Evaluation of the Groundwater Flow in Rock Masses

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ABSTRACT / The effects of fractures in rock masses on the groundwater flow and the groundwater flow system in the volcanic rocks are analyzed by GFFP—WT model, which allows more realistic analysis of groundwater system by considering the fractures in rock masses.

The evaluation of the effects of fractures in rock masses on the groundwater flow has been carried out in the 2nd Yeonwha and resulted in that the fractures mostly influence flow time because of hydraulic head distribution change. The results of the groundwater flow system analysis in the volcanic rocks are as follows. Most of groundwater once flowed in Lapilli tuff flowed out through Lappilli tuff layer. But only a small fraction of water flowed out through crystal tuff layer.

1. Introduction

The hydrological safety is one of the most important aspects in the construction of a radioactive waste repository. Radioactive waste disposed of in a repository must be isolated from the biosphere for more than several hundred years. The groundwater flow is the major driving force of radionuclide transfer from radioactive waste disposed of in underground rock masses. Therefore, reliable and practical predictions of the factors such as flow paths, flow times, and flow rates of groundwater are essential in the safety analysis of the repository.

In Korea, since the development of groundwater resources and the construction of oil storage facilities has led the the hydrological investigations and studies, the groundwater flow in aquifers has been emphasized rather than the groundwater flow in fractured rock masses. Because of the low hydraulic conductivity in rock masses, fracture properties of rock masses are major factors in the evaluation of the groundwater flow system. Also, the anisotropic and heterogeneous nature of rock masses, which is composed of various rock types, hampers using the existing models which lack the capability of handling fractured meadia. Therefore, in order to assess the hydrological safety of the underground repository, it is essential

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to understand the property of the groundwater flow system and to choose the model which is capable of handling fractures in rock masses.

2. GFFP—WT Groundwater Flow Model

TRAFRAP—WT (Transport in Fractured Porous Media with Water Table Boundary Conditions) [1] is a two—dimensional finite element code designed to simulate groundwater flow and solute transport in fractured rock masses. This code was developed under a joint cooperation between Hydrogeologic Inc. and the International Groundwater Modeling Center of Holcomb Research Institute.

GFFP—WT(Groundwater Flow in Fractured Porous media with Water Table boundary condltions) presented in this paper is a modification of TRAFRAP—WT. This program is able to analyze only groundwater flow. Moreover, its boundary condition dimensions were doubled for the application to the larger flow area, and the program was converted from PC version to the Cyber version which allows a larger memory capacity and faster computation. At present, this model is a two—dimensional code. But if it is modified to a three—dimensional code in future, it can analyze the connectivity of fractures more accurately.

This model uses either the dual—porosity or the discrete—fracture approach. In the dual—porosity approach, the system is assumed to contain numerous fractures and both the domains of fractures and porous rock matrix can be represented as two overlapping continuum[2]. In the discrete—fracture approach, the system is assumed to contain several fractures and each fracture can be represented discretely with a detailed description of the fracture geometry. For example, in the case of a disturbed zone near a repository tunnel, it is appropriate to use the conceptual dual—porosity model for groundwater flow. Alternatively, in the case of a fault adjacent to a repository subsystem, it is more appropriate to use the discrete—fracture modeling approach.

Assuming that one is dealing with a single confined fractured formation, the vertically integrated equation for flow in the fracture domain can be written as

$$\frac{\partial}{\partial X_i}\left[T_{ij}\frac{\partial h}{\partial X_j}\right]=S\frac{\partial h}{\partial t}-\phi-q, \qquad i=1,2$$

Nomenclature

h : hydraulic head in the fracture

Tij : transmissivity tensor

S : storage coefficient of the fractured formation

ϕ : volumetric rate of fluid transfer per unit area, from the porous matrix blocks to the fractures q : volumetric rate of fluid flow per unit area via sources.

3. Analysis of the Effects of Fractures on the Groundwater Flow in the Study Area, the 2nd Yeonwha Mine

In order to analyze the effects of fractures in rock masses on the groundwater flow with the GFFP – WT model, the 2nd Yeonhwa mine located in Samchuck, Kangwondo was selected as a study area. As shown in Fig.1, the area consists of sedimentary rock, granite gneiss, and granite porphyry which penetrated sedimentary rock. This area includes two long fracture zones, each of which has a breadth of 1 or 2 m, developed to the west from the surface to the depth. Several short fracture zones are developed in the vicinity of these two fracture zones.

The hydraulic conductivities of sedimentary rock, granite gneiss, and granite porphyry are assumed to be 5.0 $\times$ 10^{-7} m/sec, 5.0 $\times$ 10^{-8} m/sec, and 10^{-8} m/sec, respeptively, based on existing data [3,4]. The mean porosity of rock masses is assumed to be 5 %. Under a steady–state condition without considering fractures in rock masses, the analyzed results of the groundwater flow system in the flow area using the GFFP – WT model are shown in Fig. 2.

The flow paths and flow times of the water flowed in points A, B, C and D are shown in Table 1. A and B flow paths have shorter flow times than C and D because they pass through the sedimentary rock having higher permeability and the steeper hydraulic gradient of

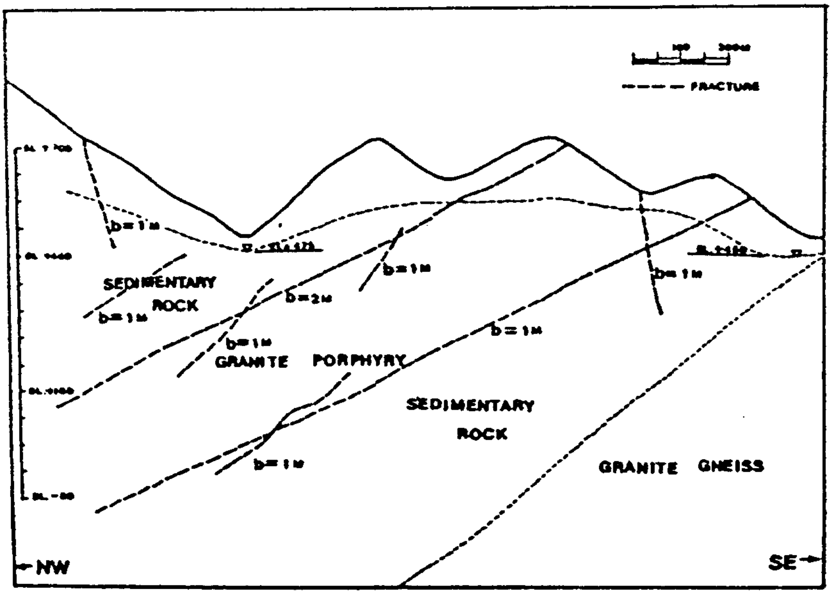

Fig. 1 Cross section for geologic structure fractures at the 2nd Yeonhwa

groundwater than C and D. C and D flow paths have longer flow times, because they pass through the granite gneiss and the granite porphyry zone having the lower permeability and hydraulic gradient of groundwater.

Next, the groundwater flow system in the flow area is analyzed by the same model with consideration of fractures in rock masses. Based on existing data, the hydraulic conductivities of the fracture zones with breadths of 1 and 2 m, are assumed to be 10^{-6} m/sec and 3.0×10^{-4} m/sec, respectively. The mean porosity of the fracture zones is assumed to be 30 %. The analyzed results of hydraulic head distribution and the flow path using the GFFP−WT model are shown in Fig. 3.

The results, when fractures are considered, are as follows: the flow time in the NW side of the flow area becomes longer since the hydraulic head distribution values generally become smaller, while the flow time in the SE side of the flow area becomes shorter since the hydraulic head distribution values generally become larger. The flow paths and the flow times of groundwater flowed in points A, B, C and D are shown in Table 2.

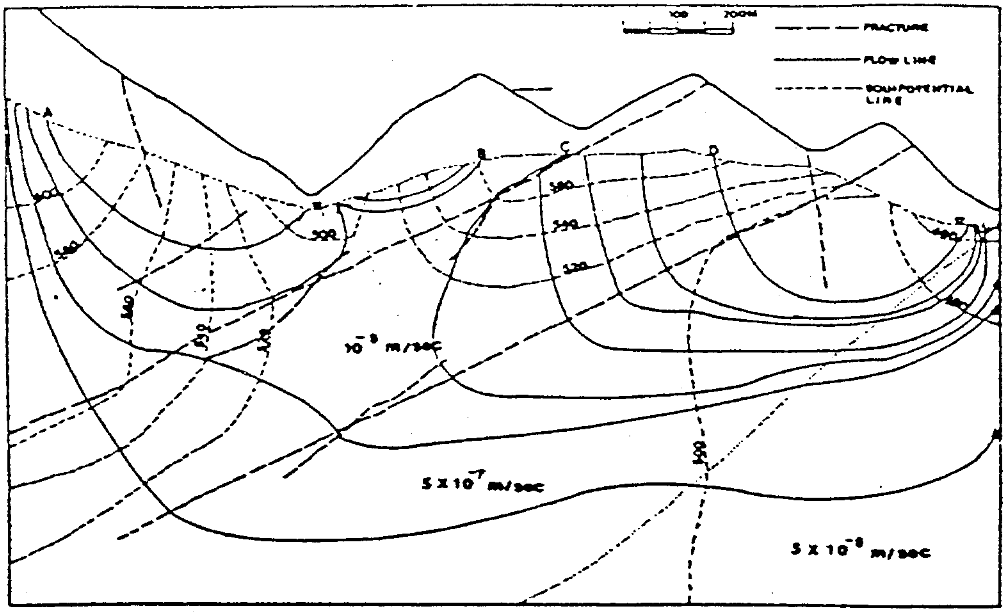

Fig. 2 Hydraulic head distribution and flow path (without consideration of fractures)

Table 1 Flow length and flow time
(without consideration of fractures)

path	length	flow time
A	620 m	7 year
B	298 m	4 year
C	1250 m	530 year
D	668 m	120 year

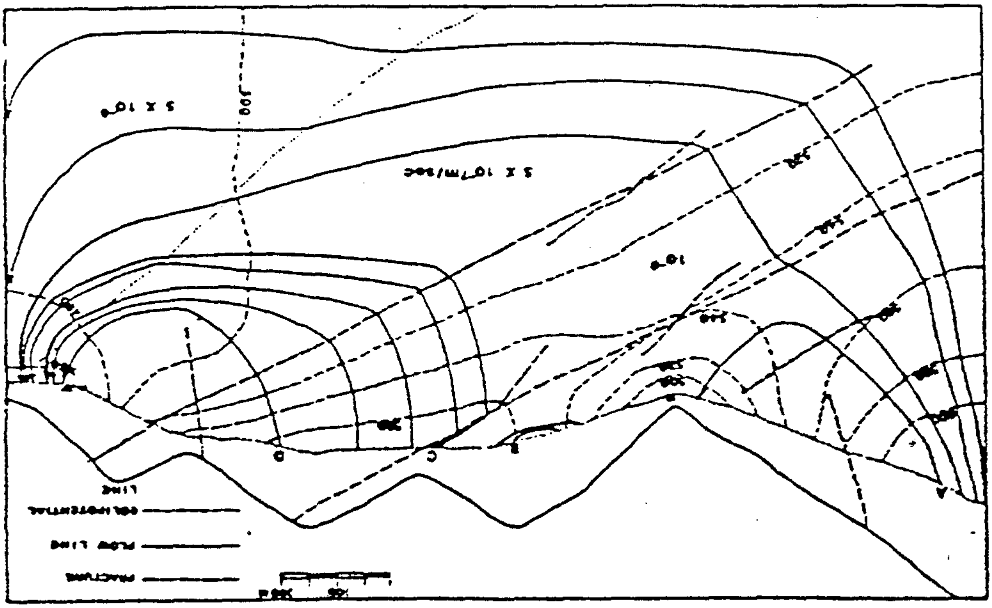

Fig. 3 Hydraulic head distribution and flow paths (with consideration of fractures)

Table 2 Flow length and flow time (with consideration of fractures)

path	length	flow time
A	685 m	10 year
B	98 m	2 year
C	1178 m	430 year
D	617 m	85 year

When Table 2(with consideration on fractures) is compared with Table 1 (without consideration of fractures), the flow time of flow path A becomes longer by about 3 years, while the flow times of flow paths C and D become shorter by about 100 years and 35 years, respectively. Therefore, it is found out that fractures considerably influence the flow path and the flow time of groundwater.

4. The Flow System Analysis in the Volcanic Rock Area

For a flow system analysis, a volcanic rock area (latitude 36° 14′~36° 17′, longitude 129° 20′~129° 25′) was chosen. Based on preexisting geological map and field survey data, geological structure and fracture system are drawn up.

4.1 geology and permeability of rock masses

The study area is composed mainly of volcanic rocks, and the Tertiary Chonbuk conglomerate, and the Quaternary alluvial overlie the volcanic rocks unconformably (Fig.4). The cross section along the A−B line consists of crystal tuff, mudstone, rhyolitic tuff, Lapilli tuff, and tuffaceous sandstone.

Fracture system was investigated as follows: the fracture zone with a breadth of about 10 cm developed slantingly to the east within crystal tuff zone, and the fracture zone with a breadth of 30 cm developed slantingly to the west within Lapilli tuff zone.

Based on previous documentation, surface condition, permeability, the hydraulic conductivities of each rock type, and fracture were decided. Assumed hydraulic conductivities for crystalline rock, Chonbuk conglomerate, mudstone, rhyolitic tuff, Lapilli tuff, and tuffaceous sandstone are 2×10^{-9} m/sec, 3×10^{-6} m/tec, 3×10^{-9} m/sec, 3×10^{-9} m/sec, 2×10^{-7} m/sec, and 5×10^{-6} m/sec, respectively. The mean porosity of rock masses is assumed to be 5 %. The hydraulic conductivities of the fracture with a breadth of 10 cm and 30 cm are assumed to be 2×10^{-7} m/sec and 10^{-6} m/sec respectively. The mean porosity of the fracture zones is assumed to be 30 % (Fig. 5).

4.2 Groundwater flow system analysis

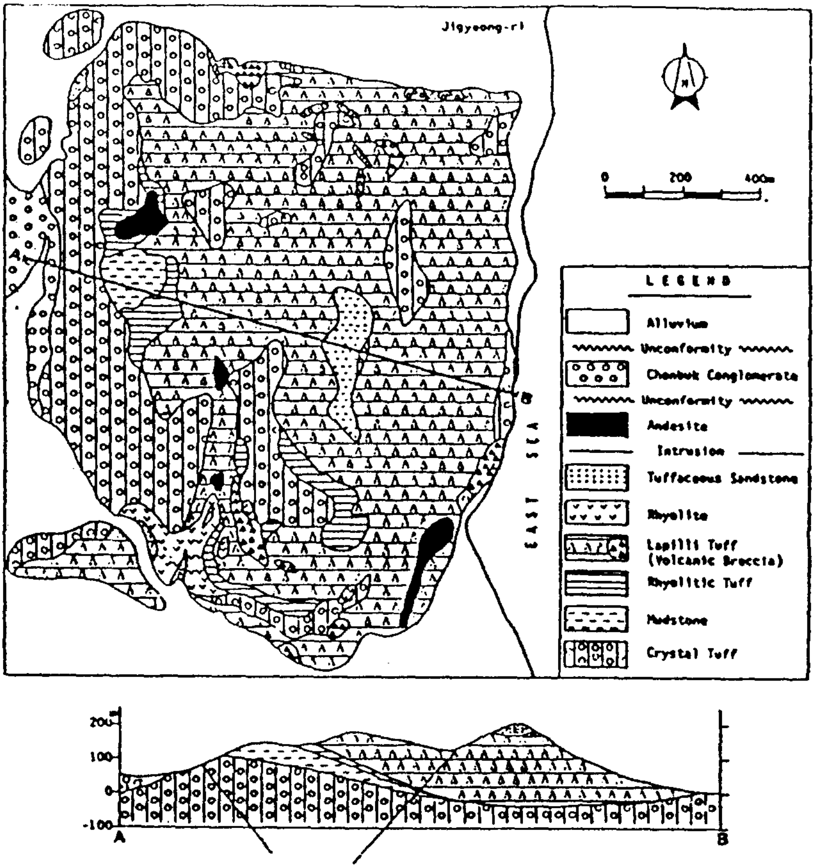

Fig. 4 Geologic map of the study area

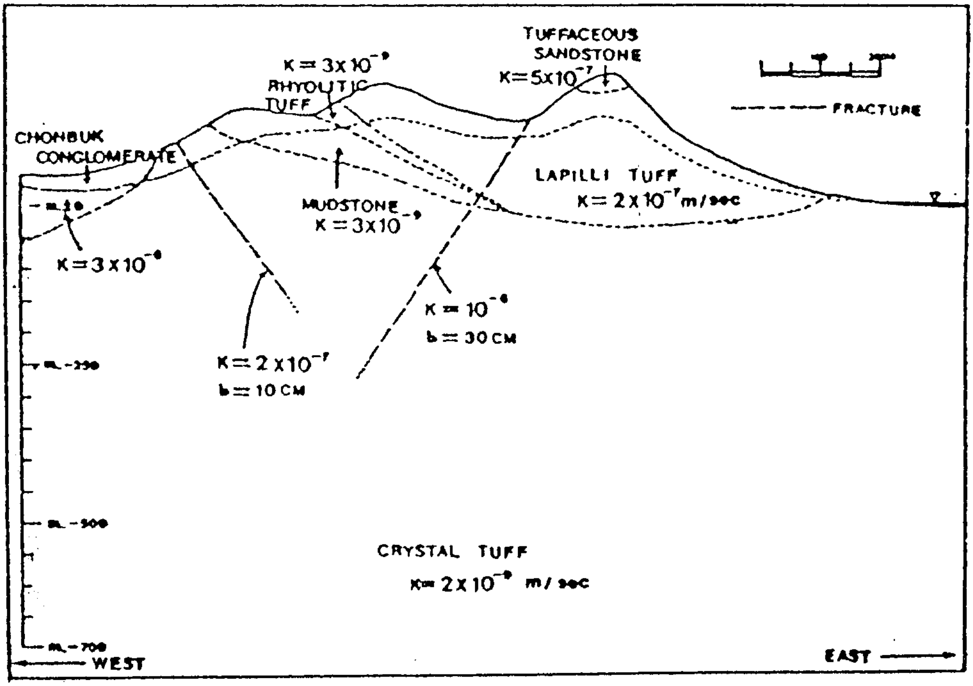

Fig. 5 Water table and the hydraulic conductivity of each rock type

The results of the groundwater flow system analysis under the steady−state condition are shown in Fig. 6. The flow lengths and flow times of the water flowed in arbitrary points A, B, and C are shown in Table 3.

The flow length of the flow path A is longer only by 6.8 and 2.7 times compared with those of the flow paths B and C. Meanwhile, flow time is longer by 937 and 800 times, because the hydraulic conductivity of Lapilli tuff zone is 100 times higher than that of crystal tuff, and the hydraulic gradient is steeper in Lapilli tuff zone than in crystal tuff zone. While the flow length of flow path C is longer by 2.5 times than that of flow path B, the flow time of flow path C is longer only by 1.2 times. The reason is that the hydraulic gradient around the mountain peak in the right side of figure, where flow path C passes through, is steeper than that around the mountain valley where flow path B passes through.

Therefore, it is concluded that Lapilli tuff layer is unsafe, while crystal tuff layer is safe from hydrological perspective.

5. Conclusions

From the application of the GFFP−WT model which is capable of considering fractures in rock masses, the following conclusions are obtained:

(1) The results to analyze the effects of fractures on the groundwater flow

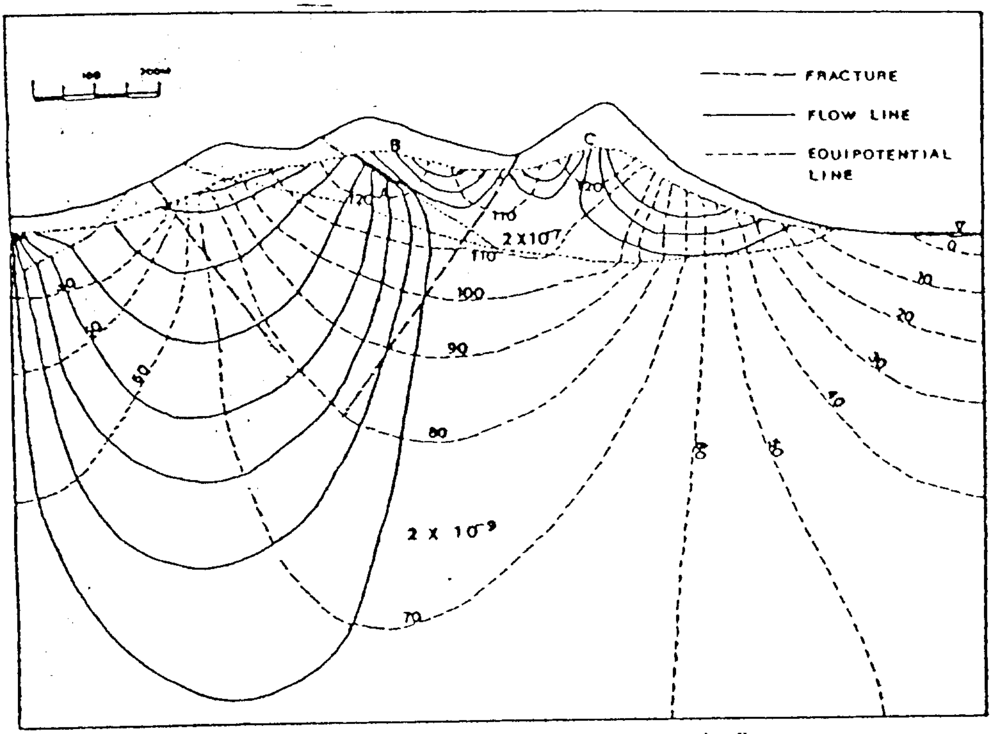

Fig. 6 Hydraulic head distribution and flow path in the flow area

Table 3. Flow length and flow time in the flow area

path	length	flow time
A	1263 m	13600 year
B	185 m	15 year
C	468 m	17 year

in the 2nd Yeonhwa mine:

– The flow time in the NW side of the flow area becomes longer because of generally decreasing hydraulic head values by the effects of fractures.

– On the other hand, the flow time in the SE side of the flow area becomes shorter because of generally increasing hydraulic head values.

(2) The results to analyze the groundwater flow system in volcanic rock area:

– Lapilli tuff layer is evaluated as unsafe area, while crystal tuff layer is evaluated as safe area from hydrologic perspective.

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