A New Double Shearing Testing Equipment for the Shear Behaviour of Rocks and Discontinuities under Static and Shock Loads

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Abstract. The dynamic mechanical behaviour and characteristics of rocks have been investigated using different techniques to evaluate the engineering structures under dynamic loads. The authors devised a new experimental apparatus to investigate the behaviour of rocks under shock waves. A new double shearing jig shown in figure 1 was developed and it was used to study the shearing of rocks and discontinuities under static and impact loading conditions using the device. Double shearing tests involve various rocks and discontinuities. The authors describe the experimental results under shock load and static loading and the results are compared with each other and their implications are discussed in rock mechanics and rock engineering. Although the system is quite simple, it is shown that it is very practical to study the shear behaviour of both intact rocks and discontinuities.

1. Introduction

Various techniques and equipments are used for studying the mechanical behaviour and characteristics of rocks for evaluating the engineering structures under dynamic loads. Some direct shear devices have been developed and utilized [1-12]. These direct shear testing involves

a) One-way (uni-directional) shearing
b) Two-ways (bi-directional) shearing.

Another approach is to utilize shock loads [13-17]. Huang et al. [13] suggested a punch shear device to measure the dynamic shear strength of brittle solids. In this method, a split Hopkinson pressure bar system (SHPB) is used to apply the dynamic load to a thin disc sample by punching. The sample holder also allows the punch head to load the sample directly and in combination with momentum-trap technique in SHPB. However, there is no such test on rock discontinuities and interfaces utilizing a split Hopkinson pressure bar system (SHPB) and it is very unlikely unless some special jigs and cells are utilized.

The authors devised a new experimental apparatus to investigate the behaviour of rocks under shock waves (Aydan et al. [15]). The device is fundamentally categorized as the drop-weight apparatus and it is possible to evaluate the mechanical behaviour and characteristics of rocks and discontinuities subjected to shock waves during pre-failure as well as post-failure stages. This device is described in the next sections.
Besides these testing techniques, it is also possible to study the dynamic shear behaviour of rocks utilizing stick-slip devices, shock tests on inclined bases as well as shaking tables [18-22]. For example, shaking table tests of rock discontinuities on an incline base could be categorized as one-way shearing (Aydan et al. [19]; Aydan [22]). As for discontinuities on a specially designed shearing jig on a shaking table could be categorized as two-ways shearing despite normal loads could not be high under any type of shear waves. The testing configuration devised by Aydan et al. [20] to study the dynamic response of rock discontinuities put on an inclined base under shock loads. Shock loads were induced by a hammer to the base of the set-up and the slip behaviour of bedding plane of Marl samples was monitored. Due to the inclination of the base, the step-like slip occurred. The accelerations and slip of the upper block were measured and the measured responses yield the dynamic frictional properties of the bedding planes.

In this study, a new double shearing was developed and it was used to study the shearing of rocks and discontinuities under static and impact loading conditions. Double shearing tests involved Kimachi sandstone, Ryukyu limestone and Oya tuff. Furthermore, some double shearing tests on saw-cut discontinuities in Ryukyu limestone are carried out under both shock and static loads. The authors describe the experimental results under shock load and static loading and the results are compared with each other and their implications are discussed in rock mechanics and rock engineering

2. Shock-Testing Device and Development of Double Shearing Jig

2.1. Shock Testing Device

A simple shock testing device developed in the preliminary stage with the initial purpose of investigating the mechanism and conditions in regard with the breakage of boulders/cobbles in conglomeratic deposits occur along tectonic lines as the boulders/cobbles in such environments are found to be broken either in extension, sheared or both [23,24]. The device consisted of a steel cylinder with a weight of 8300gf having a diameter of 97 mm, a load cell, an accelerometer (figure 1a). The plastic pipe container, in which the cylinder was dropped, had an internal diameter of 100 mm and height of 500mm. The steel cylinder was dropped from certain heights and acceleration and force were measured simultaneously using YOKOGAWA WE7000 data-acquisition system.

Following this initial attempt, the authors developed a new experimental apparatus to investigate the behaviour of rocks under shock waves as shown in figure 1(b,c). The device equipped with load cell, non-contact laser transducers, accelerometer up to 500G. The non-contact type laser displacement transducers measure the displacement of the loading platen. The load cell is capable of measuring much higher dynamic loads. The displacement of the loading platen is allowed to move downward up-to 20 mm in order to prevent the total destruction of samples upon failure. The cylindrical weight can be dropped from different heights up to 500 mm with an interval of 50 mm and an impact velocity ranging from 1716 mm/s to 3132 mm/s. The device may be fundamentally categorized as the drop-weight apparatus and it is possible to evaluate the mechanical behaviour and characteristics of rocks subjected to shock waves during pre-failure as well as post-failure stages. Some additional monitoring is done using infra-red camera and high-speed video camera.

The maximum nominal velocity at the time of impact on samples can be computed from the following formula:

\[ V_{\text{max}} = \sqrt{2ghd} \]  

(1)

where \( g \) is gravitational acceleration and \( H_d \) is drop height. In this study, we also define maximum nominal strain rate by dividing the maximum nominal impact velocity by the sample height or sample diameter as given below:

\[ \dot{e}_{\text{max}} = \frac{V_{\text{max}}}{L} \quad \text{or} \quad \dot{e}_{\text{max}} = \frac{V_{\text{max}}}{D} \]  

(2)

Maximum acceleration is obtained from the acceleration response during the experiment. It is anticipated that it would increase in amplitude with the increase of strength of rock samples.
2.2. Static Testing Device

Two static testing devices were utilized. The device named OA20KN and shown in figure 2(a) is displacement-controlled, its loading capacity is 20 kN. When samples cannot be sheared by this device, another testing machine with a capacity of 100 kN, which is manually operated, is utilized for double shear tests (figure 2b).

2.3. Double Shearing Jig

The device was initially used to test samples under uniaxial compression and Brazilian tensile shock loading condition and rock samples having thoroughgoing discontinuity planes with different angle under bonded and unbonded condition together with confinement provided by grouting material [25]. A special double-shearing jig has been recently developed and utilized on coral and sandy Ryukyu limestone and Oya tuff (Aydan et al. [16,17]). This device is also capable of shearing rock discontinuities and interfaces (figure 3). The device is able to apply normal loads on the discontinuity plane and the normal load on intact rock, discontinuities and interfaces under impact loads can be measured continuously. Furthermore, the same jig can be used under static loading conditions. The nominal samples size is 30x30x100 mm (figure 3b). Nevertheless, different size sample longer than 80 mm can be used.
be also used with some adjuster platens. Rosette type strain gauges are attached in the close-vicinity of anticipated shear planes.

![Double Shearing Jig](image)

(a) Top view  (b) Side view

**Figure 3.** Top (a) and side (b) drawing of double shearing jig.

3. **Double Shearing Tests**

3.1. **Double Shearing Samples and Their Physico-mechanical Properties**

Samples of Kimachi sandstone, coral and sandy (locally known as Awaishi) Ryukyu limestone, Oya tuff were prepared. The nominal size of samples were 30x30x100 mm. However, samples longer than 80 mm with a cross section less than 30 by 30 mm can also be tested together with the utilization of adjuster platens. Such tests were also carried out to check the possibility using the same rocks. Table 1 summarizes mechanical properties of samples used.

| Rock                    | \( \gamma \) (kN/m³) | \( V_p \) (km/s) | \( V_s \) (km/s) | \( \sigma_{iR} \) (MPa) | \( \sigma_{iBend} \) (MPa) | UCS (MPa) | Cohesion (MPa) |
|-------------------------|----------------------|------------------|------------------|-------------------------|-----------------------------|-----------|----------------|
| Kimachi Sandstone       | 19.7                 | 2.93             | 1.96             | 4.1                     | 9.3                         | 43.1      | 8.64           |
| Coral Limestone         | 20.4                 | 3.97             | 2.19             | 3.9                     | 12.2                        | 23.7      | 8.6            |
| Sandy Limestone         | 22.4                 | 4.43             | 2.49             | 3.4                     | 10.1                        | 28.1      | 12.0           |
| Oya tuff                | 16.6                 | 1.87             | 1.15             | 0.5-1.0                 | 2.4                         | 4.7-11.2  | 2.5            |

3.2. **Experiments and Test Results**

Tests on Kimachi sandstone, coral and sandy Ryukyu limestone and Oya tuff have been carried out under 0, 2 and 4 kN confining loads. We just show experimental results for Kimachi sandstone for all confining forces as the overall responses are quite similar except the strength properties. Figure 4 shows the time responses of shear stress, strains and confining force variations during the tests. Figure 5 shows the state of samples and failure surface after the test. Figure 6 shows the Mohr-Coulomb yield criteria for static and dynamic tests. It is of great interest the dynamic strength is higher than the static strength and results obey the linear Mohr-Coulomb criterion.
Figure 4. Time responses of shear stress, confining load and strain during static and dynamic tests.

Figure 5. Views of samples tested under different confining load and failure surfaces.
Figure 6. Mohr-Coulomb failure criteria for static and dynamic loading tests.

4. Double Slip Tests

Double slip experiments were presently carried out only on saw-cut surfaces of coral limestone and sandy limestone. Figure 7 shows time-responses of shear stress, confining pressure relative slip for static and dynamic experiments. In static tests, the confining pressure was varying in relation to shearing while it was almost constant during dynamic tests. Although the cause is not clear, it may be due to some arching action taking place during static tests. Figure 8 shows the views of samples while figure 9 shows Mohr-Coulomb yield criteria for static and dynamic tests. Static test results were in accordance with previous experiments reported by Aydan et al [14]. Under dynamic loads, the dynamic strength also increases as noted from figure 9. It was also interesting to note the striation did occur on the slip surfaces as they are noted on fault surfaces in nature (figure 10).
5. Conclusions
A newly developed double new shearing jig utilized in static and dynamic tests showed that the shearing behaviour of intact rock as well as discontinuities can be evaluated and the tests are much simpler and easier to conduct. However, it is necessary to increase the test number as well as to test other rock types and natural discontinuities. As well known, the fault/shear zones consist of intact rock blocks bounded by discontinuities with or without gouges and the intensity of fracturing in adjacent rock differs depending upon the amount of relative slip exist in nature. The device can be effectively utilized for carrying out tests on the formation of fault/shear zones as well as some information on their mechanical behaviour although actual fracture zones are more complicated in nature.

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