3-8 Parameter estimation for numerical analysis of groundwater seepage and mass transport in final disposal site

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ABSTRACT

It is important to estimate the behavior of the groundwater seepage for evaluating of performance in the waste final disposal site. And, that the quantity of the leachate with the rainfall infiltration is reduced greatly contributes to the reduction in the control cost after the land fill completion. Then, this study focused the dielectric method which measured amount of water content, and the examination of the applicability on groundwater around the disposal site and infiltration in the disposal site, the technique which measures the migration phenomenon of the leachate was made to be a purpose. As an effect expected here, it is mentioned that that the evaluation technique based on measured data is established as an Asia region peculiar application technology becomes possible.

Concretely, in this year, the examination on dispersion length necessary for advection numerical analysis as a base of effective porosity and dispersion coefficient was carried out.

KEYWORDS

dielectric constant, groundwater seepage, mass transport, saturated/unsaturated zone

INTRODUCTION

Numerical analysis of the saturated-unsaturated seepage for evaluating the rainfall infiltrating behavior and of the advection-dispersion for evaluates the behavior of mass migration is mainly used, when migration phenomenon of the leachate in waste final disposal site is handled. It becomes a premise in carrying out the evaluation in which to accurately input the physical parameter of the ground shown in addition to initial condition and boundary condition of the model in **Table 1** is appropriate. However, there is still a technique which measures this physical parameter in situ especially in comparison with the improvement in the analytic technology in the establishment stage. Especially, the establishment of the quick and convenient test method is required, because there is a restriction of testing condition and test equipment in situ situation. In this study, the applicability of laboratory and in-situ test examined unsaturated hydraulic conductivity and soil water characteristic curve is focused. The aim of first year was to suggest of the convenient technique using dielectric constant for measuring this physical parameter is used by seepage analysis.

Table 1 Parameters for numerical analysis of groundwater seepage and mass transport

Seepage	Transport (Migration)
Hydraulic conductivity (Anisotropy),ksat	Effective porosity (real velocity)
Hydraulic Conductivity / Degree of saturation relationship, k	Dispersion coefficient
Suction / Degree of saturation relationship, SWCC	Molecular diffusion coefficient
Specific yield / porosity	Tortuosity factor
Specific storage	Decay constant
	Distribution coefficient/Retardation factor

In this second year, the examination on dispersion length necessary for advection numerical analysis was carried out as follows;

1) Determination of effective porosity of porous media by using FDR

The in-situ test method was suggested: the dielectric constant sensor insert in the ground, measuring the change of the dielectric constant when the liquid differs from water dielectric constant is injected around the sensor.

2) Determination of dispersion coefficient (Sensor method)

FDR method is the dielectric constant sensor of the original development and dielectric constant prototype sensor obtained from market, the applicability using the tracer test with the measuring method of the transfer behavior of the leachate was examined.

MATERIALS AND METHODS

1. Determination of effective porosity of porous media by using FDR

Since there is no in situ measuring method for the effective porosity which is the parameter related to the mass transport, the in-situ test method was suggested that the dielectric constant sensor insert in the ground, measuring the change of the dielectric constant when the liquid differs from water dielectric constant is injected around the sensor. In this time, the ethanol solution was injected for sand which adjusted the porosity for the saturated condition as the basic research in the laboratory, and the effective porosity was calculated. In addition, for the result validity, the tracer test was separately carried out. The schematic diagram for measuring physical parameters by dielectric method with the object in this study is shown in **Fig.1**. FDR of dielectric constant measurement method was originally developed in this laboratory was used. The electrode which is connected in measuring instrument and coaxial cable is inserted in the ground through the pipe. The filling pipe has been installed in the equal pipe, and the effective porosity of the ground is calculated from the amount of change by the injection of the liquid in which differs from water dielectric constant. Still, the mean value of inserted part is measured, because the FDR method measures the local value over whole area of the electrode, the FDR-V method is a measurement only of the tip of the electrode.

In order to verify the validity of the results in the injection test, one dimensional tracer test shown in **Fig.2** was carried out. The tracer was injected into pulse (**Fig.3**) using ethanol solution which made the density to equal the water.

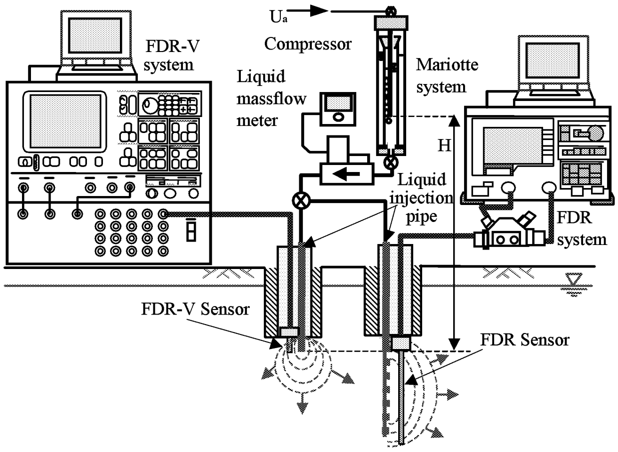


Fig.1 Schematic diagram for measuring physical parameters by dielectric method

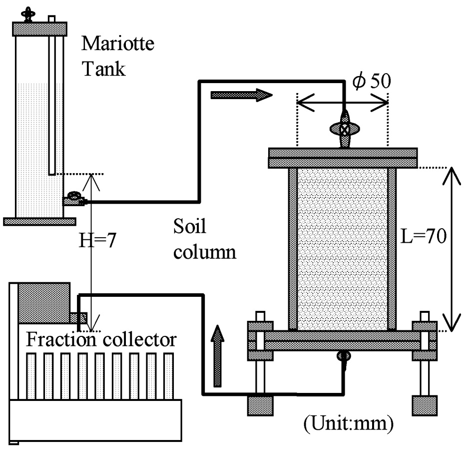


Fig.2 Schematic diagram of tracer test

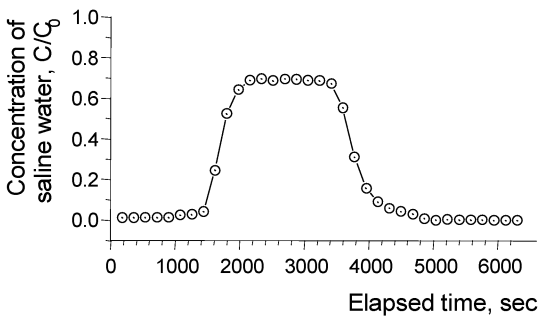


Fig.3 Breakthrough curve

2. Determination of dispersion coefficient (Sensor method)

The three-dimensional fundamental equation of advection-dispersion analysis is shown in following equation.

$$R\frac{\partial C}{\partial t}=\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial C}{\partial z}\right)-v_x\frac{\partial C}{\partial x}-v_y\frac{\partial C}{\partial y}-v_z\frac{\partial C}{\partial z} \quad \cdots\cdots\cdots\cdots \quad (1)$$

where D is dispersion tensor, v is flow velocity tensor, C is concentration, R is the delayed coefficient (in the cohesive soil, this term is big in the term which adsorbs to soil particle surface and inside of the solution, and it is shown as a cleaning ability of the soil). It is necessary to require dispersion coefficient D_x, D_y, D_z ($L^{2/}T$) in order to quantitatively handle **Eq.(1)**. To determine the dispersion coefficient to be dispersion tensor (D_{ij}) by Scheidegger(1961) and Bear(1961), the following equation is proposed.

$$D_{ij} = \alpha_T |v| \delta_{ij} + (\alpha_L - \alpha_T) \frac{v_i v_j}{|v|} + D_m \tau \delta_{ij} \quad \cdots\cdots (2)$$

at the one dimensional, $D = \alpha_L v + D_m \tau$ ······ (3)

where $\alpha_L$is longitudinal dispersion length (L), α_T is width dispersion length (L), v_i is pore flow velocity (L/T), |v| is mean value of the pore flow velocity (L/T), D_m is molecular diffusion coefficient (L^2/T), τ is tortuosity factor, δ_{ij} : is a Kronecker delta (δ_{ij}=0 in i=j, δ_{ij}=1 in i≠j). Determination method of the dispersion length, there are generally two methods by the one-dimensional column test, one is to measure the concentration-change of the tracer in the column middle point and method for measuring in the meantime, and the other is to measure concentration-change of the effluent in the downstream edge. The applicability for the method that in this study, it measured the concentration-change of the tracer in column middle point by the dielectric constant sensor, and that it obtains the dispersion coefficient from the aging variation should be examined.

In making above-mentioned **Eq.(1)** to be one-dimensional governing equation, it is shown in **Eq.(4)**.

$$R\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial C}{\partial z} \right) - v\frac{\partial C}{\partial z} \quad \cdots\cdots (4)$$

where R is a term on the adsorption, dispersion coefficient D becomes main parameter by making to be R=1 in the safe side evaluation generally. The case in which there is no flow becomes diffusion coefficient for this dispersion coefficient. Therefore, it grows by the flow velocity in order to show this value in the relationship between following equation, and in order to show in **Fig.4**.

$$D = \alpha v + D_0 = \alpha v + D_m \tau \quad \cdots\cdots (5)$$

where α is dispersion length (in homogeneous sand (D_{10}=0.1mm), this value is small in unit of length, and it is about 0.01cm), v is the flow velocity (it is called the real velocity, and it will be defined at the value from velocity v_d required by the Darcy's law and the effective porosity n_e as follows).

$$v = \frac{v_d}{n_e} \quad \cdots\cdots (6)$$

When the solution of concentration (C_0) is made to inject at t=0 in top of column, the place (C=0) which permeates in fixed flow velocity (v) in the tracer test by one-dimensional column shown in **Fig.5**, concentration (C(z, t)) in point of z in having time t is made to be R=1 in **Eq.(4)**, and it determines following initial condition and boundary condition.

Initial condition: $C(z,0) = 0$ ······ (7)

Boundary condition : $\left.\begin{matrix} C(0,t) = C_0 \\ C(\infty,t) = 0 \end{matrix}\right\}$ ······ (8)

The solution of the equation of **Eq.(4)** consists for the following equation of the condition of the superscription.

$$\frac{C}{C_0} = \frac{1}{2}\operatorname{erfc}(\lambda) \qquad (9)$$

where, $$\lambda = \frac{z - vt}{2\sqrt{Dt}} \qquad (10)$$

erfc(λ) is complementary error function shown by the following equation, and as a relation of **Fig.6**.

$$\operatorname{erfc}(\lambda) = 1 - \frac{2}{\pi}\int_0^{\lambda} \exp\left(-y^2\right)dy \qquad (11)$$

By advection dispersion experiment of the one dimension of **Fig.5**, change of concentration C(z, t) at z=z_1 is measured, and the value of (z_1, t_1) is determined from the result, and the dispersion coefficient is obtained from following equation, when the value of λ_1 from **Fig.6** is obtained.

$$D = \frac{1}{4}\frac{(z_1 - vt_1)^2}{(\lambda_1)^2 t_1} \qquad (12)$$

The relationship between dispersion coefficient and flow velocity (v) is required as **Fig.5** by the measurement in the technique equal to this method of the value of the dispersion coefficient at various flow velocity, and the gradient (α) is called longitudinal dispersion length (α_L) at dispersion length of the infiltration direction.

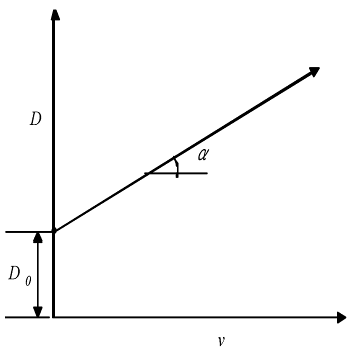


Fig.4 Dispersion coefficient

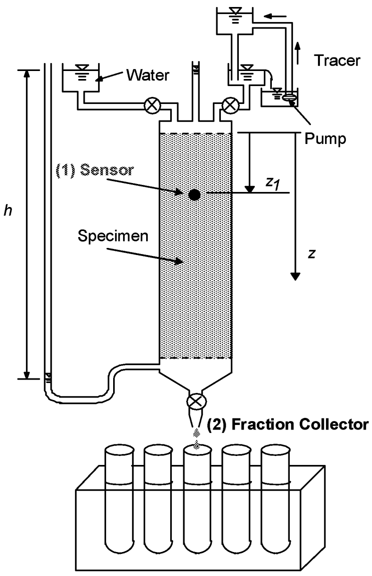


Fig.5 Tracer test

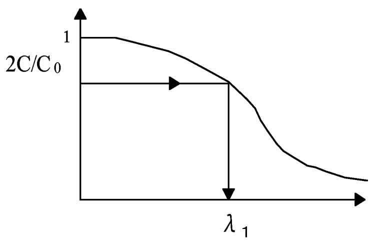


Fig.6 Complementary error function

The tracer test was carried out by test equipment shown in **Fig.7** on the basis of the above-mentioned test method. Toyoura sand was used for the sample, and saturated condition of the 0.40 porosity (effective porosity is 0.38) was prepared. The tracer was made to be sodium chloride aqueous solution of concentration (3.0%, 1.0%, 0.3%) of three step. FDR sensor and prototype dielectric constant sensor (ε =1-80, EC=0-23 mS/cm) from market were installed at the central height of specimen. The test to begin by passing the distilled water after the specimen manufacture from the bottom, to perfectly removed the bubble. The sensor output was recorded by switching tracer liquid after steady flow was obtained by injecting de-aired water from upper part of specimen. By switching de-aired water after output value settled down in the constant value again, the tracer liquid was discharged from the specimen. By injecting the distilled water after the test end from the bottom of specimen, it was returned to the initial state by the flushing of the extra tracer liquid. Then, the test was repeatedly carried out by raising flow velocity in increasing water head difference hydraulic gradient.

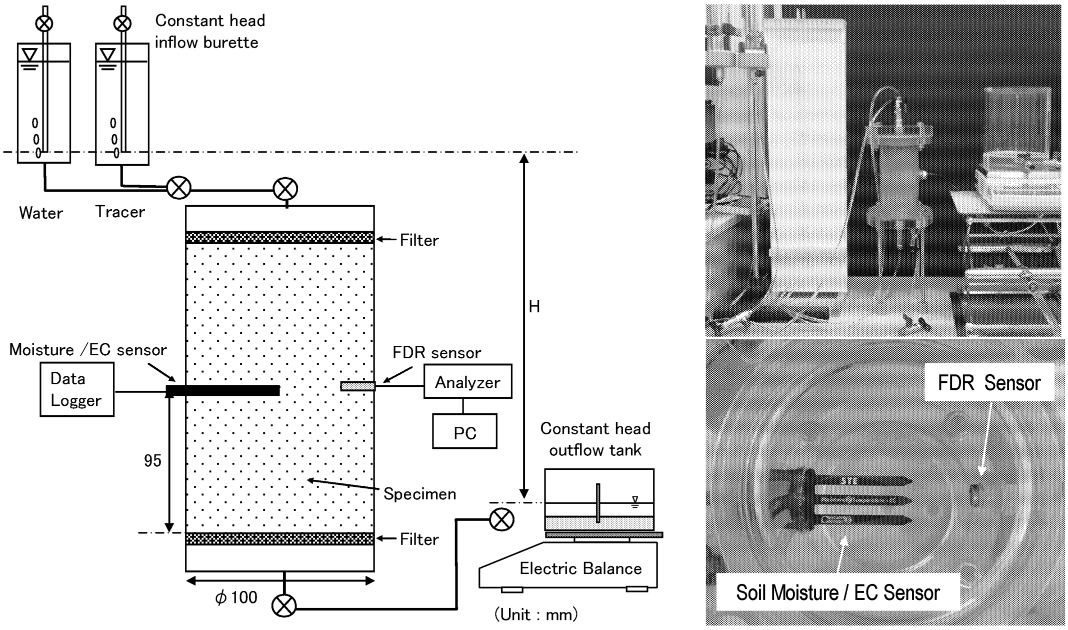


Fig.7 Schematic diagram of tracer test

RESULTS AND DISCUSSION

1. Determination of effective porosity of porous media by using FDR

The porosity is obtained from the relationship between dielectric constant and volume water content, if the electrode is inserted in the saturated condition, and if the dielectric constant is measured before the liquid injected. The calibration curve measured three kinds of sand is shown in **Fig.8**. The measuring result of this method is shown in **Fig.9**. Though the effect of the disturbing of electrode and part by the insertion has appeared, it can be measured at the error within 10%.

The change of the dielectric constant was measured by the injection of ethanol aqueous solution (95%). As the example, the result of carrying out for the Narita sand is shown in **Fig.10**. The dielectric constant began to lower from the after injection, and it converged on the constant value.

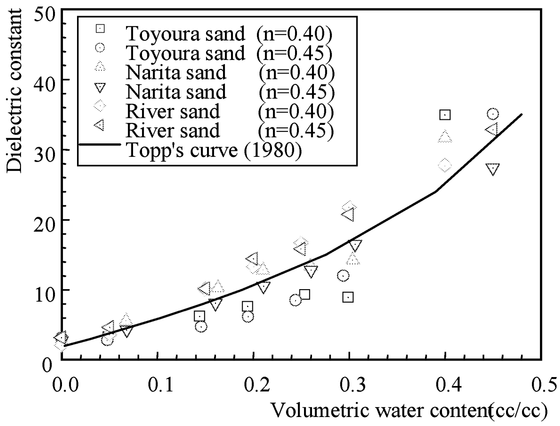


Fig.8 FDR calibration curve for sand

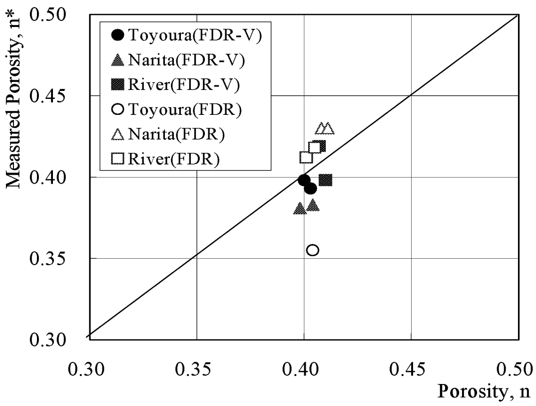
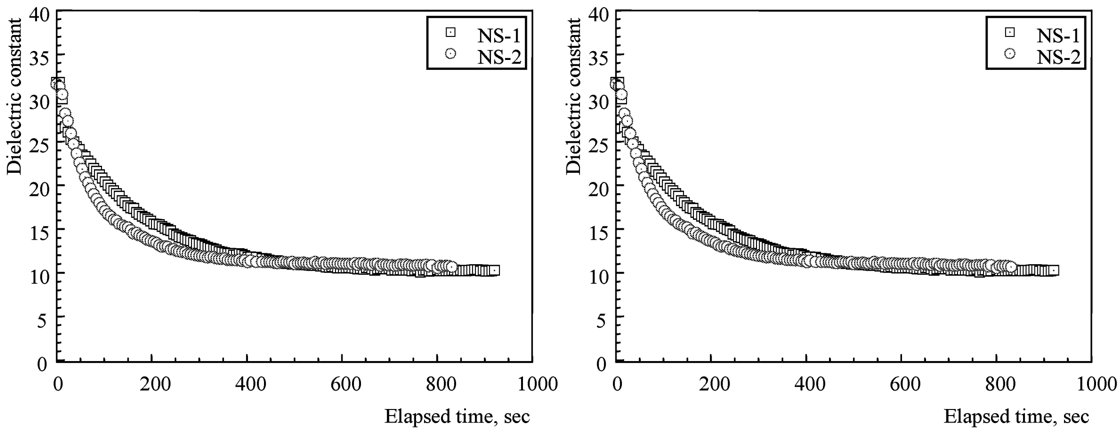


Fig.9 Measurement result of the porosity



(a) FDR-V (b) FDR

Fig.10 Response of dielectric constant by injecting ethanol (95%, Narita sand)

The effective porosity can be calculated according to the following equation from these results.

$$\varepsilon_{ep} = \varepsilon_s(1-n) + \varepsilon_w(n-n_e) + \varepsilon_{eth} \cdot n_e \quad \cdots\cdots \quad (13)$$

where ε_s, ε_w, ε_{eth} are dielectric constant of soil particle, water, ethanol solution, n and n_e are porosity and effective porosity, ε_{ep} is a dielectric constant of the ground after the injection. This measurement result became also a value of about 80～95% of the porosity is shown in **Table 2**. FDR-V shows high value from FDR results, because the mean value of the infiltration part by the injection is more shown of wide FDR method compared to the FDR-V method measured in surface. **Fig.11** shows the comparison the effective porosity from the injection test and tracer test. It can find that the results are almost good agreement from this figure.

Table 2 The effective porosity measurement result by the injection

Method	Sand	Dielectric constant		Porosity	Measured	Ratio of
		$\varepsilon_{\text{-initial}}$	$\varepsilon_{\text{-final}}$	n	n_e*	n_e*/n
FDR-V	Toyoura	32.75	8.18	0.400	0.382	0.955
		32.37	8.49	0.403	0.381	0.945
	Narita	31.76	10.39	0.404	0.356	0.881
		31.57	10.93	0.398	0.340	0.854
	River	34.65	10.04	0.407	0.366	0.899
		33.02	9.06	0.410	0.384	0.937
FDR	Toyoura	29.59	9.92	0.404	0.363	0.899
		29.59	10.05	0.404	0.361	0.894
	Narita	35.65	12.08	0.408	0.334	0.819
		35.66	10.98	0.411	0.354	0.861
	River	34.05	10.92	0.401	0.343	0.855
		34.49	11.66	0.405	0.337	0.832

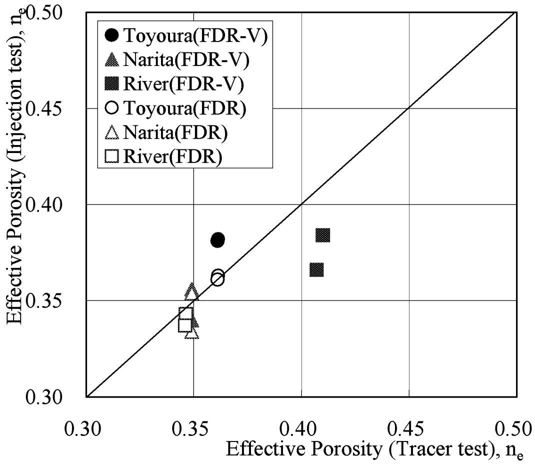
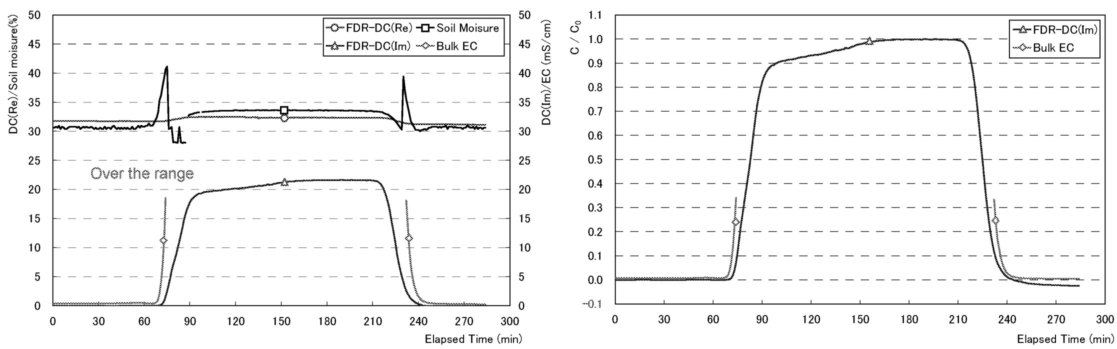


Fig.11 The comparison of the measurement result of the effective porosity

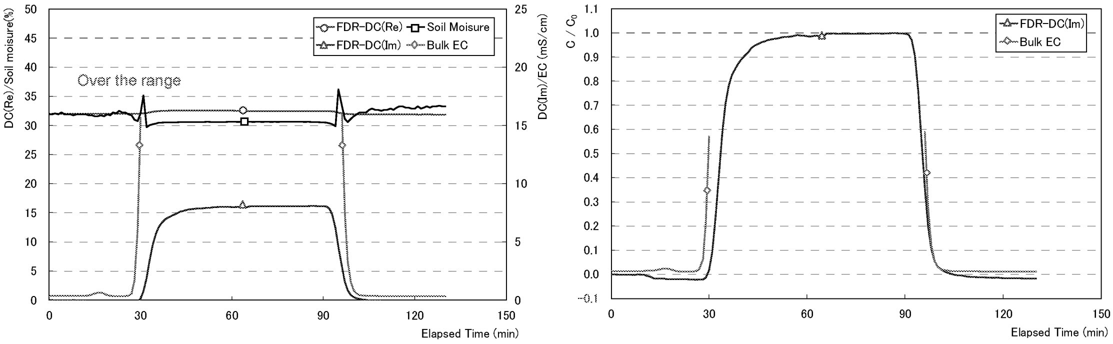
2. Determination of dispersion coefficient (Sensor method)

Fig.12 and **Fig.13** are presented tracer test results respectively carried out at C=3.0% tracer solution concentration and C=1.0%, measuring result and breakthrough curve (variation of the concentration). Since that anyway measured increasing variation of the concentration in the FDR sensor, but measuring range exceeded of electric conductivity in dielectric sensor. The dielectric sensor at the measured water content became a result of generating large fluctuation in point of time in which the tracer solution reached near the sensor. In the measurement in which it is put in the high density tracer, the dielectric constant sensor will be indicated large error of measured water content.



(a) Measured data (b) Breakthrough curve

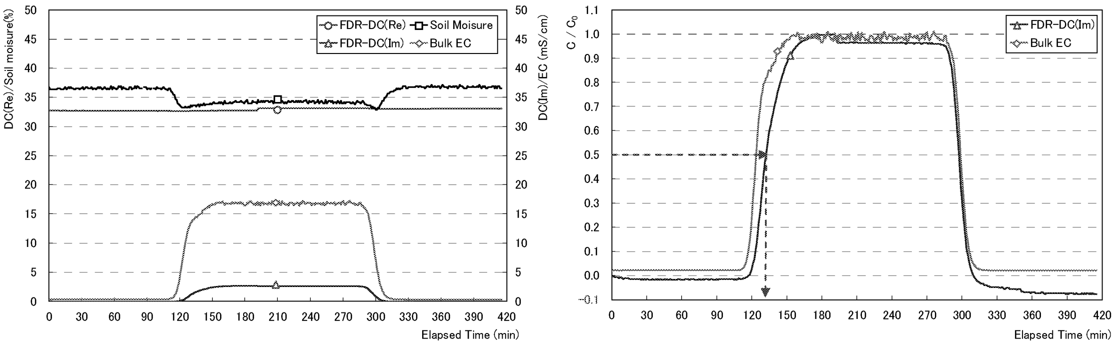
Fig.12 Tracer test results (C=3.0%, i=0.026, v=1.67×10^{-3}cm/s)



(a) Measured data (b) Breakthrough curve

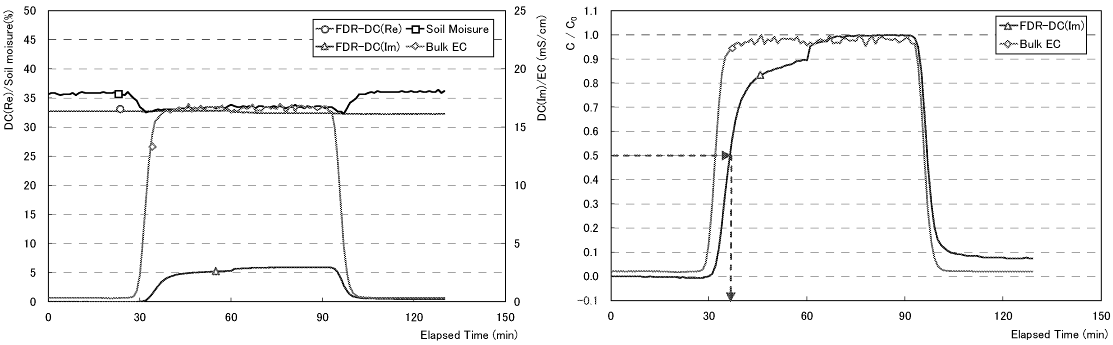
Fig.13 Tracer test results (C=1.0%, i=0.105, v=4.23×10^{-3}cm/s)

Based on the above-mentioned result, concentration of the tracer solution to be C=0.3%, the test result that hydraulic gradient was made to change in three step, shown in **Fig.14** to **Fig.16** respectively. In this tracer concentration, the dielectric constant sensor did not exceed the measurement limit, and it was possible to catch the increasing variation of the concentration. The relationship between real velocity and relative concentration is shown on the basis of the measured value of the FDR sensor in **Fig.17**. This figure shows that the time in which the concentration begins to rise has quickened, as the flow velocity increases. Still, there was the fluctuation by the dielectric sensor even in this concentration for the measured value of water content.



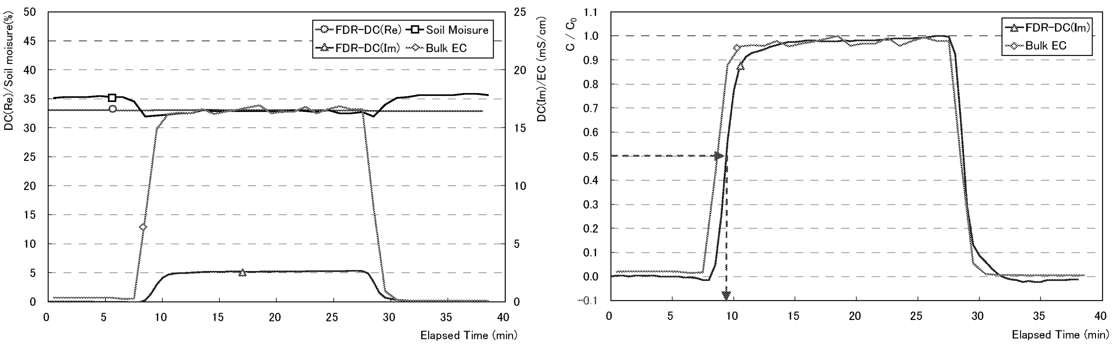
(a) Measured data (b) Breakthrough curve

Fig.14 Tracer test results < Case1> (C=0.3%, i=0.026, v=1.26×10^{-3}cm/s)



(a) Measured data (b) Breakthrough curve

Fig.15 Tracer test results <Case 2> (C=0.3%, i=0.105, v=4.07×10^{-3}cm/s)



(a) Measured data (b) Breakthrough curve

Fig.16 Tracer test results <Case3> (C=0.3%, i=0.421, v=1.53×10^{-2}cm/s)

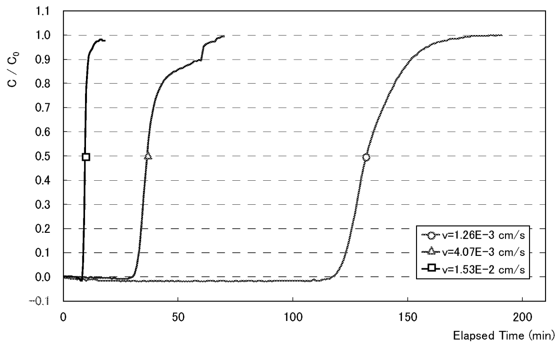


Fig.17 Relative concentration and real velocity

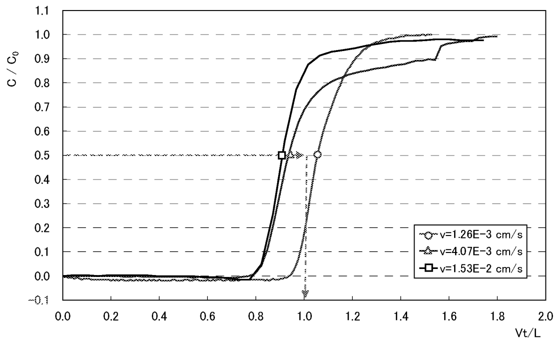


Fig.18 Relative concentration and Vt/L

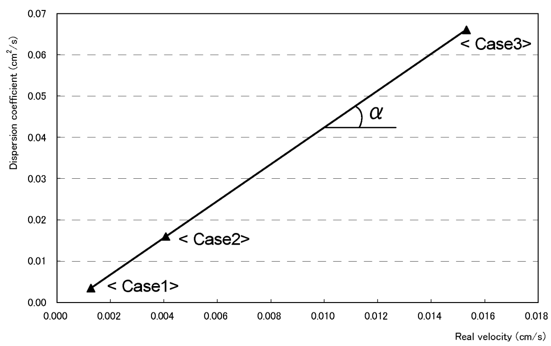
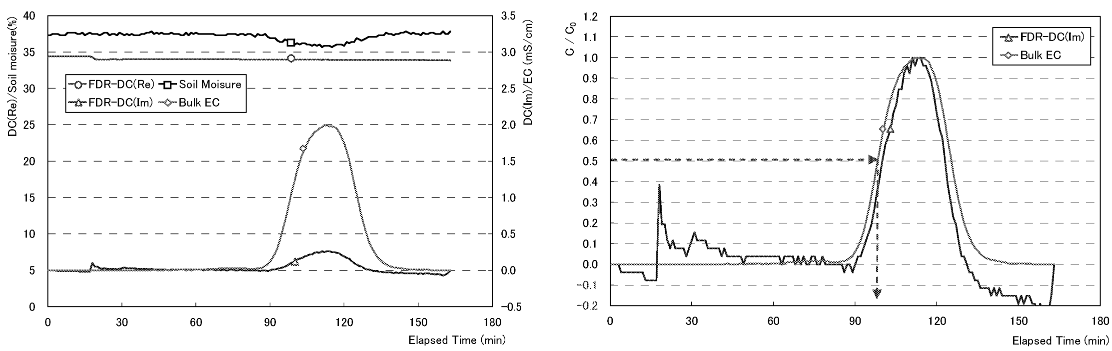


Fig.19 Dispersion coefficient



(a) Measured data (b) Breakthrough curve

Fig.20 Tracer test results (leachate from a landfill site, i=0.042, v=1.66×10^{-3}cm/s)

Table 3 Sensor output for tracer

Tracer	Solution	Sensor output	
	EC (mS/cm)	DC	EC (mS/cm)
NaCl : 3.0%	41.2	72.7	×
NaCl : 1.0%	14.8	14.5	×
NaCl : 0.3%	4.91	-7.78	×
Leachate	0.84	—	—

×: Out of the measuring range

In the calculation of the dispersion coefficient in **Eq.(12)**, it is necessary to satisfy Vt/L=1 in the relative concentration at 0.5. The relationship between Vt/L and relative concentration is shown in **Fig.18**. This result can be agreement of satisfying Vt/L=1 approximately, although the result seem to be the error for the injection start time of the tracer. Then, complementary error function was obtained on the basis of the concentration-change of the breakthrough curve, and the dispersion coefficient was obtained. The dispersion coefficient got for real velocity in each test case is shown in **Fig.19**. The longitudinal dispersion length consisted with about 4.5cm.

Fig.20 is presented the result carried out with the leachate collected in disposal site to be the tracer solution. The result of measuring the each tracer solution by electric conductivity total, FDR sensor, dielectric constant sensor is shown in **Table 3**. Though the leachate in the disposal site was considerably lower than the sodium chloride solution used in the precious tracer test, it was possible to measure the concentration-change in the sand column, the dielectric sensor became a result of exceeding the range.

CONCLUSIONS AND PERSPECTIVES

Firstly, this study proposed the determination of effective porosity of porous media by using FDR. This method is based on the dielectric sensor inserted in the ground, the liquid differed water dielectric constant are injected around the sensor, the effective porosity will be obtained from the change of the measured value. Injection test was carried out for the purpose of getting a basic data for examining the effectiveness for several kinds of sand. As the result, the porosity about 80-95% was shown each measured value, and the good result was obtained compared to tracer test.

Secondary, the one-dimensional column tracer test was carried out, and the dispersion coefficient was obtained from the method for measuring the concentration-change in column middle point using dielectric constant measurement method. In the measurement in which it is put in the high density, the dielectric constant sensor as the result, the applicability for the high-dense tracer was good for the FDR sensor, but the dielectric sensor from market was indicated the limit of concentration and measured value with large error for water content.

In further study, the measurement technique of advection and dispersion behavior of the ground in situ will be proposed. Concretely, using above-mentioned FDR sensor and dielectric constant sensor, permeability test which evaluates the rainfall infiltration and tracer test using the borehole which evaluates migration phenomenon of the leachate are carried out, and in situ measuring method of each parameter is examined.

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