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DEVELOPMENT OF METAL-SEAL PACKER TO ESTIMATE IN-SITU FRACTURE APERTURE

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ABSTRACT

To develop a Hot Dry Rock power generation system, artificial fractures within a rock must be newly created or natural fractures must be stimulated by hydraulic pressurization. Fractures play an important role as a heat exchanger within a rock. In the case of conventional geothermal reservoir that consists of natural fractures, fractures also play an important role as a geothermal fluid path. Especially in HDR development, if the thickness of the fracture is too thin, then the injection pressure would be very high and an economical operation would be difficult. In hydraulic fracturing or stimulation operation, estimation of the spatial fracture aperture distribution with elapsed time is very important to decide the total volume injection of water and to decide the pumping power. Nevertheless, it is difficult to estimate the in-situ fracture aperture and there have been not enough data about fracture aperture. As a basic study of estimating the fracture aperture within a borehole, a 'Dual Single-Packer' has been developed. This paper describes the principle of the packer and experimental results of in-situ and laboratory experiment obtained by the new packer.

1. INTRODUCTION

In developing a HDR artificial reservoir, and estimating a performance of fracture-type natural reservoir, knowledge of a fracture aperture is very important. If we could observe the fracture opening and closing phenomena directly within a borehole, we would be able to estimate the fracture behavior more precisely. In this paper, newly developed packers to measure a fracture aperture directly are introduced. We developed three packers that had different diameters and sealing element materials. All the packers were manufactured based on the same principle. So called 'Dual Single-Packer' that had a diameter of 10 mm were manufactured and used in a laboratory to examine a fracture behavior in detail. Adding to this, packers for practical use that had diameters of 76mm were manufactured and used in Kamioka mine, Gifu prefecture in 1998. In this experiment, two types of packers were used. One had a hard rubber-seal element and the other had a metal-seal element (Takehara *et al*., 1999).

2. EXPERIMENTAL PROCEDURES

2.1 Principle of Newly Developed Packer

The conceptual diagram of newly developed packer is shown in Figure 1. This new type of packer is called 'Dual Single-Packer'. Figure 1(a) shows the principle of conventional straddle packer. This type of packer is usually used in a hydraulic fracturing and/or stimulation operation. As is shown in Figure 1(a), a specific interval within a borehole is sealed by a pair of inflatable sealing elements. As the sealing elements are fixed rigidly to a center pipe, sealing elements constrains opening and closing movement of newly induced fracture. Figure 1(b) shows the principle of Dual Single-Packer. The packer consists of two single packers that can move independently. One sealing element is fixed to one blind pipe. And another sealing element is fixed to another pipe. The former pipe penetrates the latter pipe as is shown in Figure 1(b). After transverse fracture is made, the relative movement of two pipes gives equivalent or corresponding value of fracture openings. Thus by measuring a relative movement of two co-axial pipes, aperture of fracture could be estimated.

Figure 2 shows the photograph of Dual Single-Packer with hard rubber sealing element used in the laboratory. In a laboratory experiment, a borehole is drilled to penetrate the cubic rock specimen, as will be mentioned later, two pipes are not co-axial but connected in series as is shown in the figure. Figure 3 shows the practical packers that have diameters of 76mm. In this figure, conventional straddle packer (Double Packer), Dual Single-Packer with hard rubber sealing element (Rubber-Seal Packer) and Dual Single-Packer with metal sealing element (Metal-Seal Packer) are shown from up to down.

2.2 Hydraulic Fracturing Experiment at a Laboratory

The test specimen used for the laboratory experiment was the Inada granite that had a dimension of 20cm x 20cm x 20cm. The borehole for hydraulic fracturing that had a diameter of 10mm was drilled vertical to the rift plane. The mechanical properties of the Inada granite are summarized in Table 1. The cubic specimen was set into the rigid frame made of steel as is shown in Figure 4. Four flat jacks surrounding sides of specimen were inserted into the clearance between the specimen and the rigid frame, and the pressure of 8 MPa was applied. Because of this confinement by flat jacks, a fracture is generally generated in parallel to free surface. In other words, the direction of fracture extension was perpendicular to the borehole. A photograph of the equipment is shown in Figure 5. LVDTs with accuracy of 0.25μm were used for measuring the surface displacements of free surfaces. A total number of 24 LVDTs was placed against the free surfaces as is shown in Figure 4. The distances of LVDTs were 2, 5 and 8cm from the center of the borehole. The set of LVDTs were placed not only one on free surface, but also on opposite side. These surface displacements were recorded by the data logger through the amplifier and the noise-filter. The injection pressure and the flow rate were also recorded by the same data logger. The capacity of pressure transducer was 50 MPa. The Dual Single-Packer, shown in Figure 2, was inserted into the borehole. The hard rubber was compressed and expanded within the borehole by clamping the nut at packer end.

2.3 In-situ Hydraulic Fracturing Experiment

In 1996, a hydraulic fracturing experiment had been carried out at the Mozumi tunnel of Kamioka Mining & Smelting Co., which is located at the Gifu prefecture, Japan. Mizuta *et al.* (1997) showed the results of the hydraulic fracturing experiment and fluid injection experiments in detail. In analyzing the experimental result, Mizuta *et al*. (1996) used the combination of Finite Element Method and Boundary Element Method, for the quasi three-dimensional flow analysis and three-dimensional elastic analysis, respectively. The analysis could roughly explain the obtained experimental results. Yamashita *et al*. (1997) estimated the relation between the hydraulic pressure inside the fracture and in-situ stress distribution in the horizontal direction of a borehole for hydraulic fracturing and a fracture aperture. From these analyses by Mizuta and Yamashita, the direction of the fracture extension, in-situ stress state and so on have been already clear to some extent.

In 1998, the artificial fracture re-opening experiment using the 76mm Dual Single-packers were carried out. Takehara *et al*. (1999) already reported the details of the experiment.

3. Experimental Result

3.1 Laboratory experimental result

In the laboratory experiment, the hard rubber was used as the sealing element of a packer. In a hydraulic fracturing and succeeding injection stage, not only the fracture aperture but also the deformation of sealing was measured. The deformation of sealing elements must be subtracted to estimate the fracture aperture. In order to estimate the relation between the borehole pressure and the sealing elements' displacement, the calibration was made before hydraulic fracturing experiment. The pressure was applied repeatedly as is shown in Figure 6. In this procedure, the pressure was increased up to 15 MPa at first. The purpose of this pressurization was to deform the sealing element as large as possible. The value of 15 MPa was chosen not to cause the hydraulic fracturing. Then the pressure was repeatedly increased up to 5 MPa, 10 times then up to 10 MPa, 10times. The residual displacements after pressure relief against applied pressure were obtained. This residual displacement is caused by plasticity of the rubber element. This relation was used to calibrate the sealing elements' deformation with applied pressure within the borehole.

The surface displacement obtained by LVDTs during hydraulic fracturing is shown in Figure 7. The amount of surface displacements around the borehole increased after breakdown and succeeding fracture propagation. And after reaching to a maximum value, it decreased rapidly. After a pressure relief, observed surface displacements took a constant residual value. This means that a fracture was not completely closed after pressure relief. Figure 8 shows the history of injection pressure and displacement obtained by the Dual Single-Packer during hydraulic fracturing. Overall tendency is almost same as the surface displacements shown in Figure 7, but a residual displacement after pressure relief was much larger compared to that of surface displacements.

3.2 *In-situ* experimental result

In *in-situ* fracture re-opening experiment, a pair of LVDTs, that had maximum ranges of the 10mm and 5mm, respectively, were used to measure the relative displacement of the packer section through the two co-axial pipes (Figure 1(b)). Surface displacements of the gallery wall at the vicinity of borehole were also measured by LVDTs. These experiments were carried out 6 times in total. Although metal (lead) was used as a sealing element, plastic deformation was also observed in these experiments before the shut-in. The injection pressure just before the shut-in at the experiments, metal-seal packer displacements and wall surface relative displacements at the vicinity of borehole before and after the shut-in are shown in Figure 9.

4. DISCUSSION

Yamashita *et al*. (1996) used basically the same equipment and specimen and conducted the same kind of laboratory experiment as ours. The main results obtained by Yamashita were;

1. The breakdown pressure was about 23 MPa,
2. Surface displacement near a borehole was about 50–60 μm at breakdown,
3. The residual surface displacement after pressure relief was about 30 μm.

These values are almost the same as our experiment shown in Figure 7. In his paper, the result of Dual Single-Packer was not described. Instead of estimating fracture aperture directly by Dual Single-Packer, he used Finite Element Method and estimated the aperture of fracture as about 50 μm. The important conclusion of his experiments is that the surface displacement near borehole and the fracture aperture at the breakdown has almost the same value.

From Figure 8, the displacement of Dual Single-Packer increased instantaneously about 49 μm at the breakdown. If the assumption is made that the pressure was kept at almost constant value within a very short time at the breakdown, the deformation of rubber sealing element should be constant. Thus the sudden increment of 49 μm might be equivalent to fracture opening at breakdown. This value almost coincides with Yamashita's conclusion.

About the residual displacement by Dual Single-Packer after pressure relief, the value of about 99 μm was obtained as is shown in Figure 8. This value included plastic deformation of the sealing element when it experienced highest pressure*, i.e.* 23.8 MPa. By straightly extrapolating the result of the calibration experiment shown in Figure 6, this plastic deformation was estimated to be 23 μm. Thus the difference between 99 μm and 23 μm, *i.e.* 76 μm might be the fracture aperture after pressure relief. This estimated value of fracture aperture is about 50% larger than that of fracture aperture at breakdown. The fracture aperture after pressure relief should much less than 49 μm. Therefore, the fracture aperture estimated from Dual Single-Packer over-estimated the real fracture aperture. The reason is not clear at present. One of the possibilities might be that the extrapolation of the data in Figure 6 was not correct. Further experiment or research should be needed at this point.

As for the Dual Single-Packer with metal sealing element in *in-situ* experiment, the relation between observed wall displacement and packer displacement is very clear as is shown in Figure 9. It was possible to estimate a fracture aperture from a packer displacement (Takehara *et al*., 1999). The main difference in laboratory experiment and *in-situ* experiment is that the former packer used rubber seal elements and the latter packer used metal seal elements. From the results shown above, the metal seal Dual Single-Packer has an advantage in estimating fracture aperture.

5. CONCLUSIONS

In this paper, the newly developed Dual Single-Pacers to measure a fracture aperture directly are introduced. These packers were used in *in-situ* experiment and in laboratory. In a laboratory experiment, the packer has a possibility to estimate the fracture aperture directly during breakdown. But the packer over-estimated a fracture aperture after pressure relief. The reason might be the plastic behavior of the rubber seal element. On the other hand, there was a clear tendency between wall displacement and packer displacement at *in-situ* experiment. From the comparison between laboratory and *in-situ* experiment, metal-seal packer has an overall advantage compared to rubber-seal packer in order to estimate the fracture aperture directly. The authors are now developing a laboratory size Dual Single-packer with metal seal element.

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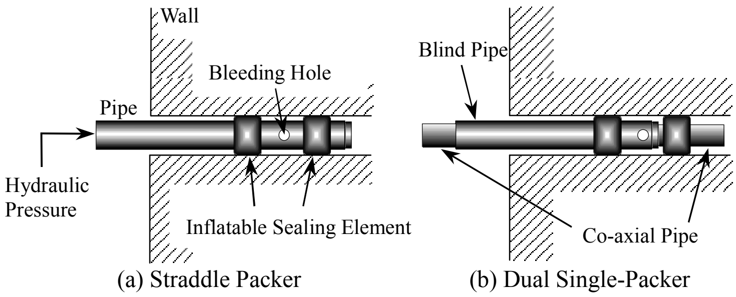

Figure 1. Conceptual diagram of packers.

Table 1 Mechanical Properties of Inada granite.

Property	Value
Uni-axial Compressive Strength	20.0MPa
Tensile Strength	4.03MPa
Young's Modulus	24.3GPa
Poisson's Ratio	0.11

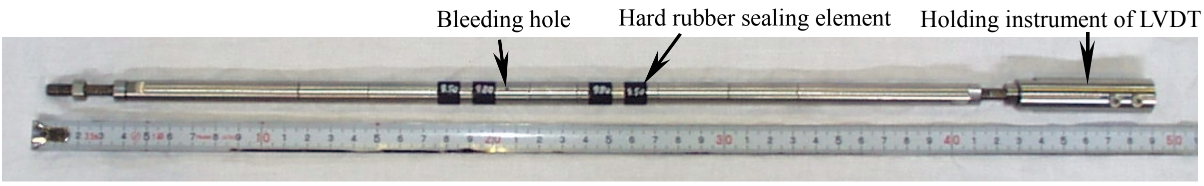

Figure 2. Dual Single-Packer for the laboratory experiment.

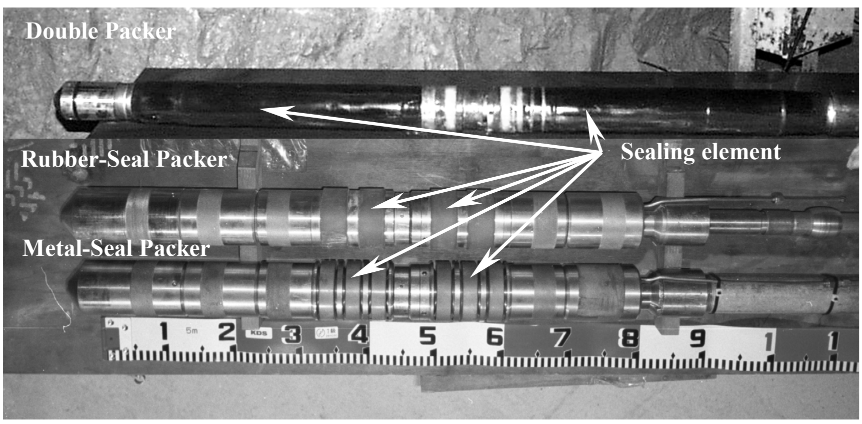

Figure 3. Three kinds of packers used in *in-situ* experiments.

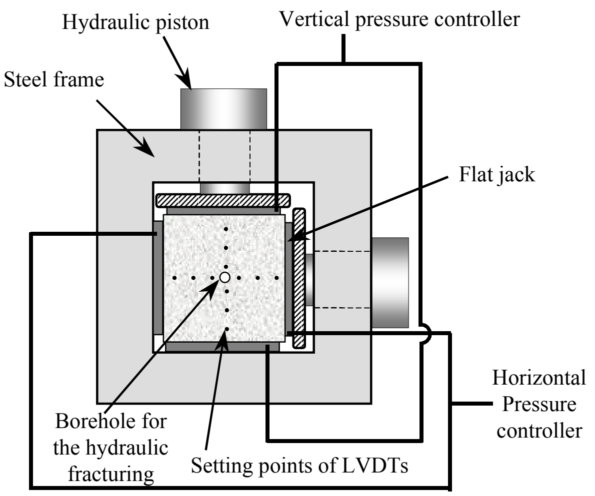

Figure 4. Schematic view of experimental equipment.

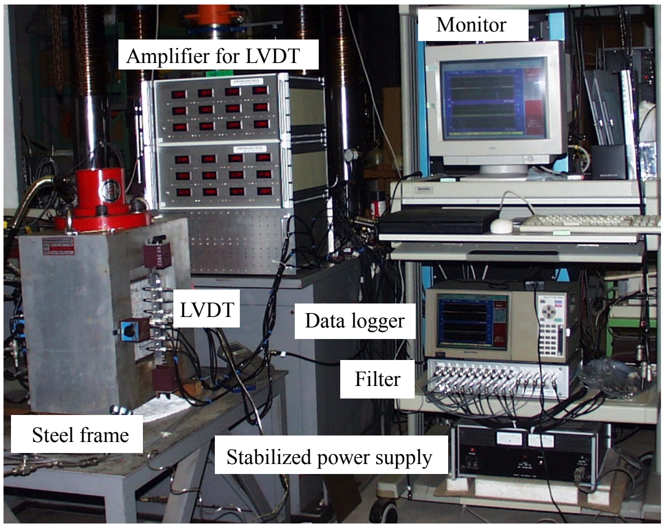

Figure 5. Devices for the Hydraulic fracturing experiment.

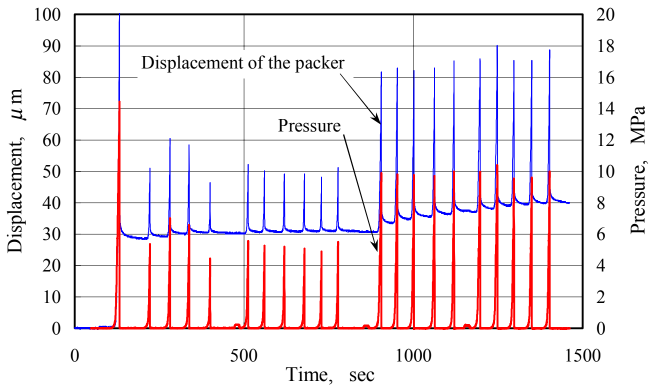

Figure 6. History of pressure and displacement by Rubber-seal packer at the laboratory experiment.

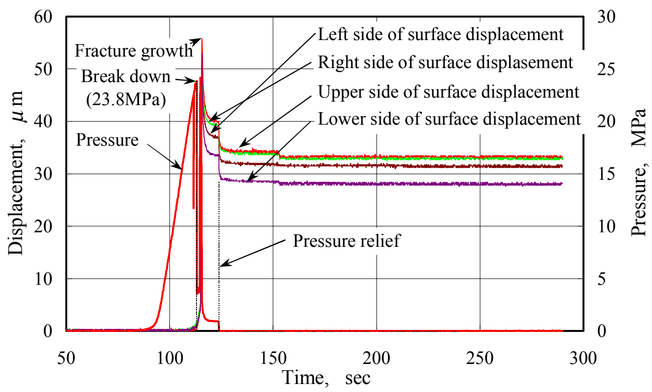

Figure 7. History of pressure and displacements by Rubber-seal packer at the laboratory experiment.

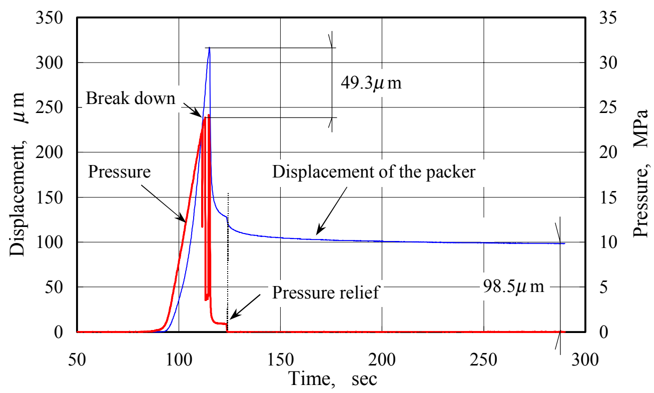

Figure 8. History of pressure and displacement by Rubber-seal packer at the laboratory experiment.

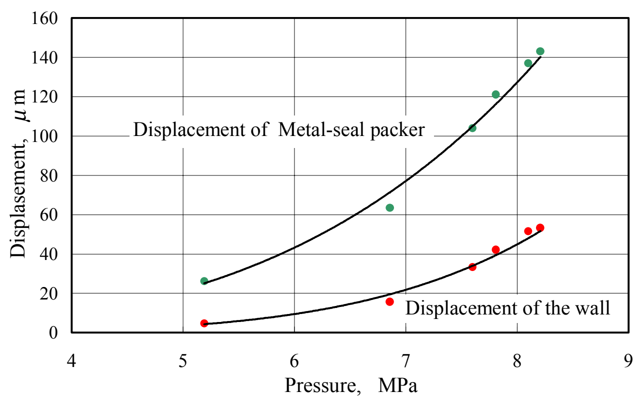

Figure 9. Displacements versus pressure by Metal-seal packer at in-situ experiments. (after Takehara, 1999)