Case Studies of PSDDF Application for Phased Placement of Dredged Soils

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A technical paper submitted for review and possible publication in
Marine Georesources & Geotechnology

October 27, 2011

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Abstract: Use of Terzaghi's one-dimensional consolidation theory is not recommendable in case of consolidation of highly deformable soft clays such as dredged soils. To deal with this special condition, it is necessary to consider non-linear finite strain consolidation behavior. A one-dimensional non-linear finite strain numerical model, PSDDF (Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill), has been widely recognized as a useful tool to predict the settlement of fine-grained dredged materials. In this paper, two case studies of using PSDDF are discussed to illustrate the applicability and accuracy of PSDDF. The first case study is to discuss a series of PSDDF simulations for laboratory phased placement of a marine clay dredged from Busan, Korea. The other is an expectation of service life of Craney Island Dredged Material Management Area near Norfolk, Virginia, in the United State. The excellent agreement between measured and calculated values shows PSDDF is a reliable tool to predict the settlement of dredged material if representative input parameters are used.

Keywords: non-linear finite strain consolidation, PSDDF, dredged material placement, phased placement

INTRODUCTION

The thickness of dredged fill is gradually decreased by the process of sedimentation, primary consolidation, secondary compression, and desiccation. Such processes can be fully implemented in the microcomputer program PSDDF (Stark et al. 2005a, b). The sedimentation process is completed shortly after dredged material deposition and therefore is not included in PSDDF because it has little, if any, effect on the long-term storage capacity or service life of a placement area.

The major input parameters governing the primary consolidation calculation in PSDDF are the void ratio-effective stress and void ratio-permeability relationships obtained from a series of laboratory consolidation tests. Cargill (1986) described recommended laboratory testing procedures to obtain these relationships. Once the initial void ratio and boundary conditions are defined, and appropriate relations of void ratio-effective stress and void ratio-permeability are specified, the void ratio in soil layers under consolidation can be calculated by the finite difference technique in PSDDF for any future time. The void ratio distribution in the saturated dredged fill layer is used to calculate the corresponding effective stresses and pore-water pressures, and thus the degree of consolidation can be estimated.

Two case studies of using PSDDF were carried out to illustrate the applicability and accuracy of PSDDF. The first case study is to discuss a series of PSDDF simulations for laboratory phased placement of a marine clay dredged from Busan, Korea. Using the effective stress-void ratio-permeability relationship obtained in laboratory experiments for the dredged soil obtained from Busan, a series of PSDDF simulations have been conducted. A laboratory test was performed to verify the results of PSDDF simulation. The filling schedule and layer thickness at each stage were made identical with the PSDDF simulation condition. The other is an evaluation of service life of Craney Island Dredged Material Management Area near Norfolk, Virginia, in the US.

INPUT PARAMETERS FOR PSDDF

Initial void ratio

The initial void ratio (e00) is the void ratio at which sedimentation ceases and self-weight consolidation commences. The effective stress in the dredged material at this point is assumed to be zero. In PSDDF, a appropriate value of the initial void ratio is required for every dredged material and it is the starting point for the

self-weight consolidation calculation. The initial void ratio can be chosen from a curve-fitting to the void ratio-effective stress relationship from the self-weight consolidation test (Cargill 1986). Abu-Hejleh et al. (1996) indicated that the initial void ratio could be obtained by carefully sampling from the surface of the settled clay at the end of self-weight consolidation. However, because the initial void ratio is difficult to measure in common laboratory experiments, it is desirable to develop a correlation between initial void ratio and more measurable index properties of a given material such as PI or LL (Morris 2007, Stark et al. 2005a, b). Figure 1 shows schematically void ratio distribution after placement of a new dredged layer over the old dredged layer in which self-weight consolidation is carrying out.

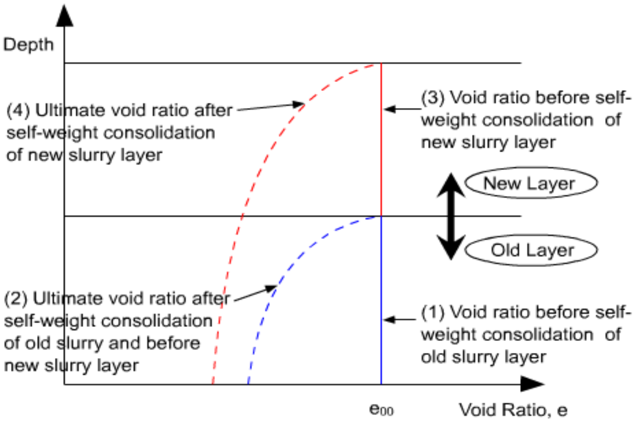


Fig. 1 Void ratio distribution after placement of new dredged layer

Effective stress-void ratio-permeability relationships

The major parameters controlling the primary consolidation behavior of dredged material are the void ratio-effective stress and the void ratio-permeability relationships. Defining these relationships requires two types of laboratory consolidation tests. A self-weight consolidation test yields the void ratio-effective stress and the void ratio-permeability relationships at the effective stress less than about 1.0 kPa. The large strain consolidation test or the CRS consolidation test provides the relationships at the effective stresses greater than 1.0 kPa. The results of the two tests should be combined to obtain the void ratio relationships for the range of effective stresses encountered in the disposal area (Cargill 1986).

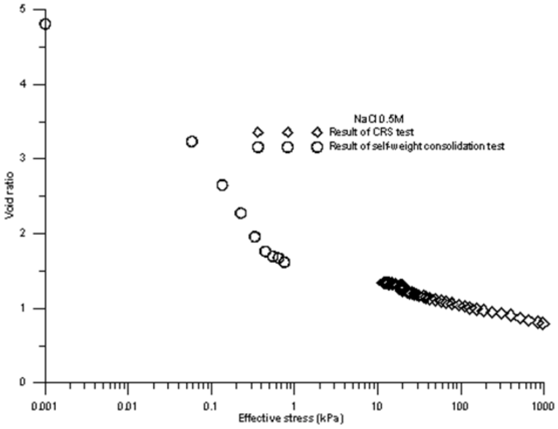
CASE 1: LABORATORY PHASED PLACEMENT OF BUSAN MARINE CLAY

Soil Index Properties

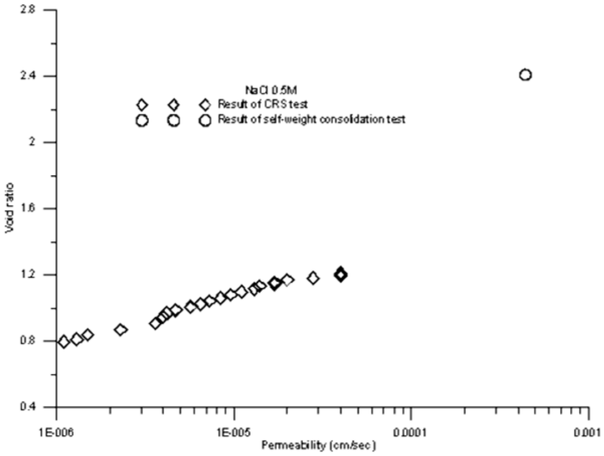
Because the purpose of this study is to simulate numerically and experimentally the phased placement of a dredged soil, a marine clay from the new port site in Busan was sampled and used in this study. Its index properties measured in the laboratory as follows: Specific gravity = 2.67, Plastic limit = 24.6%, Liquid limit = 36.2%. The marine clay is classified as CL according to USCS. To maintain uniformity of soil specimen, the clay sample is oven-dried and passed through a #40 sieve.

PSDDF Input Parameter

The initial void ratio of the given soil specimen in this study is measured as about 4.8. This value will be an initial value for both the numerical and experimental simulations. For the input parameters in the simulation of PSDDF, a series of the self-weight consolidation tests and the CRS test has been performed to set up the void ratio-effective stress and void ratio-permeability relationships for the dredged marine clay mixed with NaCl 0.5M solution adjusting sea water salinity as shown in Figure 2. The permeability at the low effective stress level is evaluated by implementing the linearized finite strain consolidation theory (Cargill 1986, Morris 2002).



(a) Void ratio-effective stress relationship



(b) Void ratio-permeability relationship

Laboratory Experiment

A laboratory experiment was carried out to compare with results of the PSDDF simulation. To perform the laboratory simulation, an acrylic column was designed in this test. The column is made of transparent acrylic, of which shape is cylindrical with an inside diameter of 15cm. It consists of 10 separable segments with the height of 10cm to facilitate sampling. To evaluate excess pore water pressure during the consolidation process, a set of standpipes is equipped. The experimental equipment and measurement system are described in Figure 3. During the laboratory simulation, the change of surface elevation and the profile of excess pore water pressure at each time step have been measured to compare with the results of the PSDDF simulation. Three filling steps have been scheduled in the laboratory simulation. The height of each filling step was 26.5cm. The filling schedule and layer thickness at each stage are identical with the PSDDF simulation condition.

Fig. 3 Experimental equipment of laboratory test

Comparison between Numerical and Experimental Simulations

Figure 4 shows the comparison of surface elevation changes between the laboratory measurement and PSDDF simulation. As can be seen in Figure 4, the laboratory test results correspond overall well with the results of PSDDF simulation. Comparing to the surface settlement measured in the laboratory test, the PSDDF simulation slightly underestimates the surface settlement. One of the reasons for this discrepancy seems to be attributable to the effect of secondary compression that is not considered in the present PSDDF simulation because the parameters of the secondary compression were not obtained in the current laboratory testing program.

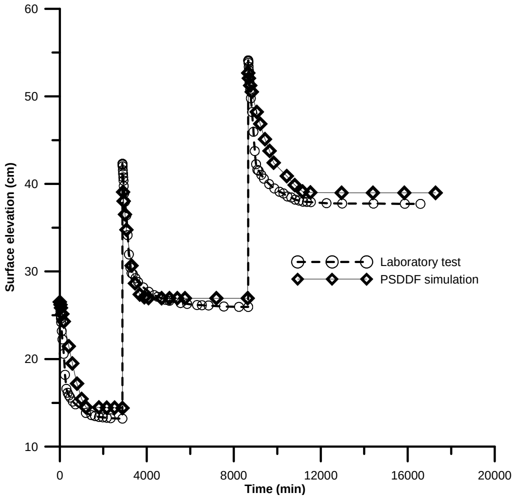
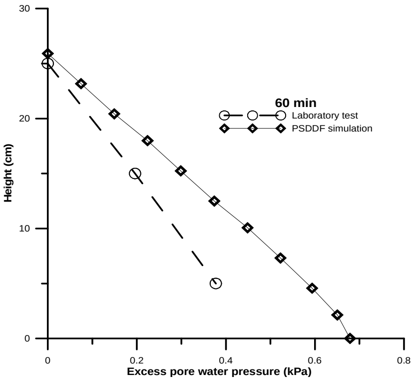


Fig. 4 Comparison of surface elevation changes between laboratory test

and PSDDF simulation

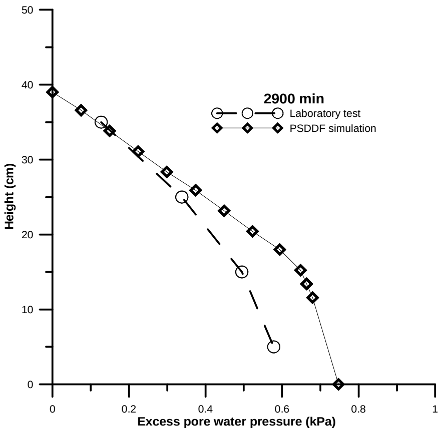
Figure 5 provides for the comparison of excess pore water pressure distribution between the laboratory measurement and PSDDF simulation at each filling stage. The trends of excess pore water pressure distribution between the laboratory test result and PSDDF simulation are similar to each other except for the very early time of simulation. The excess pore water pressure resulted from the PSDDF simulation has a tendency to show a little larger value in early time. It may be attributed partly to a time gap between the laboratory test and PSDDF simulation. The reported times on the graphs are based on the measured time of laboratory test. The printout times of the PSDDF simulation are slightly different from that of laboratory test. For example, a 60 minute in the PSDDF simulation means the time of 57.6 minute exactly.



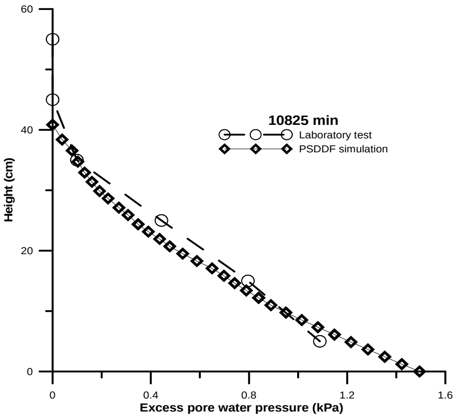
(a) Filling stage 1 (60 min)

Fig. 5 Comparison of excess pore water pressure distributions

between laboratory test and PSDDF simulation results



(b) Filling stage 2 (2900 min)



(c) Filling stage 3 (10825 min)

Fig. 5 Continue

CASE 2: EVALUATION OF SERVICE LIFE OF CRANEY ISLAND

To illustrate the applicability of PSDDF, another case study involving the service life and long-term filling schedule for the Craney Island Dredged Material Management Area (CIDMMA) near Norfolk, Virginia, is presented. Stark et al. (1994) presented a case study for this site using a prior version of PSDDF, PCDDF89. They illustrated the applicability of PCDDF89 by showing the simulation results of PCDDF89 in good agreement between field survey results and calculated settlements. In this paper, the Craney Island Dredged Material Management Area (CIDMMA) is reanalyzed using PSDDF, which considers secondary compression, and using recently updated filling schedules for dredged materials and field survey results to investigate the accuracy and usefulness of PSDDF.

Since 1956, the Craney Island Dredged Material Management Area (CIDMMA) has been used for containment of dredged material from navigable channels and harbors near Hampton Roads, Virginia. The 8.9 square kilometer area has received most, if not all, of the annual 3.1 to 5.4 million cubic meters of fine-grained dredged material that is dredged in the Norfolk/Hampton Roads area.

The CIDMMA was expected to exhaust capacity around the year 2000 (Palermo and Schaefer 1990). However, if only selected unsuitable (i.e., contaminated) material could be placed in the CIDMMA, the service life could be extended. An analysis of the service life of the CIDMMA under the Restricted Use Program (RUP) was conducted by the U.S. Army Engineer Waterways Experiment Station to evaluate the benefits of the RUP (Myers et al. 1993). A simulation of the filling history from 1956 to 1984 is compared to field settlement data to calibrate the input parameters for conditions existing prior to subdivision of the area and implementation of dewatering operations. Two cross dikes were constructed in 1983 to divide the 8.9-km^2 (2200-acre) placement area into three compartments. Simulations of filling history from 1983 (the time of cross dike closure) to 1992 were conducted for each of the three compartments in the CIDMMA. Finally, simulations of projected filling rates from 1992 are used to determine the service life for the north compartment of the CIDMMA under the proposed RUP. Stark et al. (1994) and Myers et al. (1993) provide additional details on the CIDMMA and the dredging scenario.

PSDDF Input Parameters

The void ratio-effective stress and void ratio-permeability relationships for both the dredged fill and compressible foundation material for Craney Island, Virginia, were obtained from the published reference (Stark et al. 2005b), and used to evaluate the service life of the north compartment of the CIDMMA under the proposed RUP. The void ratio–effective stress and void ratio-permeability relationships were obtained from the results of self-weight and large strain, controlled rate of strain (LSCRS) consolidation tests. Additional consolidation parameters such as the ratios of C_r/C_c and C_α/C_c, void ratio, and permeability of incompressible foundation were estimated from the consolidation and index property tests and are presented in Table 2. The desiccation parameters used in the simulation represent an active dewatering condition. The average monthly pan evaporation and precipitation used for the simulation are obtained from Brown and Thompson (1977) and National Climatic Center (1980), respectively.

Table 1 Input Parameters for CIDMMA Simulation

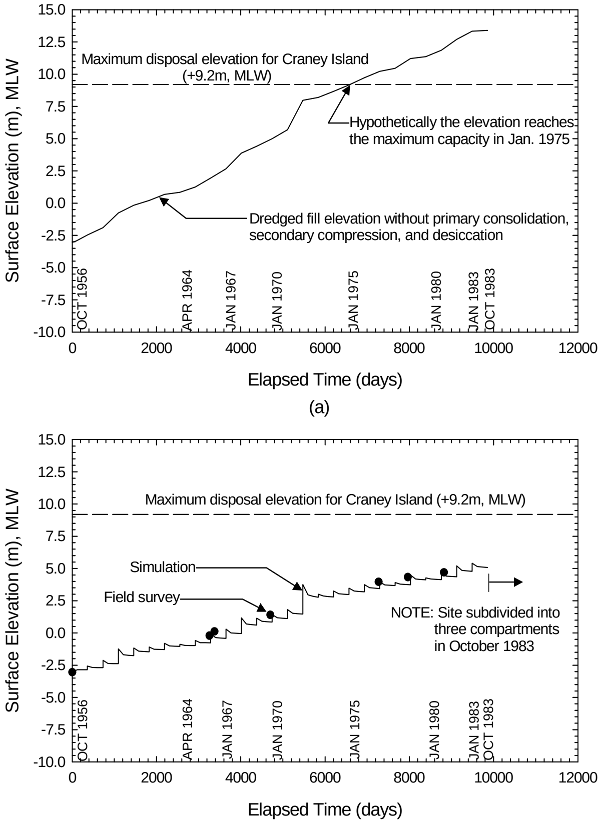
Parameter	Values
Surface drainage efficiency	100 %
Maximum evaporation efficiency	100 %
Saturation at end of desiccation	80 %
Maximum crust thickness	0.31 m
Time to desiccation after filling	30 days
Elevation of fixed water table	0.46 m (MLW)
Void ratio at saturation limit	6.5
Void ratio at desiccation limit	3.2
Initial void ratio (zero-effective stress)	10.5
C_r/C_c	0.2
C_α/C_c	0.04
Void ratio of incompressible foundation	0.65
Permeability of incompressible foundation	10^{-7} cm/s

Simulation Results

Simulation of the filling history from October 1956 to October 1983 is shown in Fig. 6. The main objective of this simulation was to calculate the void ratio and effective stress profiles in the dredged fill and compressible foundation in October 1983 (the time of cross dike closure). For comparison purposes, the surface elevation of accumulated dredged fills without primary consolidation, secondary compression, and desiccation is plotted in Fig. 6(a). It can be seen that the surface elevation reaches the designated maximum placement elevation around January 1975. Obviously, settlement was occurring from October 1956 to January 1975, and thus the CIDMMA did not reach the maximum surface elevation in January 1975. This illustrates the importance of incorporating estimates of the primary consolidation, secondary compression and desiccation in planning activities.

Another simulation was conducted to incorporate the effects of primary consolidation, secondary compression, and desiccation using PSDDF, see Fig. 6(b). It can be seen that the results are in excellent agreement with the measured surface elevations. In summary, PSDDF provides a reasonable estimate of settlements of the dredged fill and compressible foundation induced by primary consolidation, secondary compression, and desiccation at the CIDMMA.

The calculated void ratio and effective stress profiles reflect the consolidation and desiccation that occurred between October 1956 and October 1983. These profiles are used as a starting point for subsequent simulations using the RESTART option in PSDDF. The excellent agreement with field surface elevations indicates that the input parameters are representative of field conditions and can be used to estimate the service life of the CIDMMA under the proposed RUP.



(a)

(b)

Fig. 6 Simulation of surface elevation at CIDMMA from 1956 to 1984: (a) without accounting for primary consolidation, secondary compression, and desiccation and (b) with accounting for primary consolidation, secondary compression, and desiccation

Simulation of the filling history from October 1983 to 2070 in the north placement compartment is shown in Fig. 7. It can be seen from Fig. 7 that the calculated surface elevations are in good agreement with field survey data. The final field survey was performed in April 2000. Dredged material was initially placed in the center compartment. After approximately 0.3 m of dredged material was placed in the center compartment, dredged material was placed in the south compartment. Placement was moved to the north compartment after a 0.3 m thick lift was placed in the south cell, and this cycle is repeated until an elevation of +9.2 m (+30 ft) MLW is obtained in all three compartments. It can be seen from Fig. 7 that the north compartment reaches its capacity in September 2057. This estimated storage capacity is almost 10 years shorter than the case study performed by Stark et al. (1994) because the actual dredged material filling schedule between 1992 and 2002 was more aggressive than the schedule assumed by Stark et al. (1994).

In summary, the results of the simulation show that reducing the amount of dredged material placed in Craney Island under the RUP and rotating placement among the three compartments will significantly extend the service life of this facility. However, The RUP option will result in ocean dumping of some material.

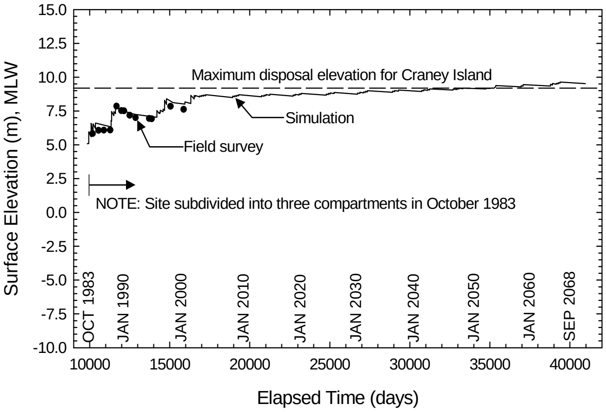


Fig. 7 Simulation of surface elevation for Baseline Maintenance Dredging Case in North Compartment of the CIDMMA from 1984 to 2070

CONCLUSION

When impounding dredged soils in the placement area, the soil behaves like slurry, which experiences the sedimentation and consolidation process during reclaiming work. The void ratio-effective stress and void ratio-permeability relationships, obtained by combining results of the self-weight consolidation test and the CRS test or large strain consolidation test, should be obtained for analyzing long-term settlement behavior of dredged materials by a numerical program, PSDDF. In the first case study to simulate numerically and experimentally the phased placement of dredged soils, the PSDDF simulations correspond overall well with the results of the laboratory experiments. In addition, the excellent agreement between measured field surface elevations and calculated surface elevations for the second case study described herein indicates that PSDDF is a reliable tool to predict the behavior of dredged material if representative input parameters are used.

ACKNOWLEDGEMENTS

The present research was financially supported partially by Korea University Young Professor Research Fund and by Korea Research Foundation Grant (Grand No. D00218).

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