FLUID FLOW MONITORING DUE TO HYDRAULIC FRACTURING BY THE MISE-À-LA-MASSE MEASUREMENTS

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ABSTRACT

Hydraulic fracturing experiments has been conducted for making a man-made circulation system at Akinomiya by CRIEPI since 1987. The mise-à-la-masse surveys using a casing pipe as one current electrode has been carried out for observing fluid flow behaviors during massive hydraulic fracturing operations since 1988 by Kyushu University on the site.

Apparent resistivity values were mapped before and after massive fracturing operations and monitored during pumping operations for estimating fracture extents. The injected fluid flow was continuously detected and monitored in a real time with a personal computer system at the site. The distribution of fractures derived from the detected flow paths show good agreements with the geometry of fractures obtained by televiewer and acoustic emission data.

The present hole-to-surface survey was very useful for mapping fluid flow paths during fracturing operations, while hole-to-hole survey could give informations on fracture depths connected between injection and production wells on the site.

INTRODUCTION

Several geophysical exploration methods have been applied to the problems of detecting and mapping fractures due to hydraulic fracturing operations with practical success. The most widely used ones are seismic surveys such as AE and micro-seismics for locating the events. If there are drillholes in the surveyed area, several geophysical methods such as hole-to-surface and hole-to-hole surveys could be applied.

The mise-à-la-masse measurements (hole-to-surface) using a casing pipe as one current electrode has been developed and applied to geothermal investigations over geothermal field (Ushijima, 1989).

The method has been firstly applied to map and monitor fractures due to hydraulic fracturing experiments by the joint research of CRIEPI and Kyushu University (Kaieda et al., this issue, 1990).

The field survey has been conducted in August-September, 1988 and July-August, 1989 during massive fracturing operations at Akinomiya site of CRIEPI, Akita Prefecture, Japan.

THEORETICAL COMPUTATION

The potential due to a burried point source of current in a infinite medium at a distance r is

$$V = \frac{\rho_1 I}{4\pi}\left[\frac{1}{\sqrt{(z-d)^2+r^2}} + \frac{1}{\sqrt{(z+d)^2+r^2}}\right] \quad (1)$$

The potentila of a line source of current (steel casing pipe) can be derived by a process of integration starting from eq.(1).

$$V = \int_0^{\ell} \frac{\rho I}{4\pi\ell}\left[\frac{1}{\sqrt{(z-d)^2+r^2}} + \frac{1}{\sqrt{(z+d)^2+r^2}}\right] dz \quad (2)$$

If the potential is measured on the ground surface, eq.(2) becomes in a simple form:

$$V = \frac{\rho I}{2\pi}\frac{1}{\ell}\ln\left(\frac{\ell+\sqrt{\ell^2+r^2}}{r}\right) \quad (3)$$

Therefore, the apparent resistivity value for the four electrode array used in the field survey is expressed as

$$\rho_a = K \cdot \frac{V}{I} \quad (4)$$

where K is named as a geometric factor for the mise-à-la-masse (hole-to-surface) surevy and defined by the following equations:

$$K = 2\pi\left(\frac{1}{\ell}\ln\frac{\overline{P_2C_1}\left(\ell+\sqrt{\ell^2+\overline{P_1C_1}^2}\right)}{\overline{P_1C_1}\left(\ell+\sqrt{\ell^2+\overline{P_2C_1}^2}\right)} - \frac{1}{\overline{P_1C_2}} + \frac{1}{\overline{P_2C_2}}\right)^{-1} \quad (5)$$

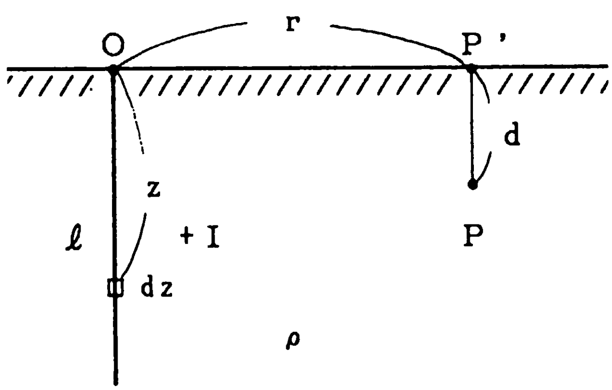

Figure 1. Derivation of theoretical potentials for the line source-to-surface survey.

FIELD SURVEY

Figure 2 shows the electrode array used in the present survey. A current electrode C1 is connected to the wellhead of casing pipe of hydraulic fracturing well (injection well). The well is earthed into the conductive formations (40 ohm-m) to 390 m depth (TD = 400 m). The distant earthing electrode C2 is taken 300 m NW direction from the well. The fixed potential electrode P2 is also set 200 m SE direction from the well. The potental electrode P1 is moved in a grided manner with 10 m separation for mapping surveys. The mapping surveys were repeatedly carried out before and after each pumping operations. However, P1 at 20 stations are fixed with 5 m or 10 m intervals for monitoring surveys during massive fracturing operations. A commutated electric current of 2 A intensity which has a frequency of 0.1 Hz is introduced through a casing pipe and the resulting voltages on the ground surface are observed by the digital recording system with a personal computer.

The voltages at stations are filtered and digitized and stacked 30 times and stored on the floppy disket of PC (NEC 9801 VM). The observed data are processed, then the resistivity changes can be monitored on the CRT during massive fracturing operations with the present computer-controlled system on the site.

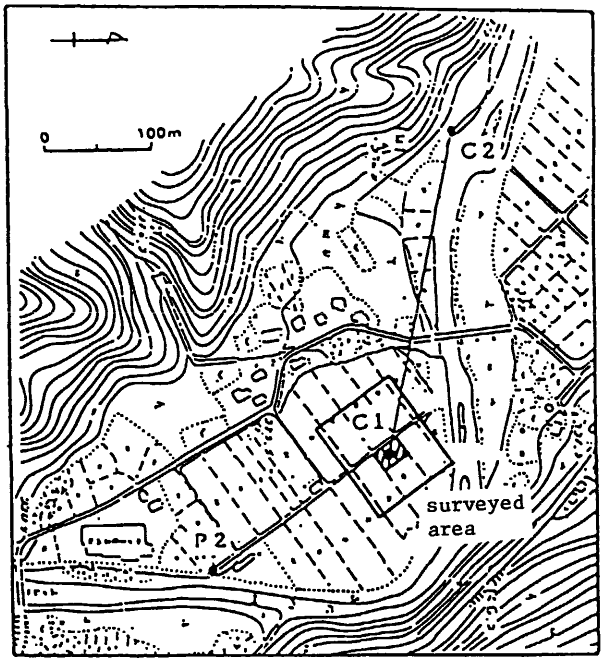

Figure 2. Electrode array for the Hole(Line Source)-to-Surface survey at Akinomiya, Japan.
C1, C2: Current electrode
P1, P2: Potential electrode
(non-polarizing electrode)
P1 electrode is moved at 69 stations for mapping surveys, P1 electrode is fixed at 20 stations for monitoring survey and is connected to the logging tool for crosshole survey.

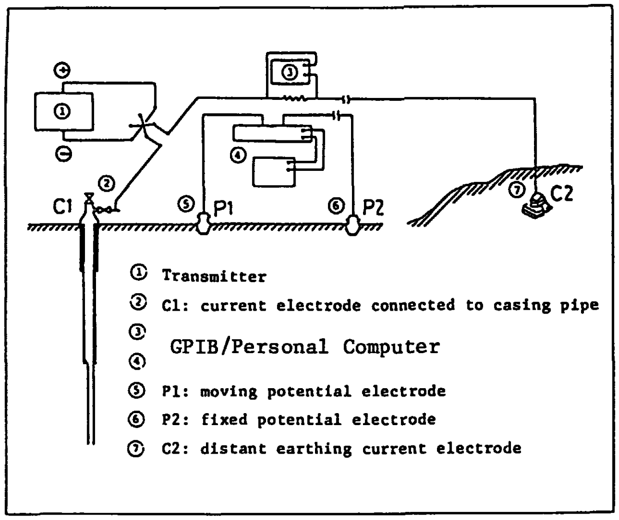

Figure 3. Automatic data acquisition system for the mise-a-la-masse survey.

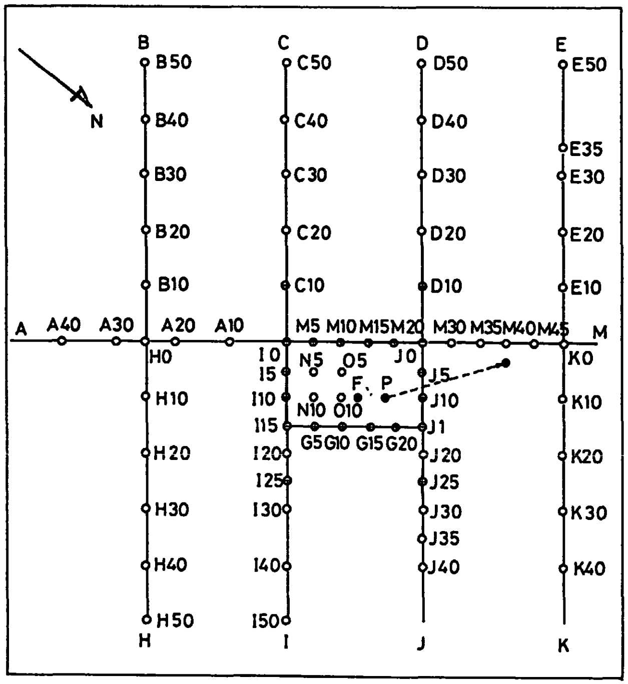

Figure 4. P1 electrode stations used for the mise-a-la-masse measurements.
Solid circles: F=fracturing well, P=production well (directional well)
Open circles: Mapping survey stations (69)
Cross circles: Monitoring survey stations (20).

MAPPING SURVEY

Mapping surveys were repeatedly conducted at 69 stations before and after fracturing operations over the surveyed area (Fig. 4).

Apparent resistivity distributions can be calculated for each mapping survey data.

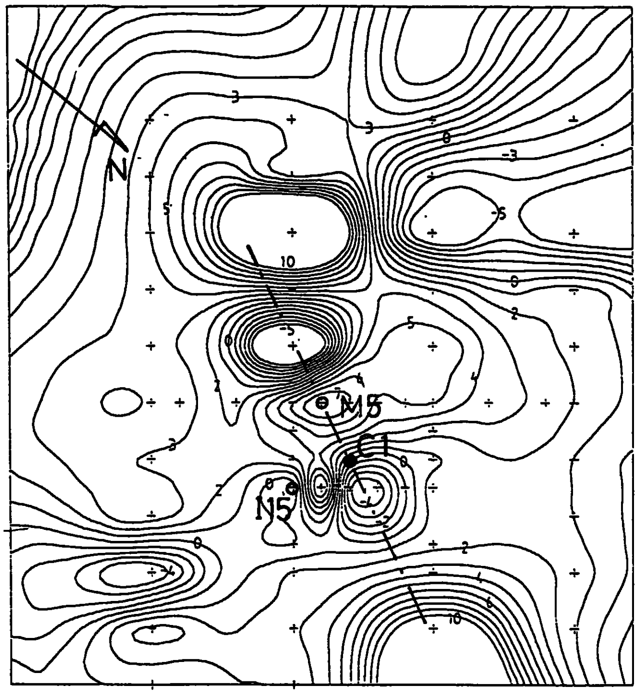

Figure 5. Resistivity changes in percent (%) between before and after massive fracturing operations. (after run / before run)

Apparent resistivity changes can be obtained by comparing with two mapping data as shown in Fig.5.
Average reistivity values in the surveyed area are slightly increased from 42.4 ohm-m before fracturing conducted on July 9, 1989 to 43.3 ohm-m after massive fracturing operations measured on July 22, 1989, because a large amounts of river water (70 ohm-m) were injected during operations.
The distribution of the major fractures can be estimated from Fig.5 as N25°E direction in this area.

MONITORING SURVEY

Electric potentials were continuously measured at 20 stations surrounding the fracturing well as shown in cross circles in Figure 4.
Examples of observed potentials over the period of July 10 to July 25 in 1989 are shown in Figures 6a and 6b. The potentials observed at station I15 (NE direction of the well) shows almost constant values of about 40 mV/A within 3 % variations.
However, the potentials at station M5 (SW direction of the well) show drastic changes during massive fracturing operations. The values change from 40 mV/A to 60 mV/A on July 13, 1989.
The same large changes were observed at stations of M10, M15, M20. Therefore, fluid flows extend to the SW direction from the fracturing well.
Apparent resistivity changes give flow paths with time functions as shown in Figures 7.

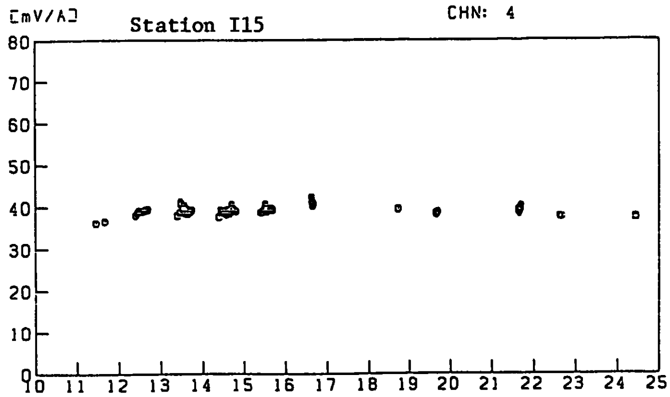

Figure 6a. Observed potentials at station I15 with time (days), July 10 - July 25, 1989.

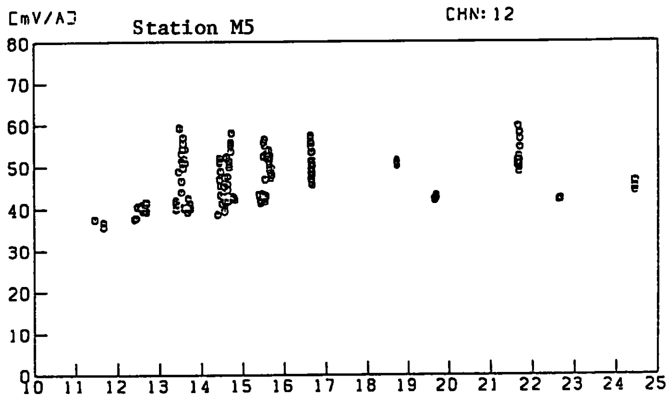

Figure 6b. Observed potentials at station M5 with time (days), July 10 - July 25, 1989.

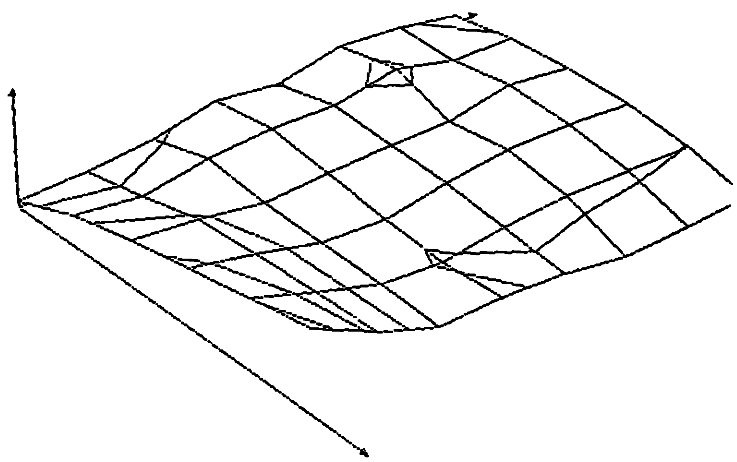

Figure 7a. Resistivity changes before fracturing observed at 9:30 on July 13 (30 min. before hydraulic fracturing).

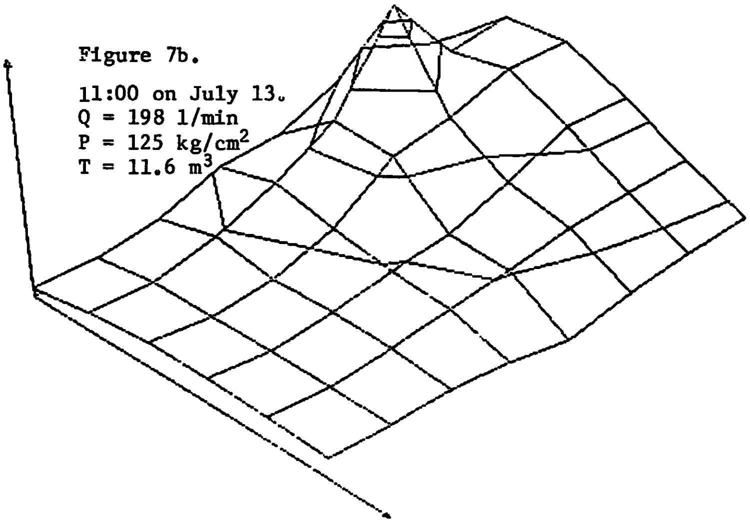

Figure 7b.
11:00 on July 13.
Q = 198 l/min
P = 125 kg/cm^2
T = 11.6 m^3

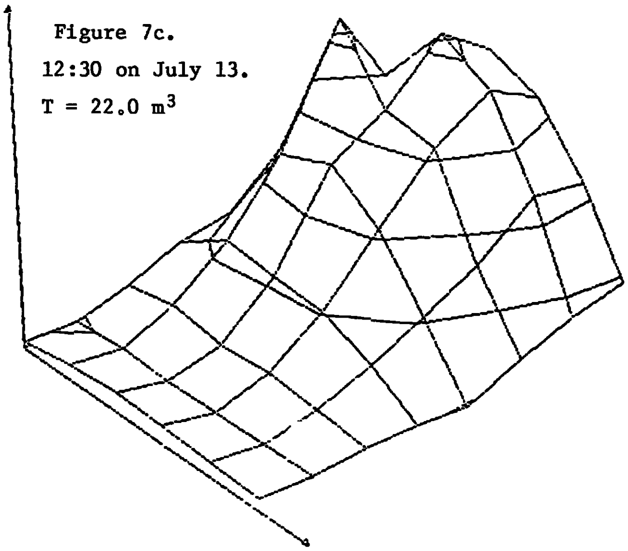

Figure 7c.
12:30 on July 13.
T = 22.0 m^3

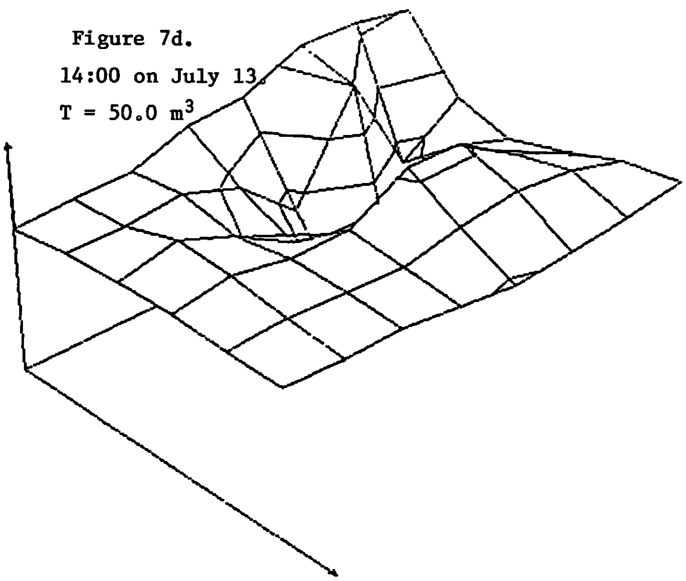

Figure 7d.
14:00 on July 13.
T = 50.0 m^3

CROSSHOLE MISE-À-LA-MASSE SURVEY

The foregoing mise-a-la-masse survey (hole-to-surface) techniques provide distribution of fractures, but less information about the depth of flow paths connected between injection and production holes. Anomalies derived from the previous survey are already checked by the drilling of production well in this site.

Hole-to-hole (crosshole) survey was also conducted during fracturing operations for locating the major flow paths more accurately.

Fracturing well was used as a source hole and production well was used as a receiver hole.

The electrical well logging was conducted in the production well for the mise-à-la-masse array.

Electrical resistivity data obtained by the computer controlled system shows that the major fractures exist at depths between 320 m and 330 m.

Self potential data was also obtained during the data processing of stacking operations with a personal computer. SP log shows more clearly depths of fractures connected between injection and production holes in the surveyed area.

CONCLUSIONS

The mise-à-la-masse measurements using a casing pipe of fracturing well as one current electrode has been carried out for the periods of Aug. 27 to Sept. 12 in 1988 and July 8 to August 25 in 1989.

Mapping surveys were repeatedly conducted before and after each massive hydraulic fracturing operations at 69 stations in the surveyed area.

Monitoring survey was continuously conducted during fracturing operations at 20 stations surrounding the fracturing well with a computer-controled data acquisition system on the site.

(1) Mapping survey indicated the major fracture orientation (N25°E direction) over the surveyed area.
(2) Monitoring survey suggested the major flow paths connected between injection and production wells in a real time by means of a personal computer.
(3) Crosshole survey verified the major flow paths with depths during fracturing operations.

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