

## (25) Numerical study of breaking down of full scaled pile top by means of blast method

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## 1. Introduction

Breaking down of the pile top and mechanical removals of concrete structures pose a risk to the occupational health of those involved in the operation and also to others in the vicinity, due mainly to the noise hazard. A controlled blasting method utilizing charge holders was suggested to prevent the need for the mechanical breaking methods. (Fourney *et al.* 1978, Katsuyama *et al.* 1983, Nakagawa *et al.* 1986, Nakamura *et al.* 1997 and Nakamura 1999) Recently in-situ blasting experiments were conducted to examine the effectiveness of a diamond-shaped charge holder in breaking down of the concrete pile top.

This study proposes a numerical method to simulate fracture propagations in the full scaled concrete pile top by means of blasting method. The influence of the shot time lag and spacing distance of the diamond-shaped charge holders on the fracture patterns were investigated.

## 2. Dynamic Fracture Process Analysis(DFPA) and condition of the analyses in blasting using diamond-shaped charge holder

This study improved the dynamic fracture process analysis (DFPA) code (Cho *et al.*, 2003 and Cho *et al.*, 2008) to describe breakage of concrete pile top by blast technique using charge holders. In the dynamic fracture process analysis, the increment displacement form of a dynamic finite element method is used to explain large displacement behavior. A re-meshing

algorithm is used to model crack propagation, assuming that tensile fractures, i.e., crack initiation, propagation, and interconnection, occur at element boundaries. Therefore, the cracks are modeled as separations from element boundaries that do not change the shape of the elements. At each element boundary, the fracture potential is checked at every time-step. The fracture potential is calculated from the ratio of the normal stress and tensile strength at the element boundary. If the fracture potential of two elements exceeds 1, the node between the elements is separated into two nodes. Since the cracking and fracture processes are treated as the separation of elements, contact problems, i.e., overlapping of the separated elements may occur due to the perpendicular compression stress that is applied to the separated elements. This problem is solved iteratively to prevent meshing overlaps when the separated elements are in contact with each other.

### 2.1 Condition of the analyses

Fig.1 shows the finite element layout for the analysis models which has a circular free face and 4 diamond-shaped charge holders installed 515mm from the center of the model (Model 1). The model was divided into triangular elements. The diameter of outside boundary is 1500mm and the diamond-shaped charge holders are 36.4mm, respectively. The model considers the geometry of the full scaled concrete pile specimens. Thickness of the charge holder is 1.6mm. The minimum size of the elements used in this study is 1mm.

The analysis model applied the same parameters used and calculation conditions as listed in Table 1. The model conditions having different shot time lags and spacing distance between the diamond-shaped charge holders and the center of the model was shown in Table.2

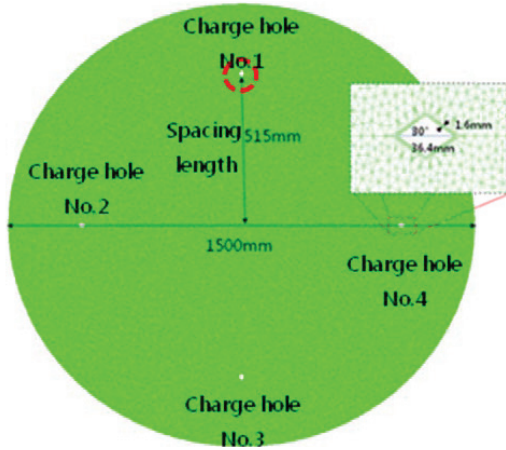


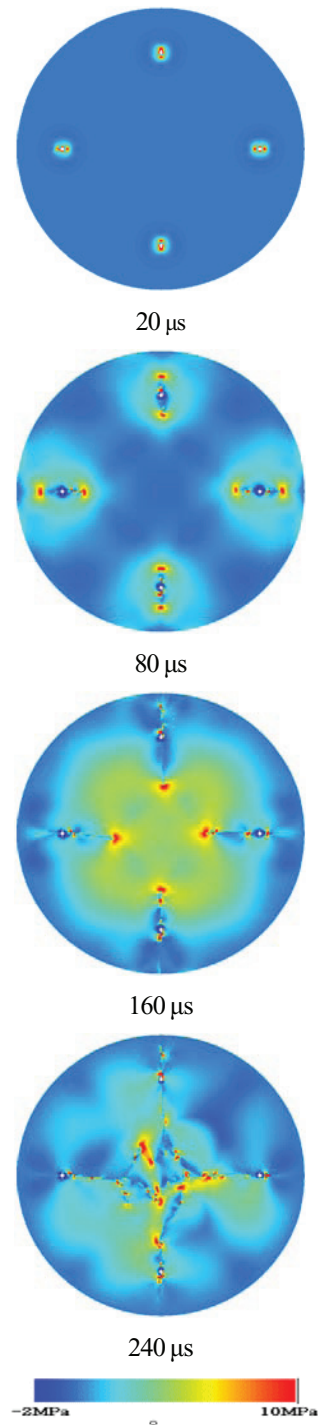
Fig. 1 Finite element layout for the analysis model

Table 1. The parameters used and calculation conditions.

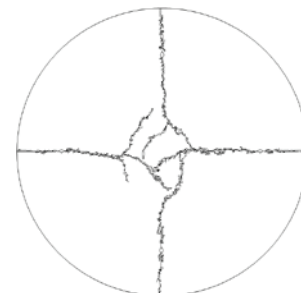
Parameters	Value
Density ( $\text{kg/m}^3$ )	2170
Elastic modulus $E$ (GPa)	36.17
Poisson's ratio $\nu$	0.249
Mean compressive strength $\chi$ (MPa)	80
Mean tensile strength $\chi$ (MPa)	8
P wave velocity $C$ (m/s)	4500
S wave velocity $C$ (m/s)	2601
Coefficient of uniformity	5

Table 2. Conditions of the analysis models

Model	Shot time lag	Distance from the center (mm)
1	0 $\mu\text{s}$	515
2	2 holes at 200 $\mu\text{s}$	515
3	200 $\mu\text{s}$	515
4	0 $\mu\text{s}$	415
5	0 $\mu\text{s}$	580



(a) Maximum principle stress distribution



(b) Resultant fracture pattern

Fig. 2 Maximum principle stress distribution and resultant fracture pattern in Model 1

### 3. Dynamic fracture processes of the analysis model having diamond-shaped charge holders

#### 3.1 Model description and simulation results

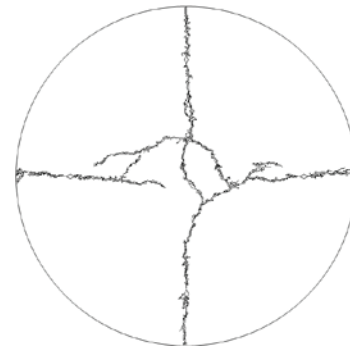
Fig.2 shows maximum principle stress distributions and resultant fracture patterns for Model 1 with the lapsed time. In Fig. 2(a), red color intense indicates tensile stresses and blue color intense indicates compressive stresses. At 20 $\mu$ s, tangential tensile stress fields concentrate around the tips of the charge holders. After 60 $\mu$ s, the tensile cracks generated from the tips of the charge holders propagate toward the center and the outside boundary. At 240 $\mu$ s, the cracks bifurcate around the center of the model and connect each other. Fig. 2(b) shows resultant fracture patterns as a result of the Model I analysis. It was concluded that the concrete pile may separate into 4 fragments by means of control blast technique using charge holders.

#### 3.2 Influence of the shot time lag of the diamond-shaped charge holders on the fracture processes

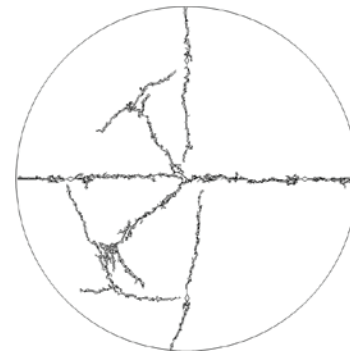
To examine the influence of the shot time lag of the diamond-shaped charge holders on the fracture pattern, the models which have different shot time lags for two holders and each hole had been analyzed. Fig. 3 compares the resultant fracture patterns of Model 2 and 3 which have different shot time lags for two holes and each hole respectively. A pair of No.1 and No. 3 charge holders in Model 2 has no shot time lag, while a pair of No. 2 and No. 4 charge holders has the shot time lag of 200 $\mu$ s. Fig. 3 (a) shows the resultant fracture patterns of Model 2. The fracture plane connecting No 1 and No 3 charge holders are generated while the cracks propagated from No. 2 charge holder does not connect with the fracture plane. Charge holders in Model 3 have 200  $\mu$ s of shot time lag. The order of firing was No. 4, No. 1, No. 2 and No. 3. Fig. 3 (b) shows the resultant fracture patterns of Model 3. Cracks generated from the first shot bifurcated around the center of the model and propagated toward the upper and lower sections of No. 2 charge holder. The fracture planes connecting charge holders are generated. This may lead to 4 more fragments of the model. Ultimately, it is concluded that the although the shot time lag of charge holders effects on the crack propagations, it seems that the shot time lag does not effect on removing of the concrete pile.

#### 3.3 Influence of the spacing of the diamond-shaped charge holders on the fracture processes

In order to investigate the influence of the spacing of the diamond-shaped charge holders on the fracture pattern, the

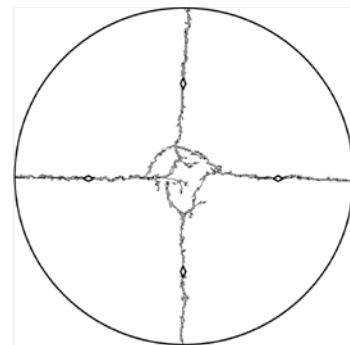


(a) Model 2

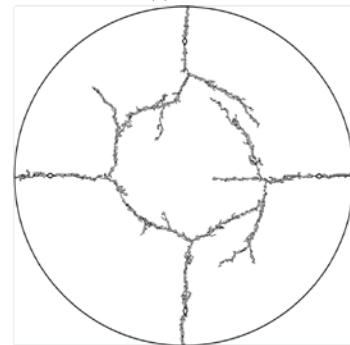


(b) Model 3

Fig. 3 Resultant fracture patterns of the analysis models considering different shot time lags.



(a) Model 4



(b) Model 5

Fig. 4 Resultant fracture patterns of the analysis models considering different distances from the center of the model

models which install four charge holders at 415 mm and 580mm long distance from the center of the model were analyzed. Fig. 4(a) shows the resultant fracture pattern of Model 4 which has 415mm spacing distance. The cracks bifurcated around the center and connected each other. This may leads to removing of the concrete pile model. Fig. 4(b) shows the resultant fracture pattern of Model 5 which has 580mm spacing distance from the center. Cracks bifurcated at early time and did not occur around the center. This may cause a failure of breaking down of the concrete pile. Ultimately, it is concluded that the the spacing distance of charge holders effects on the removing of the concrete pile and might be a important parameter for designing the concrete pile top breakage method utilizing charge holders.

#### 4. Conclusion

This study proposed a numerical method to simulate fracture propagations in the full scaled concrete pile top by means of blasting method. The influence of the shot time lag and spacing length of the diamond-shaped charge holder on the fracture patterns were investigated. The findings from this study are followed as;

From the analysis results from Model 1 utilizing four diamond-shaped charge holders with no shot time lag, tangential tensile stress fields concentrated around the tips of the charge holders lead to predominant crack propagations. At late stage, the cracks bifurcated around the center of the model and connect each other. Finally, this led to removing of the concrete pile.

To examine the influence of the shot time lag of the diamond-shaped charge holders on the fracture pattern, Model 2 and 3 which have different shot time lags for two holes and each hole repectively had analyzed. Ultimately, it is concluded that the although the shot time lag of charge holders effects on the crack propagations, it seems that the shot time lag does not effect on removing of the concrete pile.

In order to investigate the influence of the spacing of the diamond-shaped charge holders on the fracture pattern, the models which install four charge holders at 415 mm and 580mm long distance from the center of the model were analyzed. Ultimately, it is concluded that the the spacing distance of charge holders effects on the removing of the concrete pile and might be a important parameter for designing the concrete pile top breakage method utilizing charge holders. This work (Grants No.113431) was supported partially by Business for Cooperative R&D between Industry, Academy, and Research Institute funded Korea Small and Medium Business Administration in 2010.

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