A new simple shear test of rock prism specimen by torsional shearing

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ABSTRACT: This study proposes a new simple shear test method by torsional shearing of rock prism specimens. In this test, multiple radially placed prismatic specimens are torsional sheared under normal load. To validate the test method, a torsional loading apparatus capable of carrying 50 kN normal load and 300 kN cm torque was prepared, and the proposed test was conducted using prismatic mortar specimens which strength are equivalent to soft rock (UCS < 25 MPa). The size of the prismatic specimen is 20 mm height, 20 mm width, and 70 mm depth. The stress-strain characteristics of the mortar specimens were consistent with the previously conducted trends in uniaxial compressive and tensile strength. Peak shear stress in simple shear tests at under 0.9 MPa normal stress conditions equals tensile strength. Almost equal tensile strength was obtained when compared to the results of the proposed test.

Keywords: Simple shear, prismatic specimen, torsional shearing, soft rock.

1 INTRODUCTION

To evaluate the stability of rock masses during earthquakes and rock foundation for offshore wind turbines subjected to wave action, it is necessary to evaluate the mechanical properties of rock masses in simple shear mode. A typical simple shear mode test is a torsion test. Talesnick & Ringel (1999) carried out torsion tests using hollow cylindrical specimens of sedimentary rocks to determine the anisotropic elastic parameters. For the same purpose of identifying anisotropy, the authors also proposed a method of identifying anisotropic parameters using hollow torsion tests (Togashi et al. 2018). In addition, Paterson & Olgaard (2000) conducted torsion tests using solid specimens to clarify geoscientific phenomena.

On the other hand, unlike the indirect shear test, which controls the principal stress, the simple shear test, in which the shear force (torque) is directly applied, has a problem in the transmission of the shear force. In the simple shear test using the soil material, the shear force is transmitted by making the cap uneven. However, the methods in the field of soil mechanics cannot be easily applied to rocks that are hard and have a low strain level until failure. In the above two previous studies

(Talesnick & Ringel 1999 and Paterson & Olgaard 2000), the cap and the specimen were rigidly bonded with an adhesive and sheared by applying a confining pressure of several tens of MPa.

In this study, we propose a simple shear test of a rock prism specimen using torsion as a completely new test method. This is a test in which torque is applied to prismatic specimens set radially. Experimental results using mortar specimens equivalent to soft rock are introduced.

2 TESTING METHOD AND CONDITIONS

2.1 A new simple shear test of rock prism specimen by torsional shearing

The authors propose a new simple shear test using prismatic specimens, as shown in Figure 1. This is a torsional shear test for multiple radially arranged prismatic specimens under normal stress condition. The cap and pedestal are channeled to match the shape of the end face of the prismatic test piece, and the shear force is transmitted to the test piece through the channel.

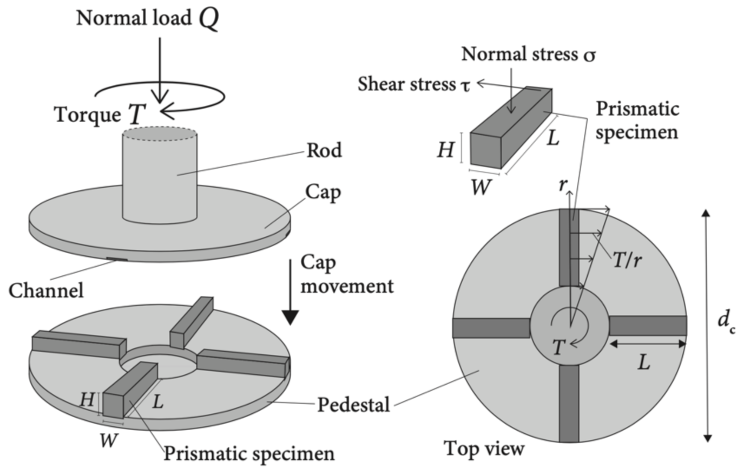

Figure 1. New simple shear test of rock prism specimen by torsional shearing.

The proposed test applies only a direct load and a shear load, similar to the famous simple shear test apparatus for soil by the Norwegian Geotechnical Institute (Hanzawa et al. 2007). Even under this load condition, tensile/shear failure can be achieved in the simple shear mode as shown in Figure 2. That is, shear failure (red line) and tensile failure (blue line) can be controlled by increasing or decreasing the normal stress. This figure shows a linear failure criterion, but the Hoek-Brown failure criterion can also be applied. This report presents the results of verifying the validity of the test method using mortar specimens with UCS equivalent to soft rock.

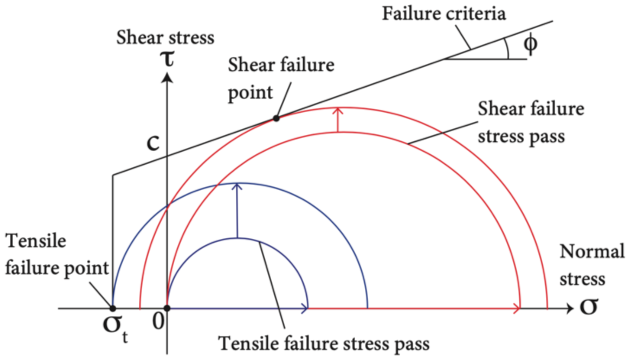

Figure 2. Tensile and shear failure mode expected in the proposed test.

2.2 Testing apparatus and conditions

As shown in Figure 3, a torsion loading device was built up for conducting the proposed test. This is an enhanced loading capacity of a general-purpose loading device for soil, with a loading capacity of 50 kN direct load and a torque of 300 kN cm. A load cell capable of measuring the same degree of normal and shear load was installed on the top of the rod. Figure 3 right shows the simple shear cell for the proposed test. The dimensions of the prismatic specimen are W 20 mm × H 20 mm × L 70 mm. Eight grooves with a depth of 2 mm were formed radially at equal intervals from the center of the cell. The outer diameter of the cap and pedestal was 200 mm. The prismatic specimen was placed point-symmetrically in the center of the cell to prevent bending force to the rod.

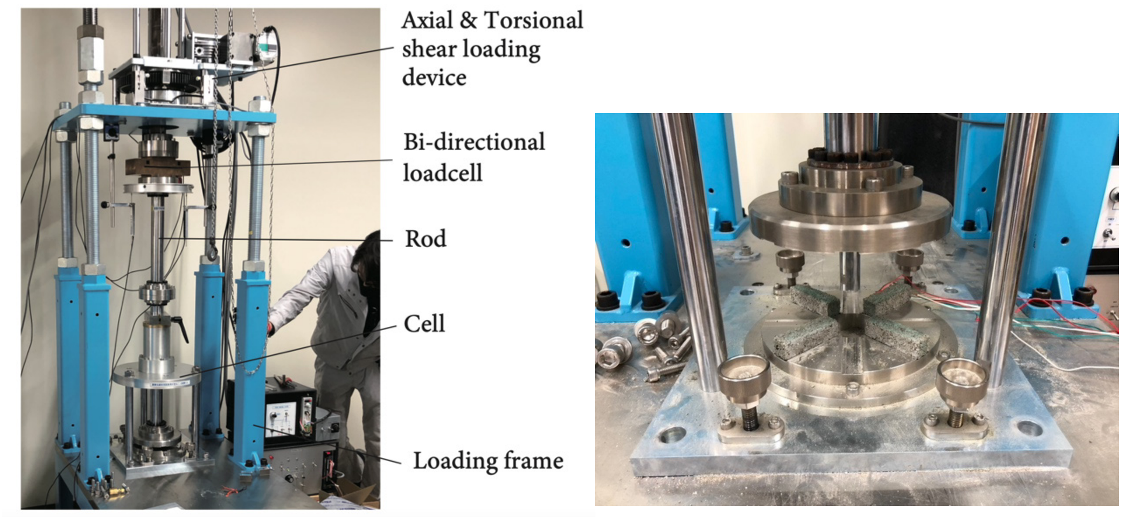

Figure 3. Torsional shearing test apparatus and cell structure.

Similar to the conventional torsion test by using torque, the shear force acting on the specimen increases linearly to the outer diameter direction. Here, the average normal stress σ and shear stress τ acting on the specimen center are determined by the following equations.

$$\sigma = \frac{Q}{nLW}, \tau = \frac{T}{nLW\left(\frac{d_c}{2} - \frac{L}{2}\right)} \tag{1}$$

Here, n is the number of prismatic specimens to be installed, Q is the vertical load, T is the torque, and d_c is the outer diameter of the cell. In this report, $n = 4$, the specimen was placed in a cross shape, a direct load of 5 kN (a normal stress of about 0.9 MPa) was applied, and displacement-controlled shearing was performed by fixing the vertical displacement of the cap. As for the measurement, the normal load and torque were measured with a two-way load cell installed on the top of the rod. For vertical displacement, axial displacement of the cap was measured at two points with a contact-type displacement gauge, and shear displacement and rotational angle (engineering shear strain itself) were measured with a wire displacement gauge.

2.3 Mortar specimen with strength equivalent to soft rock

In order to investigate the applicability of the proposed method to simple shearing of rock, prismatic specimens were prepared by mortar. The finer the grain size of the sand contained in the mortar, the more the hydration reaction of cement is inhibited and the strength decreases (Tariq & Maki 2014). Here, the weight ratio of mortar was fixed at 49.6% sand, 34.7% cement, and 15.7% water. Using silica sand No. 3, 4, and 5, specimens were prepared by varying the grain size of the sand. The specimens were prepared by compacting well using a mold of W 20 mm × H 20 mm × L 70 mm. In all cases, the curing period was one week. Table 1 shows the uniaxial compressive strength q_u and tensile strength σ_t of the specimen for each grain size. These are the results of a separate uniaxial compression/cracking test of a cylindrical specimen prepared under the same conditions as a preliminary study of the proposed test. As expected, the finer the particle size, the lower the strength of the mortar specimen. In addition, the strength characteristics of soft rock with $q_u < 25$ MPa can be expressed (JGS3811-2004).

Table 1. Strength characteristics of mortar specimen in each sand particle size.

Silica sand No.	Average grain size (mm)	q_u (MPa)	σ_t (MPa)
3	1.8	20.0	1.07
4	0.9	14.5	0.92
5	0.6	7.73	0.32

3 PROPOSED TEST RESULTS

Figure 4 left shows the relationship between shear stress and shear strain obtained in the proposed test of the mortar specimen. It shows the shear stress increment after increasing the normal stress to a given value, and the shear strain illustrated hereafter is the engineering strain. The shear stress-strain relationship shows a sharp decline after showing a peak value. The smaller the silica sand number, the larger the grain size. This agrees with the trend of uniaxial compressive strength and tensile strength shown in Table 1.

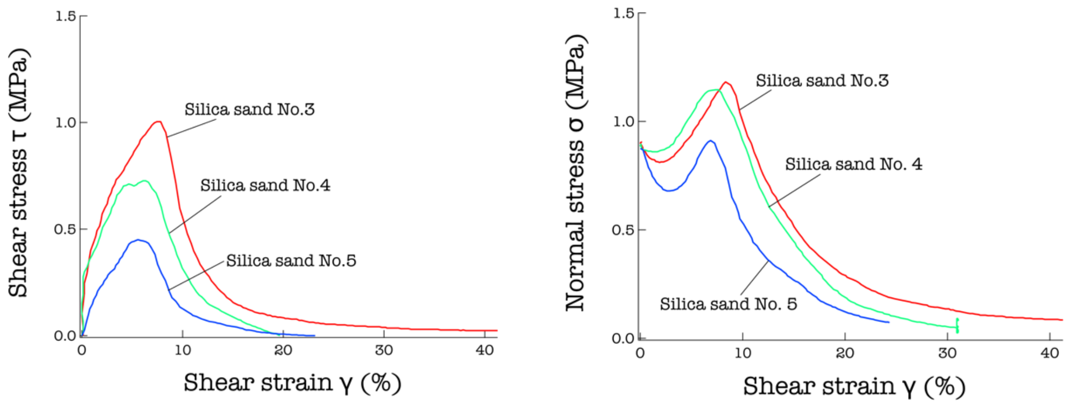

Figure 4. Relationships between shear stress, normal stress and shear strain.

Figure 4 right also shows the relationship between normal stress and shear strain. In the early stage of shearing, the normal stress is constant in the case of silica sand No. 3, which has high strength, and slightly decreases in the cases of silica sand No. 4 and 5, which have low strength. Simple shearing is a constant-volume deformation, and it is considered that some plastic deformation occurred in the case of low strength because the shearing was performed with the vertical displacement of the cap fixed. Subsequently, the normal stress increases in both cases. The peaks of normal stress and shear stress occur at the same shear strain level. This is due to suppress the positive dilatancy with the cap. The peak value of the normal stress is also larger in the strong case.

4 DISCUSSION

Figure 5 shows the failure planes of specimens cross section after simple shearing in each case. The fracture surface angle is approximately 45° in all cases. This can be interpreted as follows. Figure 6 shows the stress path of simple shear mode in tensile failure. The point reaching the failure criterion in tension and the pole P_p with respect to the plane form an angle of 45°. Therefore, in the case of tensile fracture, the fracture surface angle is 45°. The test case this time is tensile failure. At this time, the peak shear stress increment τ_{max} is equal to the tensile strength σ_t. The same can be said for tensile failure even if non-linear failure criteria are used.

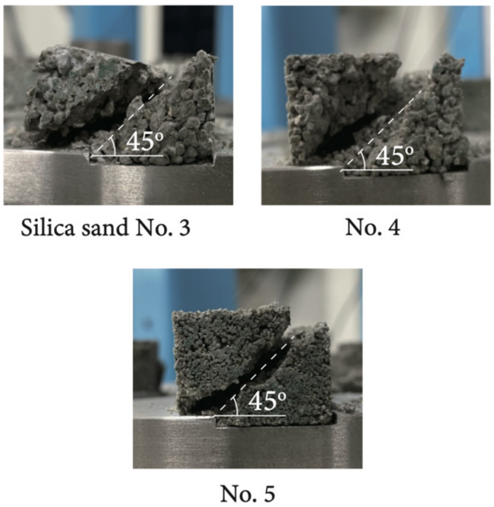

Figure 5. Failure plane in each specimen after simple shearing.

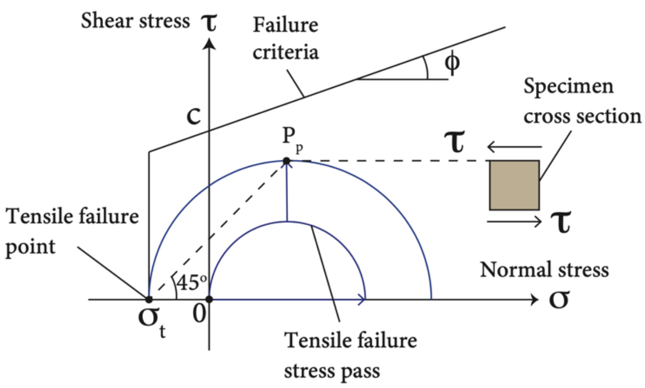

Figure 6. Stress pass in simple shear test for tensile failure.

Table 2 summarizes the peak value τ_{max} of the shear stress increment in each case. A value roughly equal to the tensile strength σ_t in Table 1 was obtained, which is a reasonable result. There is a slight difference in the results between Silica Sand No. 4 and No. 5, and one of the reasons is thought to be the variation in the properties of the specimens depending on the compaction. As described above, the applicability of the simple shear test of the proposed torsion-based rock prism specimen to soft rock was confirmed.

Table 2. Peak values of shear stress increment.

Silica sand No.	τ_{max} (MPa)
3	1.00
4	0.73
5	0.45

5 CONCLUSIONS

The authors proposed a completely new simple shear test in which a torque is applied to a prismatic specimen placed radially, and deformation in a simple shear mode is imparted to the specimen. In this report, three types of mortar specimens with different strength equivalent to soft rock were used to conduct verification experiments based on the proposed test. As a result of the shear test in the same normal stress field ($\sigma \approx 0.9$ MPa), it was confirmed that the peak value of the shear stress corresponding to the set mortar strength was obtained. In addition, as a result of analyzing the angle of the failure surface, it was confirmed that the specimen in this case show tensile failure under. The results of the prior compression test and the tensile strength evaluated from the simple shear test were almost the same, confirming the validity of the proposed test.

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