Modification method of ground model for reclamation analysis of dredged clays with high accuracy

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ABSTRACT

The ground surface of reclaimed ground with dredged clays settles due to self-weight consolidation for a long term. In the case where the vertical drains are installed in such a reclaimed clay ground, the settled space can receive additional dredged clays. In this paper, the modification method of ground model for the reclamation analysis using the results of ground surveys was proposed to obtain the prediction of time-mud surface elevation in the disposal pond with high accuracy, and the numerical results for the area III of Shinmoji-Oki disposal pond was reported.

Keywords: dredged clay; disposal pond; prediction method, reclamation analysis, ground survey

1 INTRODUCTION

Recently, navigation channels and anchorage area are required for extending and deepening as the cargo ships become huge. To extend and deepen the navigation channel, the dredging of sea bottom is carried out. The sea bottom soils generated by the dredging work is discharged into the disposal pond surrounded by the dykes in the sea in order to protect the marine environmental condition.

The Shinmoji-Oki disposal pond shown in Fig.1 has been received a large amount of dredged clays generated from dredging project of Kanmon Waterway and near navigation channels, and the vacant capacity of this disposal pond has been decreasing. In such a case, to create the proper plan of dredging project up to the full of disposal pond, it is necessary to predict the relationship between time and elevation of mud surface in the disposal pond with high accuracy. Therefore, the modification method of ground model for reclamation analysis in consideration with the results of ground surveys is proposed, and the results of reclamation analysis using the proposed method is reported.

2 OUTLINE OF SHINMOJI-OKI DISPOSAL POND

Figure 1 shows the Strait of Kanmon between the Honshu and Kyushu Islands in Japan. Kanmon Waterway located in this Strait is one of the busiest sea routes in Japan. To accommodate larger ship traffics, the dredging in this waterway has been conducted, and the dredged materials, mostly clays have been discharged into the Kanda-Oki and Shinmoji-Oki disposal ponds shown in Fig.1

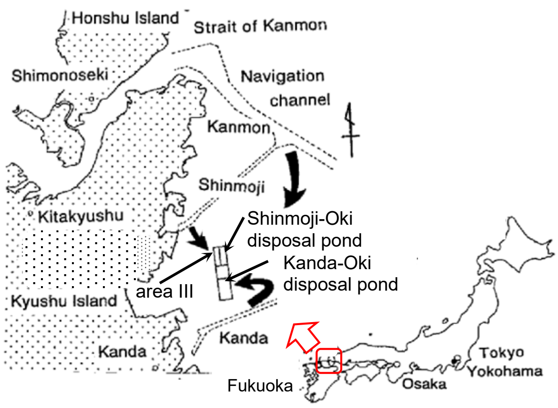


Fig. 1. Site of Shinmoji-Oki disposal pond.

The Shinmoiji-Oki disposal pond is separated into three areas, area I, II, and III. Here, the area I and II were reclaimed with dredged clays up to 2002, and are now used as an airport. At present, the area III is working as a disposal pond, and it warries to be short of capacity of disposal pond up to the open of a new one.

Figure 2 shows a plan view of area III of Shinmoji-Oki disposal pond. In the same figure, two (north and south) excavated parts and five points of ground surveys are drawn. From 1998 to 2001, two excavated parts were dredged from the original sea bottom with DL-7 m to about DL-22 m, in order to use as reclamation materials for the airport construction.

From 2003, the sea bottom materials dredged from navigation channels around this disposal pond have been discharged into the area III. In this dredging work, the drag-suction ship and grab dredger were used. The dredged clays generated by the former were discharged into the pond by the pipe line, and those by the latter were reclaimed by the belt-conveyer around the west revetment of area III. Total amount of dredged clays up to 2010 was about 9,700,000 m^3 at the dredged site. The dredged volume by the grab dredger was about 3,580,000 m^3 and its ratio was approximately 0.4. From 2011 to 2017, the dredging work using only a drag-suction ship was performed, about 3,450,000 m^3 of dredged clays were reclaimed in the area III.

To increase the capacity of area III, several projects were carried out from 2011 (Nakamichi, et al., 2015). The height of extra-fill of 4 m was constructed with the mechanical dewatered clay lumps from 2011 to 2014. The construction of extra-fill generated about 2,150,000 m^3 of capacity increment for disposal pond. Moreover, the ground improvement works using plastic board drains (PBD) in and around the two excavated parts at the area III were performed from 2013 to 2015.

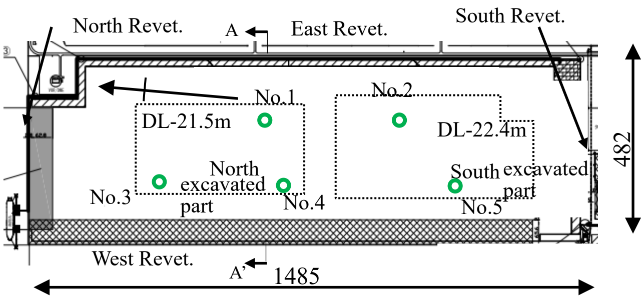


Fig. 2. Outline of area III and sites of ground surveys.

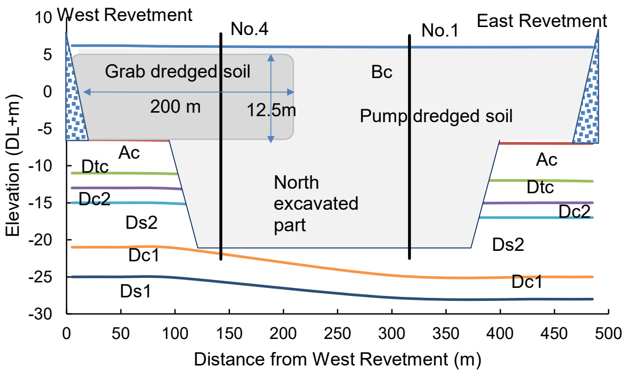


Fig. 3. Soil profile at A-A' plane of area III at 2012.

Figure 3 shows the soil profile at the A-A' plane of area III for the conceptual design of vertical drain method. The occupied space of grab dredged soil was assumed as a rectangular parallelepiped with 1430*12.5*200 m because the total volume of grab dredged soils and the elevation of mud surface at 2010 were approximately 3,580,000 m^3 and DL+5.5 m.

3 RESULTS OF FIVE GROUND SURVEYS

To confirm the condition of ground installed PBD's, the ground surveys at five points shown in Fig.2 were performed in July 2016 at No.1-No.3 and in July 2017 at No.4 and 5. Figure 4 shows the distributions of water content, liquid limit, water content normalized by liquid limit (w/w_L), and fine fraction content (F_c). The elevations of mud surface at the installation of PBD's at No.1, 2 and No.3 – 5 reached DL+1.0 – +1.5 m and DL+3.5 – +4.0 m, respectively. It was clear that the settlements of No.3 – 5 near the west revetment of area III were smaller than those of No.1 and 2.

The water content, liquid limit and fine fraction content of soils from DL-5 to -10 m at No.3, 4 and 5 were 25 – 60 %, 28 – 70 %, and 15 – 60 %, respectively. It was considered that this stratum was piled up sandy clay with low plasticity, caused by the reclamation of grab dredged materials up to 2010. Because of the consolidation of improved layer, the elevation of layer accumulated grab dredged materials went down from the original model at the design of vertical drain.

The w/w_L – depth relations were located in a narrow area in spite of the depth and place. The w/w_L values of layer improved by vertical drains were from 0.7 to 0.9, and the value at deep position became smaller caused by the overburden pressure. On the other hand, those accumulated on the improved layer were above 0.9.

4 MODIFICATION METHOD OF GROUND MODEL

In this project, the reclamation program named as CONAN (Katagiri et al., 2001) was used to explain the history of discharging of dredged clays. Here, the CONAN was developed based on the general one-dimensional consolidation theory with the constitutive equation not to take viscosity into account.

The modification method of ground model to obtain the prediction with high accuracy are as follows. Here, the initial model was the ground model predicted using reclamation analysis at the design of vertical drain (Nakamichi, et al., 2015).

i) The distribution of solid height at unit thickness for the initial model, h_{su_i} and total solid height of h_{su_i}, h_{s_i} were calculated. Here, the solid height meant the volume of soil particles at a unit size.

ii) From the distribution of measured water contents, the distribution of solid height at a unit thickness for the actual ground, h_{su_m} and total solid height of h_{su_m}, h_{s_m} were calculated.

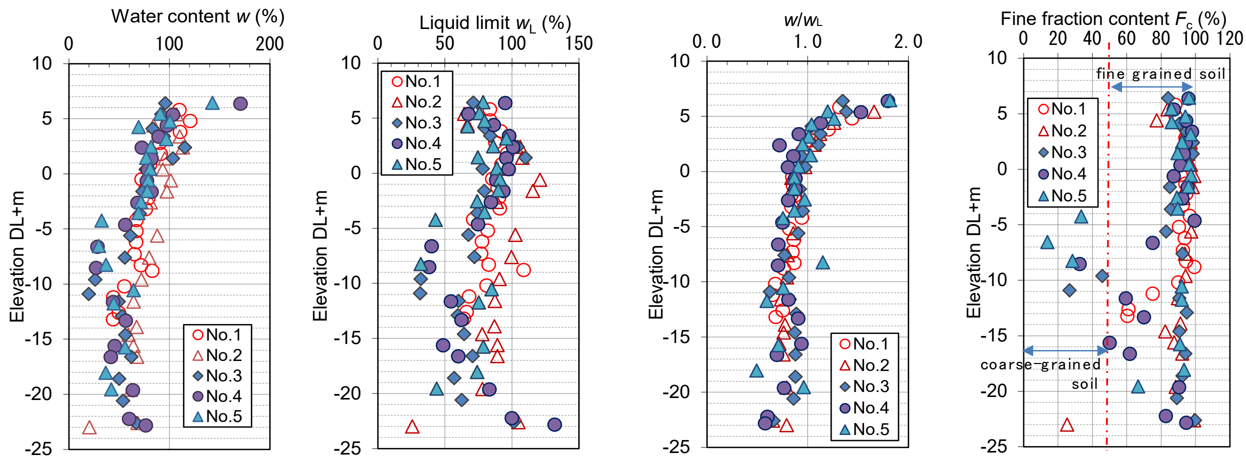
iii) A modified model for the back-analysis was assumed as h_{s_m} and the water content of discharged clay was changed.

iv) A back-analysis to the modified model was performed using the consolidation parameters at the initial analysis.

v) The result of back-analysis was evaluated in comparison with measured data such as time-mud elevation and water content distribution.

vi) In the case where the result of back-analysis was disagree with the measured data, returned to iv) using the modified consolidation parameters.

vii) In the agree case, the adequacy of modified consolidation parameters were judged. The adequacy of consolidation parameters was used the relationship between liquid limit and consolidation



(a) water content (b) liquid limit (c) w/wL (d) fine fraction content

Fig.4. Results of ground surveys performed at No.1 – No.5.

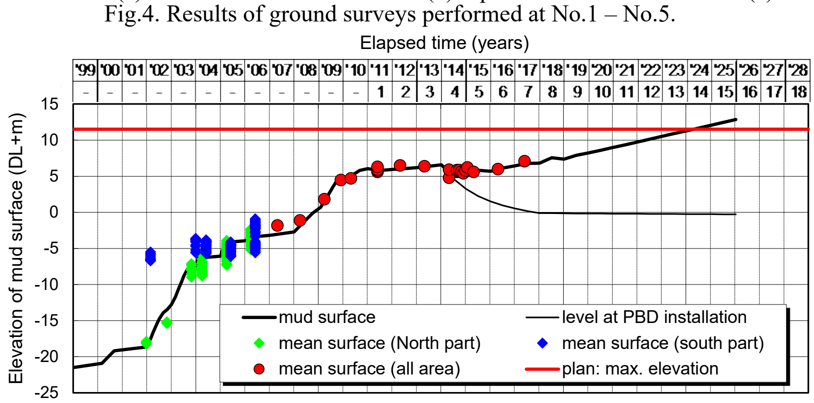
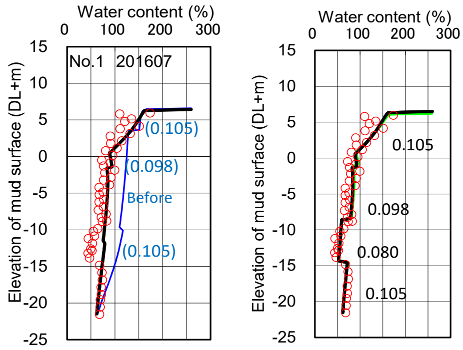


Fig.5. Time – elevation of mud surface relation in north part with pump-dredged clay.



(a) original model (b) after modification

Fig. 6. Water content distribution.

parameters reported by Egashira et al., (2001).

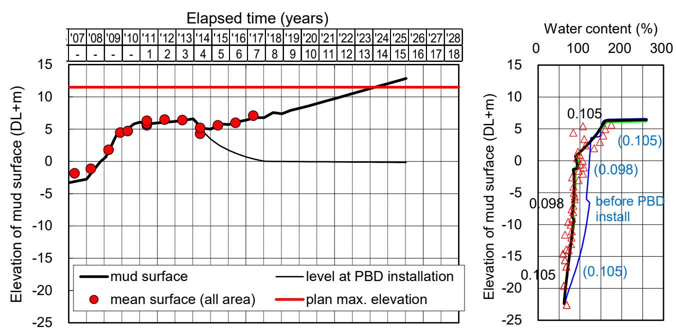
5 RESULTS OF RECLAMATION ANALYSIS USING MODIFIED MODEL

Figure 5 shows the calculated relation of time and elevation of mud surface in the north excavated part during the reclamation with pump-dredged clay, using the proposed method. The fine solid line in the same figure means the relationship between time and mud surface level at the PBD installation.

Figure 6(a) is the water content distributions obtained from the ground survey and the result of prediction at the design, and Fig. 6(b) is the result of back-analysis using the proposed method. The water content of dredged clay at the stratum from DL-15 to -10 m is changed as the result of the modification of α-value as shown in Figs. 6(a) and 6(b). Here, the α-values mean a slope of log p – log f (=1+e).

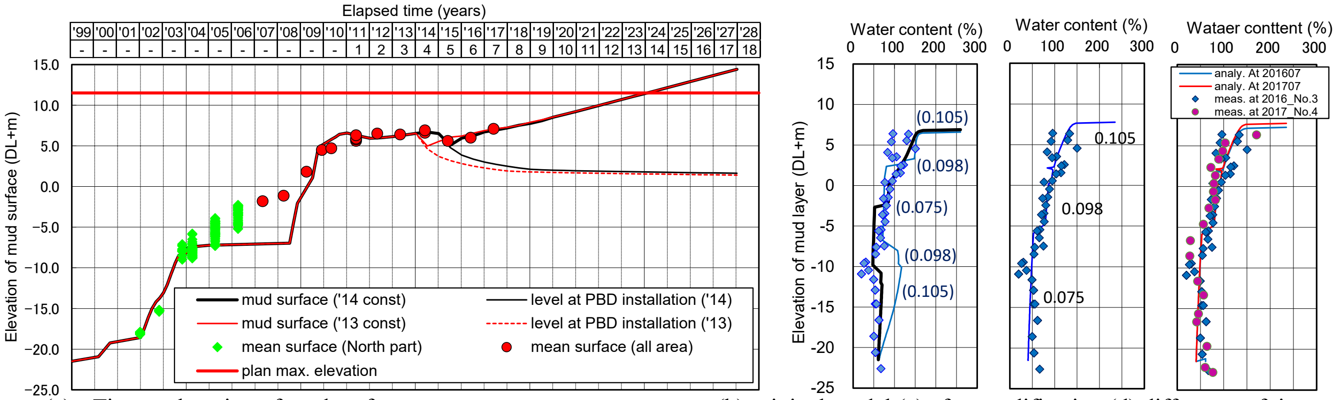
Figure 7 shows the relations of time and mud surface, and the water content distributions at July 2016 in the south excavated part with pump-dredged clay. In this case, the modification was not performed because the result of back-analysis was in agreement with the measured data.

Figure 8(a) shows the modified relations of time and elevation of mud surface in the north excavated part including with the grab dredged clay, using the proposed method. In this area, the installation of PBD's were performed at 2013 and 2014. The ground survey points of No. 3 and 4 shown in Fig. 2 were respectively located in the PBD installation areas of 2013 and 2014. These relationships between time and mud surface level installed the PBD's differed as shown as the fine black solid and red fine broken lines. The relations of time and mud surface elevation differed because of the timing of installation of PBD's. However, these lines were piled up after the installation of PBD at 2015. Here, from 2004 to 2009, the numerical result disagreed with the measured data. This was assumed that the grab dredged clay of 2,780,000 m^3 reclaimed from 2008 to 2009 pushed out the accumulated clay up to DL-7 m. This assumption was caused by the fact where the grab dredged clay occupied from DL-7 m to DL+5 m was confirmed by the ground survey at 2011.



(a) time-elevation of mud surface (b) distribution of w

Fig. 7. Results of back-analysis in south part.

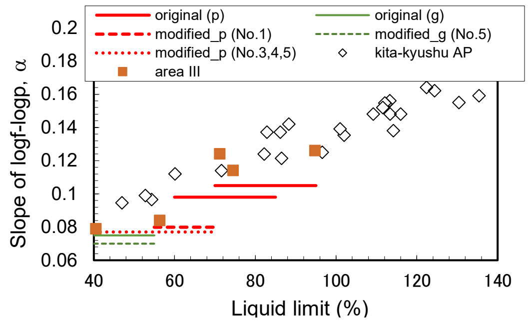


(a) Time – elevation of mud surface (b) original model (c) after modification (d) difference of time

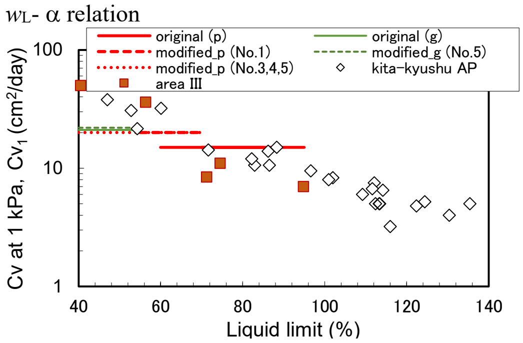
Fig. 8. Results of back-analysis in north excavated part with grab dredged clay.

Figure 8(b) shows the numerical results of water content distribution before and after 3 years from the installation of PBD's using the original ground model at the initial design. Figure 8(c) shows the water content distribution of modified model at July 2016. The numbers in those figure are the α-value, and the α-value of layer below DL-5 m was set at 0.075 in consideration with the distribution and some scatter.

Figure 8(d) shows the water content distributions of the north excavated area with grab-dredged clay at July 2016 and July 2017. The measured data of No.4 drawn in the same figure are smaller than those of No.3 obtained at July 2016, and the progress of consolidation was confirmed. The numerical results by the same ground model at two points are approximately expressed the water content distributions at the same time and the difference of time.



(a) w_L- α relation



(b) w_L and C_{v1} relation

Fig. 9. Relationships between w_L and α, C_{v1}.

Figure 9 shows the relationships between liquid limit and original consolidation parameters at the design expressed as solid lines, and identified consolidation parameters using the modified ground model expressed as broken lines. In the same figures, the relationships between liquid limit and consolidation parameters obtained from the multi sedimentation tests for the clays from Kitakyushu airport (Egashira, et al., 2002) and from area III (Kunita, et al., 2017).

The consolidation parameters of original ground model expressed as solid lines are located in the below part of range of past data in the w_L - α relation, and in the center part of range of past data in the w_L - C_{v1} relation. Here, the C_{v1} means the value of C_v at the consolidation pressure of 1 kPa. Moreover, the identified consolidation parameters of modified ground model expressed as broken lines are also located in the below part of range of past data in the w_L - α relation, and in the below part of range of past data in the w_L - C_{v1} relation. It is concluded that the identified consolidation parameters are located in the narrow zone obtained from the past data, and are appropriate from the point of clay properties.

6 CONCLUSION

From the results of ground surveys, the modification method of ground model for reclamation analysis of dredged clays was proposed, and its appropriateness was confirmed from the results of back analysis to the area III of Shinmoji-Oki disposal pond and the evaluation of identified consolidation parameters in consideration of the liquid limit of clay.

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