대한지하수환경학회 · 한국토양환경학회
공동 심포지엄 및 추계학술대회 논문집
1998년 11월 20일 서울대학교 교수회관

Characterization of Conductive Fractures in Fractured Rocks using Borehole Logging Data

조 민조*, 이 대하*, 이 승구*, 김 형찬*

*한국자원연구소

요 약 서

본 연구에서는 전기전도도, 온도, 유속 검층을 이용하여 시추공내의 유동성 단열구조를 확인하고 각 유동성 단열구조를 통한 시추공간의 수리적 연결관계를 해석하였다.

검층은 자연상태와 인근 시추공으로부터의 양수에 의한 부정류상태에서 각각 실시되었다. 자연상태에서는 지하수 유동이 매우 느려 유동성 단열구조가 쉽게 인지되지 않으나, 부정류 상태에서는 각 시추공간의 수리적 연결성을 보여준다.

각 시추공별 검층에서 나타나는 유동성 단열구조는 모두 일치하지 않으며, 특히 부정류 상태에서의 유속 검층에서는 타 검층에서 인지된 유동성 단열구조중 일부만이 시추공간에 서로 수리적으로 연결되어 있음을 보여준다.

key word : 검층, 유동성 단열구조, 자연상태, 부정류상태

I. Introduction

It is important to characterize conductive fractures in fractured rocks because the fractures serve as major conduits of groundwater flow. However the distribution of conductive fractures is very difficult to characterize in situ just using one of the established techniques. This difficulty may arise from the heterogeneity and anisotropy of three dimensional distribution of conductive fractures in the rock mass.

The study was conducted with three boreholes(B-1, B-2 and B-3) installed at the Samgwang Mine Field Site, which is located in the southwestern part of the Charyeong Mountains within the Chungnam Province.

Three different logging techniques, electrical conductivity logging(Pedler et al., 1990; Tsang et al.), temperature logging(Lewis and Beck, 1977; Drury and Lewis, 1983), and flow logging(Hess, 1966; Molz and Young, 1993; Paillet et al., 1994) were performed to characterize the hydraulically conductive fractures intersecting boreholes among the fractures, which were identified by core, caliper and televiewer logs. The loggings were conducted under both ambient and transient conditions in which one well was pumped at a constant rate of 8.4 ℓ/min or recovered after pumping.

II. Identification of Conductive Fractures

1. Electrical conductivity logging

Where formation water entering into the well through conductive fractures differs in dissolved solids contents, the locations of inflows are indicated on electrical conductivity logs. Peaks on the logs then may indicate the locations of conductive fractures.

The profiles of the boreholes under ambient condition exhibit sharp peaks at the locations of the conductive fractures.

The electrical conductivity logs were also obtained from the boreholes while one of those was pumped to detect the locations of conductive fractures by enhancing the flow field and to infer the degree of connectivity of the fractures between the boreholes. The profiles of the boreholes B-1, B-2 during pumping the boreholes B-3 show no considerable differences as compare with the profiles obtained under ambient condition. But the profiles of the boreholes B-2 and B-3 logged during pumping the borehole B-1 show additional sharp peaks which are not determined under previous procedures. This may be according to increasing flow potential between the boreholes B-2 and B-1, and between the boreholes B-2 and B-1 by pumping.

The measurements for electrical conductivity was also performed in the boreholes B-1 and B-3 during recovery. During recovery of the borehole B-1, groundwater mainly flows into the borehole, some additional conductive fractures are distinguished on the electrical conductivity log while the log obtained during recovery of the borehole B-3 only show already defined conductive fractures.

2. Temperature logging

The geothermal gradient usually varies with numerous local factors including geographical location and lithology. As fractures are intersecting the borehole and groundwater flows through or between the fractures, the temperature profile will be also affected and may show a slight deflection within a zone of the fractures.

The temperature logs of the boreholes under ambient condition exhibit noticeable deflections of the profiles at the locations of conductive fractures.

The temperature logs were also obtained from the boreholes while one of those was pumped to detect locations of conductive fractures by enhancing the flow field. The profiles of the boreholes B-1 and B-2 obtained during pumping the borehole B-3 show no considerable differences as compare with the profiles obtained under ambient condition. The temperature logs under transient condition were also obtained in the boreholes B-2 and B-3 during pumping the borehole B-1. The temperature profile of the borehole B-2 does not show any noticeable difference as compare with the profiles from previous experiments. However, the profile of the borehole B-3 indicates new additonal conductive fractures.

Another temperature measurements were made in the boreholes B-1 and B-3 during recovery after pumping. New additinal conductive fractures are identified during recovery of each borehole B-1.

3. Flow logging

Characterization of vertical distribution of flow in the borehole by flow logging may provide specific depths of conductive fractures where groundwater enter or exit the borehole. When grondwater enters or exits the borehole through the conductive fractures, vertical flow varies in rate or direction.

Measurements in three boreholes under ambient condition reveal almost constant downwards vertical flow over the whole section. Therefore, locations of conducting intervals can not be indicated on the profiles.

The profiles of flow logs in the borehole B-1 during pumping the borehole B-3, in the borehole B-2 during pumping the borehole B-1, and in the borehole B-3 during pumping the borehole B-1 show noticeable changes in rate of vertical flow, which may indicate fractures conducting groundwater flow. The interpreted zones of groundwater flow entering or existing the borehole are closely related to the conductive fractures identified from electrical conductivity and temperature logs of the borehole.

Ⅲ. Characteristics of Conductive Fractures

A number of fractures were identified from core, caliper and teleview loggings. However, only a few fractures are identified to be transmitting groundwater from the electrical conductivity, temperature and flow loggings.

Analysis of groundwater flow in fractured rocks can be done in several scales including a borehole and inter-borehole scales. In general, the relative heterogeneous and anisotropic hydrogeological properties of fractured rocks make the analysis of groundwater flow in inter-borehole scale much more difficult. Conductive fractures of different strikes and dips and from different fracture sets may intersect each other between boreholes in unknown paths. Therefore, two or three dimensional distributions of the conductive fractures can be hardly assessed. Because of such difficulty, groundwater flow in the study was analyzed in a borehole scale and the flow between the boreholes was only inferred.

The conductive fractures intersecting each borehole were identified from the electrical conductivity and temperature loggings of the boreholes. However, flow measurements under ambient condition revealed negligible groundwater flow through the fractures. In the study, therefore, groundwater flow in and across a borehole was analyzed under transient condition.

From the flow measurements in the boreholes B-2 and B-3 during pumping the borehole B-1, several fractures identified as hydraulically conductive from the electrical conductivity and temperature logs showed no evidence of groundwater flow across the boreholes. For example, groundwater enters the borehole through some conductive fractures in the borehole B-2, which can not be considered as hydraulically connected to the borehole B-1, and couples of inflow and outflow of groundwater across the borehole B-3 were identified as connected not before drilling but after completion of drilling.

Ⅳ. Conclusions

Among the logging methods, the electrical conductivity log is found to be the most sensitive to groundwater flow within boreholes, particularly, under transient condition.

From the profiles of temperature logs, it is also possible to identify conductive fractures through which groundwater flows. In this study, two distinctive types of fractures are recognized; the first type is shown as a fracture transmitting groundwater both before and after drilling, while the second type is shown as a fracture transmitting groundwater after drilling but not before.

It is very hard to identify any conductive fractures from the profiles of rate and direction of vertical flow obtained from the flow logging under ambient condition. However, the flow logging under transient condition is more helpful for defining hydraulically connected fractures between boreholes among the conductive fractures identified from previous loggings.

In this study, complete trace of groundwater flow between boreholes could not be made. In spite of several limitations, however, measurements and interpretations of numerous data performed in this study may be helpful for partial understanding of groundwater flow patterns in the study area. And the results from this study may be helpful for design of aquifer tests and tracer test within the specific zones.

References

Drury, M.J. and Lewis, T.J., 1983, Water movement within Lac du Bonnet batholith as revealed by detailed thermal studies of three closely spaced borehole, Tectonophysics, vol. 95, pp. 337-351.

Hess, A.E., 1986, Identifying hydraulically conductive fractures with a slow-velocity borehole flowmeter, Canadian Geotechnical Journal, vol. 23, pp. 69-78.

Lewis, T.J. and Beck, A.E., 1977, Analysis of heat-flow data - detailed observations in many holes in a small area, Tectonophysics, vol. 41, pp. 41-59.

Molz, F.J. and Young, S.S., 1993, Development and application of borehole flowmeters for environmental assessment, The Log Analysts, pp. 1-11.

Paillet F.L., Crowder, R. and Hess, A., 1994, High resolution flowmeter logging- A unique combination of borehole geophysics and hydraulics, in Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP 94), Environmental and Engineering Geophysical Society, pp. 361-404.

Pedler, W.H., Barenvik, M.J., Tsang, C.F. and Hale, F.V., 1990, Determination of bedrock hydraulic conductivity and hydrochemistry using a wellbore fluid logging system, 4th National Water Well Assoc., Outdoor Action Conference, Proceeding, National Ground Water Association, pp.39-51.

Tsang, C.F., Hufschmied, P. and Hale, F.V., 1990, Determination of fracture inflow parameters with a borehole electrical conductivity logging method, Water Resources Research, v. 24, pp. 561-578.