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Dynamic analysis of non-homogeneous concrete blocks mixed by SiO_2 nanoparticles subjected to blast load experimentally and theoretically

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HIGHLIGHTS

- Dynamic analysis of non-homogenous concrete block is presented.
- The effect of soil foundation is considered.
- The structure is subjected to blast load.
- The experimental and theoretical analyses are presented.
- The concrete blocks are reinforced by SiO_2 nanoparticles.

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ABSTRACT

In this paper, dynamic analysis of non-homogenous concrete block resting on soil foundation subjected to blast load is presented experimentally and theoretically. The non-homogenous concrete block is made from two concrete blocks filled by barite. The concrete blocks are reinforced by SiO_2 nanoparticles where the Mori-Tanaka model is used for calculating the effective material properties of the structure. The soil medium is simulated by spring constant of Winkler medium. Based on Mindlin theory, energy method and Hamilton's principle, the motion equations are derived. The transferred weighting differential quadrature method (TW-DQM) is used for solution of the theoretical model. In addition, the experimental tests are done for obtaining the maximum velocity of the structure in vertical, radial and tangential directions. Comparison of experimental tests and theoretical model are close to each other which show the accuracy of the mathematical modeling. The effects of different parameters such as volume percent of SiO_2 nanoparticles, agglomeration of SiO_2 nanoparticles, soil medium, length and width of the structure, discontinues distance and the slope discontinuity are shown on the maximum velocity of the structure. The results show that increasing the discontinues distance higher than 40 cm, the vertical maximum velocity dose not any significant changes. It can be concluded that the slope discontinuity of 45 degree is an optimum value. With comparing the result of Geophone 1 (before discontinuity) and Geophone 3 (after discontinuity), it can be concluded that the wave speed will be reduced about 230% which can improve the safety of the structure.

1. Introduction

The resistance strengthening of concrete structures across the blast load is one of the important subjects for geomechanic and aerospace industries. For example, for keep up the weapons and military bases from the waves induced by blasts, the concrete structure is used. In this paper, a new idea is introduced for improving the quality and resistance strengthening of concrete protective structures. This idea is using from a non-homogeneous concrete structure with applying a filling material between two concrete blocks. In addition, we consider the effect of nanoparticles with mixing the concrete blocks with SiO_2 nanoparticles.

In the field of concrete structures subjected to blast and impact loads, different studies have been reported. Nam et al. [1] carried out to assess and to compare a comprehensive finite element analytical model of Fiber reinforced polymer (FRP) that can properly consider the properties of FRP as a retrofit material for concrete

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structure under blast loads. For the blast in the concrete, detonation wave model and dynamics model of concrete were established by Wu et al. [2] and the Smoothed particle hydrodynamics (SPH) method was adopted to research the damage effect of concrete by TNT blast. Pandey et al. [3] demonstrated the effect of an external explosion on the outer reinforced concrete shell of a typical nuclear containment structure. Brun et al. [4] explored the coupling between finite element codes based on implicit and explicit time integration schemes for blast analyses on a reinforced concrete frame structure. The blast-resistant capacities of ultra-high strength concrete (UHSC) and reactive powder concrete (RPC) were experimentally evaluated by Yi et al. [5] to determine the possibility of using UHSC and RPC in concrete structures susceptible to terrorist attacks or accidental impacts. Bastante et al. [6] described a new model for predicting the extent of blast-induced damage (BID) in rock masses. The blast damage behaviour of reinforcing bars embedded in a High Strength Concrete (HSC) exposed to blast loading was investigated by Yun and Park [7]. Effect of blast-induced vibration from new railway tunnel on existing adjacent railway tunnel in China was presented by Liang et al. [8]. Experimental modal analysis of a prestressed concrete double-tee joist roof subject to blast was presented by Kernicky et al. [9]. In order to properly evaluate the HSC slab subject to blast loading, an explicit analysis program was used. The failure mechanism of a concrete slab–soil double-layer structure subjected to an underground explosion was investigated by experimental and numerical methods by Tan et al. [10]. A spatial reliability analysis was conducted by Shi and Stewart [11] to predict the damage for reinforced concrete (RC) columns subject to explosive blast loading. In another work by Shi and Stewart [12], a structural reliability analysis was conducted to predict the damage and risk reduction for RC wall panels subjected to explosive blast loading. Jeyarajan et al. [13] investigated the progressive collapse behaviour of steel concrete composite buildings subject to ground blast explosion using nonlinear dynamic analysis and conventional alternate path approach. Anandavalli et al. [14] adopted a new approach for modeling RC structures is analyse a blast loaded Laced Reinforced Concrete (LRC) structure. A series of field tests were conducted by Xu et al. [15] to investigate the behaviour of Ultra high performance Fiber reinforced concrete (UHPFRC) columns subjected to blast loading. In total four 0.2 m $\times$ 0.2 m $\times$ 2.5 m UHPFRC columns were tested under different designed explosions but all at a standoff distance of 1.5 m. General procedures for vulnerability assessment and retrofitting of a generic seismically designed bridge were outlined by Biglari et al. [16] and the bridge's damage criteria for blast resistance were explained. Kong et al. [17] developed a numerical model for investigating the capacity of the Carbon Fiber Reinforced Polymer (CFRP) patch to improve the blast response of cracked reinforced concrete (RC) slab. In order to clarify the requirements for satisfactory coupling on rock, six methods to monitor vibrations with blasting seismographs were investigated by Segarra et al. [18] in the longitudinal component of the vibratory motion. Using the improved Hilbert–Huang transform (HHT), Li et al. [19] investigated the problems of analysis and interpretation of the energy spectrum of a blast wave. Using analytical solution, Duc et al. [20] investigated the nonlinear dynamic response and vibration of sandwich auxetic composite cylindrical panels. Duc et al. [21] presented a new approach – using analytical solution to investigate nonlinear dynamic response and vibration of imperfect functionally graded carbon nanotube reinforced composite (FG-CNTRC) double curved shallow shells. Three-dimensional nonlinear finite element (FE) analyses of a tunnel in rock with reinforced concrete (RC) lining subjected to internal blast loading was studied by Tiwari et al. [22].

However, to date, no report has been found in the literature on blast response of the non-homogeneous concrete blocks considering the effect of thickness, type of filling material and the slope discontinuity. Motivated by these considerations, in order to improve optimum design of concrete blocks subjected to blast load, we aim to present a theoretical model for the non-homogeneous concrete blocks reinforced by SiO_2 nanoparticles. The non-homogeneous concrete block is made from two slop concrete blocks filled by barite. The Mori-Tanaka model is applied for obtaining the equivalent material properties of concrete blocks reinforced by agglomerated SiO_2 nanoparticles. The motion equations are obtained using Mindlin and energy method. DQ-Newmark methods are used to calculate the wave velocity of the structure. The effects of different parameters such as volume percent of SiO_2 nanoparticles, agglomeration of SiO_2 nanoparticles, soil medium, length and width of the structure, discontinues distance and the slope discontinuity are elucidated.

2. Theoretical formulation

Fig. 1 shows two slope concrete blocks reinforced with agglomerated SiO_2 nanoparticles filled by barite. The length, width and thickness of concrete block are shown by L, b and h, respectively. In addition, the angle of slope discontinuity is presented by θ with respect to the vertical axis. The Cartesian coordinate is considered in the middle surface of plate in which x, y and z represent the axial, vertical and transverse directions, respectively. A blast hole before the discontinuity is considered with the diameter D and height H.

2.1. Basic relations

In order to mathematical model of the structure, a quadrilateral plate model with the Mindlin theory is used. Based on this theory, the displacement fields can be written as [23]

$$u_1(x,y,z,t) = u(x,y,t) + z\phi_x(x,y,t), \tag{1}$$

$$u_2(x,y,z,t) = v(x,y,t) + z\phi_y(x,y,t), \tag{2}$$

$$u_3(x,y,z,t) = w(x,y,t), \tag{3}$$

where u, v and w are the mid plane displacement in x-, y- and z-directions, respectively; ϕ_x and ϕ_x are the rotations of cross section about y- and x-axis, respectively. The strain-displacement relations can be expressed as follows

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} + z\frac{\partial \phi_x}{\partial x}, \tag{4}$$

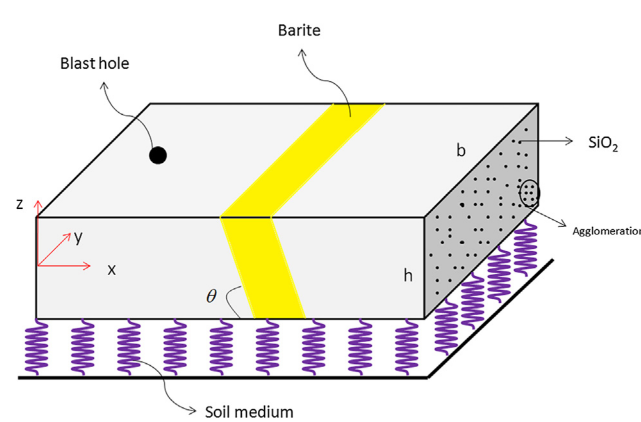

Fig. 1. A schematic figure of non-homogeneous concrete blocked filled by barite under blast load resting on soil medium.