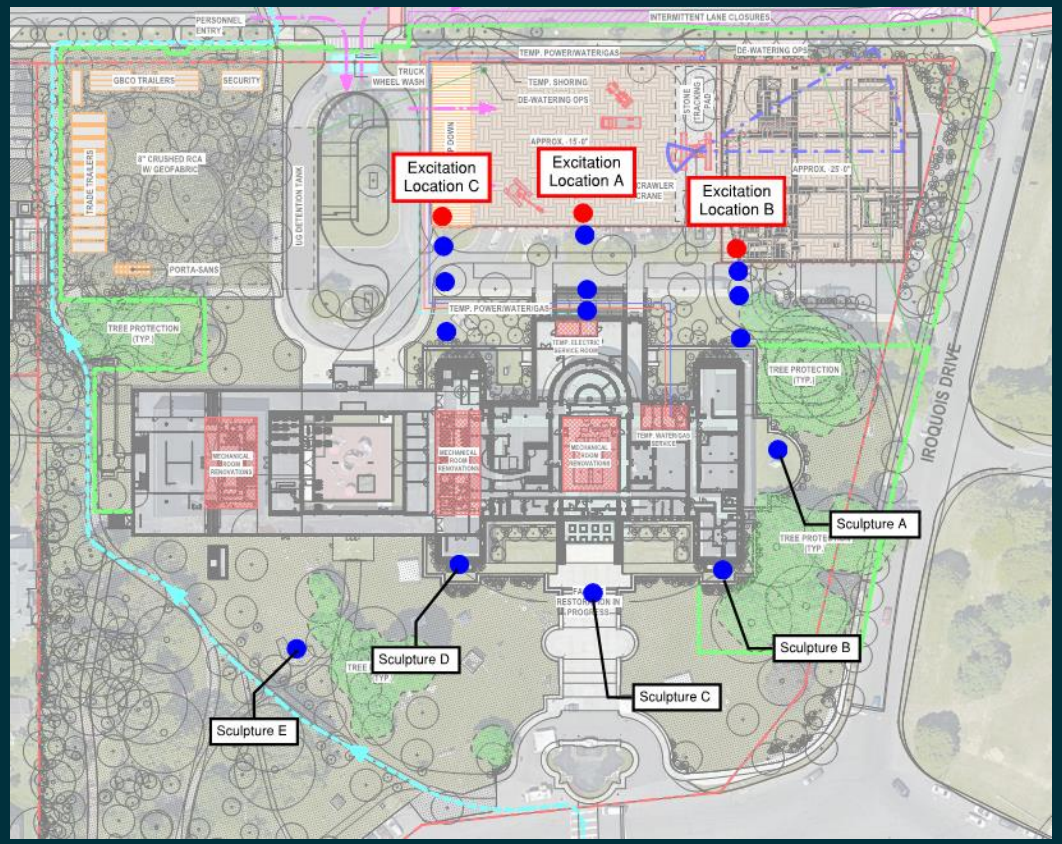
Preconstruction testing



VIBRATION MONITORING

Damage assessment

CONCLUSIONS

CONCLUSIONS

The effects of construction vibrations on structures depend on the source of vibrations, the distance to the source, the vibration frequency, amplitude and duration, the type and condition of both structure and foundation soil, etc.

Available data-driven vibration damage criteria are often misinterpreted. Exceedance of such thresholds does not necessarily correlate to the appearance of structural damage.

It is good practice that the construction team educate adjacent owners and residents about the type of construction activities that will take place, explain the anticipated vibration and noise levels that may be experienced, and outline what measures will be implemented to minimize the risk of damage.

THANK YOU