

Contents

Preface xv

1 INTRODUCTION: FOCUS, ORGANIZATION, AND THEMES

1

- Purpose of This Book, 1
- Who Should Use This Book, 3
- How the Book Is Organized, 3
- Why Frequency Is Important, 4
- Why Blast Design Is Included, 4
- Cosmetic Nature of Vibration-Induced Cracking, 5
- The Importance of Regulations, 5
- How This Book Helps in Practice, 6

2 GROUND STRAINS FROM PLANE-WAVE APPROXIMATIONS

7

- Plane Waves, 7
- Compressive (Longitudinal) Plane-Wave Equations, 8
- Strains from Particle Velocities, 10
- Relationships Between Strain and Particle Motions, 10
- Propagation Velocity and Dynamic Stress, 12
- Transmission and Reflection, 14
- Shear (Distortional) Plane-Wave Equations, 17

v

3	TYPICAL VIBRATION HISTORIES AND ELEMENTARY ANALYSIS	19
	General Characteristics of Construction Vibrations,	19
	Sinusoidal Approximation of Construction Vibrations,	24
	Calculations with the Sinusoidal Approximation,	27
	Typical Construction Vibration Records,	28
	Principal Frequency,	33
	Peak Component and True Vector Sum,	35
	Propagation Velocity,	37
	Special Character of Surface Waves,	38
	Surface Waves and Ground Motion at Large Distances,	39
4	PREDICTION OF PEAK PARTICLE VELOCITY	41
	Attenuation of Construction-Induced Vibrations,	41
	Dominance of Rayleigh Waves for Construction Vibrations,	43
	Simplified Attenuation Relationship Leading to Scaling,	44
	Derivation of Cube-Root Scaling,	45
	Implications of Cube-Root Scaling,	49
	Square-Root Versus Cube-Root Scaling,	50
	Statistical Scatter of Peak Particle Velocity,	51
	Statistical Terminology,	53
	Simplified Calculations of Attenuation Equations,	54
	Preconstruction Tests,	55
5	RESPONSE SPECTRA AND STRUCTURAL RESPONSE	61
	Response Spectra with a Rubber Band,	61
	Origin of the SDF Model,	63
	Mathematics of the SDF Model,	64
	Structural Properties from Measured Vibration Response,	65
	Value of the SDF Response,	67
	Response Spectra and Pseudo-Spectral Response Velocity,	69
	Response Spectra and Tripartite Paper,	70
	Variation of Response Spectrum Shapes,	73
	Response Spectra and the Importance of Frequency,	76
	Response Spectrum Bounds,	77
	Translation of Pseudovelocitv to Strain,	78
6	STRUCTURAL NATURAL FREQUENCIES AND DAMPING: ESTIMATION AND MEASUREMENT	81
	Illustration with Measured Response,	81

Estimating Natural Frequencies and Damping of Structures,	84
Variation of Residential Response Properties,	85
Typical Ratios of Excitation and Structural Frequencies,	87
Fourier Transfer Functions for Response Properties,	88

7 RESONANCE, HIGHER MODE, AND TRAVELING-WAVE RESPONSE **93**

Misuse of Continuous Excitation and Resonance,	93
Analysis of High-Frequency Excitation with MDF Systems,	99
Effect of Structure Length and Traveling Waves,	101

8 COSMETIC CRACKING AND ITS DOCUMENTATION **104**

Cosmetic Nature of the Threshold of Cracking,	105
Overview of Investigations for Cracking Thresholds,	105
Comparison with a Recent Study of Pile-Driving Response,	110
Inaccuracy of the Word <i>Damage</i> ,	110
Importance of Wall Materials,	111
Preconstruction Crack Surveys,	112
Crack Inspection Forms,	114
Photographs of Construction-Induced Cracks,	117

9 RESPONSE SPECTRA OF MOTIONS CAUSING CRACKING **122**

Individual Case Studies,	122
Cracking Bounds of Response Spectra and High-Frequency Motions,	134

10 FREQUENCY-BASED CONTROL OF CONSTRUCTION VIBRATIONS **137**

Velocity-Frequency Control Bounds,	137
Methods to Determine Dominant Frequency,	141
Fourier Frequency Spectra,	142
Visual and/or Zero-Point-Crossing Frequency Determination,	147
Case Study of Visual and Spectral Determination of Dominant Frequency,	150
Synthesis of Control Techniques,	154

11	<i>PREDICTION OF PRINCIPAL FREQUENCY AND RESPONSE SPECTRA FOR CONSTRUCTION BLASTING</i>	156
	First Step: Prediction of Displacement and Acceleration, 156	
	Prediction of Principal Frequencies, 159	
	Prediction of Response Spectra, 161	
	Steps in the Prediction Process, 163	
	Example of Prediction, 164	
 12	 <i>PROBABILITY OF CRACKING AND FATIGUE FROM REPETITIVE LOADING</i>	 167
	Probabilistic Study of Thresholds of Cracking, 168	
	Fatigue and Repetitive Loading, 175	
	Test House with Gypsum Wallboard, 178	
 13	 <i>COMPARISON OF ENVIRONMENTAL AND VIBRATION-INDUCED CRACK MOVEMENT</i>	 182
	Multiple Origins and Natural Movements of Cracks, 182	
	Crack Movements from Everyday Activities and Environmental Changes, 186	
	Instrumentation of Test House for Comparison of Environmental and Vibration Effects, 187	
	Computerized Surveillance Instrumentation, 188	
	Long-Term Environmental Responses, 191	
	Soil Deformation, 192	
	Structural Response to Ground Surface Movement, 192	
	Vibration Response Time Histories, 195	
	Weather-Induced Micro Cracks Measured with Inductance Gauges, 198	
	Comparison of Wall Deformations Produced by Environmental Effects and Vibration, 199	
 14	 <i>AIR-BLASTS AND CONSTRUCTION NOISE</i>	 203
	Air-Blast and Noise Measurement, 204	
	Effect of Weighting Scales, 206	
	Propagation of Construction Noise, 206	
	Pile-Driving Noise, 209	
	Air-Blast Characteristics, 209	
	Propagation and Scaling of Air-Blasts, 213	
	Focusing Effects, 214	

Structural Response to Air-Blasts,	217	
Air-Blast-Induced Cracking,	218	
Scientifically Observed Air-Blast Cracking,	221	
15 PILE DRIVING		225
Pile-Driving Equipment and Technology,	225	
Case Studies and Typical Soil Deposits,	230	
Vibration Environment,	232	
Vibration Characteristics,	233	
Mechanical Model and the Importance of Transmitted Energy,	236	
Surface Motions,	240	
Structural Response,	241	
Monitoring,	245	
16 IMPACTING, VIBRATING, ROTATING, AND ROLLING CONSTRUCTION EQUIPMENT		247
Equipment Summarized,	247	
Decay or Attenuation of Vibration with Distance,	248	
Transmitted Energies,	250	
Influence of Impact-Medium Stiffness,	254	
Scaled Energy Attenuation Plots,	254	
Waveform and Dominant Frequency,	257	
Amplification Factors,	259	
Human Response,	263	
17 EXPLOSIVE DEMOLITION		265
Blast Design,	265	
Demolition Details for Reinforced Concrete Column Structure,	269	
Demolition Details for a Steel Girder Bridge,	273	
Case History Data with Measured Environmental Effects,	274	
Resultant Air-Blast and Ground Motion,	276	
Normalization of the Impact Motions,	280	
18 VIBRATION STABILITY OF ROCK SLOPES		285
Comparison of Earthquake and Blasting Waveforms,	285	
Two-Block Analysis (No Consideration of Wavelength),	288	
Distinction of Input Acceleration Functions,	291	
Expected Behavior for Increasing Excitation Frequency but Constant Particle Velocity,	292	

	Effect of Wavelength and Frequency with Multiple-Block Analysis, 293	
	Interpolation of Results, 295	
	Summary of Important Observations and Practicalities, 296	
19	BLAST DENSIFICATION OF SANDS	299
	Overview, 300	
	Comparison of Studies, 303	
	Surface and Subsurface Ground Motions, 303	
	Comparison of Ground Motions from Different Experiments, 307	
	Settlement, 311	
20	PERMANENT DISPLACEMENT AND PILE-DRIVING VIBRATIONS	315
	Sources of Transient and Permanent Deformation During Construction, 315	
	Case History Illustrating the Importance of Permanent Deformation, 317	
	Soils Susceptible to Vibratory Densification, 320	
	Comparison of Vibration Amplitudes Necessary for Cosmetic Cracking and Vibratory Densification, 323	
	Comparison of Vibration Settlement with Deformation Resulting from Loss of Lateral Support During Adjacent Excavation, 324	
	Practical Guidelines, 325	
21	FRACTURE AND PERMANENT DEFORMATION OF ROCK AND CONCRETE	327
	Curing Concrete, 327	
	Blasts in Concrete, 329	
	Cracks in Adjacent Rock, 331	
	Unlined Openings in Rock, 334	
	Well Response, 336	
	Throw of Fly Rock, 338	
	Block Movement from Gas Pressure Forces, 339	
22	RESPONSE OF PIPELINES AND BURIED STRUCTURES	342
	Restrained Response, 342	
	Axial and Circumferential (Hoop) Pipe Strains, 343	

Hoop or Circumferential Stresses,	344	
Bending, Stretching, and Circumferential Strains,	346	
Field Verification of Robustness of Pipelines and Buried Structures,	348	
Measured Particle Velocities and Strains,	353	
Expected Particle Velocities,	355	
Pipe Stress Calculations,	359	
American Gas Association Tests,	360	
Practical Precautions when Blasting Close to Pipelines, Basement Walls,	363	
23 HUMAN RESPONSE		366
Typical Human Response,	366	
Interplay Between Ground Motion and Air-Blast,	367	
Air Over Pressure-Induced Rattle of Walls,	369	
Ground Motion-Induced Floor Vibration,	372	
Exposure Levels and Affected Population,	375	
Perception, Annoyance, Comfort, and Proficiency,	375	
24 MICROVIBRATIONS, EQUIPMENT, SENSITIVITY, AND OCCUPANT-INDUCED VIBRATIONS		379
Guidelines for Sensitive Instrumentation,	379	
Differences Between Continuous and Impulse Terminology,	381	
Observations of Specific Performance,	383	
Footfall-Induced Floor Vibrations,	387	
Structural Transmission of Ground Motions,	392	
Comparison of Common Construction Activities with Microvibration Criteria and Occupant-Induced Floor Motions,	395	
25 INSTRUMENTATION AND MICROCOMPUTERS		399
Transducer Terminology,	400	
Why Specifications Are Written in Decibels,	401	
Transducer Attachment,	403	
Displacement Transducers,	404	
Strain Gauges,	406	
Velocity Transducers,	408	
Acceleration Transducers,	410	
Preamplifiers and Amplifiers,	413	
Tape Recorders,	415	

Permanent Recorders,	417	
Cables,	417	
Calibration,	418	
Field Systems,	419	
Microcomputer Digitizer and Response Spectrum Analyzer,	420	
Digitization of Time Histories,	422	
26 SPECIFICATIONS FOR THE CONTROL OF CONSTRUCTION VIBRATIONS		425
Blasting and Vibrations (Division 1),	426	
Pile-Driving Vibrations (Division 2),	444	
Air Overpressure (Division 3),	449	
27 THE EXPLOSION PROCESS AND EXPLOSIVE PRODUCTS		454
Explosion Process,	454	
Transmission of Detonation Pressure,	456	
Importance of the Delayed or Explosion Gas Pressure,	457	
Properties of Various Explosives,	458	
How Explosive Type Affects Ground Motion,	459	
28 MILLISECOND-DELAY INITIATION SYSTEMS		462
Variation of Initiation Systems,	462	
Sources of Error in Initiation Times,	466	
29 BLAST DESIGN		470
Why Blast Design Is Included,	470	
General Considerations,	471	
Langefors' Equation,	473	
Common Practice and Langefors' Equation,	475	
Fragmentation,	477	
Delay Intervals Along a Row,	478	
Delay Intervals Between Rows,	478	
Effect of Bench Height, Burden, and Spacing,	479	
Decking,	480	
Powder Factors and Fragmentation,	480	
Design Method When Vibrations Are Not Critical,	482	
Design Method When Vibrations Are Critical,	483	
Controlled Blasting,	485	

30 TIMING, GEOMETRY, AND LOADING EFFECTS ON PARTICLE VELOCITY

490

- Reduction of Particle Velocities with Millisecond Delays, 490
- Large Burdens, Presplitting, and Smooth-Wall Blasts, 494
- Geometrical Effects, 494
- Delay Overlapping and Surface Waves, 496

31 ANALYTICAL SOFTWARE

503

- Getting Started, 504
- Input Procedures, 507
- Output Examples, 509
- Obtaining NUVIB, 520

APPENDICES

523

- A: Answers and Explanations of Selected Problems, 523
- B: Supplemental Specifications for Controlled Blasting, Close-In Blasting, Densification of Sand, and Demolition, 562
- C: References, 580
- D: List of Symbols, 596
- Index, 600