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Air-Blast Induced Ground Displacement

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Abstract

Outburst of nuclear explosion produces moving air-overpressure above ground surface. These overpressure fronts move at super-seismic speeds near ground zero and cause ground motion. Hence, determination of air-blast induced ground displacement is the first essential step in design of underground protective structures in super-seismic zone. For simplified analysis, air-blast load is modelled as linearly decaying pressure with time and using one-dimensional elastic wave propagation model, free-field vertical displacement response of elastic half-space can be expressed as a closed-form solution. However, such a simplified solution seems to be of very little practical utility in addressing problems in geotechnical environment. Hence, a new closed-form solution is proposed for displacement time-history which accounts for linear-inelasticity, plastic wave propagation velocity, and geometric stress attenuation. A conceptual pseudo-static procedure which computes vertical displacement as a static problem at each time instant based on dynamic properties of geomaterials is utilized to achieve the proposed solution. Predictions of the proposed model are compared with results of one of the atmospheric nuclear tests conducted at Nevada Proving Grounds and a reasonable agreement is obtained.

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Keywords: Stress waves; Ground displacement; Air-blast; Wave propagation; Super-seismic zone

1. Introduction

Aboveground nuclear explosion produces moving air-overpressure on ground surface which generates stresses and motion in ground. A simple and reliable estimate of air-blast induced free-field ground displacement is required for design of shallow-buried protective structures [1]. Near ground zero, magnitude of overpressure is significantly high

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and shock fronts move at a speed higher than P-wave velocity of ground. This region is referred as super-seismic zone. In super-seismic zone, air-blast induced ground motion is predominantly vertical [2] and experimental observations [3] suggest that ground displacement in super-seismic zone can be determined using one-dimensional wave propagation models.

In this paper, a closed-form solution is proposed for air-blast induced ground displacement using static one-dimensional approach with dynamic properties of geomaterials. Proposed expression for displacement time-history accounts for geometric dispersion, linear-inelastic stress-strain behavior of ground, and slower propagation speeds of ground shock fronts as compared to P-wave velocity. Proposed solution is validated with an ideal benchmark solution and experimental records of one of the atmospheric nuclear explosion tests conducted at Nevada Proving Grounds in late fifties.

Nomenclature

P_o	peak overpressure	W_j	energy yield of explosion (in Joules)
z	depth in the ground	α	attenuation coefficient
t_p	positive phase duration	V_L	stress propagation velocity
V_P	Seismic P-wave velocity	f	velocity ratio of V_P to V_L
P	overpressure time-history	S_m	peak vertical ground surface displacement
S	ground surface deformation time-history	W	yield of explosion (in kt)
M_L	loading modulus	M_U	unloading modulus
r	strain recovery ratio	$\sigma_{p,z}$	Peak stress at a depth z
t	time after arrival of blast wave	t_i	time of occurrence of i^{th} stress front in overpressure time-history
L_W	attenuation parameter		
ε	strain in ground at a depth z	σ	stress in ground at a depth z
M_{L1}	loading modulus of top layer	M_{L2}	loading modulus of bottom layer

2. Idealized solution

One-dimensional wave equation in elastic solids can be written as in Eq. 1 [4]. If air-blast overpressure is idealized in form of linearly decaying pressure (Eq. 2) applied on top of semi-infinite elastic homogeneous half-space, then, wave equation (Eq. 1) can be solved for boundary condition (Eq. 2) and displacement-time history as shown in Eq. 3 can be obtained. Therefore, maximum vertical deformation can be obtained as in Eq. 4.

$$\frac{\partial^2 S}{\partial t^2} = V_L^2 \frac{\partial^2 S}{\partial z^2} \tag{1}$$

$$P(t) = P_o\left(1 - \frac{t}{t_p}\right); \qquad 0 \le t \le t_p \text{ at } z = 0 \tag{2}$$

$$S(t) = \frac{P_o t_p V_L}{2M_L}\left(\frac{2t}{t_p} - \frac{t^2}{t_p^2}\right) \tag{3}$$

$$S_m = \frac{P_o t_p V_L}{2M_L} \tag{4}$$

3. Limitations of idealized model

In real life situations, several complexities occur due to the facts such as (i) ground does not behave elastically [5], (ii) near surface geo-materials become stressed beyond their elastic limits and plastic wave propagation starts which