Faculty of Engineering
Cairo University

A presentation on

Numerical Calculation of Acceleration Using Multiple Codes and Software

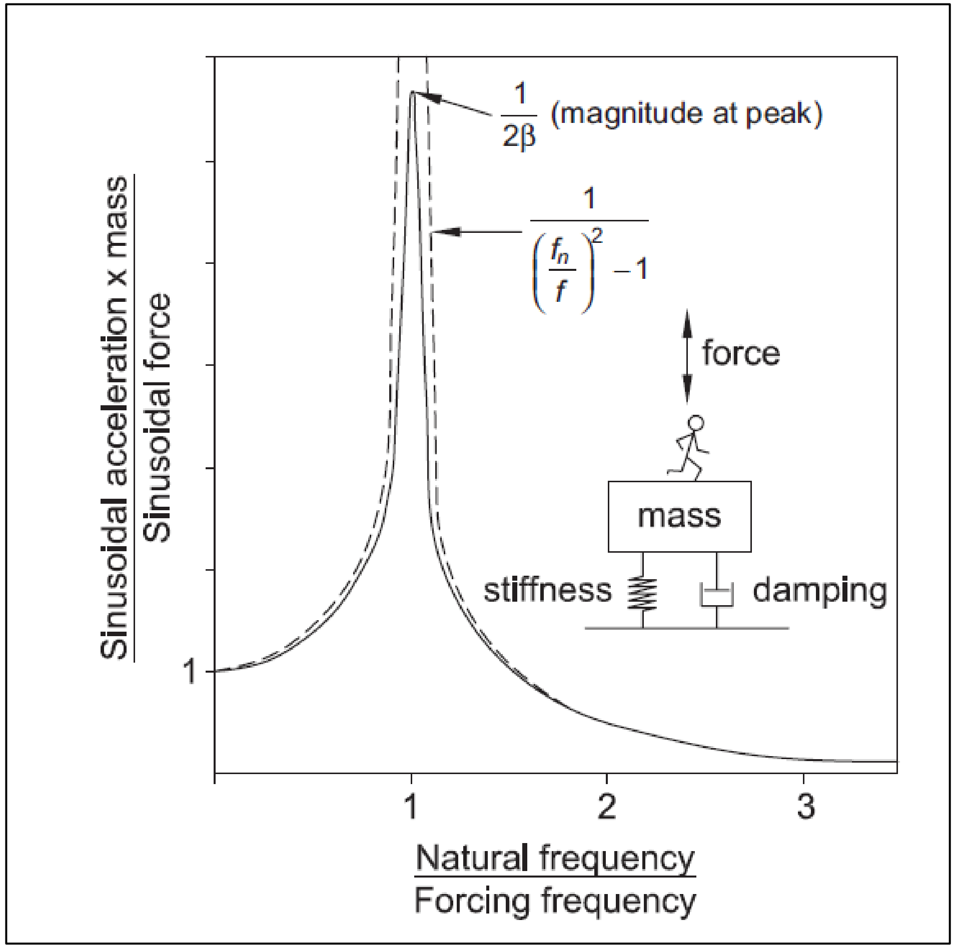
By
Eng. Abdulrahman Kamal

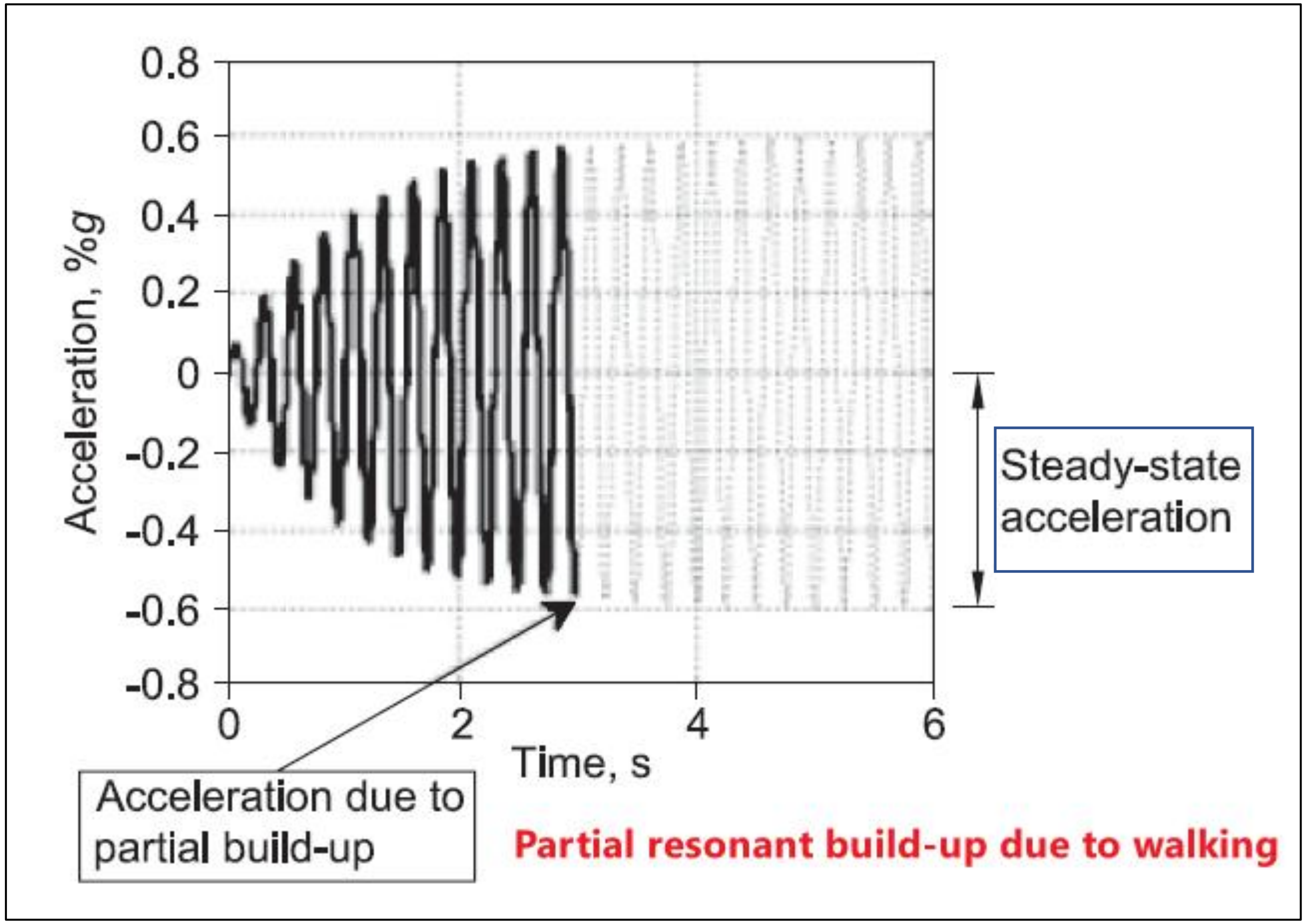
Under the supervision of
Prof. Dr. Youssef Fawzy Rashed

Introduction

- Floor vibration serviceability is often governed by acceleration (comfort), not strength.
- RAM Concept and SAP2000 can both compute acceleration, but outputs differ if assumptions differ.
- This presentation standardizes: mass source, damping, forcing model, and the reported metric (peak vs RMS).

Introduction





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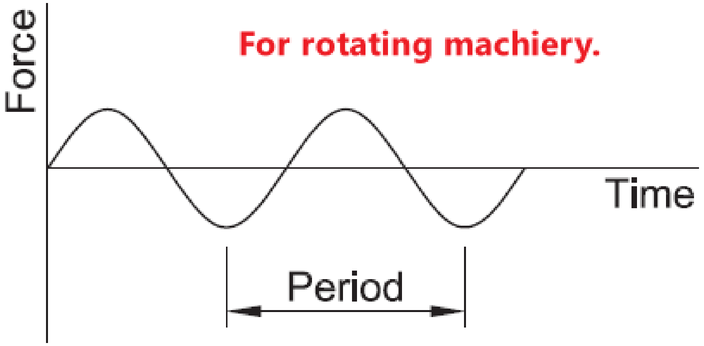
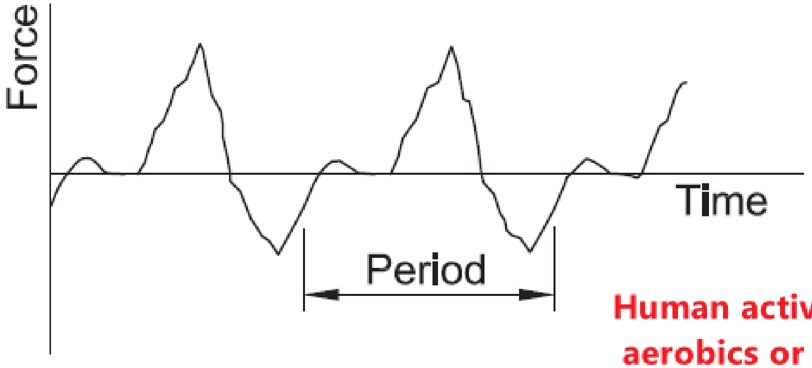
- Background: dynamic loads, DLF, and the AISC 11 approach
- RAM Concept implementation
- SAP2000 implementation
- Conclusion & Q&A

Types of dynamic loadings



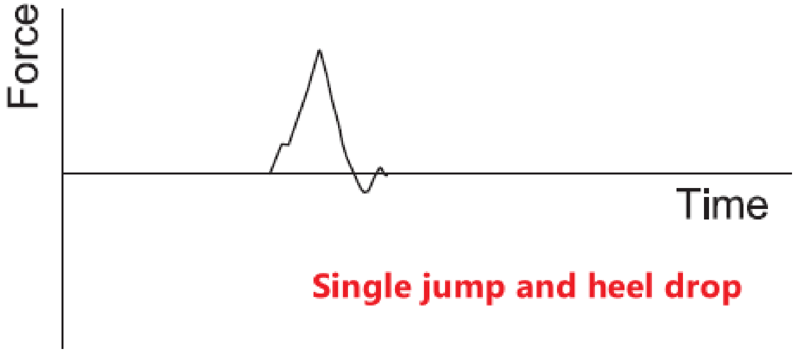
(a) Harmonic load



(b) Periodic load

Human activities as dancing and aerobics or machinery that genrate repetitive impacts.

(c) Transient load



(d) Impulsive load

Presentation Objectives

Acceleration calculation in RAM Concept vs SAP2000

- Define the vibration comfort metrics used in practice (peak, RMS, response factor).
- Explain the AISC 11 workflow: modal data → FRF → peak acceleration → response factor R.
- Show where each step appears in RAM Concept and how to replicate the same logic in SAP2000.
- Highlight common modeling choices that cause differences between software results.

Background: dynamic loads and human-induced vibration criteria
AISC 11 calculation steps (FRF, peak acceleration, response factor)
Implementation in RAM Concept (Walking Vibration Analysis)
Implementation in SAP2000 (time history + post-processing)
Comparison checklist + takeaways

Dynamic Loads in Structural Design (Examples)

A Design Guide for Footfall Induced Vibration of Structures

A tool for designers to engineer the footfall vibration characteristics of buildings or bridges

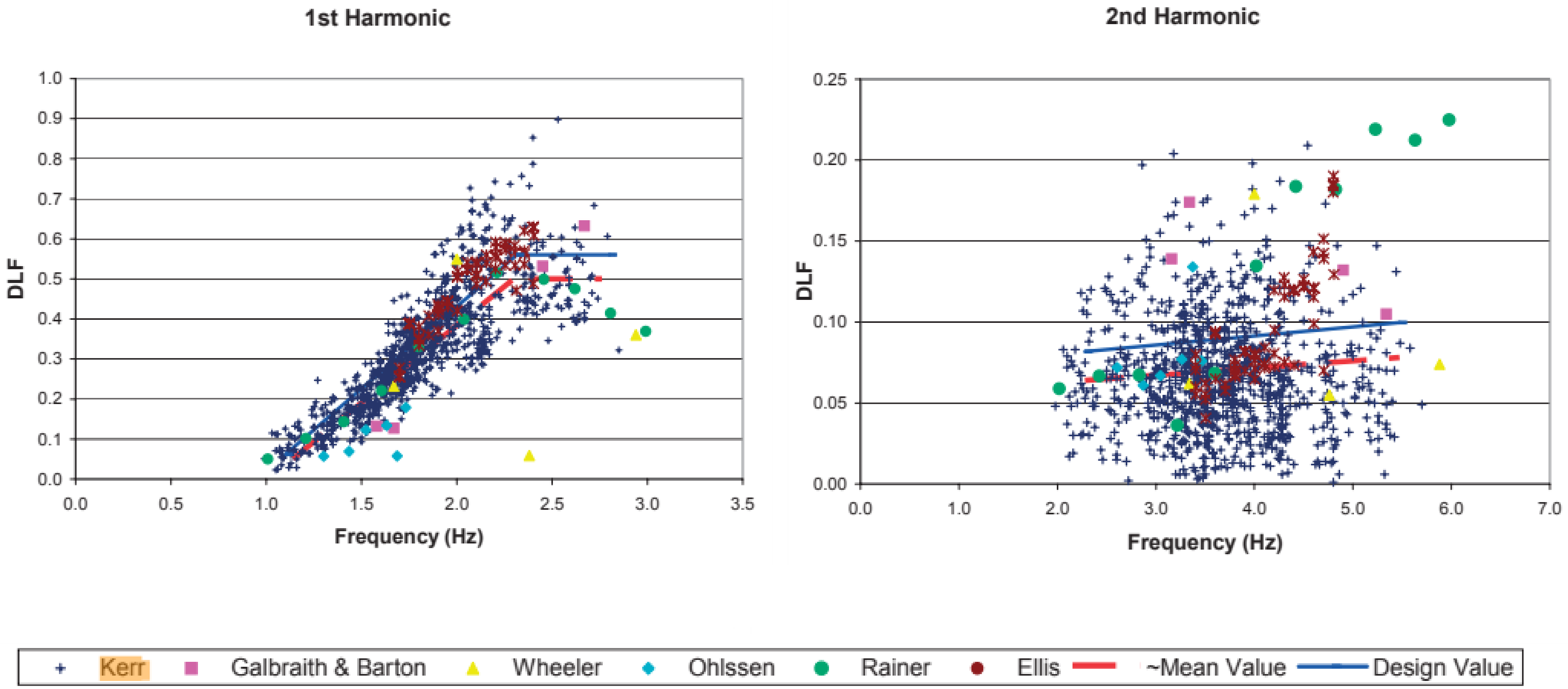
M R Willford CEng MIMechE
P Young CEng MIMechE

Published for The Concrete Centre by The Concrete Society

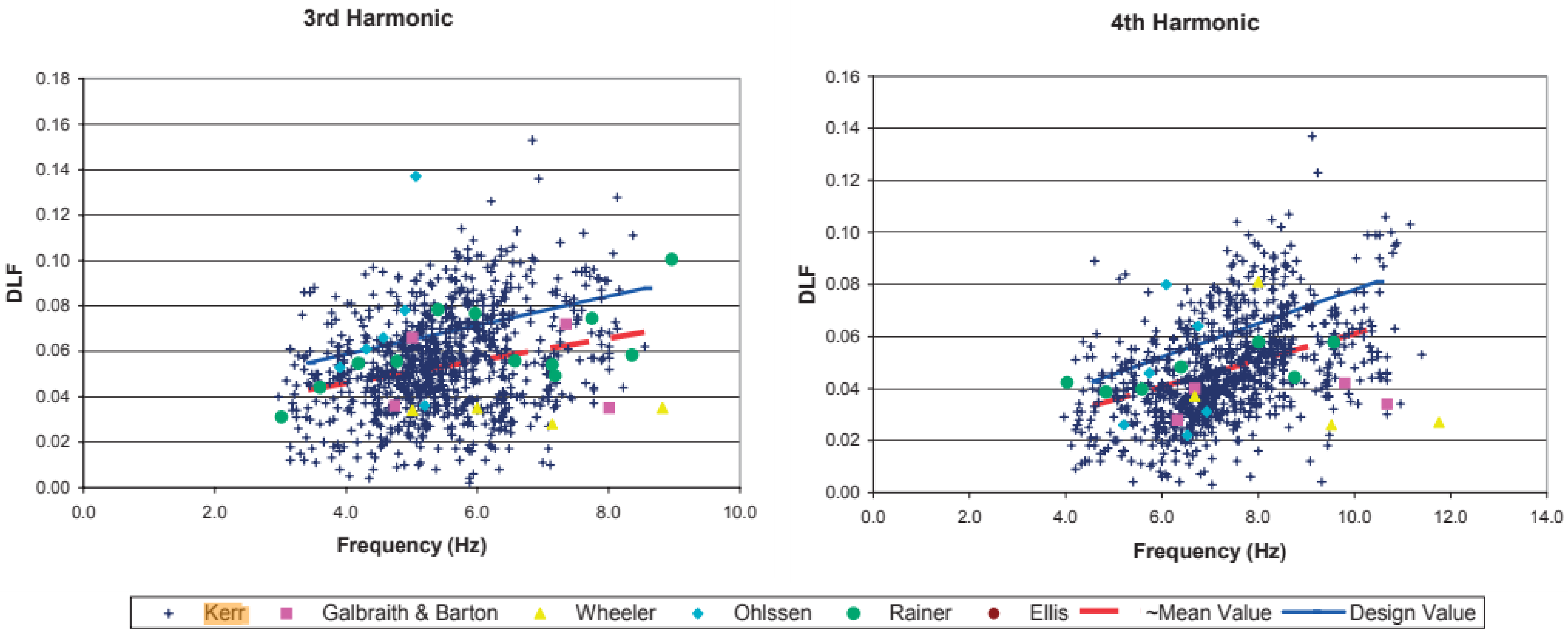
Dynamic Load Factor (DLF) and Harmonics

Harmonic number, h	Harmonic forcing frequency (Hz)	Mean value (DLF)	Coefficient of variation	Design value (DLF)
1	1–2.8	$0.37(f - 0.95), \ngtr 0.5$	0.17	$0.41(f - 0.95), \ngtr 0.56$
2	2–5.6	$0.054+0.0044f$	0.40	$0.069+0.0056f$
3	3-8.4	$0.026+0.0050f$	0.40	$0.033+0.0064f$
4	4–11.2	$0.010+0.0051f$	0.40	$0.013+0.0065f$
h>4	>11.2	0		0

DLF vs Frequency (1st–2nd Harmonics)



DLF vs Frequency (3rd–4th Harmonics)



AISC Steel Design Guide 11 (Basis for Method)

AMERICAN INSTITUTE OF STEEL CONSTRUCTION
AISC
FOUNDED 1921

Steel Design Guide

11

Vibrations of Steel-Framed Structural Systems Due to Human Activity

Second Edition

Walking Forcing Frequencies & Dynamic Coefficients

Table 2-1. Walking Forcing Frequencies and Dynamic Coefficients

Harmonic *i*	Person Walking	
	if_{step}, Hz	α_i
1	1.6–2.2	0.5
2	3.2–4.4	0.2
3	4.8–6.6	0.1
4	6.4–8.8	0.05

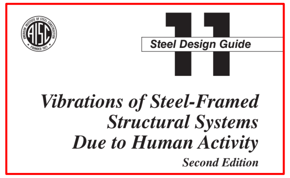
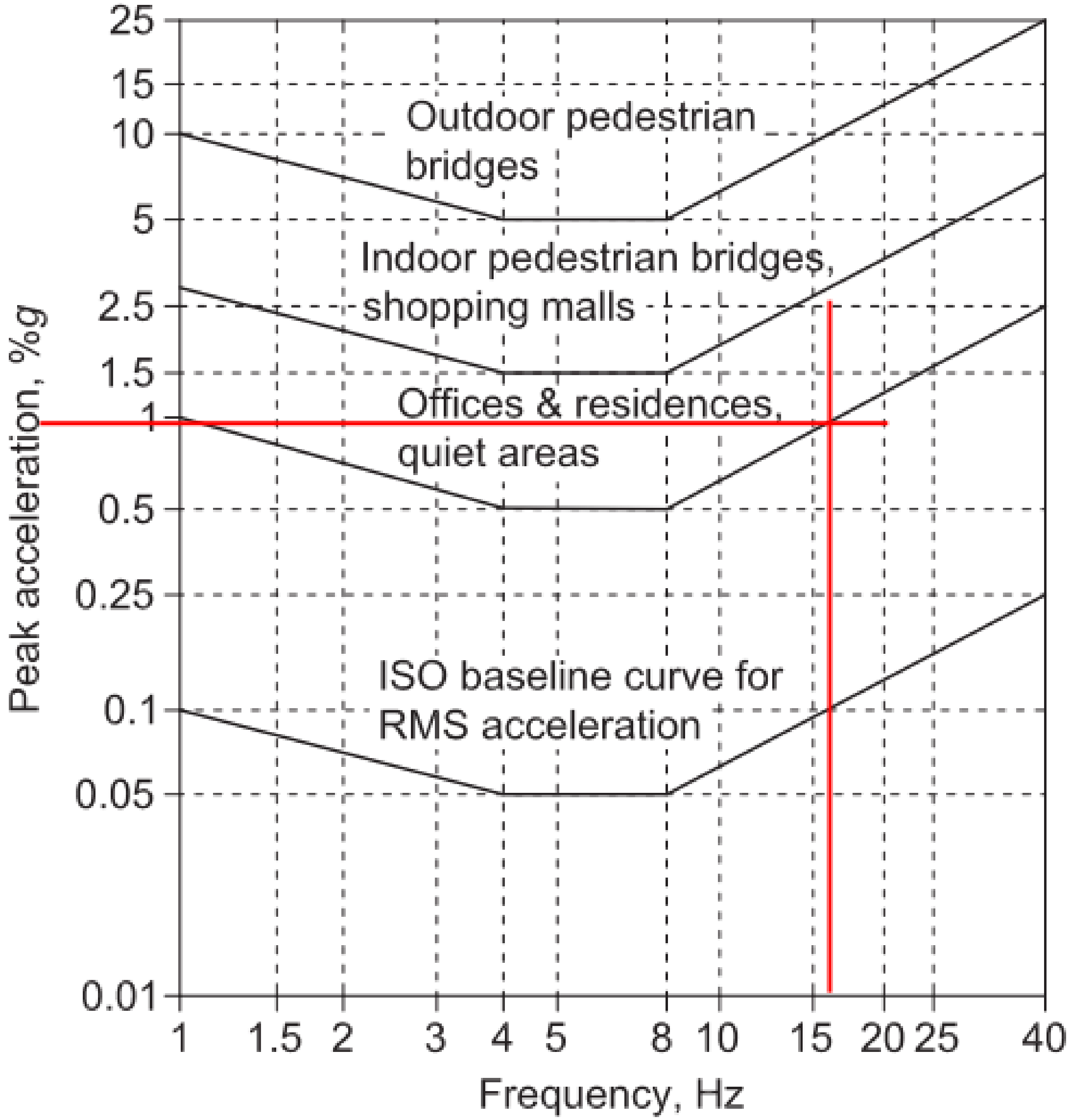


Table 1-1. Fourier Series Parameters for Individuals

Activity	Source	Q, lb	f_{step} Range, Hz	Dynamic Coefficients, α_i	Phase Lag, ϕ_i, radians
Walking	Rainer et al. (1988) Allen and Murray (1993)	157	1.6–2.2	0.5, 0.2, 0.1, 0.05	—
	Willford et al. (2007) Smith et al. (2007) Davis and Murray (2010)	168	1.6–2.2	0.4, 0.07, 0.06, 0.05	0, $-\pi/2$, π, $\pi/2$
Running	Rainer et al. (1988)	*	1.6–4.0	1.4, 0.4, 0.2, 0.1	—
	Bachmann et al. (1995)	*	2.0–3.0	1.6, 0.7, 0.2	—
	ISO (2007)	*	2.0–4.0	1.4, 0.4, 0.1	—
Stair descent	Kerr and Bishop (2001) Davis and Murray (2009) Davis and Avci (2015)	168	1.6–4.0	1.1, 0.2, 0.09, 0.06	—

*Depends on running event: 150 to 175 lb for recreational runners; 250+ lb for American football or rugby players.

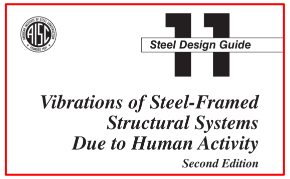
ISO Baseline Curve and Fourier Load Model



$$F(t) = Q + \sum_{i=1}^{N} \alpha_i Q \sin(2\pi i f_{step} t - \phi_i) \qquad (1\text{-}1)$$

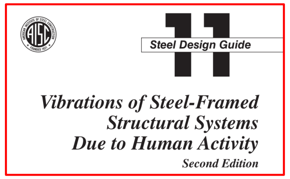
where

N = number of considered harmonics, i.e., the number of harmonics with significant amplitudes
Q = bodyweight, lb
f_{step} = step frequency, Hz
i = harmonic number
t = time, s
α_i = dynamic coefficient (ratio of harmonic force magnitude to bodyweight) for the ith harmonic
ϕ_i = phase lag for the ith harmonic, rad



Frequency Response Function (FRF)

A plot of SteadyState response due to sinusoidal load with unit amplitude versus frequency is used to determine which mode provides highest response

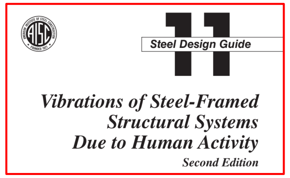


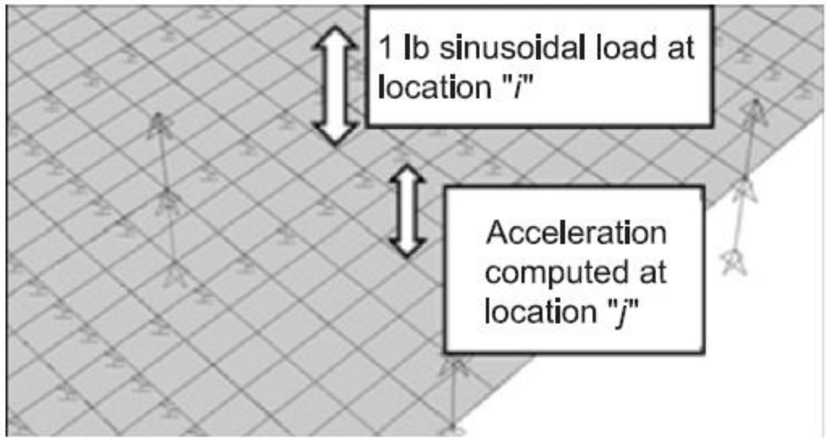
FRF is constructed by

1. Define the frequency band lower limit as 1 Hz below the fundamental frequency
2. Define the upper limit as 1 Hz above the maximum computed modal frequency
3. defining key frequencies within the band, usually at each modal frequency and several others depending on the desired resolution of the plot
4. computing and plotting the sinusoidal steady-state response at location j due to unit amplitude sinusoidal load at location i, with unit amplitude at each frequency within the band.

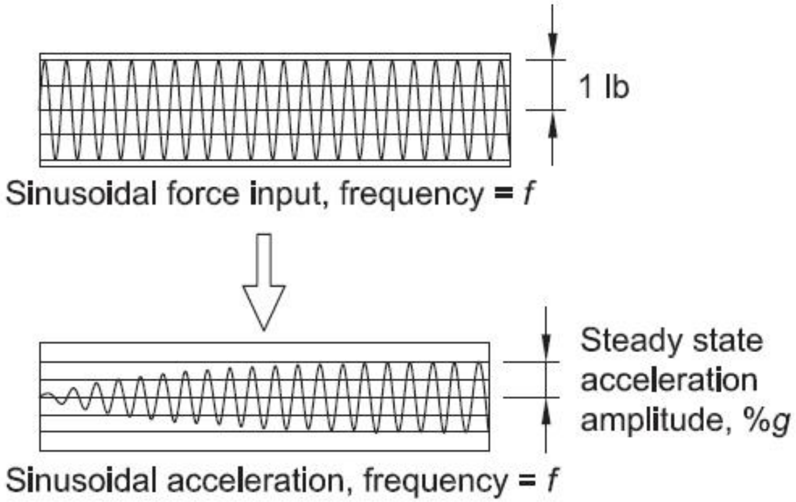
The FRF magnitude is computed for vertical unit load at the walking load location and vertical acceleration at the affected occupant location—locations i and j in

FRF Concept: Unit Load and Response Location

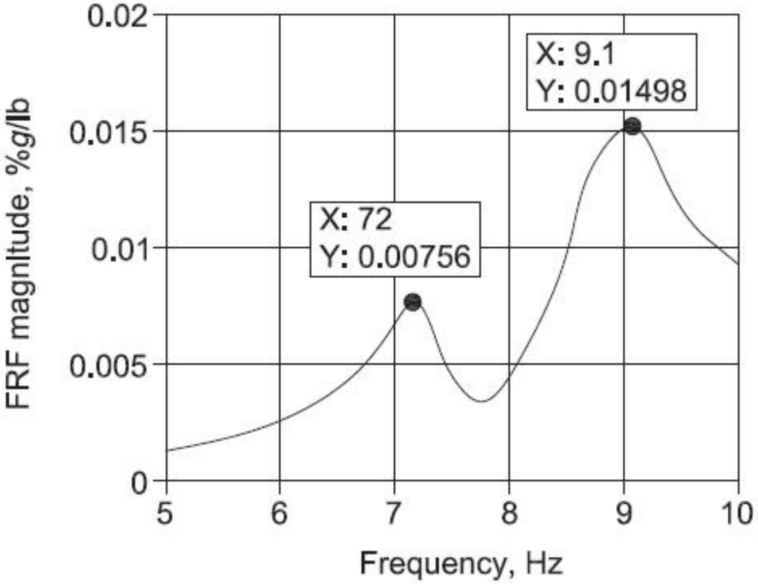




(a) Load and acceleration response locations

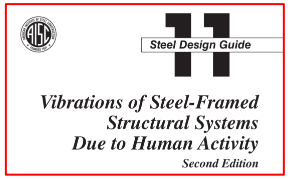


(b) Sinusoidal load with unit amplitude and resulting response



(c) FRF magnitude plot

Peak Acceleration Calculation (AISC 11)



$$a_p = FRF_{Max} \alpha Q \rho \qquad (7\text{-}1)$$

where

FRF_{Max} = maximum FRF magnitude at frequencies below 9 Hz, %g/lb

Q = bodyweight = 168 lb

α = dynamic coefficient

ρ = resonant build-up factor

$$\alpha = 0.09e^{-0.075fn}$$

where

f_n = dominant frequency, Hz

β is the viscous damping ratio

$$\rho = 50\beta + 0.25 \text{ if } \beta < 0.01$$

$$\rho = 12.5\beta + 0.625 \text{ if } 0.01 \le \beta < 0.03$$

$$\rho = 1.0 \text{ if } \beta \ge 0.03$$

The response factor

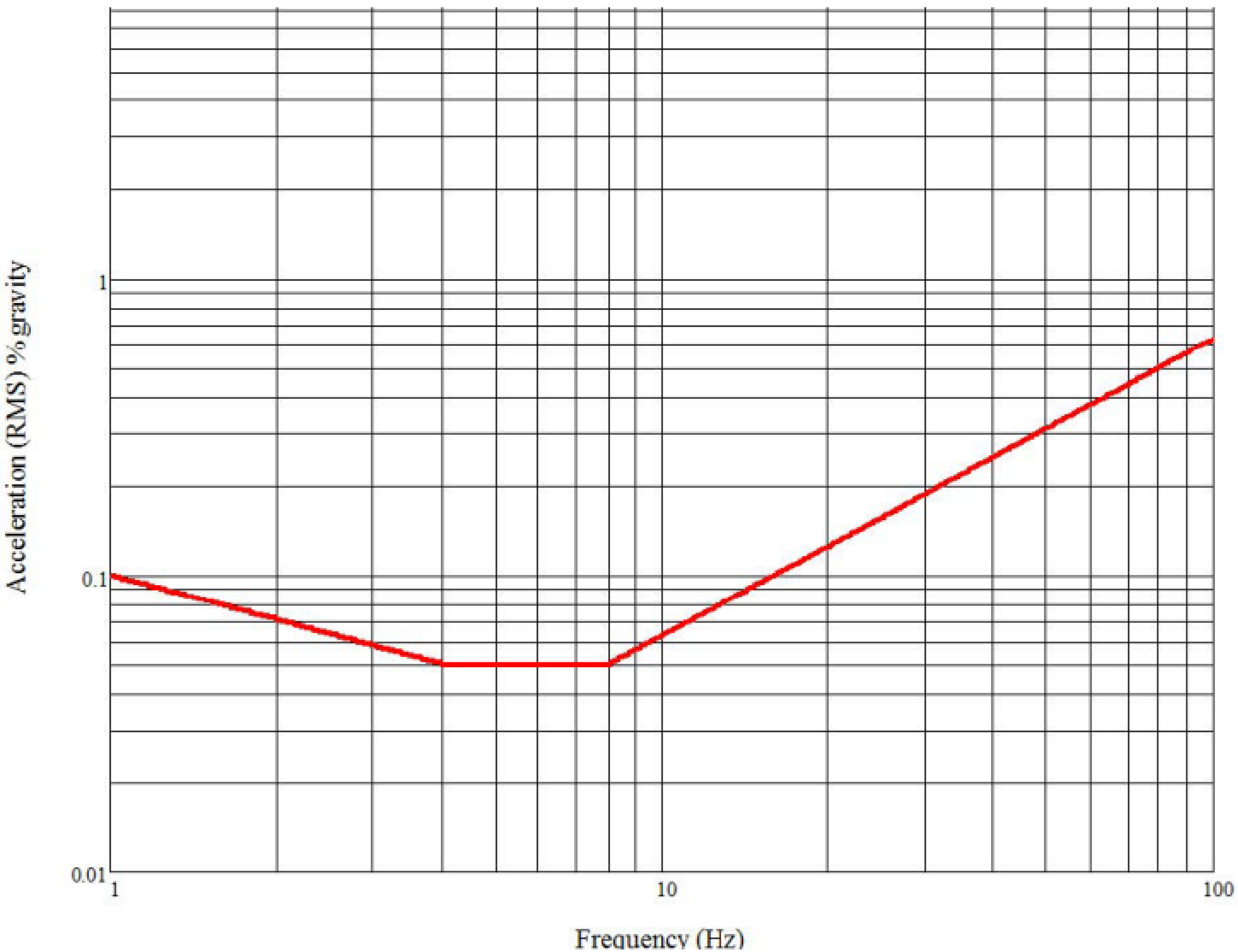
It is a multiplier on the level of vibration at the threshold of human perception.

A response factor of 1 would represent a level of vibration that is just at the threshold of human perception, and a response factor of 2 would represent twice the perceivable level.

Recommended Response Factor Limits

Environment	Response Factor Limit	Description of Use
Workshops, Office	8-10	Perceptible vibration, suitable for non-sensitive areas.
Residential	4-8	Possible perceptible vibration, suitable for sleep areas in most cases.
Operating rooms	1-4	Near the threshold of perception, suitable for sensitive sleep areas and in most instances for microscopes to 100x and other low sensitivity equipment.
Sensitive Equipment rooms	0.0625-1	Suitable for sensitive equipment, electron microscopes, etc.

Comfort Limit Curve (RMS Acceleration vs Frequency)



RAM Concept Implementation

Where the AISC 11 steps appear in the software

Ram manual

Type	Description
Resonant response	Check this option to perform a resonant response calculation. A resonant response tends to build up over time, and is generally most critical for lower frequency modes less than about 4 times the footstep frequency.
Impulsive response	Check this option to perform an impulsive response calculation. An impulsive response tends to dissipate before the next footstep, and is generally most critical for higher frequency modes.

In structures whose fundamental mode of vibration has a natural frequency larger than about 12-15Hz, the dynamic response of each footfall tends to dissipate almost entirely before the next footfall.

RAM Concept Footfall Response Model

1. RAM Concept calculates the footfall response of structures using assumed dynamic loadings that were **derived from a large number of experimentally measured footfall force time histories**.
2. Normal walking rates range from about 1.5 to 2.5 steps per second according to these studies.
3. The assumed periodic footfall function can be separated into any number of harmonic components using a Fourier series.

$$p(t) = \sum_{j=1}^{n} W\kappa \sin\left(\frac{j2\pi}{T}t\right)$$

$$k = \frac{\text{Maximum Dynamic Displacement}}{\text{Static Displacement}}$$

where

W	=	weight of the individual walking
κ	=	dynamic load factor (refer to “A Design Guide for Footfall Induced Vibration of Structures” for a detailed discussion)
j	=	harmonic number
n	=	total number of harmonic components considered
T	=	period of the footfall

RAM Concept Workflow

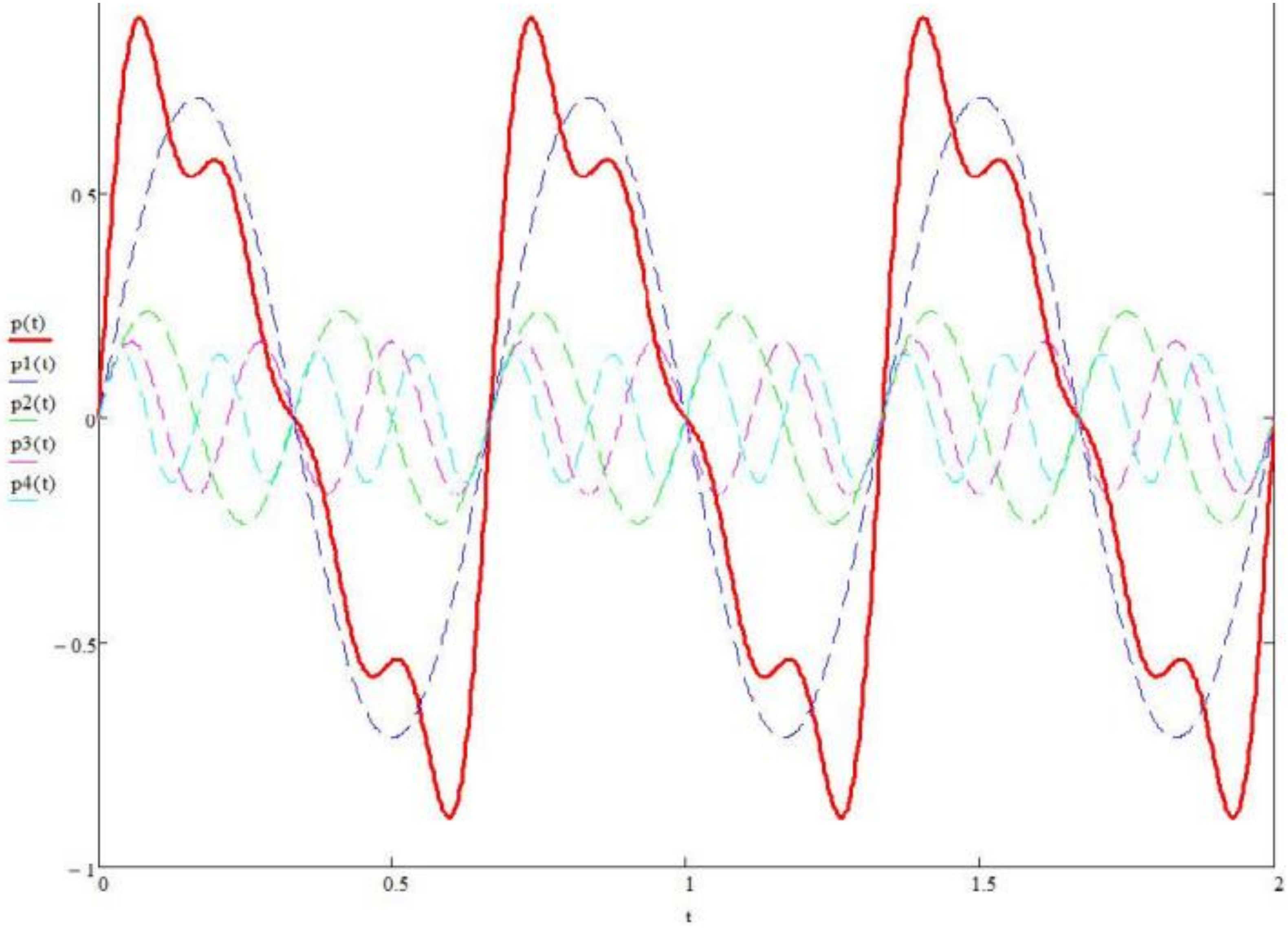


Figure 74–2: Assumed footfall forcing function built up from harmonic components

Peak Harmonic SRSS Combination for Resonant Response

Analysis is based upon a method in the Concrete Centre's design guide for vibrations [Willford, M.R. and Young, P., “A Design Guide for Footfall Induced Vibration of Structures, Concrete Centre, 2006].

This method predicts the total buildup that is possible under harmonic loading under a limited number of cycles.

It is **performed for each harmonic individually** and finds the peak acceleration.

The **results from the different harmonics are combined using a square root of sum of squares (SRSS) technique**.

RAM Concept Results Example

Analysis Method

AISC Steel Design Guide 11

Units

KN, m, C

Parameters

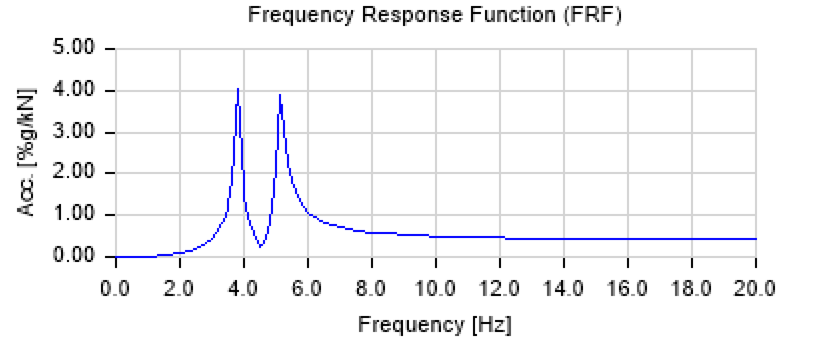
Floor Occupancy Type: Offices & Residences (options: Offices & Residences, Shopping Malls)

Pedestrian Bodyweight

Equivalent Viscous Damping: 2.5 %

Additional Details <R>

Modal Data | FRF Data | FRF Plot | Comfort Limits Plot



Show modes close to dominant frequencies

Analysis Summary

Excitation Set Name	Analysis Type	Excitation Joint	Response Joint	Dominant Freq. (Hz)	Max FRF(%g/KN)	Peak Sin. Acc. (%g)	Comfort Limit (%g)	Design DCR
R	Low Freq.	2	2	3.791	4.040146	0.191695	0.526068	0.364
R	High Freq.	2	2	9.5	0.510765	0.096219	0.59375	0.162
L	Low Freq.	4	4	3.791	4.040146	0.191695	0.526068	0.364
L	High Freq.	4	4	9.5	0.510765	0.096219	0.59375	0.162

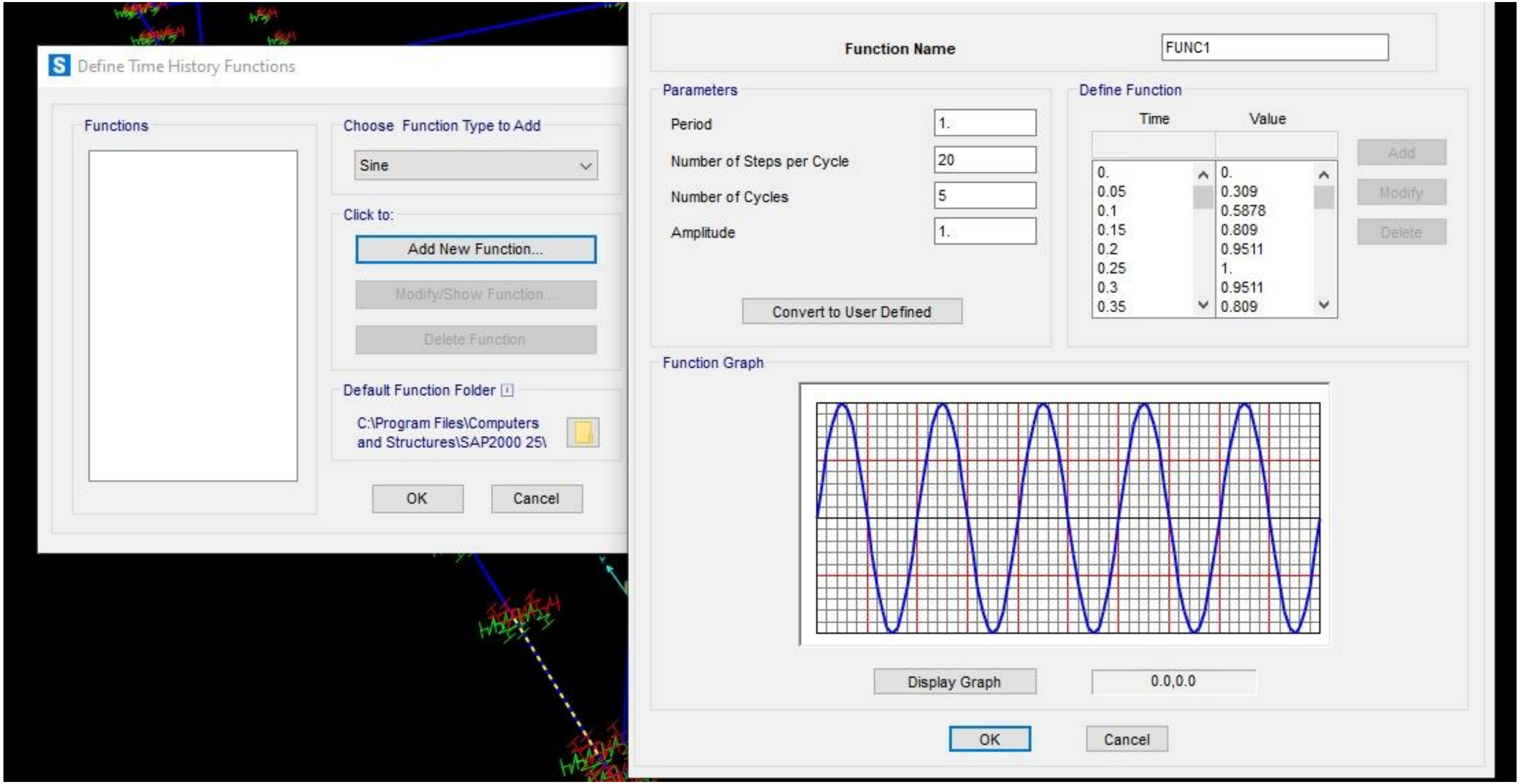
Table 4-1. Recommended Tolerance Limits for Building Floors

Occupancy	Acceleration Limit $a_o/g \times 100\%$
Offices, residences, churches, schools and quiet areas	0.5%
Shopping malls	1.5%

SAP2000 Implementation

Replicating the acceleration and comfort checks

SAP2000: Defining a Sine Time-History Function



SAP2000 Workflow (Recommended)

Step 1 — Run modal analysis: confirm dominant modes within the walking frequency band.
Step 2 — Define excitation: harmonic load (or sine time-history) at the walking location.
Step 3 — Compute response: joint acceleration time history (or steady-state amplitude).
Step 4 — Convert to comfort metric: peak or RMS acceleration, then compare with limits / R.
Step 5 — Sensitivity checks: damping ratio, mass source, boundary conditions, and mesh.

SAP2000: Extracting Acceleration and RMS

Export joint acceleration ($a(t)$) at the occupant location for the analysis case.
Peak acceleration: $a_{peak} = \max(|a(t)|)$.
RMS acceleration over a steady window: $a_{RMS} = \sqrt{ (1/T) \int a(t)^2 \, dt }$.
If using a sine with amplitude A: $a_{RMS} = A/\sqrt{2}$ (steady-state).
Convert units consistently ($m/s^2 \leftrightarrow \%g$), then compute response factor R if needed.

Conclusion

- RAM Concept (AISC 11) provides a fast, standardized vibration/acceleration check when inputs are well-defined.
- SAP2000 provides higher modeling flexibility, but requires explicit choices for mass source, damping, forcing, and RMS extraction.
- A valid comparison requires matching: modal frequencies, excitation definition, damping, and the reported metric (peak vs RMS / %g).
- Use the mismatch checklist to troubleshoot before concluding the software results are inconsistent.

Questions / discussion