# 폐기물매립지의 장기침하 특성에 관한 연구

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# A Study on the Characteristics of Long-term Settlement for Solid Waste Landfill

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## Abstract

It has been a growing concern about reusing Sudokwon landfill 2nd site and other sanitary landfills located around the metropolitan areas. In this paper, settlement characteristics of Sudokwon landfill 2nd site were studied by analyzing the data collected over the period of six years. Three equations are combined in order to modeling the long-term settlement behavior of refuse landfill caused by mechanical secondary composition and secondary composition caused by the decomposition of biodegradable refuse. It is suggested that mechanical secondary composition is linear with respect to the logarithm of time.

The models proposed by hyperbolic method and Gibson & Lo model, power creep law are considered to be suitable for the long-term prediction value of Sudokwon landfill 2nd site. The fifteen-year-period prediction value of hyperbolic method and Gibson & Lo model is considerably different from that of power creep law model. The average settlement for Block I in Sudokwon 2nd site is approximately 3.9m with 4 steps of final landfill stages.


**[Keywords** : Long-term settlement, Sanitary landfill, Hyperbolic method, Gibson & Lo model, Power creep law]

## Ⅰ. Introduction

The Sudokwon landfill 2nd site is categorized into two sector municipal solid waste filled 4 stages for sector I, under filling 4 stages for sector Ⅱ. The final stages of waste filling is 8 stage. The magnitude of waste settlement is calculated through the results of field settlement monitoring up to 4 stage as a stabilized waste filled condition. Based on the result of settlement calculation the modified landfill height is applied from the 5th stage of filling process. The waste landfill site which is situated in the soft marine clayed, the consolidation settlement and also compression of waste due to the decomposition process are simultaneously considered. It has a great difficulty to obtain the undisturbed waste specimen from the waste landfill site and the variation of waste composition for individual landfill site is greatly different. Thus, there is a limitation of reinstate the field condition in the laboratory test. Several models have been proposed to predict the settlement of waste landfill, however the development of an appropriate model is not easy to do. That is way the best fitted model is selected for the use of an individual specific landfill site.

In this study, the compression characteristic of waste were determined due to the surcharge load by the planed height of waste landfill. The compression and volume change of the lower layer of waste landfill are also determined by using hyperbolic model, power creep law model, Gibson & Lo model. As the results are compared, the height of each layer is 5.5m and this height can be increased with considering the volume of waste compression. However, the level problems related to the facilities of landfill such as gas and leachate treatment plants should be considered. By the analysis on the results of the field settlement by settlement plate will be used for the prediction of long-term settlement.

## Ⅱ. Settlement characteristics of solid waste landfill

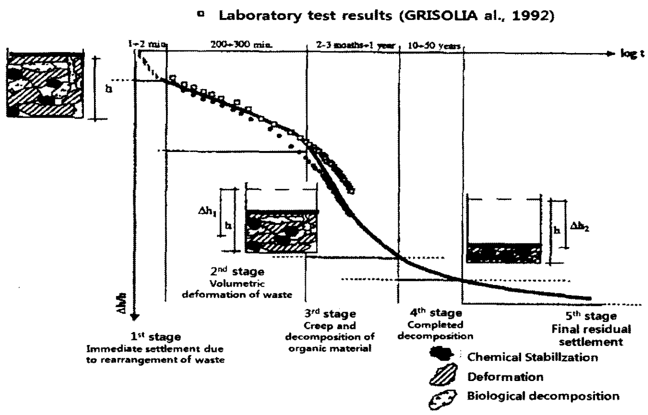
The settlement of solid waste landfill is occurred with combing of the primary compression settlement within several mouths the secondary compression settlement in the long-term period.

Eq. (1) is used to obtain the first part of settlement is caused of dissipation of pore water and gas filled in the void space in the waste. The letter part of settlement is due to rearrangement of solid matrix and waste component(Sowers, 1973; Gordon et al., 1986).

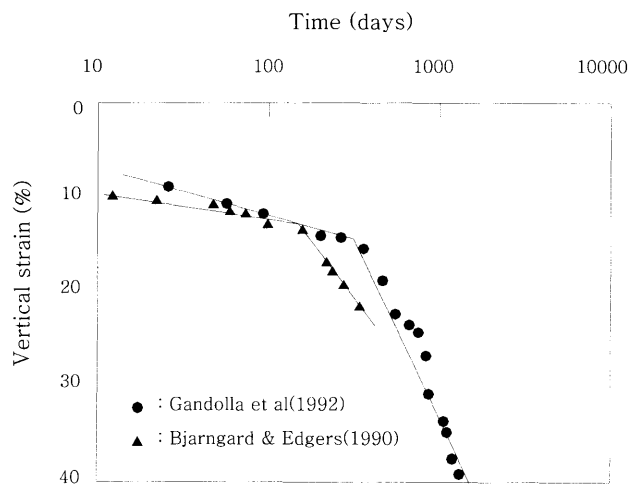
$$\triangle\varepsilon(t)_{long-term} = \triangle\varepsilon(t)_{mec} + \triangle\varepsilon(t)_{dec} \quad (1)$$

where $\triangle\varepsilon(t)_{mec}$ is caused of long-term slipperiness and waste particle rearrangement, and delayed compression. $\triangle\varepsilon(t)_{dec}$ is occurred due to the decomposition of organic matter through the biological degradation.

Grisolia and Napoleoni(1995) proposed the settlement model of solid waste landfill which is shown in <Fig 2-1>. The mechanism of settlement is categorized into 3 parts : (Ⅰ) primary settlement stage, (Ⅱ) primary residual settlement stage, (Ⅲ) secondary settlement due to decomposition and creep, (Ⅳ) completely decomposition stage, (Ⅴ) final residual settlement stage. Bjarngard and Edgers(1990) reported the settlement the settlement behavior of the solid waste landfill as shown in <Fig. 2-2>. The figure shown that the slope of the primary stage is somewhat mild like linear relationship and getting steeper as the time goes on. The reason for this is that the compression rate of waste is greatly increase with the decomposition of organic solid waste and hence the void ratio is decreased.




<Fig. 2-1> Compression curve of municipal waste




<Fig. 2-2> Long-term settlement behavior of solid waste landfill

# Ⅲ. Settlement prediction theory of waste landfill

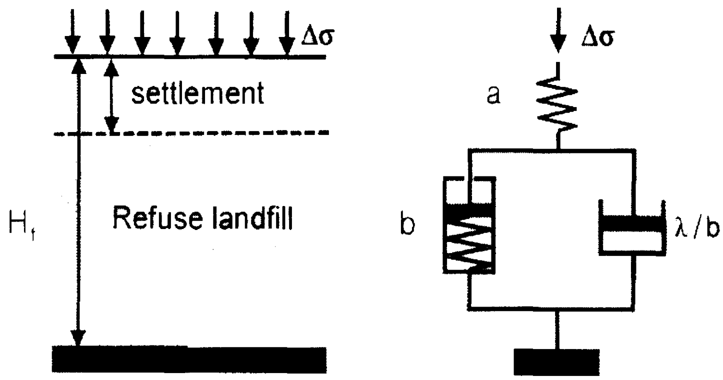
Several prediction models of long-term settlement such as Gibson and Lo model, logarithm model(Yen and Scanlon, 1975), hyperbolic model(Hoe et al., 1998), Bjarngard and Edgers model, power creep law model(Edil et a1., 1990), and Park's model(1998) are proposed by monitoring the field settlement since Sower's method(1968) which based on the consolidation theory of clayey soil. In this paper, hyperbolic model and Gibson and Lo model, and power creep law model are applied for the settlement prediction of Sudokwon landfill 2nd site.

## 1. Gibson & Lo model

Gibson and Lo Model was originally proposed to predict the settlement of peat dominated organic clay. Edil et al.(1990) used this model for prediction of the secondary compression of waste landfill with utilizing the characteristics of fluid mobilization model. The deformation rate of waste landfill with corresponding elapsed time can be expressed by Eq. (2).

$$\begin{aligned}\varepsilon(t) &= \Delta\sigma(a + b[1 - \exp(\lambda/bt)]) \\ &= \Delta\sigma \cdot a + \Delta\sigma \cdot b[1 - \exp(\lambda/bt)]\end{aligned} \quad (2)$$

This is also shown in <Fig. 3-1>. The Hookean spring is instantaneously compressed as tacking load and afterward the load is gradually transferred to the spring by mean of Newtonian dashpot ( $\lambda/bt$). Where, $\Delta\sigma \cdot a$ is final settlement.




<Fig. 3-1> Flowing model of Gibson & Lo

## 2. Hyperbolic model

The hyperbolic model is normally used to predict the soft clay settlement upon loading by filling the soil. Hoe et al.(1998) was firstly used this model to predict the settlement of municipal solid waste landfill by the following Eq. (3)

$$S=\frac{t}{1/\rho_0+t/S_{ult}} \qquad (3)$$

where suit a final settlement, ρo and suit can be obtained by the regression analysis from the relationship $t/S$ and $t$ in Eq. (4).

$$\frac{t}{S}=\frac{1}{\rho_0}+\frac{t}{S_{ult}} \qquad (4)$$

# Ⅳ. Estimation and Analysis of Settlement on Sudokwon Landfill

## 1. Compression $e_1$ on index $C_c$ and initial void ratio $e_0$

The field monitoring of compression in the first stage layer(l-A Block) of waste landfill due to the surcharged load of upper layer of waste. The compression index ( $C_c$) and variations of void ratio with respect to the applied waste layer are tabulated in <Table 4-1>.

<Table 4-1> Compression index with layer for 1-A Block 2nd landfill site

| Layer | Compression magnitude (m) | Void ration | | Measured pression ( $kg/cm^2$) | | $C_c$ |
|---|---|---|---|---|---|---|
| 1st stage layer | 0.000 | $e_1$ | 2.44 | $P_1$ | 0.00 | 1.2 |
| 2nd stage layer | 0.671 | $e_2$ | 1.998 | $P_2$ | 0.675 | |
| 3rd stage layer | 1.047 | $e_3$ | 1.75 | $P_3$ | 1.251 | |
| 4th stage layer | 1.33 | $e_4$ | 1.564 | $P_4$ | 1.588 | |

Based on the laboratory test results of waste from Sudokwon landfill site, void ratio of 2.44 is applied in the settlement calculation. Sower(1973) reported that the void ratio for uncompacted waste is ranged from 2 to 15. However, the waste in this site is well compacted and hence used void ratio of 2.44.

## 2. Secondary compression index

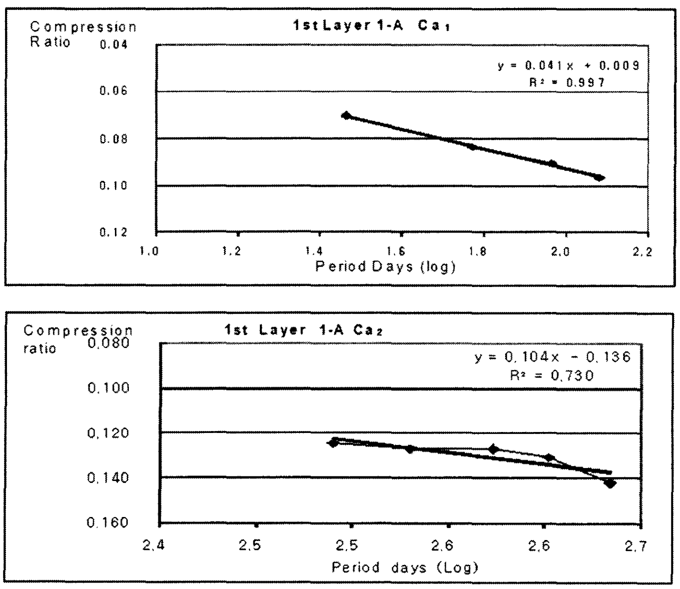
Sudokwon landfill 2nd sited has been filled since 2000. So far the 4th staged layer of waste is completely filled in the full height of 8 staged layer. The secondary by using of field settlement data for the first layer of waste due to the surcharged load of the 2nd layer waste.

Based on the field measurement data, $C_{\alpha 1}$ ranged from 0.0266 to 0.0432, with an average value of 0.0349, the settlement was occurred by the decomposition of waste after 236 days passed since filled. The range of is 0.1006~0.154 with an average value of 0.1184, which is four times greater them $C_{\alpha 1}$. All these data are listed in <Table 4-2>.

<Table 4-2> $C_{\alpha 1}$ and $C_{\alpha 2}$ for 2nd landfill site

| Category | 1st layer of 1A | 1st layer of 3B | 1st layer of 3C | 1st layer of 4C | Average |
|---|---|---|---|---|---|
| $C_{\alpha 1}$ | 0.0417 | 0.0266 | 0.0278 | 0.0266 | 0.0307 |
| $C_{\alpha 2}$ | 0.1041 | 0.1543 | 0.1006 | 0.1156 | 0.1184 |
| Decomposition period (day) | 213 days | 280 day | 213 days | 205 days | 236 days |
| Height of 2nd stage | 5.71m | 6.49m | 6.27m | 6.00m | 6.12m |

The secondary composition indices are plotted in <Fig. 4-1> through the regression analysis. The data in Fig. 4 is for an inner block of 4 stage completely filled layer. The compression index $C_{\alpha 1}$ for 1-A Block is approximately 0.0417, $C_{\alpha 2}$ is about 0.1041 through the regression analysis.

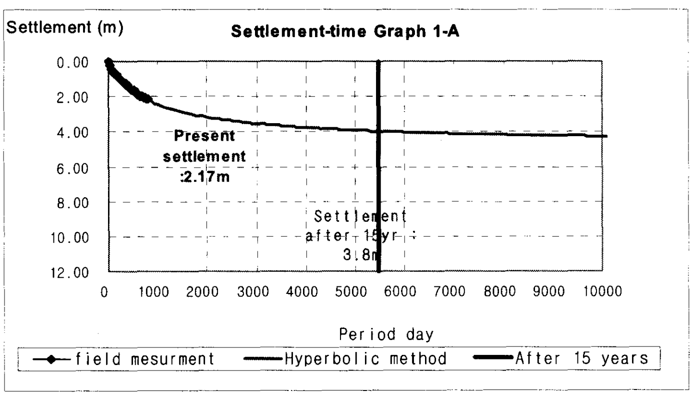



<Fig. 4-1> Secondary compression Index for 1-A Block, lst Layer

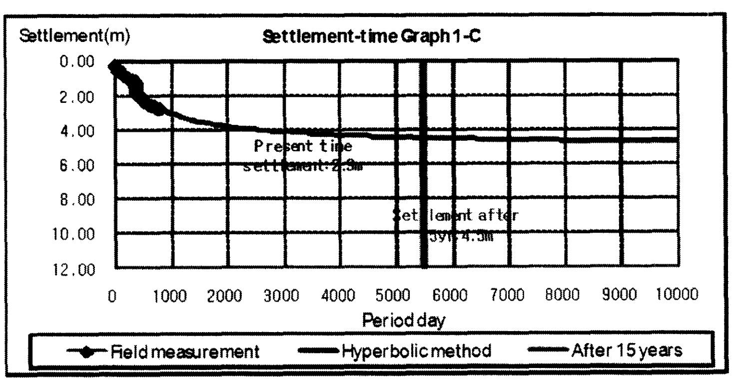
## 3. Long-term Settlement prediction in MSW Landfill site

Currently the 2nd landfill site is divided into two sectors like sector Ⅰ and sector Ⅱ. The waste filling work has been progressed about 3~5 years for Sector land the settlement is being continuously occurred with an average settlement of accumulated 5m while 1~2 years of filling work for sector Ⅱ and the settlement is progressed rapidly with an average accumulated settlement of 2m.

The long-term settlement up to year 2015 for sector Ⅰ (4 staged filled) and sector Ⅱ (2~3 staged filled) are predicted with basis on the field settlement observation. Hyperbolic method was firstly used by Hoe et al.(1998) to predict the long-term settlement of MSW landfill <Fig. 4-2> and <Fig. 4-3> show the results of field settlement observation and also the settlement prediction by using hyperbolic method for 1-A Block and 1-C Block in sector Ⅰ at the 2nd landfill site. From the trend of settlement curves in these figures, the field settlement observation is very much similar to the predicted settlement by hyperbolic method. Some deviation could be happened due to the period of waste land filling.



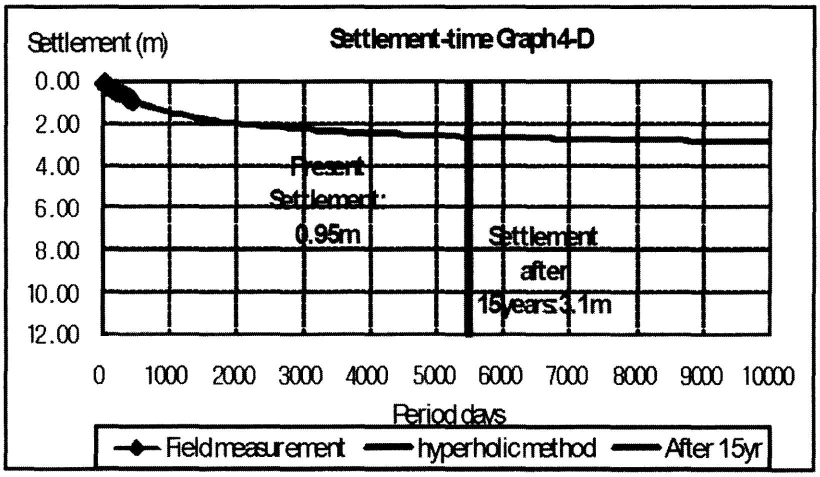

<Fig. 4-2> Settlement with elapsed time for 1-A Block



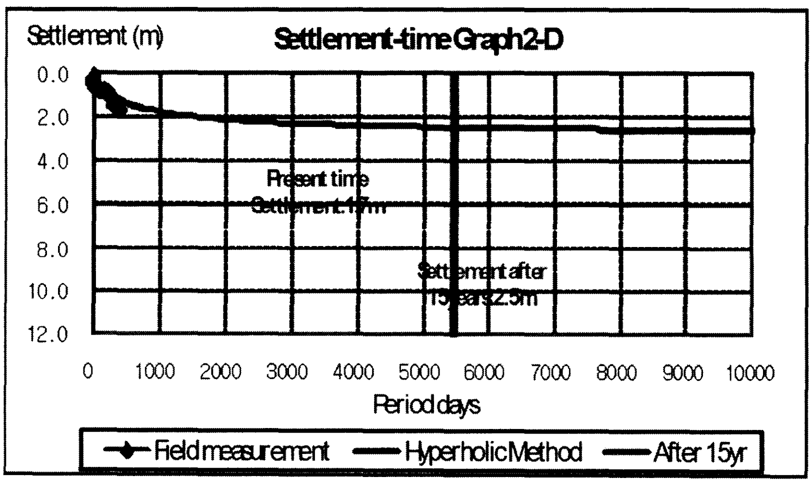

<Fig. 4-3> Magnitude of settlement with elapsed time for 1-C Block

<Fig. 4-4> shows the settlement behavior of 2-D Block of sector Ⅱ. Total field settlement at present time is about 1.7m while 1.4m settlement by hyperbolic method. This deviation (0.3m) is happened because hyperbolic method normally applied for the

long-term settlement with basis on the void ratio versus compression relationship. The prediction of lone-term settlement is estimated as 2.5m for 2-D Block and 3.1 m for 4-D Block in sector Ⅱ in <Fig. 4-5>.

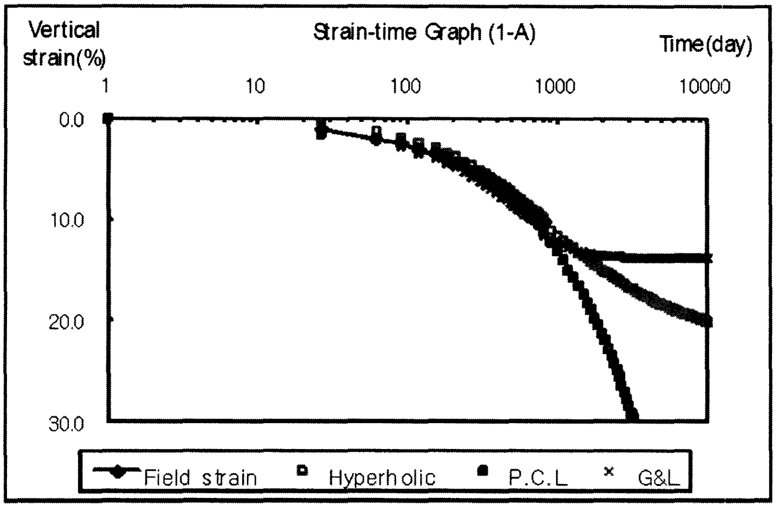



<Fig. 4-4> Settlement trend for 2-D Block in sector Ⅱ

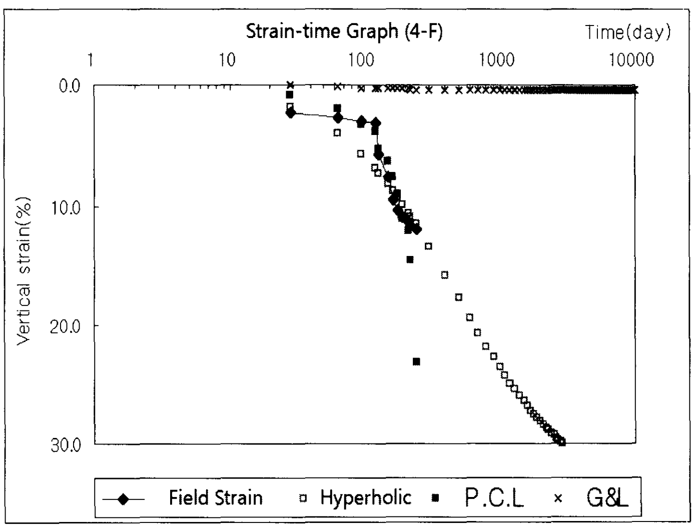



<Fig. 4-5> Settlement trend for 4-D Block in sector Ⅱ

<Fig. 4-6> and <Fig. 4-7> give the long-term settlement estimated by the various method for the 1st Block and the 2nd Block. From this figure, the variation of $S_{ult}H_0$ is similar trend to the variation of $\Delta\sigma \cdot b$ Gibson & Lo method.




<Fig. 4-6> Long-term Settlement for 1st Block

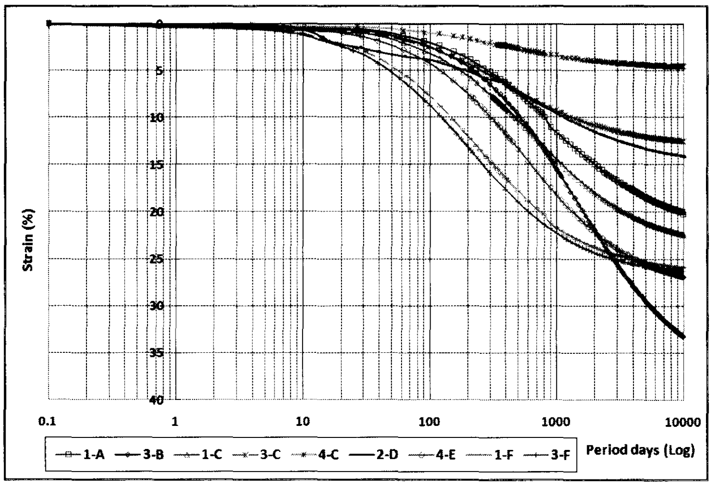



<Fig. 4-7> Long-term Settlement for 2nd Block

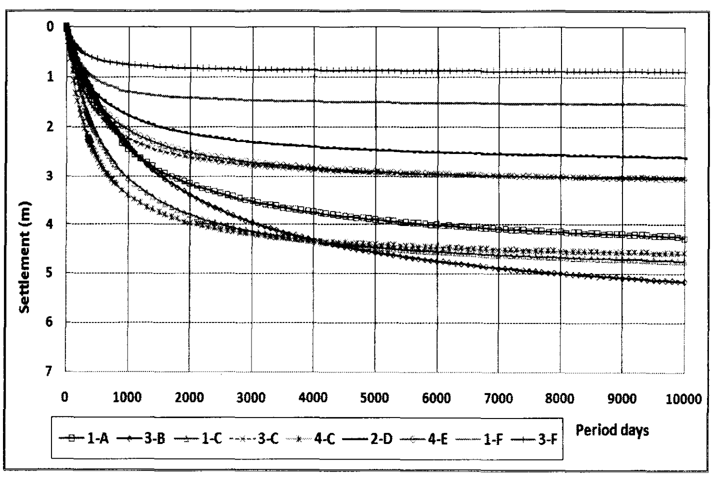
This analysis indicates that the settlement characteristics are depended on the elastic settlement and the long-term settlement due to the decomposition of waste. The long-term settlement due to the decomposition of waste as shown in <Fig. 4-6> and <Fig. 4-7>.

The long-term settlement estimated by the power creep law model gives larger value than other prediction method. This method can be used effectively to estimate the settlement for the fresh waste. The settlement predictions for various blocks by the hyperbolic method are plotted in <Fig. 4-8> and <Fig. 4-9> respectively.

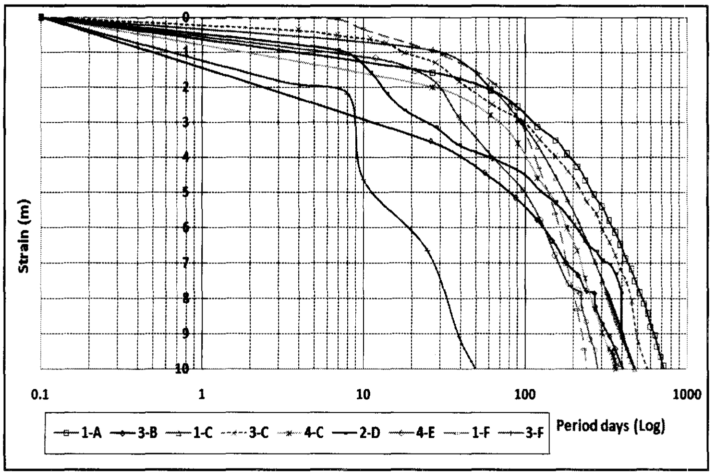
The deformation rate with elapsed time and the settlement trend for the 2nd site by the power creep law model are shown in <Fig. 4-10> and <Fig. 4-11>.



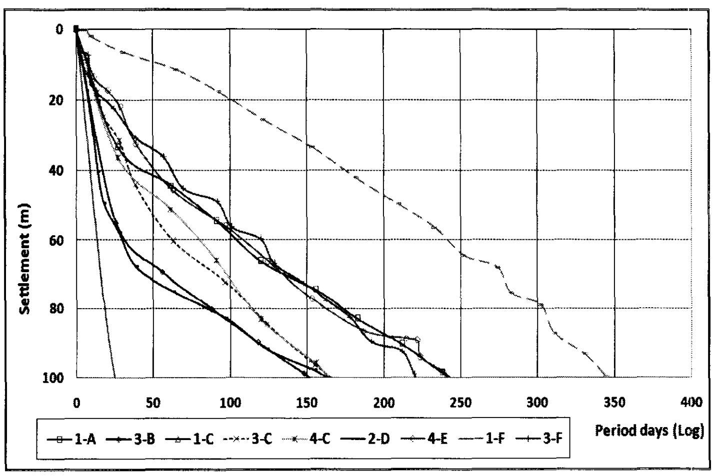

<Fig. 4-8> Deformation rate for 2nd site by hyperbolic method




<Fig. 4-9> Settlement estimation for 2nd by hyperbolic method




<Fig. 4-10> Deformation rate for 2nd site by power creep law




<Fig. 4-11> Settlement trend for 2nd by power creep law

# V. Conclusion

In this study, the compression characteristic of waste were determined due to the surcharge load by the planed height of waste landfill. The compression and volume change of the lower layer of waste landfill are also determined by using hyperbolic model, power creep law model, Gibson & Lo model. From the results of analysis, the following conclusions can be drawn:

The field settlement characteristics are similar to the results by hyperbolic model and Gibson & Lo model. Power creep law model gives a similar result to the field settlement in the first part of settlement, but it gives higher settlement in the final settlement level compare with the results by other methods.

The magnitude of long-term settlement up to year 2015, is about 3.9m for the sector Ⅰ and 2.44m for the sector Ⅱ. The final settlement could by complected in 22 years later after completion of the MSW landfill. The settlement characteristics are categorized into 3 part; elastic settlement by the decomposition of organic waste, long-term residual settlement. The secondary is a major factor to estimate the long-term settlement.

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