Stochastic estimation of consolidation settlement of upper Pleistocene clay, Ma12, layer in Osaka Bay with a particle filter method

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ABSTRACT: There are a number of man-made island in Osaka Bay. In order to maintain and manage the man-made island, we need to predict consolidation behavior. The Pleistocene clay layer of Osaka Bay has few conservation of ground survey and has characteristic consolidation characteristics of pseudo overconsolidation. Therefore, it is difficult to predict its settlement behavior only from indoor test results. Incidentally, in recent years, data assimilation methods have been spreading in various fields. Data assimilation is a method of obtaining a highly accurate predicted value by correcting a simulation by observation value. In this study, data assimilation was carried out using the measured value of the pore water pressure for the subsidence amount for the upper Pleistocene clay (Ma12) layer. And we derived Ma12's future settlement as a probability distribution.
Keywords: Data assimilation, Particle Filter, Consolidation settlement, Pleistocene clay

1. INTRODUCTION

The seabed ground of Osaka Bay, Japan, is composed by thick clay layers and sandy gravel layers, which are accumulated alternately. Therefore, the significant consolidation settlement of the clay layers occurs in the construction of man-made islands in Osaka Bay. The appropriate estimation of consolidation settlement of the man-made islands is necessary to lay the management plan for facilities on the man-made islands.

The Pleistocene clays in Osaka Bay have been called as "quasi-overconslidated clays". Their consolidation behaviors are quite distinguished from those of over-consolidated clays due to loading and unloading histories. Moreover, the in-situ consolidation behaviors are different from those given by consolidation tests in the laboratory, because of some factors which cannot be eliminated, for example, the difference of strain rate in the consolidation process. That is, it is remarkably difficult to estimate the consolidation settlement of the man-made islands in Osaka Bay based on the consolidation properties given through consolidation tests and so on.

By the way, the data assimilation technique has been developed in the weather forecasting, the maritime weather prediction, and so on. Recently, its application to geotechnical problems has been widely spreading. In the data assimilation, firstly, a large number of numerical simulations is carried out. Then, the numerical simulations of which the results match with the field observation results should be selected. After repeating these processes, the analytical results which could match the field observation results are given stochastically.

In this study, the long-term consolidation settlement behaviors of the upper Pleistocene clay (Ma12) layer in the Kobe Airport, which was constructed in the northern part of Osaka Bay, is predicted through a particle filter method (hereafter, PF), one of the most popular data assimilation techniques. Moreover, the applicability of the particle filter method is discussed from stochastic viewpoints.

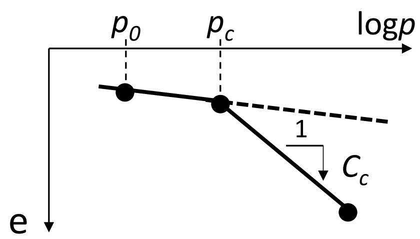

Figure 1 the conceptual diagram of the compression curve

Table 1 the range of each parameter set for analysis

	k (cm/s)	Cc	OCR
Maximum magnification	1.50	1.40	1.04
Minimum magnification	0.67	0.67	0.96

2. DATA ASSIMILATION ANALYSIS

PF is a data assimilation method that approximates the probability distribution on the state of the system with a large number of realization value sets called particles. Each particle has information on a numerical analysis model and information on physical quantities (subsidence amount, pore water pressure, etc.) at each time calculated by simulation in each model. PF also has various algorithms. Sequential Importance Sampling (hereinafter referred to as SIS) [4)] which is one of representative ones will be described. In SIS, we repeat the two calculation steps of one-period prediction and filtering. Then, we estimate a model with a high degree of conformity with the measured values. First, in the first-period prediction, we perform simulations from time *t-1* to *t*. Next, in filtering, we give weight to each particle by Bayes' theorem according to the degree of conformity between simulation result and measured value. We repeat the two steps, taking the sum of the weights calculated at each time step. This gives more weight to the particles that fit the measured values. As a result, we can estimate models with a high degree of conformity to actual measurements.

In this research, the simulation model we used is one - dimensional specialized soil - water coupling analysis. Figure 1 shows a conceptual diagram of the compression curve used in this study. This model assumes a one-dimensional consolidation state. Therefore, the compression curve is a general e-log p 'relationship. Therefore, we need to identify the compression index Cc and over compaction ratio OCR. We assimilate the three parameters of these parameters and the permeability coefficient k which determines the consolidation rate. Table 1 shows the range of each parameter set for analysis. We set these ranges considering variations in the soil test results. In the analysis, we created 700 particles with parameters randomly

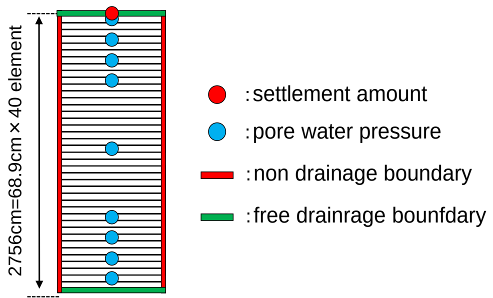

Figure 2 the one-dimensional analytical model determined within this range. Also, we assumed that the error of the measured values follows the normal distribution. In addition, we decided that standard deviation is 1 (cm) for settlement amount and 0.3 (kgf/cm^2) for pore water pressure. In addition, we decided that the error covariance of subsidence and pore water pressure is 0.

3. MEASURED VALUE USED FOR DATA ASSIMILATION

In this study, we used the data of settlement and pore pressure measured at Ma12 (layer thickness of about 27m) of Osaka Bay Miocene clay from 2002 to 2014 as actual measurement values used for data assimilation. Figure 2 shows the one-dimensional analytical model used in this study. The red circle on the analysis model shows the measurement position of the settlement amount (1 depth). The blue circle shows the measurement position of pore water pressure (9 depth, 0, 2, 4, 6, 13, 20, 22, 24, 26 m from the top).

4. DATA ASSIMILATION RESULT AND PREDICTION OF FUTURE SETTLEMENT AMOUNT

Figure 3 shows the temporal change of measured values of settlement amount and settlement amount identified by data assimilation. In addition, we decided the settlement amount that weighed average was identified from the weight distribution obtained after data assimilation. Also, Figure 4 shows the probability distribution of the subsidence amount after data assimilation at 2014. And, Table 2 shows weighted average and standard deviation of the probability distribution. The probability distribution of the settlement amount, which we have derived is a weighted average 67.15cm, the probability distribution of the standard deviation of 4.2cm.

Using this result, we derive the probability distribution of the subsidence amount of Ma12 layer about 40 years later. Figure 5 shows the temporal change of the predicted value of the settlement amount up to 2051 and the actual measurement value of the settlement amount. Figure 6 shows the probability distribution of the settlement amount at 2051. Table 3 shows the average of the predicted values of the settlement amount at 2051 and its standard deviation. The probability distribution of the amount of settlement of the Ma12 layer at 2051 we found is a probability distribution with an average of 115.38 cm and a standard deviation of 16.07 cm.

5. CONCLUSION

In this study, we performed data assimilation based on measured values of settlement amount and pore water pressure for Osaka Bay Kuroku clay layer (Ma12). And we derived the probability distribution of future sinking amount of Ma12. As a result, the settlement amount of Ma12 at 2051 can be represented by the probability distribution with an average of 115.38 cm and a standard deviation of 16.07 cm.

6. REFERENCES

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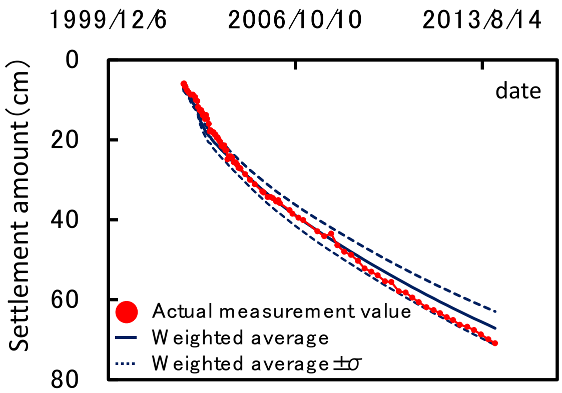

Figure 3 Change with time of settlement amount

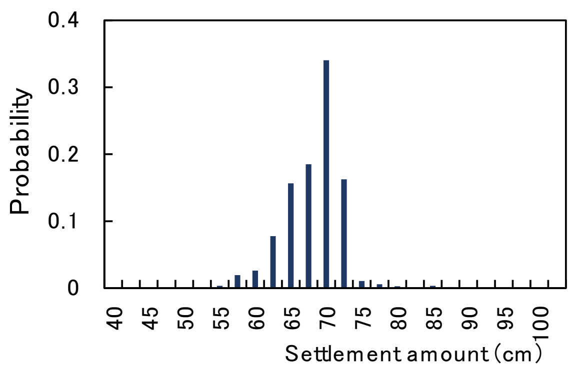

Figure 4 probability distribution of the subsidence amount after data assimilation at 2014

Table 2 weighted average and standard deviation at 2014

	Weughted Average	Standard Deviation
After Data Assimilation	67.15	4.20
Actual Mesurement Value	70.90	
		(cm)

Figure 3 Weighted average and Standard deviation at 2051

2051	Weighted Average	Standard Deviation
Settlement Amount	115.38	16.07
		(cm)

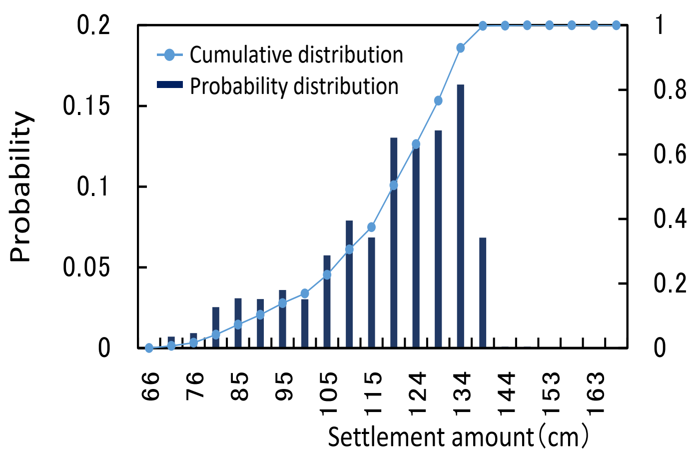

Figure 6 Probability distribution of settleatment amount 2051

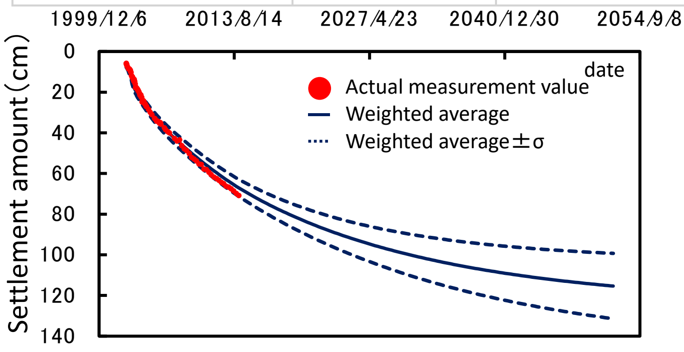

Figure 5 Change with time of settlement amount to 2051