SURVEY OF THREE-DIMENSIONAL DISTRIBUTION OF WASTE LAYERS, "ORGANIC MATTERS", BY ONE-METER-DEPTH TEMPERATURE MEASUREMENT

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ABSTRACT
According to an implementation of Closure Standard for landfill sites, it has been required developments of technologies for a hasty stabilization of existent landfill sites. There have been also required surveys methods of land filled wastes and condition grasp methods of polluted underground water and soil around landfill sites. Especially, to grasp of Organic Matter's Distribution is important for making plans and the implementation of hasty stabilization, because wastes containing plenty of organic matters were land filled at existent landfill sites. This study confirmed three-dimensional distribution of organic layers by One-Meter-Depth Temperature Measurement (OMDTM); 5-meter mesh measurement, and Thermal Conductivity Analysis; G-HEAT/3D, due to the temperature increase by degradation of organic matters in landfill sites. And High Density Electricity Exploration (HDEE) used for a waste exploration was implemented. And the obtained results were compared with other results from OMDTE and G-HEAT/3D. Finally this study considered the effectiveness of "Combined Use of Survey Methods".

INTRODUCTION
Fig-1 shows survey and analysis flow. This surveyed landfill site started to be land filled in 1980 and was closed about 10 years ago. There are some organic-rich layers because this site received domestic waste such as raw garbage, sewage sludge.

1. Field Survey  
- One-Meter-Depth Temperature Measurement (OMDTM) and High Density Electricity Exploration (HDEE)

2. Analysis (OMDTM)  
- Revise of data (temperature detector, daily variation, site conditions etc.)  
- Setting up the normal temperature at a depth of 1-meter below ground surface  
- Charting the distribution of one-meter-depth temperature  
- Analyzing the depth of organic waste layers

3. Comparative consideration of results from OMDTM and HDEE  
- Evaluation of the effectiveness of combined use of survey methods  
- Charting 3-dimensional distributions of organic waste layers by thermal conductivity analysis

Fig-1 RESEARCH AND ANALYSIS FLOW
ONE-METER-DEPTH TEMPERATURE MEASUREMENT (OMDTM)

OMDTM was a typical exploration method for hot spring sources, and applied to underground water explorations (Takeuchi; 1983). It has been used as an exploration method to grasp horizontal existence conditions of underground water flow in shallow parts of the earth (limited 15 meter below ground surface) these days. Fig-2 shows the measurement instruments and Fig-3 shows the measuring model.

This method consists of measurements and analysis of the temperature at a depth of 1m below ground surface by a mesh from 5-meter to 10-meter. In general, it is widen that the temperature difference between the normal temperature at a depth of 1-meter below ground surface and the temperature of flowing underground water in summer and winter. This reveals the distinct between existence place of underground water and nonexistence one by the difference.

This study implemented 5-meter mesh measurement and analysis of organic matters in winter. Figure-4 illustrates the results. According to the results, this study detected the distribution of the high temperature zone (above 13 degrees) in comparison with the normal temperature in 1-meter depth (nearby 10 degrees). Especially this detected the highest temperature zone shows between 17 degrees and 19 degree in a northern area. This is caused by heating sources of organic matters’ degradation. It is supposed that unstabilized organic layers exist in shallow part of the earth.

HIGH-DENSITY ELECTRICITY EXPLORATION (HDEE)

HDEE obtains, for the first step, measurement data from placed electrodes in lines on the earth. Secondly the data is inversely analyzed and true comparative resistance distribution under the ground is led as a cross-sectional figure in two-dimension. This study implemented measurements and analysis each 5-meter space based on Two-Polar Method. Furthermore, the length of the measurement line was set up 150-meter which is 5-times as long as the thickness of the waste layers (from 20m to 25m).

Figure-5 illustrates the results of HDEE and the results of OMDTM measured in line. In the results of HDEE, the comparative resistance values shows over 50Ω·m and revealed that the cover soil, as the ground surface, consists of a gravel layer. And the results from waste layers (organic layers) show values below 20Ω·m due to a high water content. Especially the results from the boundary between the cover soil and the waste layers show low values.
bellow 5Ω-m. Although there is a low comparative resistance zone around the points of 70m and 120m on the measurement lines, the one-meter-depth temperature, on the other hand, shows 11 degrees that is a little higher than normal one's. It is supposed that there is proceeded stabilized organic layers or a distribution of some other wastes.

Fig-4 THE RESULTS OF HDEE AND TEMPERATURE DISTRIBUTION IN ONE-METER-DEPTH TEMPERATURE ON MEASUREMENT LINE
(This shows the results of OMDTM on HDEE line)

Fig-5 DISTRIBUTION OF ONE-METER-DEPTH TEMPERATURE AND ELECTRICITY EXPLORATION LIN
THREE-DIMENSIONAL DISTRIBUTION ANALYSIS OF ORGANIC LAYERS

Methods of analysis

Overview: Using the measurement results obtained by OMDTM method, three-dimensional temperature distribution analysis of organic layers was conducted with the thermal conduction analysis software, "G-HEAT3D."

The methods by which observational results are inversely analyzed for ground’s thermophysical properties such as thermal conductivity have been suggested as studies of tomography. On the other hand, methods of integral equation although has been suggested as a method of identifying a heat source, it is still problematic to apply those methods to some cases under complicated boundary conditions or of varied thermophysical properties. Therefore the authors approached to estimate locations of heat sources by comparing measurement values with plenty of analytical results obtained from simulation at different locations and numbers of heat sources. In this method, first of all, FEM (Finite Element Method) analyses were conducted by changing heat source locations. Secondly, a temperature distribution was obtained at a certain location of heat sources. Comparing the measurement values with the simulation data of the temperature distribution that was appropriately layered consequently specified the location of heat sources.

Analysis of Thermal Conduction: In the analysis the FEM model including the disposal site is created and set a single heat source. Steady state analyses are carried out for obtaining the temperature distribution in the model as moving the source sequentially. Figure-6 illustrates the concept of the analyses and the thermal conduction equation states below (1):

\[
\frac{\partial}{\partial x_i} \left( K_\rho \frac{\partial T}{\partial x_i} \right) = \rho C \frac{\partial T}{\partial t}(1)
\]

Where \( K_\rho \), \( C \), \( \rho \) are thermal conductivity shown in Table-1, density and specific heat of the ground, respectively. The subscripts represent Cartesian-Coordinate-System and follows Sum-Total-Rule.
Identification of heat sources: Fig-7 and Fig-8 show the analysis model. Based on the thermal conductivity analyses with the movement of single heat source, it is assumed that the temperature at a measurement point could be obtained as following equations;

\[ t_1 = \alpha_1 T_{11} + \alpha_2 T_{12} + \ldots + \alpha_j T_{1j} + \ldots + \alpha_n T_{1n} \]
\[ t_2 = \alpha_1 T_{21} + \alpha_2 T_{22} + \ldots + \alpha_j T_{2j} + \ldots + \alpha_n T_{2n} \]
\[ \vdots \]
\[ t_i = \alpha_1 T_{i1} + \alpha_2 T_{i2} + \ldots + \alpha_j T_{ij} + \ldots + \alpha_n T_{in} \]
\[ \vdots \]
\[ t_m = \alpha_1 T_{m1} + \alpha_2 T_{m2} + \ldots + \alpha_j T_{mj} + \ldots + \alpha_n T_{mn} \]

where \( t_i \) is the measured temperature at the \( i \)th order of the measurement point, \( T_{ij} \) is the temperature at the same point as \( t_i \) caused by the \( j \)th order of a single heat source, and \( \alpha_j \) is the coefficient indicating the effect of the \( j \)th order of a single heat source on the measurement point. In the analyses the coefficient \( \alpha \) was obtained by the least-square method using \( t_n \) and the measurement values.

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![Fig-8 CROSS-SECTION OF ANALYSIS MODEL](image-url)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity W/(m K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover soil</td>
<td>1.87</td>
</tr>
<tr>
<td>Waste material</td>
<td>0.57</td>
</tr>
<tr>
<td>Base rock</td>
<td>1.10</td>
</tr>
</tbody>
</table>

### Analysis results

Figure-9 illustrates the one-meter-depth temperature distribution on the analysis model. In case of heating at organic layers in a deep part of the waste domain, the thermal variety in one-meter-depth spreads widely and gently. However OMDTM results by 5-meter-mesh method show some points appear sudden temperature changes. This is supposed that there are some heating in shallow part of waste domain. HDEE results also show lower resistance zones under the cover soil (nearby GL-5.0m). This is supposed that some organic layers caused heating are distributed in shallow part of waste domain.

This analysis detected the three-dimensional organic layer distribution caused heating. Figuer-10 illustrates a representative cross section of analysis results (No.6: Electricity Exploration Line). Using this figure, the temperature at the measurement point was obtained in case of heating in the waste domain. Consequently it was revealed that organic layers...
caused heating were distributed from 5.0-meter to 10-meter under the ground and dotted as a state of cluster in three-dimension.

![Figure-9 TEMPERATURE DISTRIBUTION OF OMDTM (°C)](image)

![Figure-10 TEMPERATURE DISTRIBUTION IN A CROSS-SECTION (No6: ELECTRICITY MEASUREMENT LINE) (°C)](image)

CONCLUSION

According to the result of this study, revealed things and future subjects are as follows:

(1) An organic layer still proceeds to be degraded continuously at landfill sites, even if it’s passed 10 years after closing. Consequently the horizontal distribution of OMDTM shows the high temperature from 17 degrees to 19 degrees due to the heating sources under the ground (organic layer). This results 7 degree higher than OMDTM that shows 10 degrees, and reflect a location of heating sources correctly.

(2) According to the results of HDEI, the lower resistance zone shows the values below 5Ω-m and locates from 3.0 meter to 4.0 meter under the cover soil equally. This is supposed there is a distribution of organic layers having high water content.

(3) HDEE confirmed the equal existence of organic layers under the cover soil. On the other hand, OMDTM confirmed the variety of the temperature that is over 5 degrees such as from 11 degrees to 17 degrees. This is cours ed by the difference of stabilization process in the same organic layer. Therefore the implementation of OMDTM is important for the detection of unstabilized organic layers.

(4) The three-dimensional analysis reproduced the distribution of heating sources (organic layer) that is above 20 degrees at the shallow parts of the landfill site.

(5) The future subjects on this study are as follows;
   [1] Research on distribution of underground water
   [2] Research on vertical distribution of temperature under ground

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