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[TECHNICAL NOTES]

Development of in-situ triaxial test for rock masses

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ABSTRACT

A new field test method was proposed for the purpose of directly measuring average stress-strain relationships and to investigate strength and deformation characteristics of rock masses. The test is conducted on a hollow cylindrical specimen prepared at the bottom of a drill-hole. Average axial as well as lateral strains can be measured in a center hole and an outer slit by a novel technique of instrumentation for cavity deformation. A set of test equipment for this test method was developed and improved at Central Research Institute of Electric Power Industry, CRIEPI, in Japan.

The purpose of this paper is the technical notes of application to some rock masses in different rock type. Trial series of tests were carried out at the site of rhyolitic tuffacious rock and rudaceous rock of Neogene system. The results, similar to conventional laboratory triaxial tests, proved that the proposed test method was successful in measuring average stress-strain relationships of large rock specimens.

Keywords: Field Test, Rock Mass, Shear Strength, In-situ Test, Strength, Deformation

1. INTRODUCTION

At present, deformation characteristics of rock masses are investigated by plate load tests and pressuremeter tests, while the strength characteristics are investigated by rock shear tests. These conventional in-situ test methods, however, have several problems as follows:

(1) Deformation and strength characteristics are investigated separately.
(2) Test results may be significantly affected by stress relief and disturbance of the loading surfaces.
(3) Stress and strain relationships are not measured directly.
(4) Strength characteristics in deep ground cannot be evaluated.

A new field test method (hereinafter referred to as “in-situ triaxial test for rock masses”) provides the solution to the above problems. The test method was proposed in 1997 (Tani, 1999). In the next year, a set of test equipment for this test method was developed at Central Research Institute of Electric Power Industry in Japan, denoted as CRIEPI (Tani, 2001).

The rock specimen is prepared at the bottom of a drill-hole. The test can be conducted at any depths and avoids creating disturbed zones by excavating. Axial and lateral strains are measured in the center hole and the outer slit of the hollow cylindrical specimen. Since the measurement is done at mid-height on the side of the specimen, any unwanted influence of the bedding errors around the top surface and of the bottom restraints can be eliminated. The outer cell is a hollow cylinder with its inner and outer sides being covered with rubber membranes. The rigid strong body of the outer cell is not needed because the surrounding rock mass takes all the reaction forces induced by the outer pressures.

2. TEST PROCEDURE

Figure 1 illustrates the test procedure for the proposed method (Tani et al., 2003). The test starts with drilling the bottom of the drill-hole into a hollow cylindrical shape, hereafter denoted as the Drilling stage. Then, this hollow

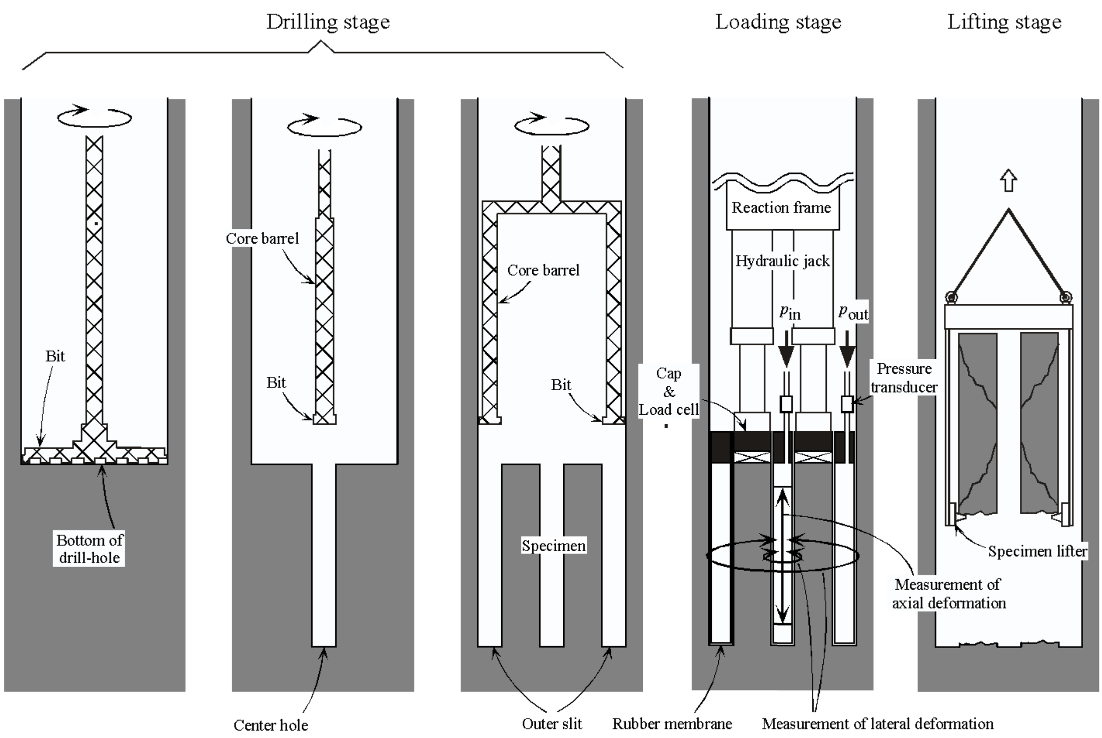

Fig. 1. Test procedure of in-situ triaxial test for rock masses (Tani, 2003)

cylindrical rock specimen is loaded axially while being pressurized laterally, hereafter denoted as the Loading stage. Finally, the sheared specimen is retrieved out of the drill-hole to the ground surface, hereafter denoted as the Lifting stage.

In the Drilling stage, firstly, the bottom of the drill-hole is prepared as a flat surface that will serve as the top of the specimen. Secondly, a conventional rotary drilling technique is used to drill a center hole of a small diameter and an outer slit of a large diameter with a suitable width. From the center hole, a drilled core can be obtained and this can provide useful information of the tested ground.

In the Loading stage, an inner cell and an outer cell are inserted into the center hole and the outer slit, respectively. The former is a solid cylinder, while the latter is a hollow cylinder, and both are equipped with rubber membranes on their lateral sides. Hydraulic pressures, p_{in} and p_{out}, are provided to both inner and outer cells to apply lateral pressures on the sides of the specimen through the rubber membranes. At the same time, axial force, Q, is loaded on the cap which is placed on the specimen.

After the Loading stage, the specimen is cut at its bottom, and lifted to the ground surface for further observation, thus the Lifting stage. As shown in Figure 1, the specimen lifter has the some wedges which are penetrate into the specimen. Close inspection is then conducted to collect any useful information as to heterogeneity, discontinuity and shear bands/fractures in the rock specimen. The purpose is two-fold: (1) to judge if the tested specimen is representative of the surrounding rock mass of interest, and (2) to examine its failure mechanism which may help improve the interpretation of the test results.

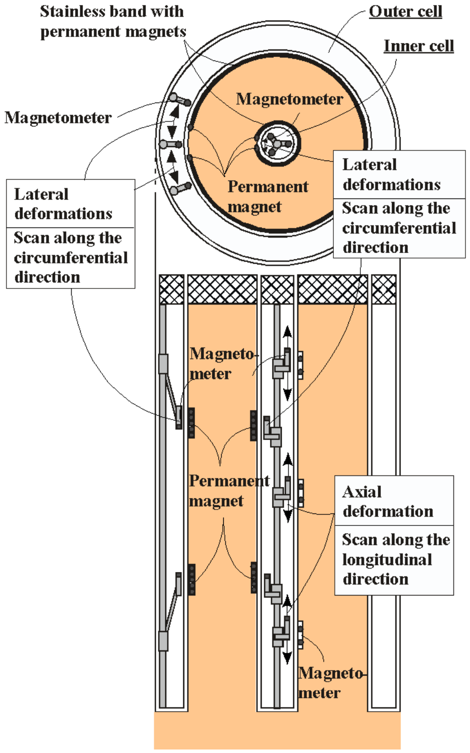

Fig. 2. Locations of ICD (Instrumentation for Cavity Deformation) measurement

3. SPECIFICATIONS OF TEST EQUIPMENT

The size of specimens is determined so that the test results can be considered for rock masses rather than for rock cores, thus designed to be 86mm in the inner diameter, 400mm in the outer diameter, and about 1050mm high. The maximum lateral pressure is 5.0MPa, while the maximum axial force is 8000kN, which is approximately 66MPa in terms of maximum axial stress.

A novel technique of instrumentation for cavity deformation, hereafter denoted as ICD, was invented for this deformation monitoring (Tani and Tachikawa, 1998). Figure 2 schematically explains the conceptual principle of ICD. This ICD utilizes magnetometers to detect small pieces of permanent magnets as displacement markers placed on the cavity wall. Both axial and lateral deformations of the cavity wall at any longitudinal location can be monitored by this single ICD system. Axial movements of a permanents magnet placed on the cavity wall can be measured by a magnetometer that scans along the longitudinal direction. On the other hand, lateral movements of a cavity wall are measured as changes of the circumferences or arc lengths.

4. TEST AT THE SITE OF TUFFACIOUS ROCK

4.1 Outline of test

Field tests were carried out at the site of abandoned open quarry in Ohya, about 100km north of Tokyo. The tested ground was Miocene deposit of rhyolitic tuffacious rock formation, generally denoted as green tuff formation or 'Arame (Coarse)' Ohya stone.

A total of seven tests, Test 1 to Test 7, were carried out. Keeping the inner and outer pressures as identical, $p_{in}=p_{out}$, various kinds of triaxial compression tests were attempted. These included six conventional single-step loading triaxial tests (Test 1-4, 6, 7) and one multiple-step loading triaxial test (Test 5; Kovari and Tisa, 1975). Confining pressures, σ_c, were set at 0.0, 0.4, 1.0, 2.0 and 3.5 MPa.

The drilled cores, 66 mm in diameter, retrieved from the center holes demonstrated that the rock mass was generally continuous with few joints. The only exception, however, was the one used for the multi-step loading triaxial test (Test 5), where a single distinct joint of discontinuity was observed at 340-346 mm from the top of the specimen.

4.2 Test result

The test result for Test 2, as the relationships between the deviator stress, $q=\sigma_a-\sigma_c$, and the axial as well as lateral strains, ε_a, ε_θ, and ε_r, is shown in Figure 3 (Tani, 2001). Axial strains, ε_a, are calculated as average axial strains measured within a mid-section which is 567 mm long in the center hole. Circumferential strains, or hoop strains, ε_θ, are calculated as average values measured at two depths in both inner and outer cells. In addition, interestingly enough, radial strains, ε_r, can be measured by this test method, unlike equivalent laboratory triaxial tests where solid cylindrical specimens are used. They are calculated from the radial displacements at the inner and outer sides of the specimen, which are otherwise estimated from circumferential/hoop strains, ε_θ, assuming the axisymmetric condition.

Figure 4 demonstrates the relationship between $q/2$ and the mean stress, $\sigma_m=(\sigma_a+\sigma_c)/2$, at peak states together with the deduced Mohr-Coulomb's failure criteria. The peak strength parameters are found as c=2.9 MPa, ϕ=18° for single-step loading triaxial tests, while lower values c=1.8 MPa, ϕ=17° are obtained from a multiple-step loading

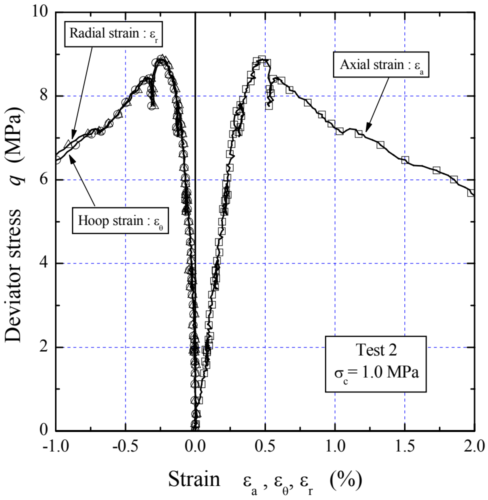

Fig. 3. Relationship between average stress and average strains forTest2 (Tani, 2003)

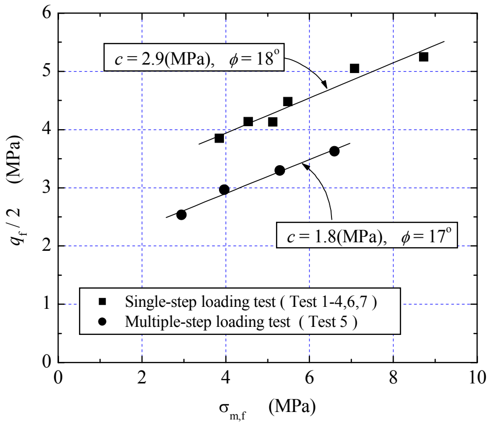

Fig. 4. Peak strengths characteristics by in-situ triaxial compression test (Tani, 2003)

Photo 1. Specimen retrieved after Test 2 (Tani, 2003)

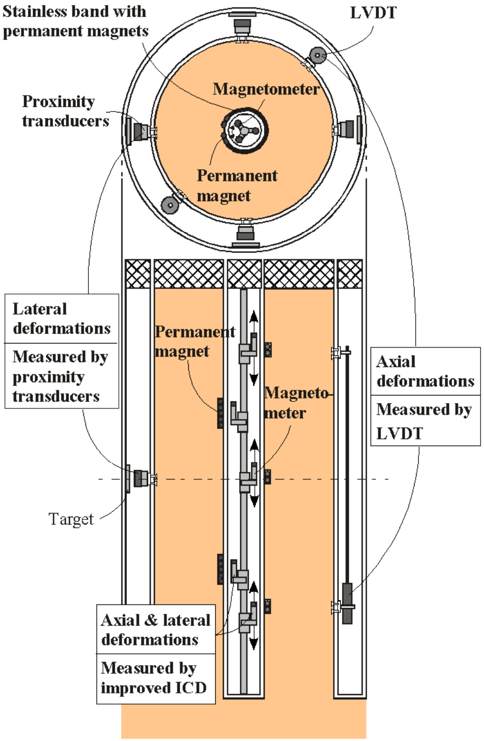

Fig. 5. Improved measurement system

triaxial test (Test 5). The discrepancy is probably due to the weaker specimen for Test 5, which exceptionally includes a distinct joint in the middle.

All the specimens were retrieved to the ground surface after the Loading stage. As shown in Photo.1, the specimen exhibited several shear bands which were steeply oblique, bearing some 50 to 65 degrees from the horizon, in the middle heights.

5. TEST AT THE SITE OF RUDACEOUS ROCK

5.1 Outline of test

Before the tests, improvements in the measuring system were made in order to raise the measurement precision and shorten the sampling interval. Figure 5 explains the conceptual principle and the arrangement of the displacement transducers. Both axial and lateral deformations of the specimen can be measured by ICD in the center hole and by two LVDTs and four proximity transducers (PT) in the outer slit.

Field tests were carried out in a 9m-deep exploratory adit (Okada et al., 2006). The rock mass at the site is sedimentary rock of rudaceous rock of Neogene system. The matrix of the rock is categorized as soft rock. The compressive strengths of the gravel of the rock are about 20 times as large as the corresponding values of the matrix.

A total of six triaxial tests were carried out, hereafter denoted as C-1, C-2, C-3, T-1, T-2 and CY respectively. These included three triaxial compression tests (C-1, C-2, C-3), two triaxial extension tests (T-1, T-2) and a cyclic triaxial test (CY).

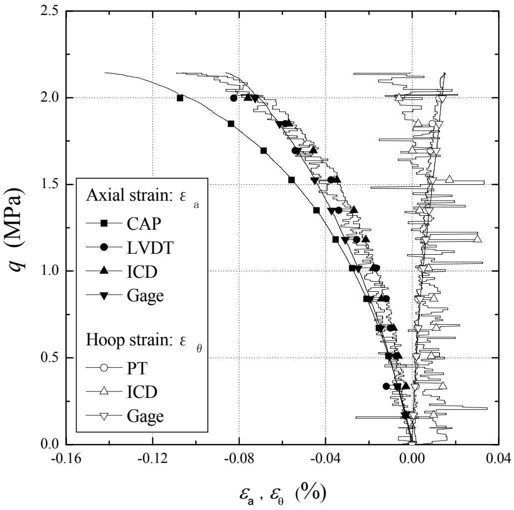

Fig. 6. Relationship between average stress and average strains for C-2

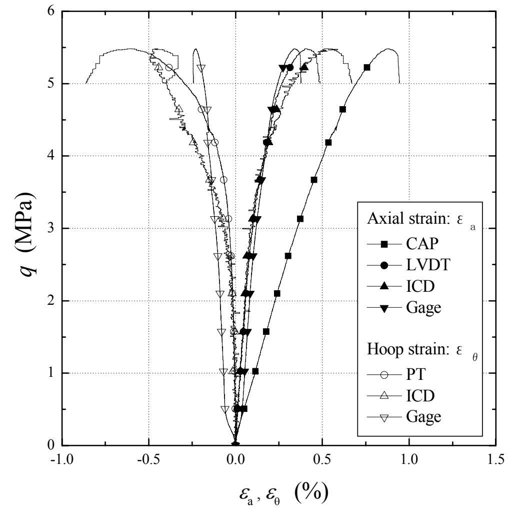

Fig. 7. Relationship between average stress and average strains for P-1

In C-1, C-2 and C-3, multiple-step loading triaxial compression tests were conducted. Confining pressures of the first step, σ_{c0} , were set at 0.2, 0.3 and 1.0 MPa. In P-1 and P-2, the specimens were directly extended in the axial direction under confining pressures. Confining pressures, σ_c, were set at 1.0 and 3.0 MPa.

5.2 Test result

Figure 6 shows the relationship between q and ε_a & ε_θ for the triaxial compression test (C-2). The axial strains measured by LVDTs, ICD and strain gages were in reasonable agreement with each others. The failure axial strains measured by the external displacement transducers (CAP) are about twice as large as the corresponding values measured by the others on the side of the specimens. The

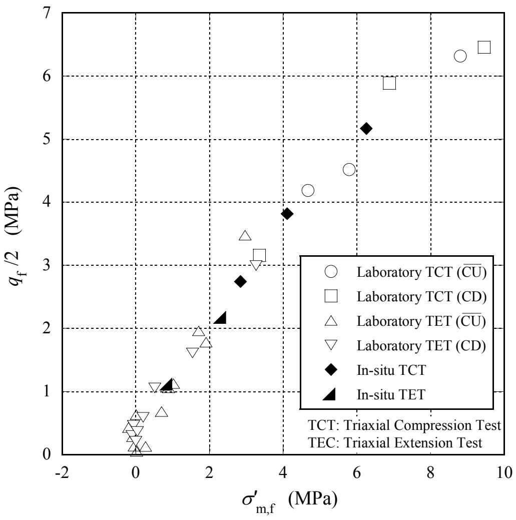

Fig. 8. Test results of laboratory and in-situ triaxial test

lateral strains measured by ICD greed approximately from the corresponding values measured by proximity transducers (PT). The lateral strains measured by strain gages were different from the others. It should be noted that strain gages with a limited gage length of 90mm are not suitable for measurements of deformation for inhomogeneous rock masses. The above-mentioned tendencies could be seen in the test results for C-1 & C-3.

Figure 7 shows the relationship between q and ε_a & ε_θ for the triaxial extension test (P-1). Like the triaxial compression test, the axial strains measured by LVDTs, ICD and strain gages were in reasonable agreement with each others. The lateral strains measured by PT agreed approximately with the corresponding values measured by strain gages, however strain values by ICD were different from the others. It can be considered that stainless bands of ICD rounding the rubber membrane of the inner cell might not follow the cavity deformation. The above-mentioned tendencies could be seen for the test results in P-2.

Figure 8 compares the test results, as the relationships between $q/2$ and the effective mean stresses, σ'_m, of laboratory triaxial tests on the small drilled cores and the in-situ triaxial tests on the large specimens. Although further studies are needed regarding scale effect, the strengths of the in-situ and laboratory triaxial tests were in reasonable agreement with each other.

Some of the specimens were retrieved to the ground surface after the tests. As shown in Photo 2, the specimen after the triaxial compression test (C-1) exhibited a shear band bearing about 60 degrees to the specimen's axis. Discontinuities observed a little below the middle of the specimen appeared before the test. As shown in Photo 3, the specimen after the triaxial extension test (P-1) exhibited a failure plane that developed perpendicular to the specimen's axis in the mid-height.

Photo 2. Specimen retrieved after test (C-1)

Photo 3. Specimen retrieved after test (P-1)

6. CONCLUSIONS

A new field test method was proposed for the purpose of directly measuring average stress-strain relationships and to investigate the strength and deformation characteristics of rock masses. Trial series of tests were carried out at the site of rhyolitic tuffacious rock and rudaceous rock of Neogene system. The results proved that the proposed test method was successful to measure average stress-strain relationships of large rock specimens for the first time in the world.

We believe that the proposed in-situ triaxial test will substitute plate load tests and rock shear tests for rock ground investigation in the near future. In order to put this test method to practical use, further examinations are needed to enhance applicability to discontinuous rocks, and thus it is important to improve the drilling method of the specimen.

ACKNOWLEDGEMENTS

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