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

지하 LPG저장공동 주변의 지하수위 강하 원인규명을 위한 파라미터추정

Parameter estimation for identification on cause of drawdown around underground LPG storage cavern

Il Yeong Han*, Dae Hyuck Lee*, Jung Eun Lee* and Kwang Pil Jung**

**R & D Center, SK Engineering and Construction Co., Ltd.*
***Engineering & Maintenance Sec., SK Gas Co., Ltd.*

ABSTRACT

In order to identify the cause of ground water drawdown of a piezometer installed around the LPG storage cavern, parameter estimations were conducted by inverse and forward numerical models. An inverse model, SK-EST developed by SK Engineering & Construction Co., Ltd.(SKEC,1997) was performed to estimate the change of the hydraulic conductivity. It was verified by the commercial forward model, AQUA3D (VATNASKIL,1995). The simulation results showed that the hydraulic diffusivity of the rock mass between the piezometer and the cavern had been increased and the change rate of the hydraulic head had been abruptly increased in response to the change of the operation pressure. Finally the statistical analysis for observed data showed the increase of the change rate of the hydraulic head and thus proved the applicability of SK-EST.

Key word : LPG storage cavern, hydraulic head and drawdown

Ⅰ. INTRODUCTION

For ten years, LPG has been successfully stored in unlined rock cavern at Ulsan LPG terminal operated by SK Gas Co., Ltd. A successful operation of the underground oil storage cavern comes from securing the gas tightness inside cavern. MSGS (Monitoring System for Gas Storage) which was developed by SK Engineering & Construction Co., Ltd. and consists of four modules such as *Information, Estimation, Prediction, and Design for water curtain remediation.*, has been used for diagnosis of gas tightness inside cavern and efficient management of monitoring data.

It happened that the hydraulic head of one of the piezometers fell from -5 m to -30 m for three months since December 1997 and the tightness around cavern remains dubious. The hydraulic head of the piezometer was classified into three stages as following. 1) the constant head stage(stage I), 2) the falling head stage(stage II), and 3) the recovering head stage(stage III) as shown in Fig.1. MSGS was applied in order to identify the cause of the drawdown for three months and to estimate the change of hydraulic properties around the cavern by operation pressure.

II. METHODOLOGY

An inverse model, SK-EST (Kang and Han, 1997; SKEC, 1997), which is a submodule of *Estimation* in the MSGS, could estimate the hydraulic conductivities from observed hydraulic head at steady-state. The model was based on the matrix equation describing the hydraulic head distribution over a given region (Frind and Pinder, 1973; Neuman, 1973). The flow equation for this problem is

$$\frac{\partial}{\partial x}\left(K\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial h}{\partial y}\right) = 0$$

The above equation for K is solved bt Galerkin finite element approach. The matrix equation is expressed by

$$\left(\begin{bmatrix} A_{uu} & A_{uv} \\ A_{vu} & A_{vv} \end{bmatrix}+\begin{bmatrix} B_{uu} & B_{uv} \\ B_{vu} & B_{vv} \end{bmatrix}\right)\begin{pmatrix} K_u \\ K_v \end{pmatrix}=\begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

where $[A_{ii}]$ and $[B_{ii}]$ are global coefficient matrix, K_u is the matrix including unknown hydraulic conductivities, and K_v is the conductivity matrix defined by boundary conditions. In addition, the forward model, AQUA3D (VATNASKIL, 1995), was applied to the estimation of change of hydraulic properties such as hydraulic diffusivity at transient state and to the verification of the numerical results of SK-EST.

III. SIMULATION RESULTS

1. Estimation of hydraulic conductivity

The average of observed heads of the piezometer was used as input data for the estimation of change of the hydraulic conductivity, K by SK-EST. The head of W/C hole was fixed as 0.0 m because it maintains at mean sea level. The averag head of the piezometer were -5.79 m (stage I), -16.11 m (stage II), and -29.64 m (stage III) while those of the cavern were -57.1 m (stage I), -65.9 m (stage II), and -62.1 m (stage III) respectively. It is shown in Fig. 2 that K is increased as $K_I < K_{II}$ (=2.8 K_I) $< K_{III}$ (=9.9 K_I) as stage proceeds to stage III. The simulation results showed that the computed hydraulic conductivity for each stage laid in the range of the values obtained from drilling test.

2. Estimation of hydraulic diffusivity

The hydraulic diffusivity, D, which is the ratio of hydraulic conductivity and specific storage, was estimated by AQUA3D in respective stage. In stage I, the observed heads were in the range of -5.09 m ~ -6.55 m. It is at the condition of D=1.13e-5 m^2/sec that the computed head fits well with the observed as shown in Fig. 3. In stage II where the head of the piezometer fell from -6.89 m to -31.39 m, D=3.3e-5 m^2/sec as shown in Fig. 3. In stage III where the observed heads were in the range of -26.15 m ~ -31.00 m, the estimated diffusivity is 3.0e-2 m^2/sec as shown in Fig. 3. The results show that the hydraulic diffusivity of rock mass has been increased for long term operation. It means that the response of ground water in the piezometer to the stress induced by operation pressure has become better, and the change rate of the hydraulic head has been increased. Also, it agrees well with the results estimated by SK-EST.

Ⅳ. CORRELATION BETWEEN MONITORED DATA

It is shown that correlation coefficient among operation pressure, water and head was increased as stage proceeded to stage III(Fig. 4). It could be understood that the increase of seepage rate was accompanied with the severe drawdown of the hydraulic head of the piezometer. The seepage rate was inversely proportioned with operation pressure. It was clearly shown that the seepage of the cavern was increased in response to the low operation pressure.

CONCLUSIONS

An inverse model, SK-EST was applied to the estimation of change of hydraulic parameters of the rock mass around the cavern. It agreed well with the results performed by the commercial forward model. It could be said that the head of a piezomter had fallen due to consistent low operation pressure for about four months while the efficiency of water curtain was poor, which led to low recharge of ground water from the water curtain to the piezometer. Therefore, it could be said that MSGS was a proper tool for the diagnosis of the gas tightness inside cavern and efficent management of the monitoring data.

REFERENCE

Kang, T. S. and Han, I. Y., 1997, A numerical model of inverse analysis for estimating the clogging in the underground LPG storage cavern, *Journal of the Korean Society of Groundwater Environment*, 4(3), 161-167.

Frind, E. O. and Pinder, G. F., 1973, Galerkin solutions of the inverse problem for aquifer transmissivity, *Water Resources Research*, 9(5), 1397-1410.

VATNASKIL Consulting Engineers, 1995, AQUA3D : Groundwater flow and contaminant transport model.

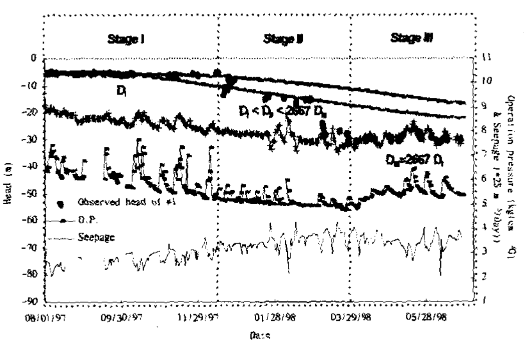

Fig. 1. Classification of monitoring stages according to hydraulic head of a piezometer

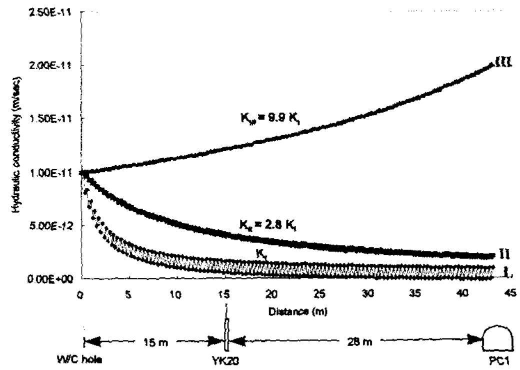

Fig. 2. The hydraulic conductivities estim by SK-EST for each stage

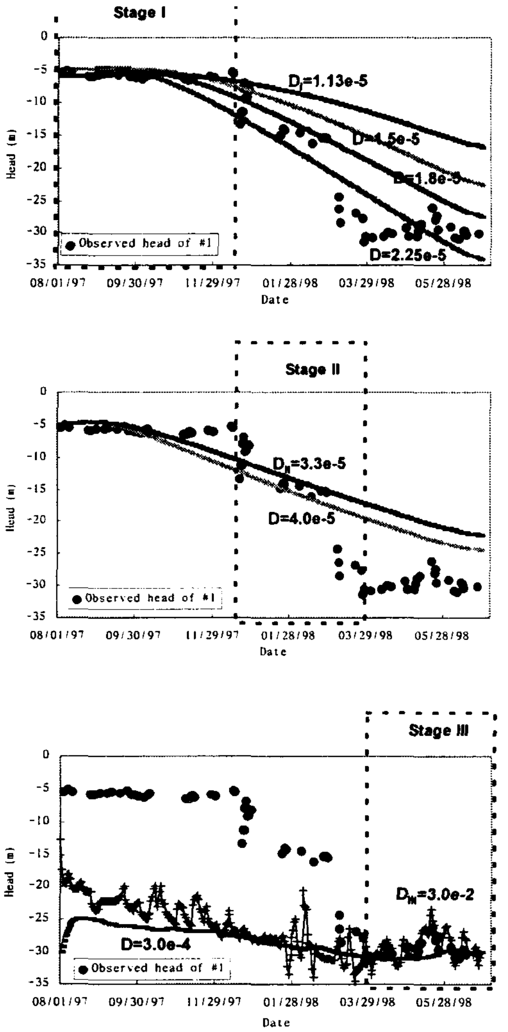

Fig. 3. Estimation of the hydraulic diffusivity for each stage

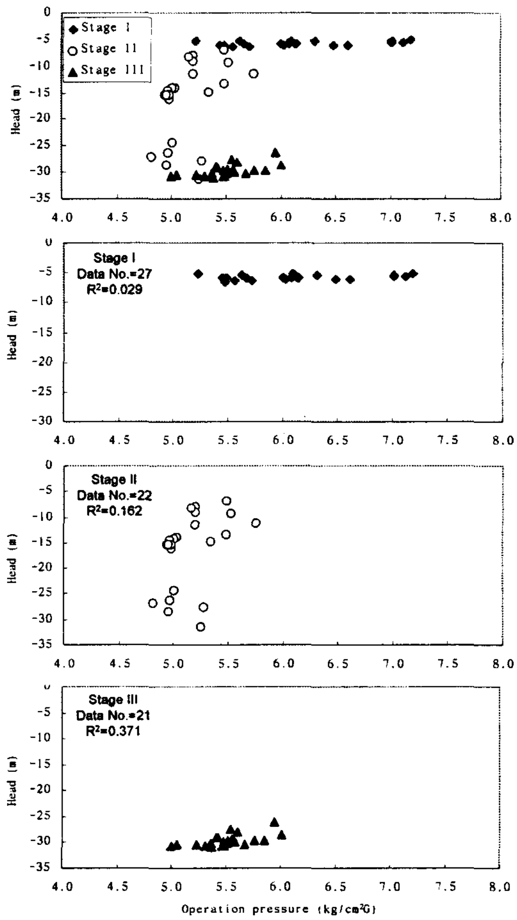

Fig. 4. Correlation between head of a piezometer and operation pressure