



## Effect of Anisotropic Stress and Fluid Pressure on the Stability of Rock around an Underground Radioactive Waste Repository

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### ABSTRACT

The high-level radioactive waste is to be disposed into a deep underground repository. Safe long-term isolation of high-level waste relies largely on stability and water-tightness of host rocks of repository. True triaxial compression tests of rocks have been carried out to investigate fracturing of rocks under anisotropic compression, water-driven fracturing and permeability change by effective and differential stresses.

### 1 INTRODUCTION

The high-level radioactive waste must be isolated longer than ten thousands years from the biosphere. In the radioactive waste management plan in Japan, the high-level waste from the reprocessing plant of spent nuclear fuel is to be vitrified, packed and carefully emplaced into an underground repository which shall be constructed at the depth of several hundreds or about one thousand meters below the ground surface. All cavities and holes in the repository are to be backfilled and sealed after the emplacement of vitrified waste.

In the multibarrier concept, long-term confinement of waste during several or tens thousand years must rely mainly upon the geologic(natural) barriers provided by the stable rock body in which the repository is constructed. The host rock body of the deep underground repository mechanically protects the assembly of engineered barriers which contain the vitrified high-level waste, and restricts percolation of groundwater and migration of hazardous radionuclides towards the biosphere. The host rock body should be homogeneous, flawless, impermeable and durable for the sake of long-term confinement of waste.

In Japan, any candidate sites nor regions have not yet been selected for the final disposal of high-level waste. Suitable host rock of repository may be a granitic stock, clay-rich layer of sedimentary formation or thick tuff unit. There exist no rock salt deposits in the Japanese islands. Geological structure and setting of the site are rather important than rock species, because faults, joints, schistosity, heterogeneous inclusions or other kinds of discontinuity of rock may control total performance of the geologic barriers. The formation of cracks, especially brittle open cracks, in the host rocks of the underground radioactive waste repository could make the penetration of groundwater much easier and spoil the "flawless" isolation of the waste. The careful investigation of fracture behavior is necessary for the host rocks around the waste repository.

### 2 FRACTURING OF ROCKS UNDER ANISOTROPIC COMPRESSION

Underground rocks suffer vertical lithostatic compressive stress due to the load of overlying rocks, and horizontal compressive stress induced by

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compression of surrounding rocks and by tectonic forces. As the rock is solid, its stress condition is essentially anisotropic and three components of principal stress are different each others. Although primary compressive stresses of some tens megapascal are usual at the depth of repository, construction of cavern temporarily and locally releases compressive stress around the repository. Gradual rebuilding of compressive stress after backfilling and sealing of repository may accompany possible future stress change of natural or artificial origin.

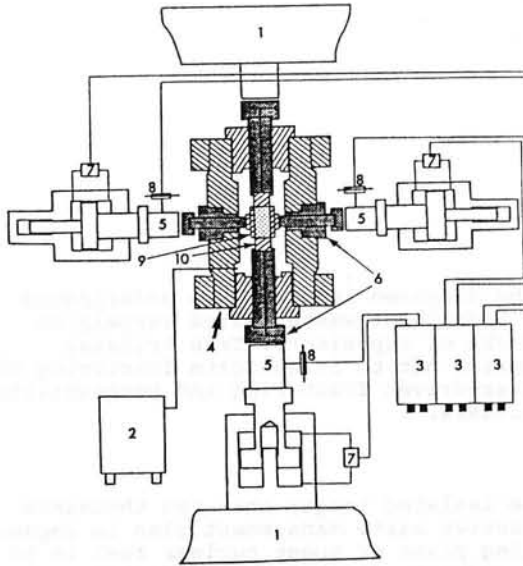


Fig.1 Schematic diagram of a new designed true triaxial compression apparatus.1:fixed upper and lower platen,2:hydraulic power supply,3:control unit,4:pressure vessel,5:load cells for axial and lateral directions,6:pistons for axial and lateral load,7:servo valve,8:displacement transducer for axial and lateral deformation,9,10:lateral and axial end pieces.

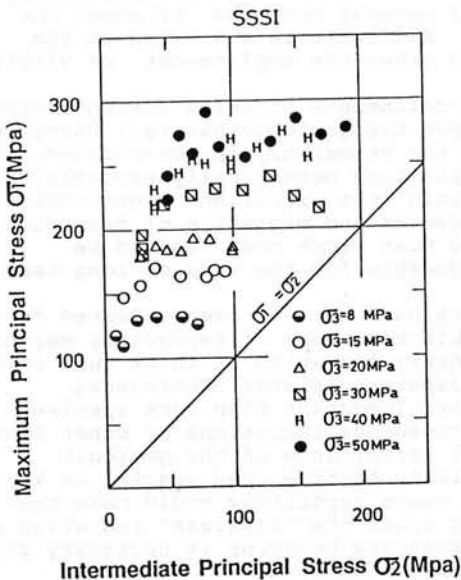


Fig.2 Fracture strength as a function of the intermediate principal stress in Shirahama sandstone.

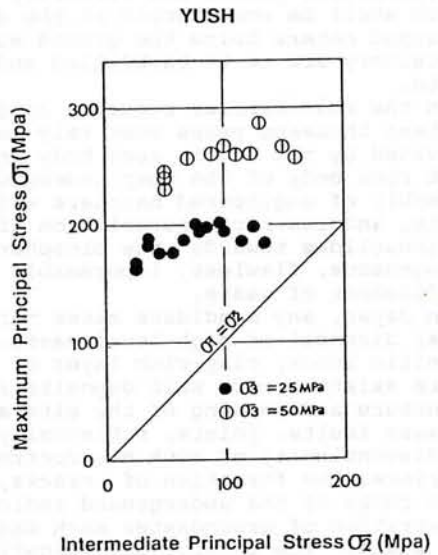


Fig.3 Fracture strength as a function of the intermediate principal stress in Yuubari shale.



Several kinds of rocks such as sandstone, shale, marble, etc., were experimentally deformed under various stress conditions with a specially designed "true triaxial" compression apparatus (Fig.1). Within this true triaxial apparatus, the permeability, dilatancy, acoustic emissions, velocity of elastic waves, etc. of rocks can be measured during the deformation experiments with the independent control of the three principal stresses and pore fluid pressure. The true triaxial compression tests clearly indicate the effect of the intermediate principal stress on the fracture strength of rocks such as sandstone (Fig.2), shale (Fig.3) and marble (Takahashi and Koide, 1989). The relatively high intermediate stress increases brittleness of rock (Fig.4).

The relatively large anisotropic stress could induce extensional microcracks in essentially heterogeneous material such as rocks even under the macroscopic compressive stress by the generalized Griffith theory for microcrack formation from inclusions (Koide, 1981). Microscopic observation and measurement of acoustic emissions of deformed rocks indicate swarming of microcracks and formation of a macroscopic shear fracture by interconnection of microcracks in rocks under the three dimensional compression. The reduction of compressive stress may cause release cracks in some rocks.

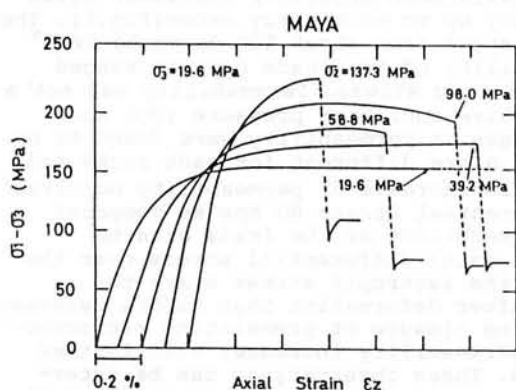


Fig.4 Differential stress versus axial strain of Yamaguchi marble for the five different intermediate stress under constant confining pressure of 20MPa.

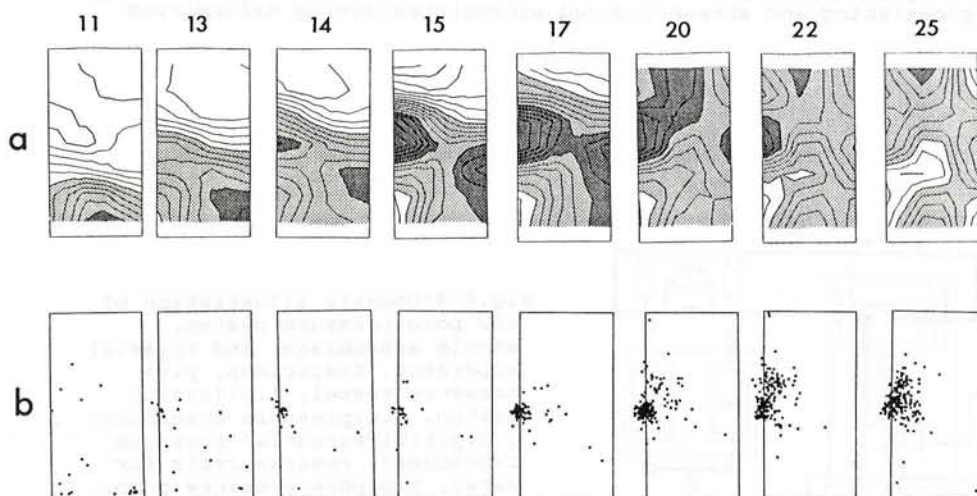


Fig.5 (a) Reconstructed P wave velocity change relative to the P wave velocity profile just before the water injection. The contour line is 1% change interval. Coarse-dotted area and fine-dotted area indicate the regions where velocity change is between +5% and +10%, and more than +10%, respectively. (b) Hypocenter distribution of AE events occurred within 20 mm of the velocity profile plane.

### 3 WATER PENETRATION AND WATER-DRIVEN FRACTURING

The sources of acoustic emissions were obtained precisely for the study of initiation and clustering of fractures in the deformed rocks. The tomographic mapping of elastic wave velocity revealed the penetration process of water into the rock specimens(Masuda et al.,1990). During forced water infiltration into a dry granitic rock in the dilatant state, migration of water front and a clear positive feedback between acoustic activity and water flow into microcracks were revealed by means of AE hypocenter locations and velocity tomography(Fig.5).

Water-driven fracturing occurs where water flows into microcracks. This positive feedback process is an important mechanism of fracture development and water channeling in deep underground rocks.

### 4 RELATION BETWEEN PERMEABILITY AND STRESS STATE

Permeability and volumetric strain were measured of the Shirahama sandstone and Inada granite under hydrostatic and deviatoric stress. A transient pulse method was used to measure the permeability up to nano darcy order(Fig.6). The permeability of the Shirahama sandstone ranged from about  $10^{-6}$  darcy to  $2 \times 10^{-5}$  darcy under isotropic stress. The permeability of the Inada granite ranged from about  $3 \times 10^{-8}$  to  $5 \times 10^{-6}$  darcy under isotropic stress. Permeability was not a simple function of the conventional effective confining pressure ( $P_c$ ) and internal fluid pressure( $P_p$ ) (Fig.7). Changes in permeability were found to be proportional to  $(P_c - \alpha P_p)$ , where values of  $\alpha$  are different for each rocks and for preferred orientation. Nearly threefold increase of permeability occurred in the Shirahama sandstone at axial differential stress 80 Mpa as compared with that the isotropic stress state. Permeability of the Inada granite increased by nearly thirtyfold at 300 Mpa axial differential stress over the value at the isotropic stress(Fig.8). At the isotropic stress state the permeability of rocks is slightly lower after deformation than before deformation. This phenomenon is probably due to the closure of preexisting microcracks. The sample became more dilatant and permeability increases with further increase of the axial differential stress. These observations can be interpreted systematically in terms of differences in the porosity or aperture of the preexisting and stress-induced microcracks during deformation.

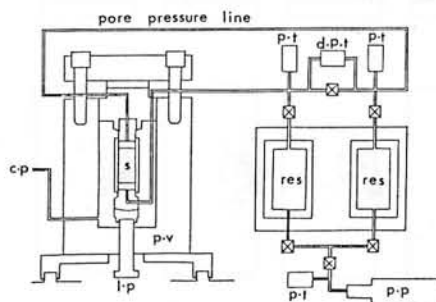


Fig.6 Schematic illustration of the pore pressure system, sample assemblage, and triaxial apparatus. S:specimen, p.v: pressure vessel, l.p:loading piston, p.t:pressure transducer, d.p.t:differential pressure transducer, res:reservoir for water, p.p:pore pressure pump.

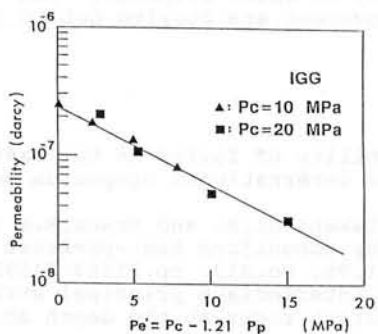
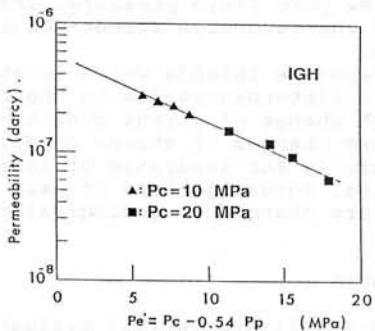
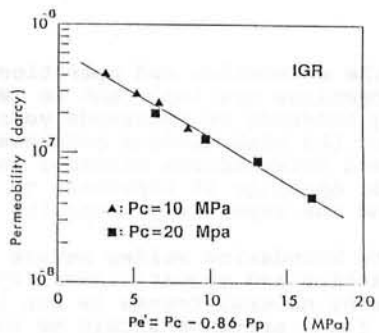


Fig.7 Permeability at modified effective pressure of the Inada granite for different preferred orientations, IGR,IGG,IGH.

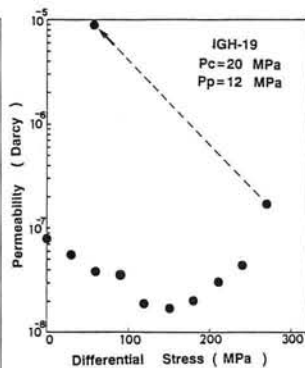
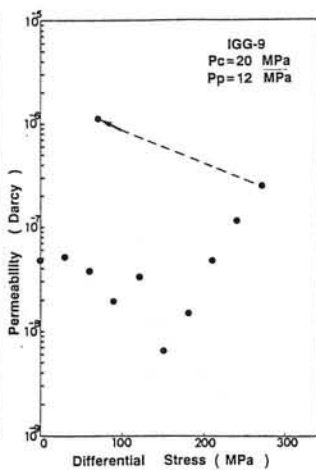
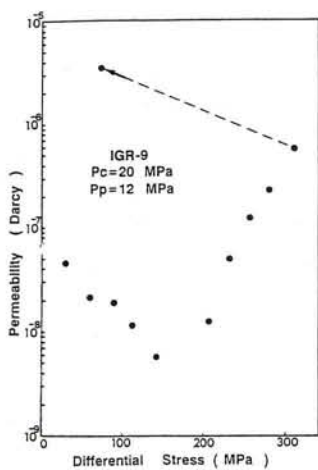


Fig.8 Permeability change as a function of axial differential stress for IGR,IGG,IGH specimens.



## 5 CONCLUSION

The estimation and control of stress during the excavation and operation of underground facilities and after closure of openings are important to keep the repository stable and to isolate waste during hundreds or thousands years. The effective isolation of waste is expected under the high minimum compressive stress combined with relatively low maximum and intermediate stresses and under low pore fluid pressure. The backfill of openings is important to provide the favorable stress conditions around the repository after its closure.

The Japanese Islands which locate near plate boundaries suffer severe tectonic disturbances due to the plate interaction and magmatic activity. Although change of stress conditions in rocks by natural forces is not large, long-term changes of stress condition and of fluid pressure should be evaluated carefully for assurance of long-term safety of waste disposal. The geological investigations of past tectonic movement are carried out to predict the future change of geological conditions.

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