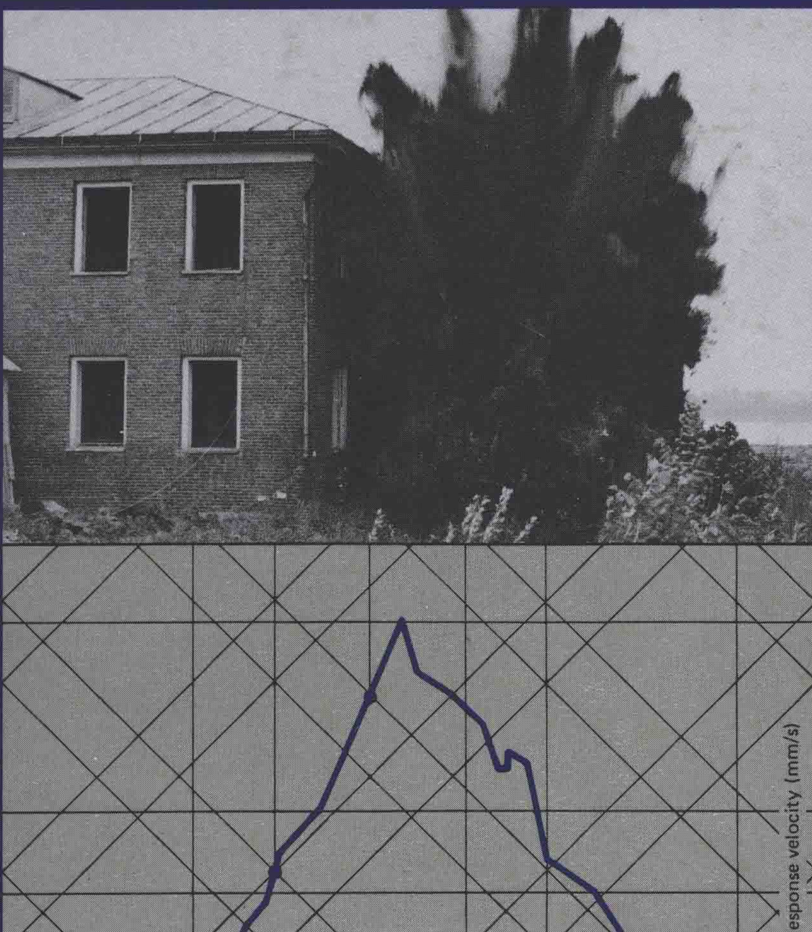
BLAST VIBRATION MONITORING AND CONTROL



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Blast Vibration Monitoring and Control

PRENTICE-HALL INTERNATIONAL SERIES IN CIVIL ENGINEERING AND ENGINEERING MECHANICS

William J. Hall, editor

Preface

This book is a condensation of consulting experience and research and is an effort to transfer advances in earthquake engineering and nuclear blast protective design to blast vibration monitoring. The transfer is made through simplified physical concepts and models as well as a synthesis of experiments conducted to establish criteria for safe blasting.

There has been a general downward drift of regulatory limits on allowable blast induced vibrations. This drift might be attributed to the tendency to take the limit of the last study and divide it in half "to be safe". Unfortunately, too many studies whose limits were divided were themselves only summaries of past work that had also divided past limits. This book presents the background for, and details of, original experiments conducted to determine safe blasting limits. By not setting limits, it allows the reader to set appropriate limits based upon the original past work.

Another tendency is the misapplication of peak particle velocity criteria for cracking in residential structures. These criteria have been applied to tunnel liners, radio towers, slabs-on-grade, and curing concrete. This book presents studies made to determine limits specifically for these and other cases. Where no studies exist, it presents methods based upon response spectra or ground strains that allow setting of appropriate criteria.

Frequency of vibration and strain form the foundation for the presentation. The importance of frequency cannot be overestimated, as it is as important as peak particle velocity in determining response of above-ground structures. For below-ground structures, frequency, in combination with propagation velocity, controls response. In both cases cracking results from induced strains where particle velocity is employed as an index of the strain level.

This book is a product of my interaction with many individuals in the field of blasting and vibration monitoring. The first and most significant was my mentor and Ph.D. advisor, Prof. A. J. Hendron, at the University of Illinois. Many of the approaches followed herein are adaptations of his.

Much of the research presented herein would not have been possible without the support provided by the United States Bureau of Mines, EXXON, and the Illinois Institute of Environmental Quality. I'm particularly indebted to the collaboration with Dr. E. D. Siskind and M. Stagg at the U.S. Bureau of Mines.

Many of the details were condensed from theses written by M.S. and Ph.D. students at Northwestern University. The field of blast vibration monitoring, and this book in particular, have benefited from their work.

The practical examples resulted from consulting assignments with groups such as Stone and Webster Engineering Co., Peabody Coal Co., EXXON Research and Engineering Co., Bechtel Inc., the United States Park Service, Minnesota Department of Transportation, Vibratech/VME, Wiss Janney Elstner, Digital Vibration Inc., and so on. The experience provided by these interactions provided an invaluable perspective for blasting problems.

Preliminary drafts of each chapter were reviewed by several experts in that subject. Many of their comments were incorporated in this edition.

I thank all of these people, both named and unnamed. I am especially indebted to my wife, Jane, and daughters, Chris and Kate, who have displayed great patience with my "author's pains" during the writing of this book.

Charles H. Dowding

Evanston, Illinois, USA
July 1984

Foreword

The evaluation of the effect of blasting vibration on structures basically involves three steps. These steps are: (1) an estimation of the ground motion produced by the blast in the proximity of the structure; (2) an analysis to evaluate the response of the structure to the ground motion; and (3) the establishment of tolerable limits for the structural response to prevent "damage". These same three stages of evaluation are also considered in the design of structures to resist earthquake motions and in the design of protective structures to resist the effects of ground motion produced by nuclear detonations.

The principles of analysis required to evaluate the effects of blasting vibrations, earthquakes, and nuclear detonations on structures are identical; the only differences are the relative amplitudes of the ground acceleration, particle velocity, and displacement as well as the frequency at which these motions occur. Although the structural dynamics approach is obviously used in the design of protective structures and earthquake resistant structures by civil engineers, the evaluation of the effects of construction or mining blasting on existing structures has developed from empirical correlations between observed damage and recorded peak particle velocities of the ground motion. These observations are useful and valid within the ranges of frequency of ground motion and the natural period of the structures for which these historical observations were made.

There are many cases which arise where either the frequency of the ground motion or the natural period of the structure are such that the empirical limits in terms of peak particle velocity are not appropriate and should not be used.

Unfortunately these limits have been adopted in many regulatory guides by various states and federal agencies and are commonly used where they do not apply. In fact, some of the most recent guidelines published by federal agencies would serve to exclude the type of construction blasting that has been employed successfully for basement excavations in New York City for many years. This misapplication has resulted because government agencies concerned with blasting vibration research have not been content to publish research results, but have felt compelled to publish peak particle velocity limits that are employed beyond their basis and the agencies' jurisdiction.

This book is refreshing in that the basic theory is presented and empirical observations are summarized such that the reader can make a rational analysis of a particular problem. The various subjects such as free-field motion and structural damage observations are very useful and save the reader much time that the author has obviously spent tracking down the pertinent observations made from many individual research studies.

The emphasis in this book on correlating the distortions and strains in a structure to damage is justified. The use of a structural dynamic analysis with the appropriate ground motion input as indicated in this book is the most rational way of arriving at the predicted values of the strains and distortions. If this process is followed, it will be automatic that specific structures that are unusual will be evaluated as individual cases. The use of this approach will also reveal where the usual regulatory limits may or may not apply.

The efforts of the author to summarize the current state of the art in blasting vibrations is commended; the tools provided in this book make it possible for an engineer to reach an independent judgment for a given problem which takes into account the characteristics of the structure, and the ground motion produced by blasting. The ability of the author to resist the temptation of setting oversimplified and possibly overly restrictive limits for the rest of the profession is equally applauded.

A. J. Hendron Jr.

Professor
Civil Engineering
University of Illinois

August 1984

List of Symbols

ENGLISH

A = area
A_v = velocity bound amplification value
A_u = displacement bound amplification value
A_a = acceleration bound amplification value
B = burden (distance between free face and blast hole)
b = intercept in linear equations
$\bar{c}$ = relative rock strength
c = propagation velocity
c_c = compressive wave propagation velocity
c_s = shear wave propagation velocity
c_1 = damping coefficient
c_d = detonation velocity
D = scaled distance, $R/W^{1/2}$
d = depth below the ground surface
= distance from neutral axis to outer fiber of beam or pipe
dB = decibels, a measure of sound pressure
d_2 = 1/2 thickness of beam
E = Young's modulus of elasticity
$\mathbf{e}$ = edge vector
F = force
f = natural frequency of a structure (Hz)
G = shear modulus
H = thickness of overburden soil layer
= horizontal component of ground motion

h = height of structure
I = moment of inertia
i = height of stemming in blast hole
J = flexibility ratio of a tunnel liner
K = wave number = $2\pi/\lambda$
K = stress concentration factor (= ratio of circumferential stresses to the initial vertical stresses)
k = spring stiffness
= gauge factor
L = width of structure
= longitudinal component of ground motion
l = length
l_p = charge density per foot at blast hole
M = constrained modulus
= moment
m = mass or mass intensity
= slope of linear equation
N = number of stories of a structure
n = fixity of hole (degree of relief)
P = sound pressure
PA = pseudo acceleration
PV = pseudo velocity
p = undamped circular natural frequency of a structure (= $2\pi f$)
p_d = damped circular natural frequency (= $p\sqrt{1-\beta^2}$)
$\mathbf{p}$ = mid point vector on a structure
Q = total charge
q = relative degree of packing of explosive
R = distance from blast to point of interest
= radial component (= L)
= Rayleigh wave designation
R_2 = distance between two sides of a structure
r = radius of tunnel liner or pipe
S = spacing between blast holes
SE = standard error of the estimate
SD = standard deviation (also shown as σ)
s = relative strength of the explosive
T = period (= $1/f$)
= transverse component of particle motion
t = time
= liner thickness
U = maximum sinusoidal displacement amplitude
u = ground particle displacement
$\dot{u}$ = ground particle velocity
$\ddot{u}$ = ground particle acceleration
V = vertical component of particle motion
W = charge weight per delay

w = dominant ground motion frequency
x = position along x axis
= absolute position of mass
Z = bench height
z = height of explosive
z_1 = depth of subdrilling

GREEK

β (beta) = percentage of critical damping ($= c_1/2\sqrt{mk}$)
γ (gamma) = shear strain
δ (delta) = relative displacement = u − x
ϵ (epsilon) = strain or change in length per unit length
θ (theta) = phase angle
λ (lambda) = wave length
ν (nu) = Poisson's ratio
ρ (rho) = density
σ (sigma) = stress
= standard deviation (also shown as SD)
τ (tau) = shear stress
= time variable of integtation
ϕ (phi) = blast hole diameter
ω (omega) = dominant ground motion circular frequency ($= 2\pi w$)

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