生産管理学会第28回全国大会 2008.9.13-14

Electrical Impedance Tomography for Underground

Kazuyo Yoneda[1], Shinichi Tamura[1], Yoshinori Nishino[1],
Hisashi Taketani[2], Kazuki Nakamura[3], Takio Shimosakon[3],
Kyohei Shimada[4], Rong Long Wan[4], Kozo Okazaki[4]

[1]NBL Co., Ltd, [2]Tsuyama College of Technology,
[3]Osaka Institute of Technology, [4]University of Fukui

Abstract

We are going to develop a method of washing out underground pollution by using water permissible pipes developed by us and pouring/draining water. This method is effective even there exist already buildings on the ground. To visualize underground pollution directly or especially underground water which can work as the resolvent for washing out, we have developed electrical impedance tomography (EIT) for underground. By quantifying underground water, we can quantify/control the purifying process. Some of the experimental results show its feasibility.

Keywords: Pollution, Underground, Electrical impedance tomography (EIT), Water permeable pipe, Washing out

1. Water permeable pipe

We, NBL Co., have developed water permeable pipe as shown in Fig.1, which is produced from scraped FRP by our unique CW (Centrifugal Winding) method [1].

Fig.1 Water permeable pipe. ϕ:0.2-2m, Length: 2-6m.

2 Washing out underground pollution

Soil washing method by flowing water is effective to purify the polluted soil which includes chemicals not purified by microorganism in the natural circulation. Surfactant, oxidation flocculant, and adhesion agent etc to wash pollution chemicals out or settle them afterward are used together. Fig.2 shows a cross section of the process of purifying polluted underground soil with the water-permeable pipes. The water containing above agents which makes flow out the pollution is injected. The pollutant flowed out is injected into deep underground.

Basically, it is considered that polluted ground can be purified because the potential chemical is supposed to be water solvable. Infiltration wash is adopted by injecting an effective material into the specified pollution. For purification, either drain of vertical or horizontal drain is chosen according to the purpose.

For catching the organic gas etc. which is contained under the soil, the sheet is attached and they are collected so as to be processed by a plant or burned out for the necessary period of time. Solid component of the collected chemical is removed and an agent necessary for stabilization in a deep underground is mixed. Likewise solved pollution components are also processed. Then they are injected with the high pressure.

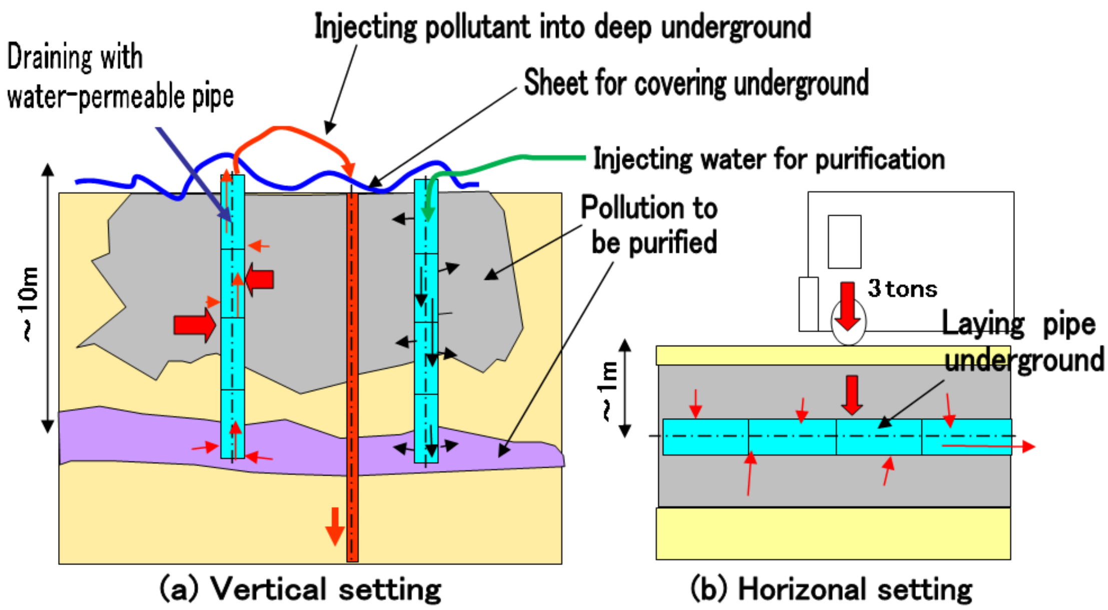

Fig.2 Purification of polluted ground with water-permeable pipes

The depth of the selected deep underground for injecting pollutant is supposed to be under the stable ground. Though its suitable depth varies from place to place, it is considered to be more than 700 m (United States example) in general. The solution by these (purification by irrigation and injection into deep underground) has the following features.

- Purification by natural circulation is impossible in the surface (shallow underground) of the earth .
- Such stabilization/purification is performed by taking a long term under the condition of high temperature and high-pressure.
- It does not cause the second pollution because it does not accompany digging, movement, and processing of soil as conventional way.
- A large scale construction is not necessary. Little waste is given off.
- Above all, the construction expense is very economical.
- The term of construction can be shortened, and another construction work can be also used together while washing it. Moreover, it is possible to wash and to purify without destroying existing buildings.

As mentioned above, it can be said that this irrigating purification method with water permeable pipe is an extremely advantageous method.

The extracted chemical is injected under the stable ground by an anticorrosion high-pressure FRP pipe as shown in Fig.2. Its depth is expected to be more than 2300m in general though it seemed to be 1500m to 2000m is suitable in Kanto region. It is determined by the detailed geological feature investigation. The drained water including chemicals is collected in tanks on the ground and mixed with the stabilization agents, and then the solid material is removed and injected with high-pressure pipe (10-15Mpa). The injected chemical is reserved for more than one million years. That is, it means that surplus materials in environment on the ground are returned to underground. This is opposite process to the production of oil in which fossil fuel is extracted. The depth is determined by the geologic research because an underground injection can be applied to various kinds of materials such as carbon dioxide, nuclear material, and deleterious substance, etc.

3. Analysis of underground pollution

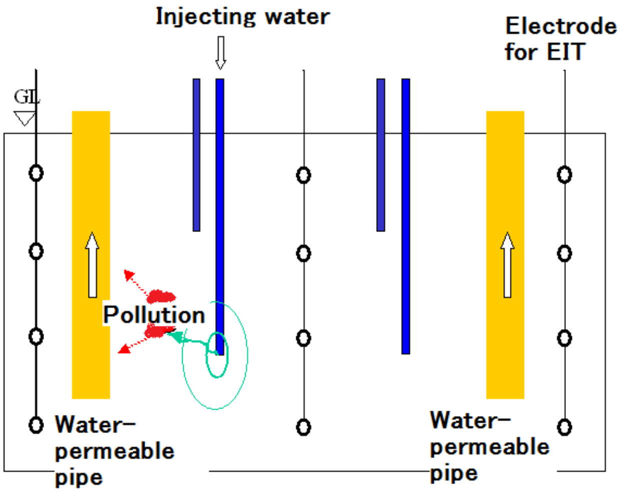

Fig.3 Distribution analysis of pollution by injecting proving water from various positions.

It may be the best way to use EIT (Electrical Impedance Tomography) to visualize the underground since it can be applied by only inserting electrodes into the underground. However, the direct visualization of pollution by the EIT may be difficult, since there are various kinds of pollutions/chemicals of especially small amount of. Therefore, it is important to combine the water flow control and analysis of flowed out materials. As shown in Fig.3, by changing the position of proving water and analyzing the washed out materials, we can identify where and how much even the small amount of various kinds of pollution materials. In order to make precise image of the pollution distribution, we must visualize the real water flow distribution of the underground for various water pouring/draining positions and amounts. To visualize this water flow, we developed the EIT for underground.

4. Electrical Impedance Tomography

- Defining electrical resistance or conductance of each internal part, an image of the solution as an inverse-problem is obtained.
- The distribution of water becomes visible because the water-irrigated parts become low impedance.
- It can be said that EIT is a method suitable for making the pollution in the soil visible.

The major mathematical modeling of EIT involves calculation of the forward and inverse problems. In the forward problem the governing equations in the EIT field which are derivable from Maxwell's Equations (electrostatic approximation for low frequency) [2,3] are

$$\nabla \cdot \left[\tilde{\sigma}(P)\nabla\tilde{U}(P)\right] = 0$$ at B (B is the object) (1)

$$\tilde{\sigma}(P)\frac{\partial\tilde{U}(P)}{\partial n} = J$$ P ∈ S (Surface) (2)

$$\int_S \tilde{U}(P)ds = 0$$ P ∈ S (3)

Here, we simplified the problem, and we made the reconstruction (inverse) problem as 2D resistance grid network as shown in Fig.4. Eight electrodes are placed at the grid points. Center grid point is a virtual electrode, where real electrode cannot be placed since there is possibility of existing building. In the experiment, each static resistance between electrode pair is measured as R12, R13,…,R45, R46, …, R68, R78, or R1, R2, …, R28.

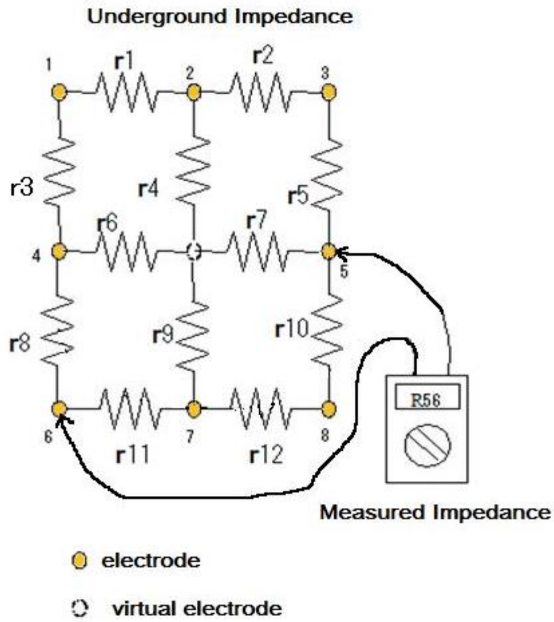

Fig.4 Simplified underground model

We define the evaluation formula of the squared sum of the differences between the theoretically calculated resistance and the measured resistance by

$$E = \sum_{i=1}^{28} (R_i - dataR_i)^2$$

where Ri is theoretically calculated resistance from the estimated virtual resistances r1, r2, …, r12 expressing underground resistance of e.g., how much the soil contains water. Ri is obtained by applying Kirchhoff's 2nd Law and Mathematica.

Then we apply the hill climbing method to solve (obtain most well explaining the measured resistances) the equation.

$$\left.\begin{aligned} r_{1(j+1)} &= r_{1j} + \alpha\left(\frac{\partial E}{\partial r_1}\right) \\ r_{2(j+1)} &= r_{2j} + \alpha\left(\frac{\partial E}{\partial r_2}\right) \\ &\vdots \\ r_{n(j+1)} &= r_{nj} + \alpha\left(\frac{\partial E}{\partial r_n}\right) \end{aligned}\right\}$$ where j is the iteration number

5. Experiment

We made experiments by the small size 2D sand box as shown in Fig.5, whose size of sand part is 13cm×13cm×3cm and eight φ5mm×3cm bolts are inserted from the bottom. Distance between bolts is 4cm.

Fig.5 Small size 2D sand box model and water injection device (syringe).

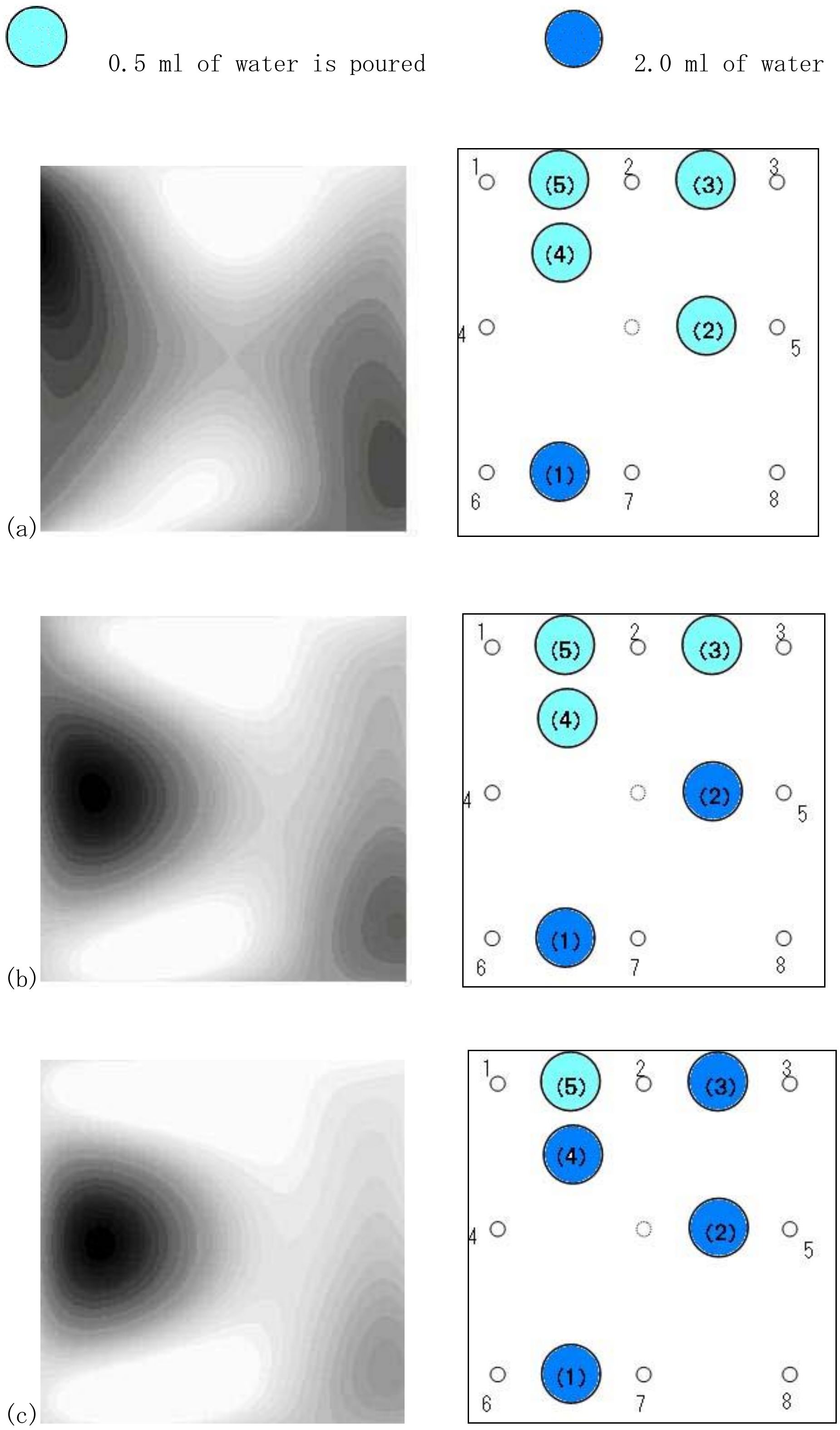

Fig.6　Reconstructed EIT (left) of the poured water (right). White means low impedance (much water).

Initially the sand is dried in an oven to control the amount of water in the sand. In this case, the sand is too dried to measure the resistance between electrodes. So, the sand is mixed uniformly with water of 10ml. In the right figures, light blue circle shows the place 0.5 ml of water is poured into the sand. Dark circle shows that of 2ml in total. The images visualizing obtained resistance values are shown in Fig.6 lefts for three kinds of water distribution, where white shows low impedance. Fig.6 rights show the illustration of poured water balls for each.

6. Conclusion

We have developed a water permissible pipe. It has a possibility to be applied to pollution purification by washing out the underground. In this process, EIT (Electrical Impedance Tomography) can visualize the underground especially water distribution. Then, we can analyze the pollutant contents/quantity by analyzing the washed out material quantitatively by the proving water and therefore can make washed out planning how much and how long the washed out should be done.

We did a small size of EIT experiment and shown that it is possible to visualize the underground even some building exists and difficult to insert the electrode in the center of the land. We can see that the poured water was depicted well using smoothing filter, though the resolution power is only 12 points. Experiments showed the feasibility of the EIT for the underground. This method is suitable for underground since it needs inserting only bar type electrodes and therefore the proposed method can be applied even for "live" land/underground.

References

[1] Toshiharu Iwatani, Masaki Nishino, Yoshinori Nishino, Yasuhiro Iguchi, Takio Shimosakon, Shinichi Tamura: "Design method of API high pressure FRP pipe", 13th European Conference on Composite Materials No.107 , Stockholm, Sweden (June 2-5, 2008)

[2] Webster JG: "Electrical Impedance Tomography". Adam Hilger 1990.

[3] Cheney M, Isaacson D, Newell JC: "Electrical Impedance Tomography". SIAM Review 1999, 41(1):