Free Access to the whole issue

E3S Web of Conferences

Volume 688 (2026)

The 2nd International Conference on Sustainable Environment, Development, and Energy (CONSER 2025)

Yogyakarta, Indonesia, October 22-23, 2025

Y.H. Irawan, A.S. Prabuwono, R. Prastowo and Hasanudin (Eds.)

E3S Web of Conferences All issues Series Forthcoming About Search Menu

Open Access

Issue	E3S Web Conf. **Volume** 688, 2026 The 2nd International Conference on Sustainable Environment, Development, and Energy (CONSER 2025)
Article Number	03008
Number of page(s)	7
Section	Design, Manufacturing, and Maintenance Technology for Sustainable Engineering
DOI	https://doi.org/10.1051/e3sconf/202668803008
Published online	20 January 2026

E3S Web of Conferences **688**, 03008 (2026)

Analysis of crack propagation and degree of damage due to explosion on dimensional variations of laboratory scale models

Yuga Maulana[1,3], Ganda Marihot Simangunsong[1*], Ridho Kresna Wattimena[1] and Patria Kusumaningrum[2]

[1] Mining Engineering Department, Institut Teknologi Bandung, Bandung, Indonesia

[2] Civil Engineering Department, Institut Teknologi Bandung, Bandung, Indonesia

[3] Mining Engineering Department, Universitas Trisakti, Jakarta, Indonesia

Editorial board

Jun Sun
Tianjin University of Science and Technology, P.R. China
website

Ming-Jun Zhang
DGUT-CNAM Institute, Dongguan University of Technology, Guangdong Province, P.R. China
website

Zhien Zhang
West Virginia University, Morgantown, West Virginia, USA

eISSN: 2267-1242

https://doi.org/10.1051/e3sconf/202668803008

Analysis of crack propagation and degree of damage due to explosion on dimensional variations of laboratory scale models

Yuga Maulana[1,3], *Ganda* Marihot Simangunsong[1*], *Ridho* Kresna Wattimena[1], and *Patria* Kusumaningrum[2]

[1]Mining Engineering Department, Institut Teknologi Bandung, Bandung, Indonesia
[2]Civil Engineering Department, Institut Teknologi Bandung, Bandung, Indonesia
[3]Mining Engineering Department, Universitas Trisakti, Jakarta, Indonesia

Abstract. Blasting activities as a method of breaking rocks often occur near free areas, such as the surface of the ground or mine walls which are not solid, the pressure waves produced by the explosion can bounce back towards the source of the explosion after reaching the free area. In this research, an explosion simulation was carried out on a laboratory scale to model the interaction between explosion and rock. Two domain model sizes, in the form of cubes made of concrete with dimensions of 30x30x30cm and 40x40x40cm, were exploded using electric detonator no.8 to evaluate their impact on rock damage. Monitoring was carried out by measuring the primary wave velocity (Vp) on the cube model at 49 points before and after the detonation. The results obtained were that the 30x30x30 cm model was broken into 6 parts so that Vp measurements could not be carried out after blasting. In the 40 × 40 × 40 cm cube model, the specimen remained largely intact after blasting, although visible cracks and partial spalling were observed. Despite this damage, the P-wave velocity (Vp) test could still be conducted, revealing a reduction in rock strength of approximately 38%.

1 Introduction

Explosions play a significant role in various industrial applications, from mining and quarrying to demolition and construction [1], [2]. Understanding the behaviour of materials under explosive loading is crucial for ensuring safety, optimizing processes, and mitigating potential hazards [3]. Laboratory-scale experiments provide a controlled environment for studying the fundamental mechanisms of crack formation and propagation due to explosions, [4]. These small-scale tests are essential for developing theoretical models and numerical simulations that can predict the response of larger systems [5]. One of the critical aspects of such studies is the size of the model domain used in experiments and simulations [6]. The domain size can significantly influence the observed crack patterns, propagation speed, and the overall dynamic response of the

* Corresponding author: ganda@itb.ac.id

material. Inadequate domain sizes might fail to capture the complete behavior of crack initiation and growth, leading to inaccurate or incomplete understanding [7]. Conversely, excessively large domains can result in unnecessary computational costs and resource usage without substantial gains in accuracy.

The effect of explosions on materials has been extensively studied, employing both experimental and numerical approaches [8]. Over the years, significant advancements have been made in understanding the dynamics of crack formation and propagation. However, the influence of model domain size on these processes remains a critical and relatively underexplored aspect [9]. To study the cumulative damage law of aqueous cracked rock and the surrounding rock of a tunnel subjected to repeated cycle blasting, tests are conducted using both field and rock-like materials models [10, 11].

The cumulative damage from blasting and the distribution of energy are analyzed quantitatively using probability and statistical methods. According to ultrasonic test data and statistical results, the effects of blasting on the tunnel's surrounding rock extend to a range of less than 1.2 meters. The occurrences of water inrush and rapid failure in rock-like material models after the eighth and ninth blasting tests, respectively, illustrate the nonlinear variation of cumulative damage in water-saturated, cracked rock masses. Previous studies have investigated the damage processes and failure mechanisms of coal subjected to repeated blasting stress waves [9]. The simulation experiment of coal damage accumulation was then planned and executed; the experiment involved measuring the samples' ultrasonic velocity and computing the damage values. The weight coefficient for tensile or compressive damage is proposed to be determined based on the percentage relationship of the current major stresses, and the tension-compression weighted damage variable is used to describe the damage characteristics of the rock [12]. The rock damage evolution law in slotting-blasting construction was investigated and tunnel slotting-blasting was simulated using the suggested approach.

This paper investigates the effect of model domain size on the formation and propagation of cracks induced by explosions in a laboratory setting where previous research has not discussed much about the influence of model domain size on laboratory-scale physical model testing. By systematically varying the domain size, we aim to identify the optimal conditions that balance accuracy and computational efficiency. Understanding these effects is crucial for improving the design of experimental setups and the development of more reliable predictive models for explosive-induced fracturing in practice.

2 Laboratory scale testing

2.1 Damage degree

Drilling and blasting will loosen the surrounding rock and increase the porosity of the rock mass. From the perspective of rock mass damage detection, the ultrasonic wave testing method is a widely used non-destructive testing technique. In the early 20th century, some researchers used ultrasonic wave testing to measure the effect of stress on wave propagation and determined the degree of rock damage based on wave speed [13, 14]. When ultrasonic waves propagate in a rock mass, if the rock is disturbed by an external load, the ultrasonic wave propagation speed will change before and after the disturbance [15]. According to the variation trend of ultrasonic wave speed in rock, the damage degree of rock subjected to load disturbance can be determined. The degree of damage has the following relationship with the degree of ultrasonic speed reduction .

$$D_S = 1 - \left(\frac{E_{rm}}{E_0}\right) = 1 - \left(\frac{v}{v_0}\right)^2 \quad (1)$$

D_S is damage degree, E_{rm} is initiation Young's modulus (MPa), E_0 is final state Young's modulus (MPa), v is initiation ultrasonic velocity (km/s), v_0 is final state ultrasonic velocity (km/s).

2.2 Cylinder model testing

The physical models were prepared in cubic form for blasting tests involving applied blast loads, while cylindrical specimens were used for laboratory testing to determine the physical, mechanical, and dynamic properties of the rock material. Blast experiment was performed on a cubic specimen by initiating a detonator installed within a centrally drilled borehole. Following the detonation, the extent of rock mass disturbance was examined through a series of dynamic measurements. Primary wave velocity was recorded prior to the blast and re-measured afterward to identify any changes attributable to the simulated explosive loading. This stage aims to analyze the degree of damage and crack profile that occurs in the concrete material after carrying out a laboratory scale explosion simulation. The material tested is in the form of a cube with dimensions of 40x40x40 cm and 30x30x30 cm. Apart from that, physical and mechanical property tests were also carried out on cylindrical samples to determine the compressive and tensile strength values of the concrete. The specifications of this sample are based on ISRM Standards to determine the properties of the cube sample (using the same mixture and composition). Determining the physical and mechanical properties of concrete was tested on cylindrical samples in the form of physical properties, dynamic properties (wave propagation speed), uniaxial compressive strength test, indirect tensile test (Brazilian test), and triaxial compressive strength test carried out at the Geomechanics Laboratory. FTTM ITB. The test results can be seen in Table 1.

2.3 Measurement of wave propagation speed (Vp) in the cube model

Wave propagation speed measurements were carried out before and after the explosion simulation on the cube material. Measurements were carried out on 2 sides of the cube surface with a total of 49 measurement points (Figure 1). Pre-blast measurements show that the average wave propagation velocity in the cube models with dimensions of 40 × 40 × 40 cm and 30 × 30 × 30 cm is approximately 3108 m/s. In contrast, measurements taken near the blasting hole at a horizontal distance of 20 cm indicate a lower average wave velocity of about 2612 m/s. Based on the Vp values, it can be seen that the Vp values of the cylinder model are relatively the same as those of the cube model (Table 1). This is due to the presence of a shot hole which is a structure or discontinuous plane with an opening of 8 mm which causes the value of the wave propagation speed to decrease.

Table 1. Concrete model property values.

Cylinder Model		Cube Model	
Compressive Strength (MPa)	26,7	Vp (m/s)	3108
Density (g/cm3)	2,12		
Vp (m/s)	3167		
Tensile Strength (MPa)	3,34		
Young's Modulus (Mpa)	4481		
Poisson Ratio	0,13		
Cohession (MPa)	12,1		
Friction Angle (°)	17,19		

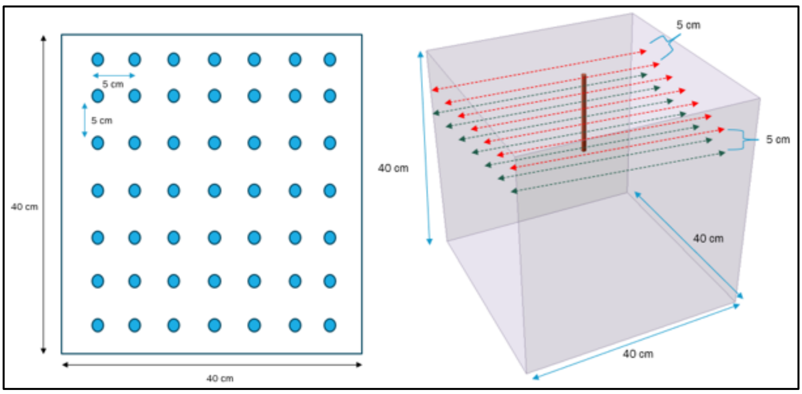

Fig 1. The position of the blast hole in the blast simulation.

3 Cube model explosion simulation

3.1 Explosion results on cube models

The cube model blasting simulation was carried out in collaboration with PT Dahana. All blasting experiments were conducted in a controlled bunker facility owned by PT Dahana, located in Subang, West Java, Indonesia. Apart from the simulation location, PT Dahana also provided detonators as explosive material in this simulation. In this blasting simulation, the shot hole is placed in the center of the cube model with a diameter and length of 8 mm and 140 mm. The explosive used was PETN weighing 5 grams, as seen in Table 2 and Figure 2. The detonator used is detonator no. 8 with a length of 11 cm, contains 5 grams of PETN and has a VOD value of 4000-5000 m/s which was obtained from the results of the VOD test carried out by PT Dahana.

Explosion simulations show different results for the two cube models. In the 40x40x40 cm Cube model, the crack profile spreads to the vertical and horizontal axes from the face of the blast hole and at the corner there is a part that has been removed due to the crack penetrating the free plane on one of the front faces of the model . This makes the shooting holes unusable so that further blasting cannot be carried out. In the 30x30x30 cm cube model, the blasting caused the cube model to break into 6 parts so that further blasting

https://doi.org/10.1051/e3sconf/202668803008

could not be carried out. In addition, blasting wave propagation speed testing could not be carried out because the model had broken (the crack profile can be seen in Figure 2 and Figure 3). Next, the 40x40x40 cm cube model was retested for the wave propagation speed value on one side of the model after blasting and obtained a reduction in results of 68% in the shot hole and 24-32% around the shot hole. The measurement results can be seen in Figure 4.

Table 2. Concrete model property values.

Model	Blasthole	Dimension Blasthole	Explosive Weights	Explosive Type
Lab Scale	Middle	8 mm x 140 mm	5 g	PETN (Detonator)

Fig 2. Results of blasting simulations on a 40x40x40 cm cube model.

Fig 3. Results of blasting simulations on a 30x30x30 cm cube model.

3.2 The damage degree due to blast simulation

In the 40x40x40 cm cube model, data on wave propagation results before and after blast simulation was obtained. Data on the value of the degree of damage and contour profile can be seen in Figure 4. The degree of damage was calculated at each measurement point trajectory and damage data was obtained which showed a figure of 0.7-0.8 at the shooting hole position. Meanwhile, around the shooting hole towards the free area, the degree of damage continued to decrease to the lowest level of 0.06. It can be seen that the degree of damage occurs around the blast hole area with a radius of 6 cm from the perimeter of the blast hole and continues to decrease as you move away from the blast hole. At the bottom left there is a contour that bends as if creating a crack line. On the other hand, it can be seen that the value of the degree of damage in the area that is further away from the blast hole, the value of the degree of damage tends to decrease or can be stated as very small.

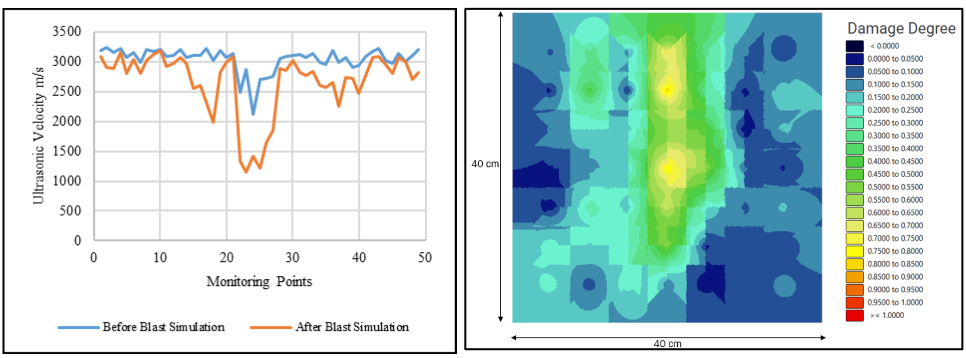

Fig 4. Graph of changes in wave propagation speed values before and after detonation and the damage degree model.

4 Conclusion

Laboratory scale explosion simulations on concrete materials show that in the model of 40x40x40 cm, the cracks develop to all sides, causing certain parts to detach. On the other hand, for the cube sample with dimensions of 30x30x30 cm, the explosion causes the concrete to break into several pieces, so that measuring Vp cannot be done. The primary wave velocity decreases up to 38% on a 40x40x40 cm cube, indicating a significant degree of damage. The damage degree value decreases as further away from the blast hole area.

References

1. L. Ji, C. Zhou, S. Lu, N. Jiang, and H. Li, Modeling study of cumulative damage effects and safety criterion of surrounding rock under multiple full-face blasting of a large cross-section tunnel. International Journal of Rock Mechanics and Mining Sciences. **147**, (2021). https://doi.org/10.1016/j.ijrmms.2021.104882
2. H. Bazzi, H. Noferesti, and H. Farhadian, Modelling the effect of blast-induced vibrations on the stability of a faulted mine slope. J South Afr Inst Min Metall. **120**(10), 591–597 (2020). https://doi.org/10.17159/2411-9717/1066/2020

3. K. Fuławka, P. Mertuszka, W. Pytel, M. Szumny, and T. Jones, Seismic evaluation of the destress blasting efficiency. Journal of Rock Mechanics and Geotechnical Engineering. **14**(5), 1501–1513 (2022). https://doi.org/10.1016/j.jrmge.2021.12.010
4. S. Xu, B. Wu, H. Zhang, S. Qi, H. Bian, and J. Wang, Directional crack propagation and optimization strategies for multi-hole shaped charge blasting in tunnel construction. Structures. **72**, (2025). https://doi.org/10.1016/j.istruc.2025.108268
5. A. Filice, M. Mynarz, and R. Zinno, Experimental and Empirical Study for Prediction of Blast Loads. Applied Sciences (Switzerland). **12**(5), (2022). https://doi.org/10.3390/app12052691
6. M. Fouad, M. N. Fayed, G. A. Hamdy, and A. Abdelrahman, Effect of blast loading on seismically detailed rc columns and buildings. Civil Engineering Journal (Iran). **7**(8), 1406–1425 (2021). https://doi.org/10.28991/cej-2021-03091733
7. Z. Hong, M. Tao, X. Cui, C. Wu, and M. Zhao, Experimental and numerical studies of the blast-induced overbreak and underbreak in underground roadways. Underground Space (China). **8**, 61–79 (2023). https://doi.org/10.1016/j.undsp.2022.04.007
8. S. M. Anas, M. Alam, and M. Umair, Air-blast and ground shockwave parameters, shallow underground blasting, on the ground and buried shallow underground blast-resistant shelters: A review. International Journal of Protective Structures. **13**(1), 99-139 (2021). https://doi.org/10.1177/20414196211048910
9. H. Chu, X. Yang, C. Wang, and W. Liang, Study on the Coal Damage and Fracture Mechanism under Multiple Actions of Blasting Stress Wave. Arab J Sci Eng. **46**(11), 10847–10854 (2021). https://doi.org/10.1007/s13369-021-05586-8
10. X. Li, Z. Zhu, M. Wang, Y. Shu, S. Deng, and D. Xiao, Influence of blasting load directions on tunnel stability in fractured rock mass. Journal of Rock Mechanics and Geotechnical Engineering. **14**(2), 346–365 (2022). https://doi.org/10.1016/j.jrmge.2021.06.010
11. Y. Zhu, Y. Tang, H. Wang, and Q. B. Zhang, Development of a dynamic cumulative damage model and its application to underground hydropower caverns under multiple blasting. International Journal of Rock Mechanics and Mining Sciences. **184**, (2024). https://doi.org/10.1016/j.ijrmms.2024.105948
12. J. Xu, Z. Wang, and G. Rui, Tunnel slotting-blasting numerical modeling using rock tension-compression coupling damage algorithm. Applied Sciences (Switzerland). **12**(13), (2022). https://doi.org/10.3390/app12136714
13. T. Zhao, P. Gong, K. Yetilmezsoy, M. Bahramian, and C. Liu, Dynamic failure and stability model analysis of thick and hard rock with wedge-structure immediate roof occurrence. Geomechanics and Geophysics for Geo-Energy and Geo-Resources. **7**(3), (2021). https://doi.org/10.1007/s40948-021-00277-y
14. E. F. Salmi and E. J. Sellers, A review of the methods to incorporate the geological and geotechnical characteristics of rock masses in blastability assessments for selective blast design. Elsevier B.V. (2021). https://doi.org/10.1016/j.enggeo.2020.105970
15. M. R. Saharan and H. S. Mitri, Numerical procedure for dynamic simulation of discrete fractures due to blasting. Rock Mech Rock Eng. **41**(5), 641–670 (2008). https://doi.org/10.1007/s00603-007-0136-9