# EXPERIMENTAL STUDY ON POROELASTIC CONSTANTS OF ROCKS

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## 1. INTRODUCTION

Carbon dioxide capture and storage has been expected for an effective method for reduction of carbon dioxide emission in atmosphere. In this method, the carbon dioxide captured is injected into underground to storage geologically from large sources such as thermal power plants. To understand the movement of the injected carbon dioxide in the ground is very important to manage this method. Therefore, many monitoring methods for injected carbon dioxide have been proposed. The method using the high-precision tilt-meters is one of the expected methods. In this method the change of surface tilts are measured, and the flow of the carbon dioxide in the underground is estimated by the inversion method. In this method, the poroelastic parameters of reservoir rock are necessary to conduct the inversion analysis. The poroelastic parameters of rocks have not been clarified enough.

Therefore, to clarify the poroelastic parameters of the reservoir rocks for the geological carbon dioxide storage, the undrained and drained triaxial compression system with the capacity of 2,000 m in depth was developed in this study.

We aimed to conduct the triaxial compression test in the drained and undrained conditions and to determine the poroelastic parameters of the reservoir rocks experimentally.

## 2. SPECIMENS AND EXPERIMENTAL PROCEDURE

### 2.1 SPECIMENS

In this study, we used Kimachi sandstone (Fig. 1) and Inada granite (Fig. 2). The specimen is a cylindrical shape, and has nominal dimensions of 75 mm in length and 30mm in diameter. The specimens were prepared by coring from the rock block. The end surface of the specimen were grinded by a surface grinder. In addition, the surface of specimen was polished where strain gauges were adhered. Moreover, steel specimen made of SUS304 without the pores was also used in this study.

Fig. 1 Kimachi sandstone specimens.

Fig. 2 Inada granite specimen.

Table 1 Dimensions, volume and porosity of specimens.

| | No. | *D* (mm) | *L* (mm) | *V* (cm$^3$) | *n* (%) |
|---|---|---|---|---|---|
| **Inada granite** | 1 | 30.8 | 70.1 | 52.1 | 1.2 |
| | 2 | 30.8 | 70.1 | 52.1 | 1.1 |
| | 3 | 30.8 | 70.2 | 52.3 | 1.4 |
| | 4 | 30.8 | 70.2 | 52.2 | 1.1 |
| | 5 | 30.8 | 70.1 | 52.2 | 1.5 |
| **Kimachi sandstone** | 1 | 30.7 | 69.9 | 51.8 | 22.0 |
| | 2 | 30.7 | 70.1 | 51.8 | 21.4 |
| | 3 | 30.7 | 69.9 | 51.9 | 22.0 |
| | 4 | 30.7 | 70.1 | 51.8 | 21.6 |
| | 5 | 30.7 | 69.9 | 51.7 | 21.7 |

## 2.2 EXPERIMENTAL SYSTEM

Fig. 3 shows the overview of the undrained and drained triaxial compression system. The experimental system mainly consists of the material testing machine, the syringe pump, the hydraulic pump and the data recording system.

The two cross strain gauges are adhered on the side surface set in middle of specimen. The axial and circumferential strains were measured during test. The axial load was measured by the load cell attached at the cross head of the material testing machine The confining and pore pressures were measured by the pressure transducers.

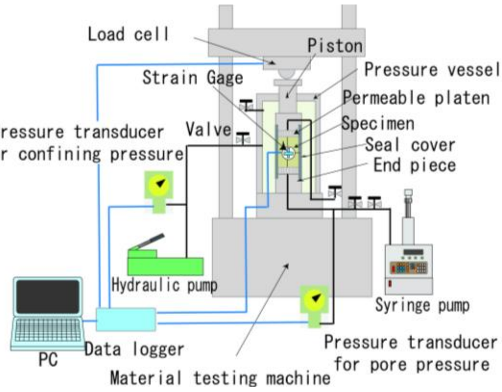

Fig. 3 Overview of undrained and drained triaxial compression system.

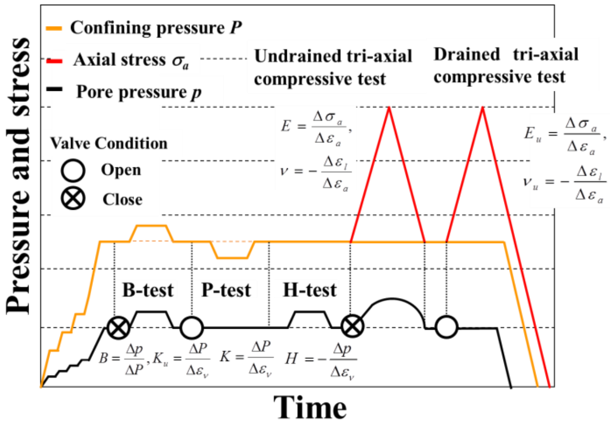

Fig. 4 Exaple procedure of tri-axial test in this study.

## 2.3 EXPERIMENTAL CONDITION AND METHOD

Fig. 4 shows the example procedure of triaxial test in this study. The elastic parameters of various rocks were measured by the following procedure in this study.

Ⅰ.The confining pressure increases in the undrained condition. The increments of the volumetric strain and the pore pressure were measured and the Skempton coefficient (*B*) and the bulk modulus in the undrained condition were calculated.

Ⅱ. The confining pressure reduces in the drained condition. The increment of measure the volumetric strain was measured, and the bulk modulus in the drained condition was calculated.

Ⅲ. The pore pressure increases in the drained condition. The increment of the volumetric strain was measured, and the poroelastic parameter of H was caluculated.

Ⅳ. The undrained and drained triaxial tests were conducted. The undrained Young’s modulus, the undrained Poisson’s ratio, drained Young’s modulus, drained Poisson’s ratio ware obtained.

## 3. RESULTS AND DISCUSSION

In this chapter, we describe the results of a series of tests was performed on Kimachi sandstone and Inada granite using a triaxial compression test apparatus designed and developed in this study. The tests for the Kimachi sandstone and the metal has implemented in the order of triaxial compression tests and drained triaxial compression B-test, P-test, H-test, undrained, for Inada granite was carried out in the order of triaxial compression tests and triaxial compression tests drainage H-test, B-test, P-test, undrained.

### 3.1 RESULTS OF METAL SPECIMEN

Shown in Figs 5 the results obtained for the test piece metal (SUS304), triaxial compression tests conducted as a series of sample does not have a gap.

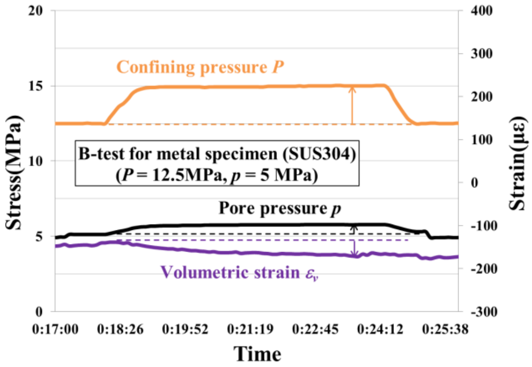

Fig. 5 Pressure and strain during B-test for metal specimen ($P$ = 12.5 MPa and $p$ = 5 MPa) .

Table 2 Increment of pore pressure measured in B-test for metal specimen (SUS304).

| | B-test | | | | |
|---|---|---|---|---|---|
| Confining pressure $P$ [MPa] | 12.50 | 18.25 | 25.00 | 31.25 | 37.50 |
| Pore pressure $p$ [MPa] | 5.0 | 7.5 | 10.0 | 12.5 | 15.0 |
| $\varDelta p$ [MPa] | 0.65 | 1.37 | 1.60 | 1.18 | 1.30 |

### 3.2 RESULTS OF ROCK SPECIMEN

We carried out a series of triaxial compression tests for Kimachi sandstone and Inada granite and calculated the poroelastic parameters of their rocks and compared with reference data(Table 4 and Table 5).

Table 4 Averaged poroelastic parameters for Inada granite

| | Inada granite | Charcoal granite[1)] | Westerly granite[1)] |
|---|---|---|---|
| $B$ [-] | 0.24 | 0.55 | 0.85 |
| $K_u$ [MPa] | 89.1 | 41 | 42 |
| $K$ [MPa] | 45.9 | 25 | 25 |
| $H$ [MPa] | 349 | 93 | 53 |
| $\alpha$ [-] | 0.16 | 0.27 | 0.47 |
| $E_u$ [GPa] | 43.8 | 49.2 | 40.3 |
| $\nu_u$ [-] | 0.31 | 0.3 | 0.34 |
| $E$ [GPa] | 42.1 | 35 | 38 |
| $\nu$ [-] | 0.29 | 0.27 | 0.25 |
| $G_u$ [MPa] | 16.7 | 18.9 | 15.0 |
| $G$ [MPa] | 16.4 | 19.0 | 15.0 |
| $K_{u\text{-}tri}$ [MPa] | 40.8 | – | – |
| $K_{tri}$ [MPa] | 36.7 | – | – |

Table 3　Comparison of poroelastic parameters for Kimachi sandstone No.3 with reference data[4].

| | Kimachi sandstone | Berea Sandstone[4] | Boise sandstone[4] | Ohio sandstone[4] | Pecos Sandstone[4] | Ruhr sandstone[4] | Weber sandstone[4] |
|---|---|---|---|---|---|---|---|
| $B$ [-] | 0.58 | 0.62 | 0.50 | 0.50 | 0.61 | 0.88 | 0.73 |
| $K_u$ [MPa] | 23.3 | 16.0 | 8.3 | 13.0 | 14.0 | 30.0 | 25.0 |
| $K$ [MPa] | 12.2 | 8.0 | 4.6 | 8.4 | 6.7 | 13.0 | 13.0 |
| $H$ [MPa] | 12.58 | 10.1 | 5.4 | 11.4 | 8.1 | 20.0 | 20.3 |
| $\alpha$ [-] | 0.97 | 0.79 | 0.85 | 0.74 | 0.83 | 0.65 | 0.64 |
| $E_u$ [GPa] | 4.6 | 16.3 | 9.5 | 17.2 | 16.0 | 34.2 | 31.5 |
| $\nu_u$ [-] | 0.77 | 0.33 | 0.31 | 0.28 | 0.31 | 0.31 | 0.29 |
| $E$ [GPa] | – | 14.4 | 9.7 | 16.1 | 13.7 | 29.6 | 27.3 |
| $\nu$ [-] | – | 0.20 | 0.15 | 0.18 | 0.16 | 0.12 | 0.15 |
| $G_u$ [MPa] | 1.3 | 6.1 | 3.6 | 6.7 | 6.1 | 13.1 | 12.2 |
| $G$ [MPa] | – | 6.0 | 4.2 | 6.8 | 5.9 | 13.2 | 11.9 |

## 4. CONCLUSIONS

In this study, as to clarify experimentally the various poroelastic parameters of a relatively hard rock such as storage of carbon dioxide target, the new triaxial compression apparatus having a capacity equivalent to 2,000 m depth was designed and developed. The main results obtained in this study are as follows:

For Kimachi sandstone and Inada granite, the undrainde bulk modulus, the drained bulk modulus, the undrained Young's modulus, the undrained Poisson's ratio, the drained Young’s modulus and the drained Poisson’s ratio were obtained experimentally. Moreover, Skempton coefficient and proelastic parameter of H were also obtainded experimentally.

## REFERENCES

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