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Engineering Fracture Mechanics 75 (2008) 2812–2825
Engineering Fracture Mechanics
www.elsevier.com/locate/engfracmech

A method for evaluating dynamic tensile damage of rock

Zhiliang Wang [a,b,*], Yongchi Li [a], J.G. Wang [c]

[a] *Department of Modern Mechanics, University of Science and Technology of China, Hefei, Anhui 230027, China*
[b] *Institut für Geotechnik, TU Bergakademie Freiberg, 09596 Freiberg, Germany*
[c] *Centre for Protective Technology, National University of Singapore, 10 Kent Ridge Crescent 119260, Singapore*

Received 30 January 2007; received in revised form 4 January 2008; accepted 7 January 2008
Available online 15 January 2008

Abstract

This paper presents two evolution laws for dynamic tensile damage of brittle rock based on light gas gun (LGG) tests. By analyzing the attenuation of sound-wave propagation in the rock samples before and after impact tests, one evolution law for dynamic tensile damage of rock is introduced and incorporated into the finite element code LS-DYNA through a user-defined subroutine. The improved code is then applied to the simulation of the tensile damage and blast crater near free face of rock mass, and the resulting crater geometry is compared with empirical formula. In addition, based on the phenomenological point of view and the velocity–time histories recorded in LGG tests, another evolution law of tensile damage is proposed to consider the nucleation and growth of microflaws in rock. Parametric analyses are carried out with the self-developed finite difference code and an optimization procedure for the parameter determination is suggested.

Keywords: Rock; Tensile damage; Evolution law; Empirical formula; Velocity–time history; Sensitivity analysis

1. Introduction

Blasting is the most frequently used means for quarrying, mining and highway rock excavation. With increasing scale of these operations, strong demands for safety, economic and ecological handling, the proper design and control of blasts as well as predictions of blast results have become imperative in most operations [1–5].

As well recognized, explosion from either spherical or cylindrical charge in a homogeneous rock will result in a shock front that propagates outwards from the blasthole. When the compressive stress waves arrive at a free face (non-transmission) of the rock mass, they are reflected and converted into tensile waves. These tensile waves interact with the compressive waves, producing tensile cracks if the tensile strength of rock is exceeded, and a blast crater caused by spallation can be observed near the free face [4]. Since the explosives and the target rock are complex materials, the blasting process is far from full understanding. Under this scenario, further

* Corresponding author. Address: Department of Modern Mechanics, University of Science and Technology of China, Hefei, Anhui 230027, China. Fax: +86 551 3606459.
E-mail address: wzL@ustc.edu.cn (Z.L. Wang).

0013-7944/$ - see front matter
doi:10.1016/j.engfracmech.2008.01.005

Nomenclature

U_0	striking velocities of flyer
c_0	elastic longitudinal wave velocities in undamaged rock
c	elastic longitudinal wave velocities in damaged rock
D	damage scale
α	attenuation factor
ξ, η, α_0, K_α	fitting constants of rock
Y_d	energy dissipation
λ, μ	Lamé constants
ε_{ij}^e	elastic strain
$\dot{Y}_d$	energy dissipation rate
$\dot{\varepsilon}_v$	volumetric strain rate
Q	charge weight
W	distance from charge center to free face
k	unit consumption of explosive
$\bar{n}$	blasting action index
r_k	radius of blast crater
p	pressure
e_0	initial energy
υ	specific volume
υ_0	initial specific volume
ρ	density
ρ_0	initial density
C_1, r_1, C_2, r_2, ω	experimental constants of explosive
V	bulk of representative volume element
V_f, V_s	volume of microflaws and solid mass in a representative volume element
$\dot{V}_n$	nucleation ratio of microflaws
$\dot{V}_g$	growth ratio of microflaws
$\dot{V}_f$	sum of nucleation ratio and growth ratio of microflaws
σ_s	tension stress
σ_0	stress at damage threshold
N_0, A_0	nucleation factor and growth factor of microflaws
χ	damage dependent exponent
t	time
Δt	time step
X, x	Longitudinal Lagrange and Euler coordinate
M	mass coordinate
u	longitudinal velocity of particle
a	coefficient of quadric-form artificial viscosity
E	Young's modulus
v	Poisson's ratio
K	bulk modulus
G	shear modulus
γ	*Murnaghan* index
σ_x, ε_x	Axial stress and strain
τ, τ^*	shear stress and trial shear stress
$\bar{c}$	local sound velocity
ζ	time scale factor
A, B, m	experimental constants of rock