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Dynamic shieldings for cultural heritage buildings under seismic action

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ABSTRACT

The goal of the present paper is to numerically investigate the effects produced by a vertical barrier located inside the ground, when the soil is subjected to seismic waves coming from a seismic source with a planar wave front. Firstly, the acceleration field on the ground surface is computed by varying both geometrical and mechanical properties of the barrier in order to determine, through a parametric study, the optimal barrier configuration to minimize the maximum magnitude of surface acceleration inside the shielded zone. Then, the above configuration is employed in the framework of a seismic analysis: a portion of a colonnade in Pompeii (Naples, Italy) is examined, with such a colonnade assumed to be located inside the shielded zone. A comparison of the seismic behaviour of such a heritage building is provided for the two cases of ground with or without the above vertical barrier.
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1. Introduction

Propagation of mechanical waves in the ground can be generated by several causes: traffic, machine foundations, explosions, earthquakes. Such a propagation is a physical phenomenon that should be taken into account when both designing new buildings and restoring cultural heritage buildings, especially in densely populated zones, since it produces disturbances to structures, interfering with the related activities and, in some cases, threatening the structure stability.

Experimental and numerical analyses of such a phenomenon are available in the literature: for example, we can recall the case of the train-induced ground vibrations [1–5].

Several suitable countermeasures against ground vibrations of generic nature, especially regarding surface waves, are available in the literature. Tsai and Chang [6] studied both open trenches and diaphragm-wall barriers by using 2D Boundary Elements Method, whereas Çelebi et al. [7] conducted experimental studies by analysing the basic characteristics of wave propagation phenomenon in order to propose suitable countermeasures to reduce soil vibrations. Xia et al. [8] analytically studied elastic waves scattering by employing cylindrical piles, and Alzawi et al. [9] performed a full scale experiment in order to examine vibration scattering by using both open trenches and GeoFoam wave barriers. Further, Ekanayake et al. [10] numerically studied the efficiency of different barrier materials related to the ground vibrations attenuation, and Saikia [11] analysed vibration screening effectiveness using a pair of in-filled trenches.

Generally, seismic control systems able to improve the structure behaviour regarding failure induced by earthquake may be subdivided into two categories:

(i) Active systems, which apply forces on the structure as a function of the earthquake forces;
(ii) Passive systems, which withstand earthquake forces by deforming themselves.

The seismic control systems represented by seismic barriers (also named *seismic shieldings*) fall into the category of passive systems, since they soften the mechanical waves energy through their hysteretic deformation. Such systems are structural elements placed into the ground, and may be of different types: vertical barriers [12–14], horizontal barriers [12–15], rough surfaces [12–14], and rows of piles [15–17].

In order to analyse the problem of wave propagation in presence of barriers located into the ground, a numerical approach is here adopted, since both closed form solutions are not available in the literature and full scale tests are expensive and time consuming.

The present research work aims to numerically investigate the effects produced by a vertical barrier located inside the ground, when the soil is subjected to seismic waves coming from a seismic source with a planar wave front. As a matter of fact, to the knowledge of the authors, studies available in the literature are

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Nomenclature

A	maximum magnitude of acceleration
A_b	maximum magnitude of acceleration with barrier
A_{nb}	maximum magnitude of acceleration without barrier (i.e. no barrier)
A_x	magnitude of acceleration registered along the X-direction
[C]	damping matrix
d	relative distance of the barrier from the seismic source
E	barrier Young's modulus
E_g	ground Young's modulus
f	frequency
h	barrier depth
[K]	stiffness matrix
[M]	mass matrix
RF	Reduction Factor
v	wave velocity
w	barrier width
α	Rayleigh mass-proportional damping coefficient
β	Rayleigh stiffness-proportional damping coefficient
λ	shortest wavelength
ξ	damping index
ρ	barrier density
ρ_g	ground density
υ	barrier Poisson's ratio
υ_g	ground Poisson's ratio
ω_n	pulsation
Δf	frequency range

generally related to propagating waves coming from point sources [1–6,9–11,18–21].

A tridimensional numerical model of soil and vertical barrier is implemented in ABAQUS/CAE Finite Element software (Simulia, Johnston, United States), by employing both finite elements and infinite elements. The proposed parametric study is carried out by varying both sizes (that is, depth and thickness) and mechanical properties (that is, density and elastic modulus) of the barrier, in order to minimize the maximum magnitude of surface acceleration inside the zone shielded by the barrier.

Finally, a case study is analysed. In particular, the open source Chrono:Engine multi-body simulation software is employed to study the seismic behaviour of a portion of a colonnade in Pompeii (Naples, Italy), with such a colonnade assumed to be located inside the above shielded zone.

2. Numerical model description

2.1. Ground numerical model

A tridimensional numerical model of the soil is implemented in ABAQUS/CAE by using both 8-node finite elements and infinite elements (Fig. 1). The infinite elements allow us to approximate the infinite system (represented by the ground) as a finite system. As a matter of fact, such elements are able to simulate a viscous boundary, that is, to eliminate the wave reflections (non-reflecting boundary).

More precisely, finite elements are adopted to model a prismatic volume with horizontal section of 30 m × 30 m (Fig. 1(a)) and depth equal to 15 m (Fig. 1(b)), whereas infinite elements are employed around such a volume in order to simulate non-reflecting ground boundary conditions [22].

The ground is considered as a linear elastic, homogeneous and isotropic medium, with a Rayleigh damping behaviour described by two constants, α and β:

$$[\mathbf{C}] = \alpha\ [\mathbf{M}] + \beta\ [\mathbf{K}] \tag{1}$$

where [**C**] is the damping matrix, [**M**] is the mass matrix, and [**K**] is the stiffness matrix. In order to evaluate the above constants, the damping index, ξ, is defined as follows:

$$\xi = \frac{\alpha}{2\omega_n} + \frac{\beta\omega_n}{2} \tag{2}$$

being ω_n the pulsation. By assuming a damping index ξ equal to 5% (value frequently adopted in the literature) and frequency range Δf from 1.5 to 20 Hz (range characterizing the most frequent

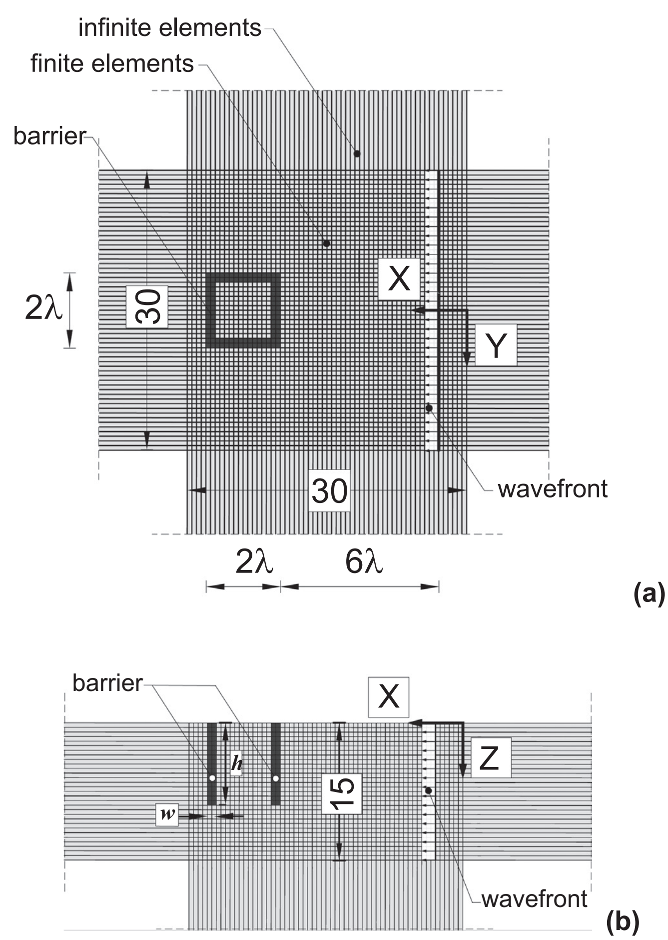

Fig. 1. 3D FE model of soil and vertical barrier: (a) plan view; (b) longitudinal view. Length in metres.

Table 1
Ground: damping and mechanical parameters.

Material	α [1/s]	β [s]	Young's modulus, E_g [Pa]	Poisson's ratio, υ_g [-]	Density, ρ_g [Kg/m^3]
Ground	0.876724	0.000740	2.04 $(10)^7$	0.31	1951.25

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