Settlement of Dredged and Contaminated Material Placement Areas. II: Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill Input Parameters

Timothy D. Stark[1]; Hangseok Choi[2]; and Paul R. Schroeder[3]

Abstract: This paper presents practical applications of PSDDF (Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill), which is described in a companion paper by the writers. In addition, consolidation and desiccation parameters for 27 dredged materials are presented from 20 U.S. Army Corps of Engineers placement areas to facilitate usage of PSDDF. The consolidation parameters of three cohesionless soils for sand capping and drainage and three compressible foundation materials are included to provide a PSDDF user with suitable parameters for these material types. To reduce the difficulty of obtaining the consolidation and desiccation parameters for dredged material, empirical correlations between the required parameters and soil index properties are presented.

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CE Database subject headings: Consolidation; Compression; Desiccation; Dredge spoil; Finite difference method; Clays; Contaminants; Parameters.

Introduction

The three most important natural processes affecting the long-term thickness of confined dredged material are primary consolidation, secondary compression, and desiccation, which are modeled in the microcomputer program PSDDF (Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill) (Stark et al. 2005). The major input parameters governing the primary consolidation calculations in PSDDF are the void ratio-effective stress and void ratio-coefficient of permeability relationships obtained from laboratory consolidation tests. Cargill (1985, 1986) and Poindexter (1988a) describe the recommended laboratory testing procedures to obtain these relationships. In addition, the specific gravity of solids and the initial void ratios of the dredged fill, cohesionless soils, and compressible foundation materials are required. As to the secondary compression, the secondary compression index (C_α) is additionally necessary to utilize the C_α/C_c concept (Mesri and Godlewski 1977). Input parameters governing the desiccation calculations in PSDDF include (1) void ratio at the saturation limit, (2) void ratio at the desiccation limit, (3) degree of saturation at the desiccation limit, (4) site drainage efficiency for desiccation drying, (5) maximum soil evaporation efficiency factor, (6) depth of second-stage drying or desiccated crust thickness, (7) average monthly Class A pan evaporation rates, and (8) average monthly rainfall.

Extensive laboratory testing is required to obtain some of these parameters, which has limited the use of PSDDF. In addition, no guidelines exist for verifying the accuracy of the laboratory data. This paper presents empirical relationships between soil index properties and consolidation and desiccation parameters of confined dredged materials, compressible foundation materials, and less compressible cohesionless sandy materials. These empirical relationships can be used for (1) planning level analyses prior to lab testing; (2) small projects where laboratory testing is impractical; (3) parametric studies of primary consolidation, secondary compression, and desiccation processes; and (4) determining input parameters for placement sites having dredged materials with index properties similar to the materials described herein. These relationships simplify the determination of the input parameters required by PSDDF.

Summary of Material Database in PSDDF

The consolidation and desiccation parameters of the 27 dredged materials were compiled from 20 U.S. Army Corps of Engineers placement sites. The data were obtained from the U.S. Army Engineer Waterways Experiment Station (now called the U.S. Army Engineer Research and Development Center, ERDC) reports, files, and existing published literature. Because cohesionless soils and compressible foundation materials are for the most part not subject to desiccation, only the primary consolidation parameters of these soils are presented. The cohesionless soils can be used to simulate sand capping or subsurface drainage layers. Table 1 provides a summary of the placement sites and index properties of the dredged materials from each site. In Table 1, the symbol h_2 represents the depth of the second-stage drying, that is, maximum crust thickness, and the symbols DREFF and CE represent a drainage efficiency factor and maximum evaporation efficiency of

[1]Professor of Civil Engineering, Univ. of Illinois, 205 N. Mathews Ave., Urbana, IL 61801. E-mail: tstark@uiuc.edu

[2]Assistant Professor of Civil Engineering, Univ. of Akron, 209D ASEC, Akron, OH 44325-3905. E-mail: hchoi@uakron.edu

[3]Research Civil Engineer, U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Rd., Vicksburg, MS 39180-6199. E-mail: Paul.R.Schroeder@erdc.usace.army.mil

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Table 1. Summary of Dredged Material Placement Areas and Material Properties in the PSDDF Database

Site	USCS	Atterberg limit LL	PL	PI	Specific gravity	Void ratio at zero effective stress (e_{00})	Void ratio at desiccation limit	Void ratio at saturation limit	Saturation at e_{DL}	h_2 (m)	DREFF	CE	References
Black Rock, Conn.	OH	112	46	66	2.56	10.75	2.82	5.16	0.50	N/A	N/A	N/A	Poindexter (1988a)
Cape Canaveral, Fla.	CH	143	40	103	2.70	11.50	2.50	3.70	0.52	0.91	1.00	0.75	Cargill (1985)
Craney Island, Va.	CH	128	38	88	2.75	10.50	3.20	6.50	0.43	0.50	1.00	0.75	Cargill (1985)
Drum Island, S.C.	CH	140	49	91	2.60	12.15	3.10	6.70	0.49	0.83	1.00	0.75	Cargill (1985)
Dutch Kills, N.Y.	OH	90	40	50	2.42	10.70	2.32	3.92	0.77	0.78	1.00	0.73	Poindexter (1988b)
Duwamish, Wash.	CH	73	34	39	2.48	9.00	2.02	3.26	0.50	N/A	N/A	N/A	Poindexter (1988a)
Earle Navy, N.Y.	SC	38	23	15	2.68	11.20	1.48	1.83	0.50	0.86	1.00	0.84	Poindexter (1988b)
Houston-Galveston, Tex.[a]	CH	75	19	56	2.74	9.37	2.19	4.30	0.85	0.81	N/A	N/A	ERDC
Houston-Galveston, Tex.[a]	CH	115	24	91	2.72	10.07	2.56	6.36	N/A	0.86	N/A	N/A	ERDC
Houston-Galveston, Tex.[a]	CH	59	19	40	2.73	9.05	2.02	3.36	0.65	0.78	N/A	N/A	ERDC
Houston-Galveston, Tex.[a]	SC	41	18	23	2.71	9.00	1.84	2.35	0.47	0.76	N/A	N/A	ERDC
Kings Bay, Ga.	CL	214	51	163	2.53	10.73	3.10	9.80	0.49	1.00	1.00	0.75	Shields (1988)
Kings Bay, Ga.	CL	201	52	149	2.57	10.67	3.20	9.30	0.50	1.00	1.00	0.75	Shields (1988)
Kings Bay, Ga.	SC	83	27	56	2.71	12.62	1.80	4.10	0.48	1.00	1.00	0.75	Shields (1988)
Lower Passiac, N.Y.	CH	101	38	63	2.50	8.90	2.28	4.54	0.50	0.83	1.00	0.63	Poindexter (1988b)
New Haven, Conn.	CH	96	28	68	2.69	8.50	1.81	4.64	0.50	N/A	N/A	N/A	Poindexter (1988a)
Newark Bay, N.J.	SC	41	22	19	2.64	8.75	1.39	1.94	0.50	0.93	1.00	0.70	Poindexter (1988b)
NWS Concord-Wetland, Calif.[a]	CH	80	27	53	2.69	9.31	2.16	4.12	0.79	0.80	N/A	N/A	ERDC
NWS Concord-Wetland, Calif.[a]	CH	110	33	77	2.7	9.79	2.41	5.53	N/A	0.84	N/A	N/A	ERDC
Port Authority, N.Y.	CH	102	37	65	2.59	9.60	2.30	4.75	0.50	0.79	1.00	0.67	Poindexter (1988b)
Port Elizabeth, N.Y.	CH	84	35	49	2.57	10.70	2.16	3.88	0.50	0.78	1.00	0.52	Poindexter (1988b)
Red Hook, N.Y.	CH	78	35	43	2.59	8.50	2.17	3.63	0.50	0.86	1.00	0.72	Poindexter (1988b)
Sequine Point, N.Y.	CH	114	41	73	2.60	9.40	2.55	5.33	0.50	0.72	1.00	0.67	Poindexter (1988b)
Stamford, Conn.	CH	71	25	46	2.68	7.30	1.60	3.42	0.50	N/A	N/A	N/A	Poindexter (1988a)
Toledo Harbor, Ohio[a]	CH	60	23	37	2.73	8.99	2.00	3.18	0.61	0.78	N/A	N/A	ERDC
Toledo Harbor, Ohio[a]	CH	89	33	56	2.7	9.37	2.19	4.30	0.83	0.81	N/A	N/A	ERDC
US Metals, N.Y.	CH	115	44	71	2.54	10.70	2.68	5.25	0.50	0.78	1.00	0.74	Poindexter (1988b)

Note: ERDC=U.S. Army Engineer Research and Development Center.

[a]Input parameters were obtained using the correlations given in the paper because initial data indicate an overconsolidated material.

Table 2. Summary of Cohesionless Cover and Drainage Material Properties in PSDDF Database

Material	USCS	PI	Void ratio at zero effective stress (e_{00})	References
Clean sand	SP	N/A	1.6	Kaufman and Sherman (1964)
Silty sand	SM	6	1.8	Kaufman and Sherman (1964)
Clayey sand	SM-SC	>10	2.0	Taylor (1948)

dredged fill materials, respectively. Monthly precipitation and evaporation data are available for all 20 sites. The summaries of consolidation properties for the cohesionless soils and compressible foundation materials are presented in Tables 2 and 3, respectively.

Information contained in Tables 1–3 can be used to estimate the required input parameters for previously studied placement sites, placement sites in similar geographic regions, or placement areas with soils having similar index properties. Subsequent sections of this paper describe the input parameters required by PSDDF and present the observed range of the parameters at these 20 placement sites. The compiled data sets for each parameter are used to develop empirical correlations between dredged material index properties and required input parameters (e.g., initial void ratio and plasticity index) except for the eight data sets from the following three sites: Houston-Galveston, Texas; NWS Concord-Wetland, California; and Toledo Harbor, Ohio. These eight data sets are not included because the void ratio relationships for these sites represent an overconsolidated material and do not contain desiccation parameters. However, these data are used to estimate the normally consolidated void ratio relationships and the desiccation parameters using the empirical correlations given in this paper.

Initial Void Ratio Correlation

The initial void ratio 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. The initial void ratio can be chosen from the best curve fit to the void ratio-effective stress relationship from the self-weight consolidation test (Cargill 1986). In PSDDF, an initial void ratio value is required for every compressible material, and it is the starting point for the self-weight consolidation calculations. Because the initial void ratio is difficult to measure, it is desirable to develop a correlation between the initial void ratio and a more measurable index property of a given material.

The dredged material index properties from the 20 placement sites are plotted on the plasticity chart in Fig. 1. There are 21 inorganic clays of high plasticity classified as CH according to the Unified Soil Classification System (USCS), 2 organic clays of high plasticity classified as OH, and 4 clayey sands classified as SC.

Fig. 2 compares the initial void ratio and plasticity index (PI) for the 19 dredged material types from the 17 placement sites (excluding the 3 sites marked with an asterisk in Table 1, which are overconsolidated). Note that three samples were tested from the Kings Bay, Georgia site. Only a correlation of initial void ratio and plasticity index for inorganic clays of high plasticity (CH) is presented in Fig. 2 because there are limited data for the other soil types. The scatter in the data is probably enhanced by the difficulties in measuring the initial void ratio. As more data become available, a better-defined relation between the initial void ratio and plasticity index may be obtained. In the interim, the recommended relationship obtained by a linear regression with $r^2=0.328$ between the initial void ratio and plasticity index for inorganic clays of high plasticity (CH) is

$$e_{00} = 8.25 + 0.02\text{PI} \tag{1}$$

where e_{00}=initial void ratio and PI=plasticity index.

For the other dredged material types, an initial void ratio of 10 to 11 is recommended for organic clays of high plasticity (OH) and 9 to 12 for sandy clays (SC).

Void Ratio-Effective Stress and Void Ratio-Permeability Relationships

Dredged Fill Materials

The major parameters controlling the primary consolidation behavior of a dredged fill material are the void ratio-effective stress and the void ratio-permeability relationships. Defining these relationships requires two different laboratory consolidation tests. A self-weight consolidation test yields the void ratio-effective stress and void ratio-permeability relationships at effective stresses less than about 0.96 kPa (20 psf). The self-weight consolidation test, described by Cargill (1985), is labor intensive and usually requires 1 to 2 weeks to complete. Consequently, these tests are expensive and infrequently performed. Standard oedometer tests (ASTM 1999) yield void ratio relationships for effective stresses greater than 0.96 kPa (20 psf). The results of the two tests are combined to obtain the void ratio relationships for the range of effective stresses usually encountered in a dredged material placement area.

Figs. 3–6 present the void ratio-effective stress and void ratio-permeability relationships measured using self-weight consolidation and typical oedometer tests for the 19 dredged material types from the 17 placement sites (excluding 3 sites marked with a superscript a in Table 1, which are overconsolidated). Figs. 3–6 show that the scatter in the void ratio relationships is large. Be-

Table 3. Summary of Compressible Foundation Material Properties in PSDDF Database

Sites	USCS	LL	PL	PI	Void ratio at zero effective stress (e_{00})	References
Drum Island, S.C.	CH	60	20	40	3.0	Cargill (1982)
Craney Island, Va.	CH	60	20	40	2.5	Cargill (1982)
Yazoo City, Miss.	CH	75	21	54	2.5	Cargill (1982)

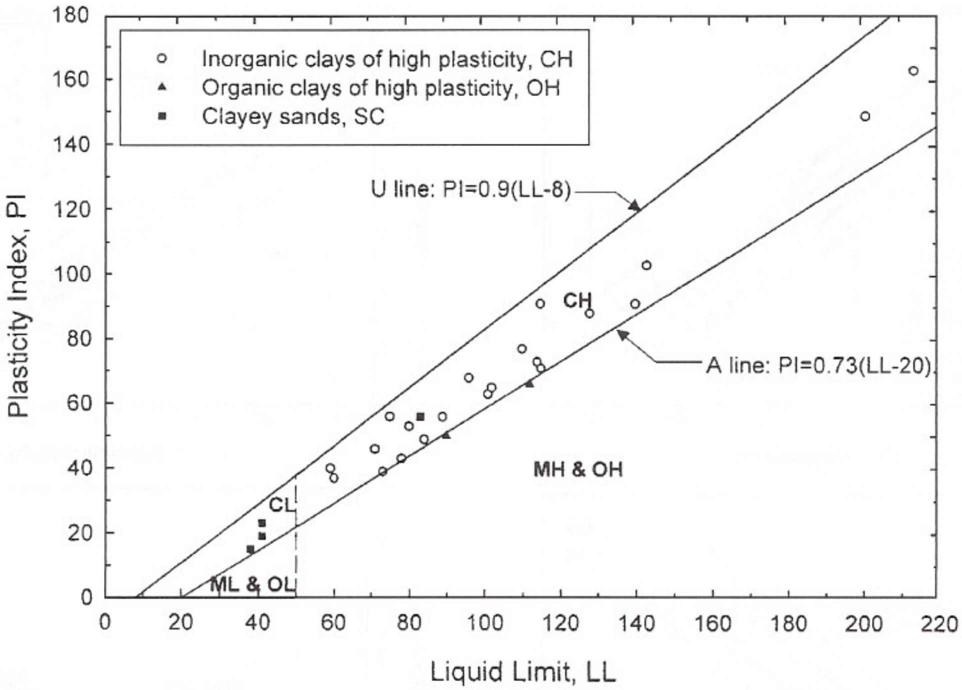

Fig. 1. Plasticity chart for dredged fill materials

cause the data have been separated according to soil classification, the scatter is probably due to difficulties in performing and interpreting the consolidation test results.

Fig. 3 presents the void ratio-effective stress and void ratio-permeability relationships for inorganic clays of high plasticity (CH) whose PI is higher than 70. Also shown in Fig. 3 are the upper and lower limits of the PI. It appears that the void ratio relationships are a function of the PI. A series of trend lines plotted in Fig. 3 describes the variation of these relationships with the plasticity indices for inorganic clays of high plasticity, that is, PI > 70. Therefore, void ratio relationships for inorganic clays of high plasticity can be estimated from Fig. 3 using the plasticity index and linearly interpolating between the trend lines for various values of PI. A void ratio-effective stress and a void ratio-permeability relationship can be estimated from the data by moving parallel to a particular trend line and estimating the void ratio at different effective stresses and/or permeability.

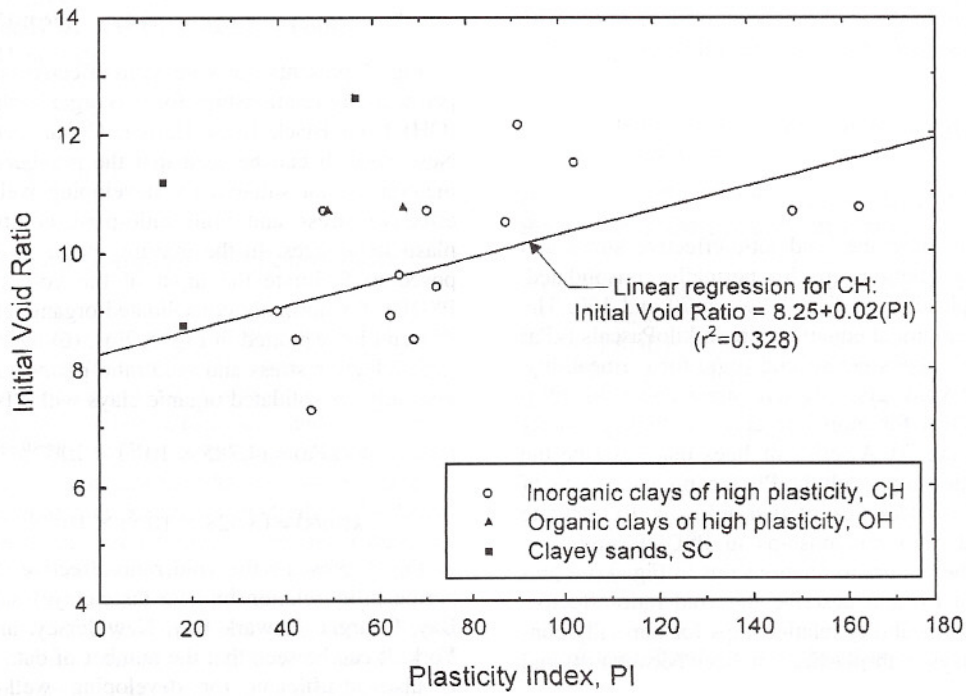

Fig. 2. Relationship between initial void ratio and plasticity index for 19 dredged materials

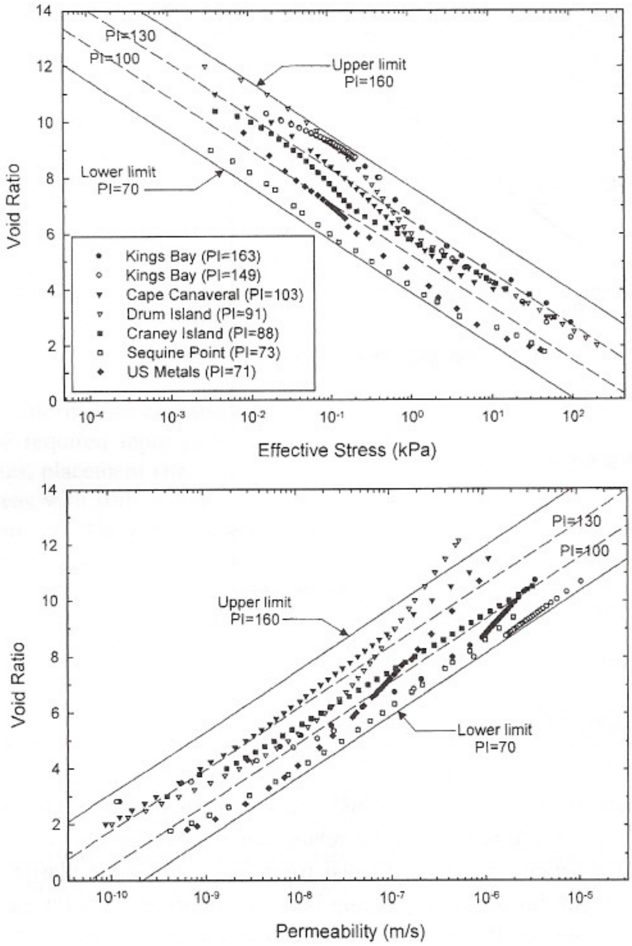

Fig. 3. Void ratio-effective stress and void ratio-permeability relationships for inorganic clays of high plasticity (CH) with $70 < PI < 160$

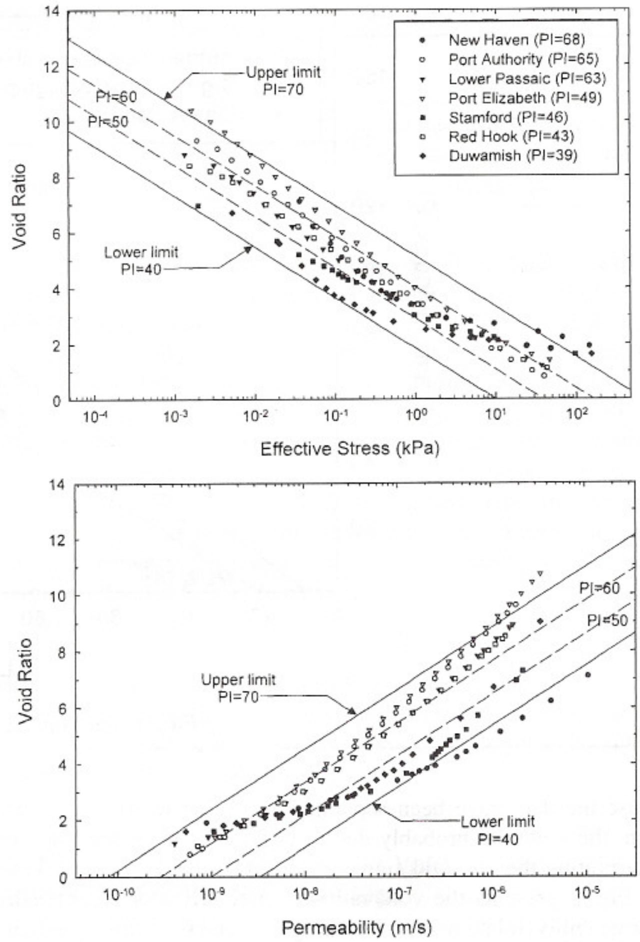

Fig. 4. Void ratio-effective stress and void ratio-permeability relationships for inorganic clays of high plasticity (CH) with $40 < \mathrm{PI} < 70$

To facilitate the input of the void ratio relationships in PSDDF, empirical equations describing the void ratio relationships in Fig. 3 are presented below:

$$\sigma'(\mathrm{kPa}) = (4.785 \times 10^{-5}) \times 10^{\{e-(0.04\mathrm{PI}+9.29)/-1.90\}} \quad (2)$$

$$k(\mathrm{m/s}) = (3.528 \times 10^{-11}) \times 10^{\{e-(0.042\mathrm{PI}-4.62)/2.175\}} \quad (3)$$

Eqs. (2) and (3) describe the void ratio-effective stress and void ratio-permeability relationships for normally consolidated, inorganic clays with plasticity indices between 70 and 160. The required units for the empirical equations are in kiloPascals (kPa) for effective stress and meters per second (m/s) for permeability.

Fig. 4 presents the void ratio-effective stress and void ratio-permeability relationships for inorganic clays of high plasticity (CH) with a PI less than 70. A series of lines that describe the variation of these relationships with the PIs for inorganic clays of high plasticity with $\mathrm{PI} < 70$ are also plotted in Fig. 4. To facilitate the input of the void ratio relationships in PSDDF, empirical equations describing the void ratio relationships in Fig. 4 are presented in Eqs. (4) and (5) and describe the void ratio-effective stress and void ratio-permeability relationships for normally consolidated, inorganic clays with plasticity indices between 40 and 70.

$$\sigma'(\mathrm{kPa}) = (4.785 \times 10^{-5}) \times 10^{\{e-(0.113\mathrm{PI}+5.09)/-1.811\}} \quad (4)$$

$$k(\mathrm{m/s}) = (3.528 \times 10^{-5}) \times 10^{\{e-(0.12\mathrm{PI}+3.80)/2.126\}} \quad (5)$$

Fig. 5 presents the void ratio-effective stress and void ratio-permeability relationships for two organic clays of high plasticity (OH) from Black Rock Harbor, Connecticut, and Dutch Kills, New York. It can be seen that the number of data sets for this material is not suitable for developing well-defined void ratio-effective stress and void ratio-permeability relationships with plasticity indices. In the interim, empirical correlations are proposed to facilitate the input of the void ratio relationships in PSDDF for normally consolidated organic clays according to the PI trend lines plotted in Fig. 5. Eqs. (6) and (7) describe the void ratio-effective stress and void ratio-permeability relationships for normally consolidated organic clays with PIs between 50 and 70.

$$\sigma'(\mathrm{kPa}) = (4.785 \times 10^{-5}) \times 10^{\{e-(0.153\mathrm{PI}+3.749)/-1.76\}} \quad (6)$$

$$k(\mathrm{m/s}) = (3.528 \times 10^{-5}) \times 10^{\{e-(0.156\mathrm{PI}+1.45)/1.974\}} \quad (7)$$

Fig. 6 presents the void ratio-effective stress and void ratio-permeability relationships for three clayey sands (SC) from Kings Bay, Georgia, Newark Bay, New Jersey, and Earle Navy, New York. It can be seen that the number of data sets for this material is also insufficient for developing well-defined void ratio-effective stress and void ratio-permeability relationships with plasticity indices. Eqs. (8) and (9) provide interim relationships to

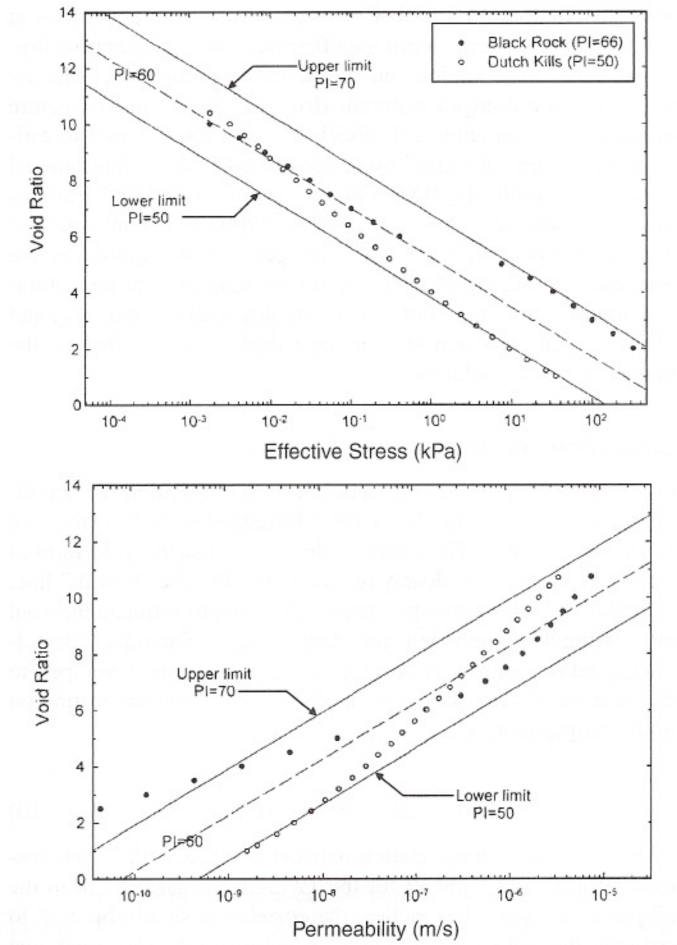

Fig. 5. Void ratio-effective stress and void ratio-permeability relationships for organic clays of high plasticity (OH) with 50<PI<70

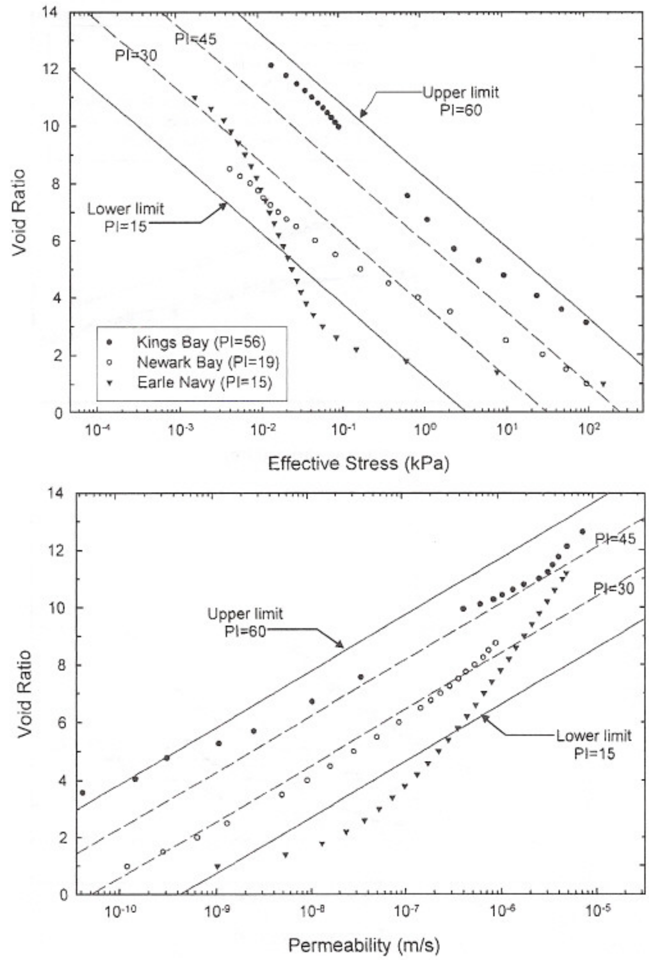

Fig. 6. Void ratio-effective stress and void ratio-permeability relationships for clayey sands (SC) with 15<PI<60

describe the void ratio-effective stress and void ratio-permeability relationships for normally consolidated clayey sands with plasticity indices between 15 and 60.

$$\sigma'(\text{kPa}) = (4.785 \times 10^{-5}) \times 10^{\{e-(0.16\text{PI}+9.70)/-2.497\}} \quad (8)$$

$$k(\text{m/s}) = (3.528 \times 10^{-5}) \times 10^{\{e-(0.117\text{PI}+7.835)/1.951\}} \quad (9)$$

Cohesionless Soils and Compressible Foundation Materials

The void ratio-effective stress and the void ratio-permeability relationships for three cohesionless sandy soils are plotted in Fig. 7. These materials represent a clean sand, a silty sand, and a clayey sand and can be used to simulate subsurface sand drainage or surface capping layers. The Unified Soil Classification System (USCS) symbols for these soils are SP, SM, and SM-SC, respectively. Compressible foundation layers under dredged fill layers may consist of previously disposed dredged materials or naturally occurring materials. Fig. 7 provides the void ratio-effective stress and void ratio-permeability relationships for three normally consolidated compressible foundation materials. The compressible foundation materials occur naturally at three different dredged placement sites: Drum Island, South Carolina; Craney Island, Virginia; and Yazoo City, Mississippi. In each case, dredged material was placed above these compressible foundation materials. PSDDF is able to simulate different stress histories for the compressible foundation layers using the normally consolidated void ratio relationships and the overconsolidation ratio (OCR), as described in the companion paper (Stark et al. 2005). This option is included in PSDDF because the compressible foundation layers may be over- or underconsolidated when placement of new dredged material starts.

Secondary Compression Model

The C_α/C_c concept developed by Mesri and Godlewski (1977) for the analysis of secondary compression-related settlement is used in PSDDF. This concept is based on the observation that the magnitude and behavior of C_α (secondary compression index) with time is related to the magnitude and behavior of C_c (compression index). The values of C_α and C_c can be determined using standard oedometer tests on undisturbed specimens of the cohesive material. The 1D oedometer test can be performed in accordance with ASTM (1999) Standard D 2435-96. For a variety of natural soils, the value of C_α/C_c is in a rather narrow range of 0.01–0.05.

Empirical Desiccation Model

Research conducted at the ERDC has indicated that evaporative drying is the most cost-effective means of dewatering dredged

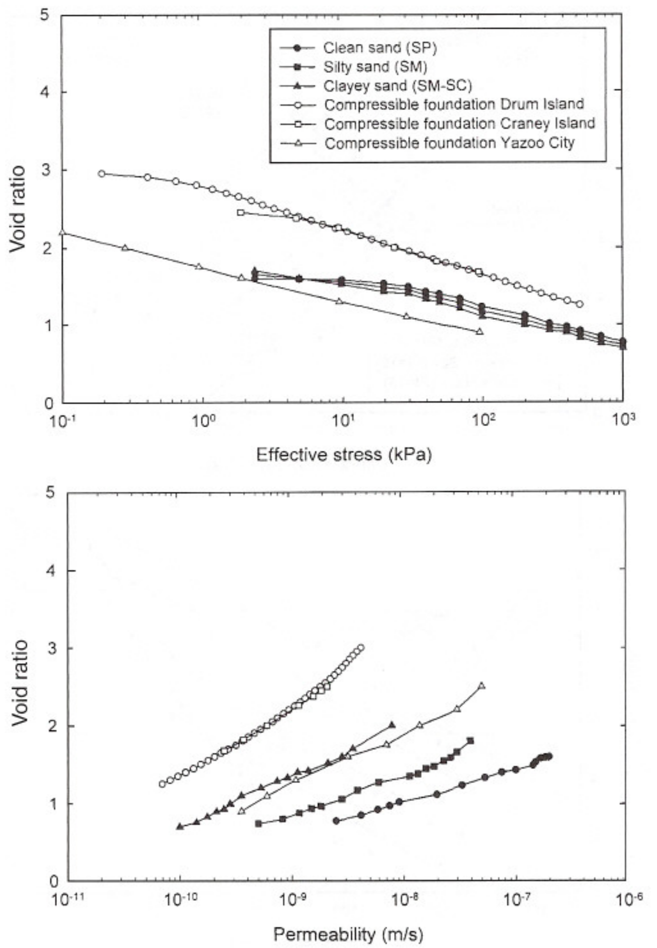

Fig. 7. Void ratio-effective stress and void ratio-permeability relationships for cohesionless soils and compressible foundation materials

material (Haliburton 1978). Climatic and drainage conditions at the containment area control the effectiveness of evaporative drying and the consolidation and coefficient of permeability characteristics of the dredged material. Because of the complex nature of desiccation, an empirical model (Cargill 1985) is used to estimate the settlement caused by desiccation. The desiccation model is based on studies by Brown and Thomson (1977) and Haliburton (1978) and described in Stark et al. (2005), the companion to this paper. The three most important parameters required by the desiccation model in PSDDF are (1) the void ratio at the saturation limit, e_{SL}; (2) the void ratio at the desiccation limit, e_{DL}; and (3) the depth to which second-stage drying occurs, that is, the maximum crust thickness.

Saturation and Desiccation Limits

Fig. 8 presents a correlation between the void ratio at the saturation limit (e_{SL}) and the PI for the 19 dredged materials from the 17 placement sites. The relationship shows that the void ratio at the saturation limit is closely related to the PI. The "best fit" line, $r^2=0.871$ drawn through the data can be used to estimate the void ratio at the saturation limit for other dredged materials. The following relationship from the linear regression was developed to describe the relationship between the void ratio at the saturation limit and plasticity index:

$$e_{SL} = 1.26 + (5.15 \times 10^{-2})\text{PI} \tag{10}$$

Fig. 9 presents a correlation between the void ratio at the desiccation limit (e_{DL}) and PI for the 19 dredged materials from the 17 placement sites. In practice, the correlation should be used to estimate the void ratio at the desiccation limit. The trend line drawn through the data is judged to be the "best fit," $r^2=0.659$. The following equation from the linear regression is used to describe the relationship between the void ratio at the desiccation limit and the PI.

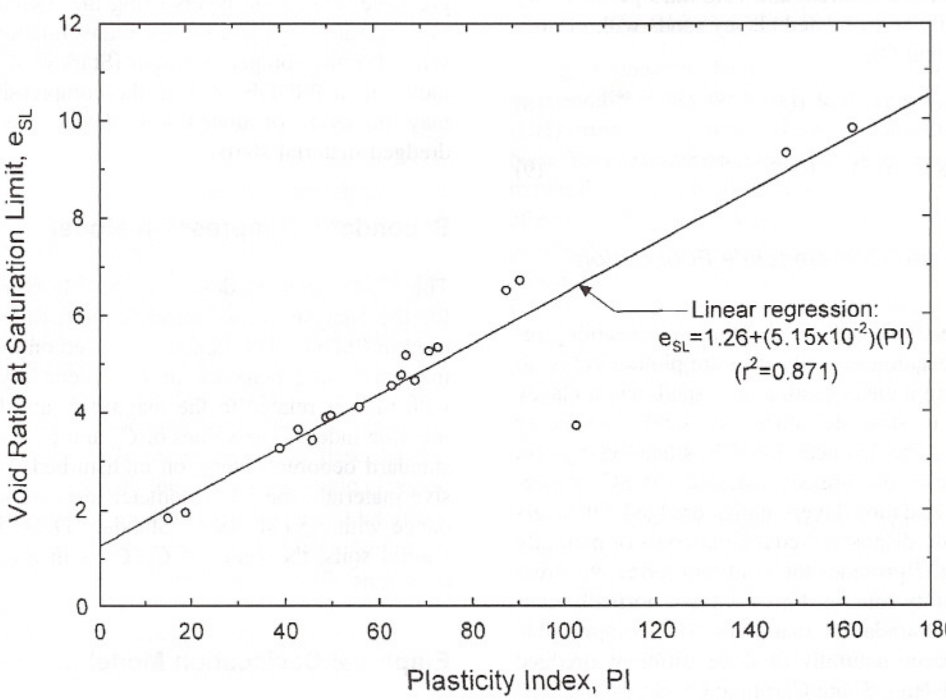

Fig. 8. Relationship between void ratio at saturation limit and plasticity index

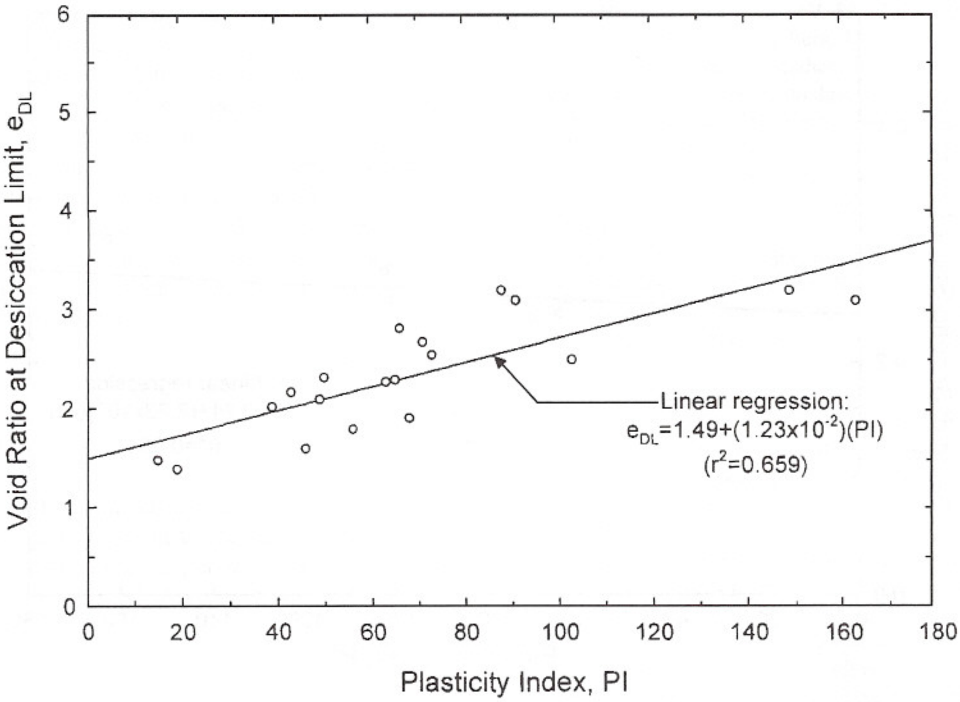

Fig. 9. Relationship between void ratio at desiccation limit and plasticity index

$$e_{DL} = 1.49 + (1.23 \times 10^{-2})\text{PI} \tag{11}$$

The saturation limit also can be verified using the relationships proposed by Haliburton (1978). These relationships suggest that the void ratio at the saturation limit can be estimated from the water content at the saturation limit. The water content at the saturation limit is empirically obtained as follows (Haliburton 1978):

$$w_{SL} = 1.8 \times \text{LL} \tag{12}$$

where w_{SL} is the water content at the saturation limit and LL is the liquid limit. The void ratio at the saturation limit can be estimated using a degree of saturation, S, equal to 100%, an appropriate value of specific gravity, G_s, and the following relation:

$$e_{SL} = G_s \times \frac{w_{SL}}{S} \tag{13}$$

Degree of Saturation at Desiccation Limit

PSDDF also requires the degree of saturation at the desiccation limit. The degree of saturation for the 20 placement sites in this study ranges from 40 to 60% and averages approximately 50%.

Degree of saturation also can be estimated using the water content at the desiccation limit. Haliburton (1978) proposes an empirical relationship between the water content at the desiccation limit and the plastic limit (PL) as follows:

$$w_{DL} = 1.2 \times \text{PL} \tag{14}$$

where w_{DL} is the water content at the desiccation limit. The degree of saturation at the desiccation limit can be calculated by using Eq. (13) and substituting w_{DL} for w_{SL} and e_{DL} for e_{SL}, respectively. The values of w_{DL} and e_{DL} are obtained from Eqs. (14) and (11), respectively.

Drainage and Evaporation Efficiency Factors

Studies by Brown and Thompson (1977) indicate that evaporation of water from dredged material occurs in two major stages. During the first stage, sufficient free water is available at the surface of the material and evaporation takes place at its full Class A pan evaporation rate. Therefore, the dredged fill evaporation efficiency for desiccation drying (CE) is equal to 1.0. In the second stage, drying proceeds at a fraction of the potential rate and thus CE is less than 1.0. The efficiency decreases as the depth of the dried crust increases (Cargill 1985). Observed values of CE range from 0.5 to 1.0, but the calculations in PSDDF are somewhat insensitive to these variations in CE. Thus sufficient data are not available to estimate CE, a value of 0.7 is recommended for actively managed placement areas. If free water is always available at the surface of the dredged material, a value of 1.0 is recommended.

The drainage efficiency factor of the dredged material containment area is the ratio of the overland runoff volume to the rainfall volume. A drainage efficiency factor (DREFF) equal to 1.0 means that all monthly rainfall is quickly removed from the placement area before it is absorbed by the drying dredged material. A DREFF equal to zero means that no surface drainage is provided to remove the monthly rainfall. As a result, the precipitation must be evaporated before desiccation can begin in the dredged material. In a well-managed dredged material placement facility, the DREFF can be assumed to range from 0.8 to 1.0. At a well-managed placement site, the outflow weir boards are removed after sedimentation is complete, and perimeter and internal trenches are excavated to promote drainage in the dredged fill. A DREFF should be reduced to approximately 0.3 if the placement facility is not managed. A minimum value of 0.3 is recommended because most placement areas are sloped to promote drainage. Thus, some drainage should occur even if the site is not actively managed.

Cargill (1985) suggests that the long-term settlements calcu-

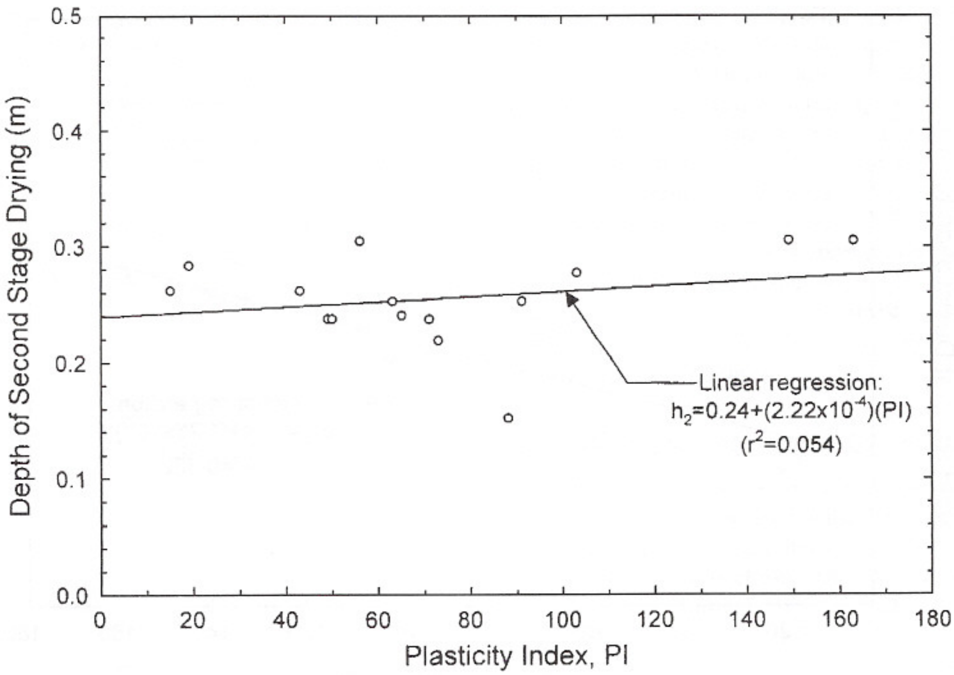

Fig. 10. Relationship between depth of second-stage drying and plasticity index

lated using PSDDF are not sensitive to the drainage and evaporation efficiency factors. In addition, the differences in intermediate settlements are usually less than 5%. Therefore, depending on the level of management in the placement area, a value of evaporative efficiency between 0.5 and 1.0 and a drainage efficiency factor between 0.3 and 1.0 should be representative of typical placement areas.

Depth of Second-Stage Drying

The reason that PSDDF is insensitive to the drainage and evaporation efficiency factors is related to the specification of the depth of second-stage drying for a particular dredged material. The formation of a crust results in settlement due to desiccation and, more importantly, consolidation induced by an increase in unit weight from the buoyant unit weight to the total unit weight of the soil. Consequently, the depth of second-stage drying determines the amount of surcharge applied by the crust and thus is an important input parameter. Under normal drying conditions, the depth of second-stage drying or maximum crust thickness will have sufficient time to develop for the range of evaporation and drainage efficiency factors previously described. Therefore emphasis should be placed on evaluating the depth to second-stage drying. The depth can be measured by cutting the dredged material between desiccation cracks and exposing a profile of the material beneath the crust. The depth of the crust is the distance from the ground surface to the start of saturated dredged material. The depth of second-stage drying is not the depth of the desiccation cracks. Management action can increase the second-stage drying depth. Depths of approximately 0.3 m (1 ft) are achievable in clayey materials.

Fig. 10 shows a relationship between the depth of second-stage drying and the PI for 15 dredged materials from the 17 placement sites. Note that the depth of second-stage drying increases slightly with increasing plasticity index. Additional data are needed to refine this relationship. This correlation can be used to obtain a preliminary estimate of the depth of second-stage drying that will develop, or in other words, the maximum crust thickness that will develop. To facilitate the input of the depth of second-stage drying, the following equation from the linear regression describes the relationship of the depth of second-stage drying and the PI:

$$h_2 = 0.24 + (2.22 \times 10^{-4})\mathrm{PI} \qquad (15)$$

where h_2=depth of second-stage drying, in meters.

Evaporation and Precipitation Data

Class A pan evaporation and precipitation data are important parameters in estimating the settlement due to desiccation. Consequently, PSDDF requires input of the average monthly pan evaporation potential and the average total monthly precipitation. Brown and Thompson (1977) present maps of average monthly pan evaporation that are based on monthly pan evaporation data collected from 1931 to 1960. Maps of the normal total monthly precipitation are available from the National Climatic Data Center (1980). More recent Class A pan evaporation and precipitation data are readily available on weather Web sites (e.g., www.noaa.gov). These data can be used in performing PSDDF for the dredged placement areas summarized in Table 1.

Conclusions

The microcomputer program PSDDF [described in the companion paper] (Stark et al. 2005) has been used successfully to estimate the long-term settlement behavior of confined dredged material. This has simplified the planning and operation of several dredged material placement areas. However, extensive laboratory testing is required to obtain the input parameters required to execute PSDDF. In addition, no guidelines exist for verifying the accuracy of the laboratory data.

To facilitate usage of PSDDF, consolidation and desiccation parameters of dredged materials from 17 placement areas are used to establish correlations between soil index properties and the input parameters required by PSDDF. The data and correlations presented herein can be used for (1) planning level analyses prior to lab testing, (2) small projects where laboratory testing is not practical, (3) parametric studies of consolidation and desiccation processes, and (4) determination of input parameters for placement sites having dredged materials with index properties similar to the material described herein. These data and correlations should reduce the amount of laboratory testing required by the users and facilitate use of PSDDF.

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