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Stresses induced by a demolition agent in non-explosive rock fracturing

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ABSTRACT

Stresses induced by a demolition agent in non-explosive rock fracturing was analysed using the theory of elasticity and the thick-walled cylinder principle. Circumferential and radial stresses in rock induced by an internally pressurized hole was first analysed under plane strain condition. Stresses perpendicular to the line connecting two adjacent holes were calculated based on coordinate transformation. A parametric study was carried out to investigate the influence of spacing and size of hole on the stress distribution. The analytical model provides a method to determine the optimum hole spacing and size as well as the time needed for fracturing rocks with properties similar to those employed to determine the pressure-time function of the demolition agent. It is found that tensile stress decreased dramatically with the increasing of hole spacing, while it increased with increment of hole size but the influence of spacing on stress changes was more significant than that of hole size. It is also concluded from the study that tensile stress in the middle of two holes decreased dramatically with a logarithmic distribution when solely increasing hole spacing. As can be anticipated more time is required for rock fracturing and breaking when hole spacing is increased for both soft and hard rocks.

1. Introduction

Non-explosive rock fracturing has been widely used in rock engineering projects such as quarry, mining, underground infrastructure construction and rock slope engineering. Fig. 1a shows a rock slope formed by a demolition agent (DA) at the Castle Peak Road in Hong Kong where blasting may pose a significant threat to human safety and was not allowed. An underground tunnel was excavated by a PRS-95 hydraulic splitter in the construction of the Mass Transit Railway (Admiralty section, Hong Kong) (see Fig. 1b). The major advantage of this "silent" rock fracturing method is no fly rock, no vibration and controllability.

Despite the significant growth in the use of the controlled rock fracturing method, more guidance for design of hole patterns in practical rock engineering would be helpful. Spacing and diameter of holes are often empirically determined for a certain lithology and requirement. Diameter of holes are generally recommended between 30 and 65 mm depending on rock property, with a spacing of holes generally ranging from 200 to 1000 mm.[1]

An empirical model was developed based on dimensional and polynomial regression analysis to determine hole spacing.[2] Gómez and Mura[3] investigated the relationship between hole diameter (l) and hole spacing (d) and concluded that spacing is proportional to diameter which can be written as $d = kl$. In that study, the value of k was experimentally determined as: $k < 8$ for hard rock, $8 < k < 12$ for medium hard rock and $12 < k < 18$ for soft rock.

Dowding and Labuz[4] reported that temperature and thermal sensitivity of rock material could influence hole spacing, and an optimum spacing of 8 times hole diameter was proposed. Natanzi et al.[5] experimentally investigated demolition of masonry walls using DA. An optimum hole pattern with a d/l of 57 and a spacing of 225 mm was reported. Actually, these studies ignored the influence of time on fracturing when investigating the relationship between spacing and diameter.

Knowledge of pressure from DA has a great importance for an improved understanding of rock fracturing. An experimental methodology to determine the internal pressure of a single hole under an expansive load has been reported by measuring the tangential strain on the external boundary of a pipe wall that was internally pressurized.[6] In that study, the pressure was suggested to be calculated taking into account three independent parameters including hole diameter, loading time and Young's modulus. The research however failed to consider the interactions of neighbouring holes under expansive loads, which is very common in practical rock engineering.

There have been some publications regarding the stresses around holes in an infinite plate. Ling[7] investigated the stresses in a plate containing two equal circular holes. The aim of that study was to introduce a theoretical solution of stresses along the edges of holes under

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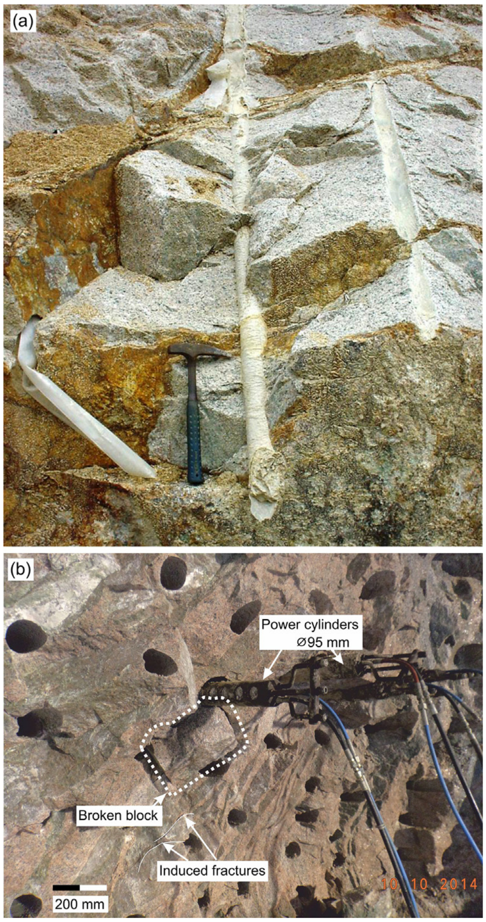

Fig. 1. (a) A demolition agent used to form slopes at the Castle Peak Road in Hong Kong where blasting was not allowed. Hammer for scale; **(b)** A hydraulic splitter (model PRS-95) was employed for the non-explosive fracturing of rock in construction of the Mass Transit Railway (Admiralty section) in Hong Kong.

external tension load. Haddon[8] studied the stresses around two unequal holes in an infinite plate using the conformal mapping and complex variable methods. Based upon the Love's stress function, Ling et al.[9] presented an analytical solution for the stresses in a thick plate containing a cavity with a zero surface stress. The aforementioned investigations succeeded in formulating analytical solutions for stresses around holes but none of these researches can be directly used to understand the stress distribution by DA when fracturing rock because of the time dependent nature of the expansive pressure. On the other hand, in the application of DA, stress concentration often occur around a hole[10–12] under incremental static loading in rock, which will lead to the initiation and coalescence of fracture between adjacent holes.[13]

The aim of this paper is to investigate stresses between two neighbouring holes under incremental expansive pressure from DA. A mathematical model comprising two internally pressurized holes was developed and influential factors including hole layout, loading time and rock property were taken into account. The relationships between optimum hole spacing and size which can used as a guidance for design of hole patterns in practical rock engineering were respectively derived for hard and soft rocks.

2. Non-explosive demolition agent

The non-explosive DA in this paper refers to a commercially available chemical powder which can expand considerably on mixing with water. In rock engineering, circular holes are drilled and terminated within rock masses and these pre-drilled holes are then filled with a

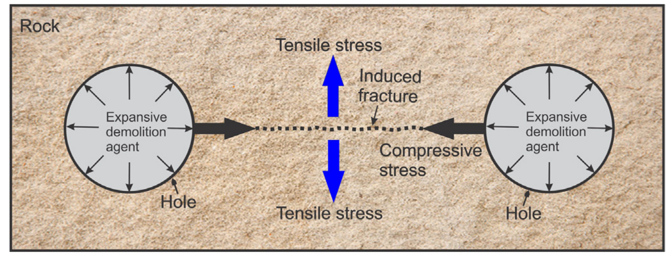

Fig. 2. Interaction mechanism of two neighbouring holes subjected to the expansive pressure from a non-explosive demolition agent. Redrawn from Natanzi et al.

mixture of DA and water at the recommended ratio (3.3 kg/L). The DA hardens gradually and expands to fracture rock, typically over 24 h.[15] The interaction mechanism of two adjacent holes with DA is illustrated in Fig. 2. Tensile stress perpendicular to the line connecting the two holes is generated by compression (due to the expansion of the DA within the holes); and the rock material in between will be fractured when the tensile stress exceeds the tensile strength of the rock.

3. Mathematical model and analysis

3.1. Stresses around a single internally pressurized hole

In this paper, the stresses arising from the interaction of two neighbouring holes is focused. Fig. 3 shows two symmetrical holes internally pressurized and the stresses acting on an element arising from Hole 2 in a polar coordinate. Assuming the two symmetrical holes with an equal radius of r_i are drilled in an elastic-plastic rock media. The DA is injected into the pre-drilled holes. The pressure (p) generated from the DA acts on the inside wall of the holes. The problem could be simplified as the interaction of two thick-walled rock cylinders internally pressurized. For the assumed cylinder, the inner radius is r_i and the outer radius r_0 equals to the hole spacing (d, from centre).

The pre-drilled Hole 2 and the surrounding rock material can be

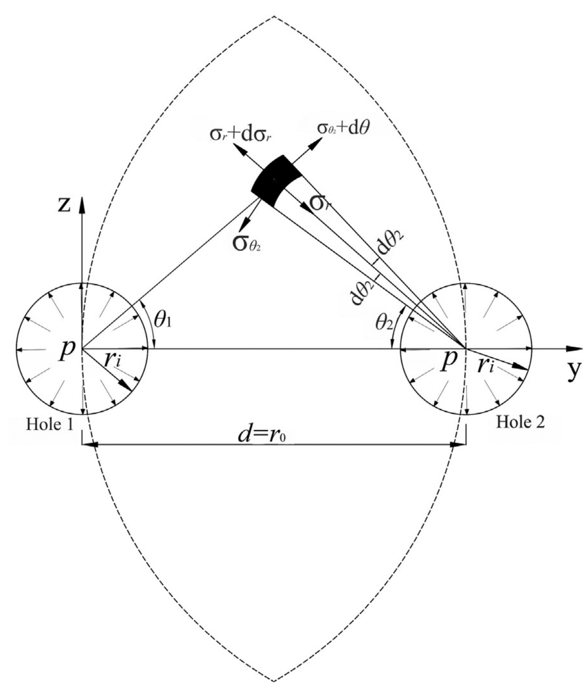

Fig. 3. Model of two symmetrical holes internally pressurized. Stresses acting on an element solely arising from Hole 2 is presented in a polar coordinate system. r is the radius and θ is the azimuth in polar coordinate.