一般講演
# 資源開発技術・岩盤工学
2018年3月27日(火) 09:00 ～ 11:45 第2会場 (3号館3F, 33号講義室)

## [1201-10-10] 花崗岩と砂岩における動的一軸圧縮強度の寸法効果に関する研究 Size effect of dynamic uniaxial compressive strength of a granite and sandstone

チョ サンホ[1]、〇Oh Se-wook[1]、Min Gyeong-jo[1]、Park Se-woong[1]、藤井 義明[2]、福田 大祐[2] （1. 韓国全北国立大学、2. 北海道大学）
Sang-ho Cho[1], 〇Se-wook Oh[1], Gyeong-jo Min[1], Se-woong Park[1], Yoshiaki Fujii[2], Daisuke Fukuda[2] （1. Chonbuk National University, 2. Hokkaido University）

キーワード：動的一軸圧縮強度、寸法依存性岩石強度、スプリット ホプキンズ 圧力 バー
dynamic uniaxial compressive strength, specimen size dependent rock strength, Split Hopkinson pressure bar

In laboratory measurements of rock properties, the specimen size dependent rock strength has always been an issue. Numerous studies have been conducted to investigate the correlation between specimen size and rock strength under various loading rate in last few decades. In this study, the dynamic uniaxial compression tests of Geochang granite and Kimachi sanstone were carried out to investigate the size-effect on rock dynamic strength. Split Hopkinson pressure bar (SHPB) system was used to load the rock specimens dynamically. Kimachi sandstone and Geochang granite specimens with different diameter and length were prepared. As a result, it has been found that the dynamic uniaxial compression strength of the granite and sandstone have been increased with increasing specimen size. That are coincident with the results revealed recently by some researchers who have showed that the uniaxial compressive strengths of sedimentary rocks significantly increase with increasing specimen diameter up to around 54mm diameter and reduce to with size increment.

# 1. Introduction

In laboratory measurements of rock properties, the specimen size dependent rock strength has always been an issue. Numerous studies have been conducted to investigate the correlation between specimen size and rock strength under various loading rate in last few decades[1-6]. Hoek and Brown[2] reported that the uniaxial compressive strength of rock is reduced with increasing specimen size. It makes sense to other famous theory which known as weakest link theory[3]. However, on the contrast to the static or quasi-static cases, the research about size-effect of rock strength under dynamic loading is limited. Under the dynamic or impact state, rock materials show significantly different fracturing process and mechanical characteristics (i.e. rate dependency) compare to that of static or quasi-static loading.

In this study, the dynamic uniaxial compression tests of Geochang granite and Kimachi sanstone were carried out to investigate the size-effect of rock dynamic strength. Split Hopkinson pressure bar (SHPB) system was used to load the rock specimens dynamically. Kimachi sandstone and Geochang granite specimens with different diameter and length were prepared.

# 2. Experiments

## 2.1 Experimental method

SHPB system, also known as Kolsky bar allows a desirable technique to determine the dynamic properties of brittle solids. This system is commonly established by three of rigid metal bars; striker bar, incident bar and transmission bar on the same axis (see Fig. 1). If the striker bar impacts the incident bar as a projectile, the dynamic compressive stress waves are generated and propagate along the incident bar to rock specimen. Rock specimen is placed between the incident bar and the transmission bar. When the stress wave arrived at the bar-specimen boundary, the portions of stress waves transmit to the transmission bar through the specimen while the remaining portions are reflected back to the incident bar, because of the difference of material impedance between metal bar and the rock specimen.

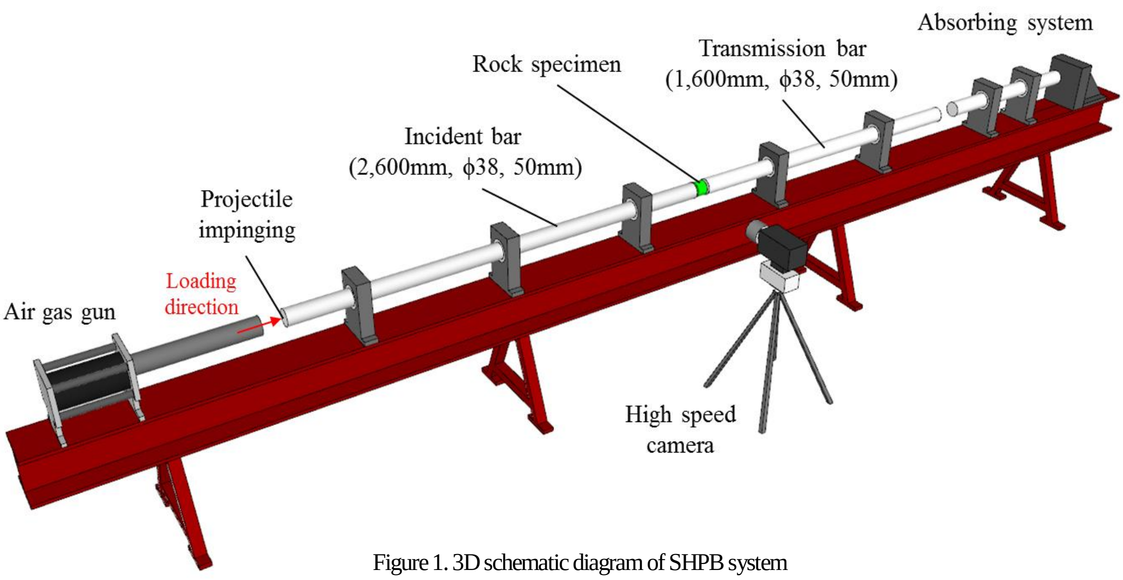


Figure 1. 3D schematic diagram of SHPB system

The applied forces on the specimen $F_1$ and $F_2$ (see Fig.2) can be calculated by following equations (1-2) :

$$F_1 = AE(\varepsilon_i + \varepsilon_r) \quad (1)$$

$$F_2 = AE\varepsilon_t \quad (2)$$

where $A$, $E$ is the area and Young's modulus of bar. $\varepsilon_i$, $\varepsilon_r$ and $\varepsilon_t$ is the measured incident, reflected and transmitted strain respectively.

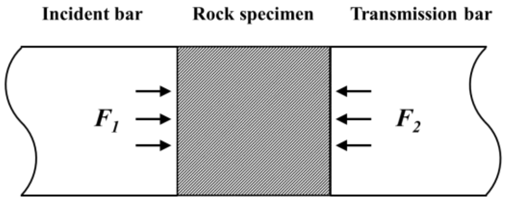


Figure 2. Loading mechanism on SHPB system

Then the applied stress $\sigma(t)$, strain $\varepsilon$ and strain rate $\dot{\varepsilon}$ can be determined by following equations (3-5):

$$\sigma(t) = \frac{A_1}{A_0} E \varepsilon_t \qquad (3)$$

$$\varepsilon = -\frac{2C_1}{L} \int_0^t \varepsilon_r \qquad (4)$$

$$\dot{\varepsilon} = -\frac{2C_1}{L} \varepsilon_r \qquad (5)$$

where $A_0$ and $A_1$ indicates the sectional area of bar and specimen respectively. The dynamic uniaxial compressive strength can be defined as the maximum value of applied stress on specimen. The strain or stress wave profiles throughout the experiments can be obtained by semi-conductor strain gauge measurements attached on the surface of incident and transmission bar.

In rock dynamic tests, it is important to achieve the dynamic force balance on both boundaries of rock specimen. Due to its nature of transient loading, specimen can be significantly affected by inertia and friction effect along dynamic tests[7,8], so that it can cause the locally premature failure before the whole areas of specimen were loaded. To prevent above stated problems, pulse shaping technique which make a delay on initial part of applied loading was adopted by using the different sizes of copper pulse shapers.

## 2.2 Sample preparation

In order to investigate the relationship between specimen diameter and dynamic uniaxial compressive strength, two different sizes and types of rock specimens were prepared. All specimens were intentionally manufactured to have 0.5 slenderness ratio (specimen length/diameter) to avoid the unexpected geometric influence. The physical and mechanical properties of rock specimens were shown in Table 1.

Table 1. Material properties of rock specimens

| Rock type | Geochang granite | Kimachi sandstone [9] |
|---|---|---|
| Diameter (mm) | 50, 38 | 50, 38 |
| Thickness (mm) | 25, 19 | 25, 19 |
| Density (Kg/m$^3$) | 2,590 | 2,000 |
| P-wave velocity (m/s) | 3,863 | 2,710 |
| Young’s modulus (GPa) | 41.3 | 6.5 |

### 2.3 Results

The dynamic uniaxial compressive tests were performed with different diameters of Geogchang granite and Kimachi sandstone specimens. Figure 3 shows typical stress wave profiles obtained by strain gauge measurements.

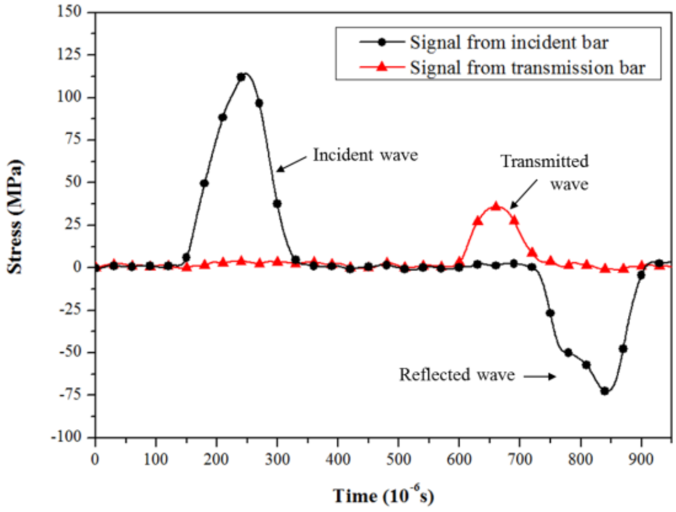


Figure 3. Typical stress wave profiles on SHPB experiment

By applying the wave shifting process to obtained stress wave profiles the dynamic force balance curve can be obtained like as shown in Figure 4. To guarantee the equivalent dynamic forces on both sides of the specimen, the superimposed wave between incident and reflected wave should be suitably matched to the transmitted wave until they arrived at peak stress. In this study, the each experimental result showed good correspondence to dynamic force balance.

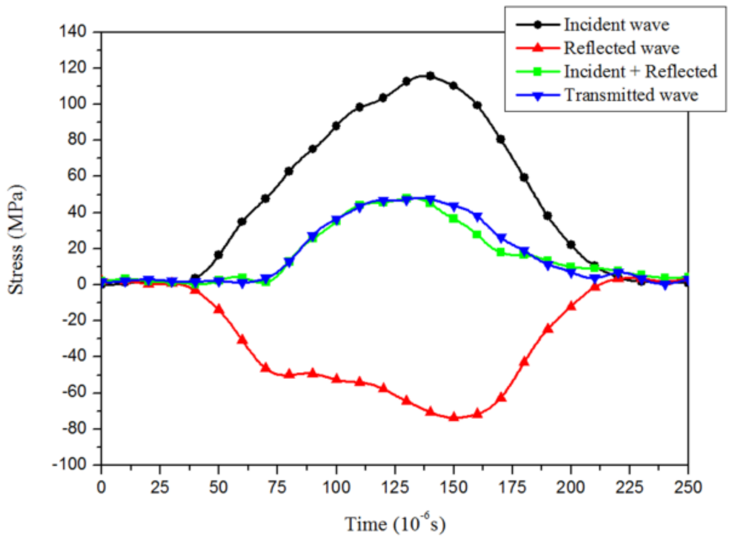


Figure 4. Verification of dynamic force balance on specimen

As a result of this study, the determined dynamic uniaxial compressive strength with different specimen diameters and rock types were plotted against the function of strain rates in Fig. 5. And the figure shows linear regression slope of experimental results in Fig. 5. It reveals that the dynamic compressive strength of Geochang granite and Kimachi sandstone both increased with increasing diameters of specimen. The averaged ratio of D50/D38 was calculated as 2.34 in Geochang granite and 3.56 in Kimachi sandstone at 50/s to 350/s ranges of the strain rates.

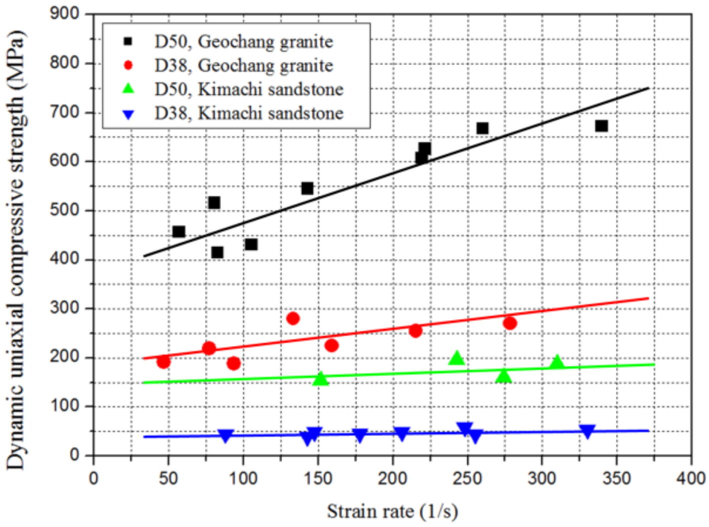


Figure 5. Determined dynamic uniaxial compressive strengths of Geochang granite and Kimachie sandstone against the function of strain rates

## 3. Conclusion

A series of dynamic uniaxial compressive tests were carried out to investigate the relationship between specimen size and dynamic strength of rock. Two different sizes (38mm and 50mm) of Geochang granite and Kimachi sandstone specimens were used in the tests. In order to apply the dynamic loading on the specimen, SHPB system was used. For guaranteeing the dynamic force balance on the specimen, pulse shaping technique with different sizes of copper pulse shapers was adopted and verified by plotting the wave validation curve. The results show that the both dynamic compressive strengths of Geochang granite and Kimachi sandstone were increased with increasing strain rate. Averaged increasing ratio of dynamic compressive strength between D50 and D38 was 2.34 in Geochang granite and 3.56 in Kimachi sandstone. From this study, it has been found that the dynamic uniaxial compression strength of the granite and sandstone have been increased with increasing specimen size.

## 4. References


1) Hoek, E., and Brown, E. T. (1997). "Practical estimates of rock mass strength." Int. J. Rock Mech. Min. Sci., 34(8), 1165–1186.
2) Hawkins, A. B. (1998). "Aspects of rock strength." Bull. Eng. Geol. Environ., 57(1), 17–30.
3) Weibull, W. (1939). "A statistical theory of the strength of materials." Ph.D. dissertation, Royal Swedish Academy of Engineering Science, Stockholm, Sweden.
4) Thuro, K. et al., (2001), "Scale effects in rock strength properties. Part 1: Unconfined compressive test and Brazilian test", ISRM regional symposium EURO ROCK 2001, Espoo, Finland.
5) Petrov, Y. and Selyutina, N., (2015), "Scale and size effects in dynamic fracture of concretes and rocks", EPJ Web of Conferences 94, 04005.
6) Masoumi, H. et al., (2016), "Unified size-effect law for intact rock", Int. J. Geomech, 16(2): 04015059.
7) Xia K. & Yao W., 2015, Dynamic rock tests using split Hop-kinson (Kolsky) bar system - A review, Journal of Rock Mechanics and Geotechnical Engineering, 7, 27-59.
8) Zhang Q.B. & Zhao J., 2014, A Review of Dynamic Experi-mental Techniques and Mechanical Behaviour of Rock Materials, International Journal of Rock Mechanics and Rock Engineering, 47, 1411-1478.
9) Jung W. Effects of strain rate and water saturation on the tensile strength of rocks. 2010. Journal of Korean Society for Rock Mechanics 20(2), 119-124.