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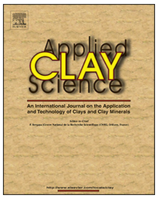

Research paper

An experimental investigation on the effect of thixotropic aging on primary and secondary compression of reconstituted dredged clays

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ABSTRACT

Dredged clay is often undesirable as a foundation soil layer since it undergoes large deformation with time. In addition, the space constraint due to ever-growing population might require to utilize the dredged-fill reclaimed lands. As such, an effort has been taken in this study to characterize the deformation behavior of dredged clay. To this end, the one-dimensional incremental load oedometer tests were administered on three reconstituted dredged clays. Samples were prepared at a moisture content ranging from 0.54–1.27 times the corresponding liquid limits. To observe the effect of thixotropic aging, prepared samples were subjected to three aging periods, such as 10 days, 30 days and 90 days. At a particular moisture content, with the increase of aging period, yield stress was observed to be increased. A unique relationship was established between yield stress ratio and initial moisture content incorporating the aging time. Compression index, C_c increases linearly as the void ratio at yield stress increases. However, C_c decreases as the yield stress increases, the decrease being rapid when the yield stress is below 7.5 kPa. Secondary compression index, C_α increases as the consolidation pressure increases, reaches a peak value and decreases thereafter. At higher initial moisture content, the secondary compressibility of dredged clays increases. Irrespective of the type of the clay, the relationship between C_α and C_c is linear in the considered stress range and time. The slope of the linear relationship (C_α/C_c) is higher for thixotropically aged clays compared to the unaged ones, indicating high secondary compressibility due to thixotropic effects.

1. Introduction

Often being removed from seabed, a large amount of dredged clays is dumped into several disposal sites or in some circumstances, are used to fill up the reclaimed lands. These dredged clays have poor engineering properties such as high natural moisture content, very low shear strength and high compressibility. The total deformation of a dredged clay layer entails both primary and secondary consolidation. The former causes due to pore pressure dissipation and the later due to compression under constant load. Therefore, both the effects need to be taken under due consideration for successful design of structures over these dredged clays. Past researches on the clays revealed that time-dependent deformation behavior is too important to be ignored (Bjerrum, 1967; Leroueil and Vaughan, 1990; Kim and Leroueil, 2001). A significant time-dependent strength and deformation characteristic of dredged clay is *thixotropic aging* (Mitchell, 1960; Park et al., 2014; Shahriar, 2016; Shahriar et al., 2016; Shahriar et al., 2018). It is an isothermal, reversible, time-dependent process under the conditions of constant composition and volume whereby the material stiffens while at rest and softens or liquefies upon remolding (Mitchell, 1960). At natural moisture content, the strength and deformation properties may significantly change due to this phenomenon. Thixotropic properties may carry great importance in the geotechnical investigation of offshore structures as well (Andersen et al., 2008).

The pronounced effect of thixotropy in non-spherical systems has been reported by Pryce-Jones (1934), Jacobson and Pusch (1972), Osipov et al. (1984), Barnes (1997), Deng et al. (2012), Ye et al. (2014). Subsequently, thixotropic effects in fine-grained soils, especially on strength and deformation characteristics have been studied by Mitchell (1960), Seng and Tanaka (2012), Farsakh et al. (2015), Shahriar et al. (2018). Mitchell (1960) observed that aging in thixotropic soils increases the resistance to compression. Seng and Tanaka (2012) concentrated on the thixotropic effect on shear modulus and observed that the increment of shear modulus under secondary consolidation is relatively low compared to that developed during the thixotropic process. Farsakh et al. (2015), while simulating pile set-up, observed that considering the consolidation effect in combination with the thixotropic effect provided close agreement with the field test data. Shahriar et al. (2018) discussed structuration during thixotropic aging and increased resistivity during primary compression at a stress level < 100 kPa for

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soft reconstituted clays, emphasizing the practical importance of thixotropic phenomenon. However, the effect of such aging on secondary compression is still unexplored by the geotechnical engineers. Although, in the existing literature, the researches on secondary compression of soils from wider origins is present, researches on dredged clays focusing thixotropic aging effects are few.

As conventional consolidation testing requires considerable time, especially when it comes to the point of estimating secondary consolidation, researches aimed at correlating secondary compression index with the soil indices that could be determined. Finally, Walker and Raymond (1968), Walker (1969), Suneel et al. (2008), Miao and Kavazanjian (2007) found a relationship between secondary compression index and ratio of vertical effective stress to pre-consolidation pressure. On the other hand, Mesri and Castro (1987), Mesri et al. (1994), Mesri et al. (1997) showed that C_α/C_c is constant for a particular clay and classified soils based on C_α/C_c value. Suneel et al. (2008) made attempts to correlate C_α/C_c with some physical properties of clay (liquid limit, plastic limit, and plasticity index). Nevertheless, Miao and Kavazanjian (2007) observed the secondary compression to be significant for dredged clays.

Review of the researches of Skempton and Northey (1952), Mitchell (1960), Suthaker and Scott (1997), Seng and Tanaka (2012), Shahriar (2015), Jeong et al. (2015) and Shahriar et al. (2018) provides conclusive evidence supporting thixotropy affects strength and deformation response of soft clays. However, thixotropic effects on secondary compression seems to be incomprehensible. Keeping this research gap in mind, the compression characteristics of reconstituted dredged clays will be rigorously studied with prime importance on thixotropy, primary and secondary consolidation. Samples, being prepared a moisture content ranging from 0.54–1.27 times the corresponding liquid limits will be subjected to thixotropic aging up to 90 days and then be tested for deformation response. Finally, the applicability of C_α/C_c concept to the dredged clays was observed.

2. Materials and sample preparation

In order to maintain navigation channel of the river Karnaphuli and Meghna, a large number of very soft clays are often removed. Immediately after the removal, these dredged clays are dumped into several disposal sites in Chittagong, Noakhali and Rangamati, located in the southern part of Bangladesh. These dredged clays in southern Bangladesh are predominantly formed of illitic or chloritic minerals (Islam et al., 2002). Shahriar et al. (2018) showed that the index properties of these dredged clays differ significantly. Geotechnical properties of the clay samples are provided in Table 1. In a view to examine the properties of dredged clays over a wide range of liquid limit and plasticity index, authors selected the samples (S1, S2, S3) listed in Table 1 from three different locations of the southern coast of Bangladesh. Variation in liquid limits, ranging from 75% to 146% was observed. Although, plastic limit varied within a narrow range (26.8% − 35.2%), plasticity index of the collected samples varied within a wider range (48.2% − 110.8%). This variation, however, has allowed examination of the properties of dredged clays over a wide range. The natural moisture content was within the range of 61.4% − 126.3%. A simple approach was used to determine the dominant clay minerals present in the samples using the Casagrande's plasticity chart and the activity of clay. In this approach, the location of soil sample in the Casagrande's plasticity chart is observed. If the Atterberg limits plot high above the A-line, but near the U-line, the clay portion in the soil sample is predominantly of montmorillonite which has an activity $>$ 1.0. The illitic clays (activity: 0.5 − 1.0) plot right above the A-line whereas the kaolinites (activity: 0.3 − 0.5) plot below the A-line (Casagrande, 1948; Mitchell and Soga, 2005; Holtz et al., 2011). These zones are clearly identified in Fig. 1.

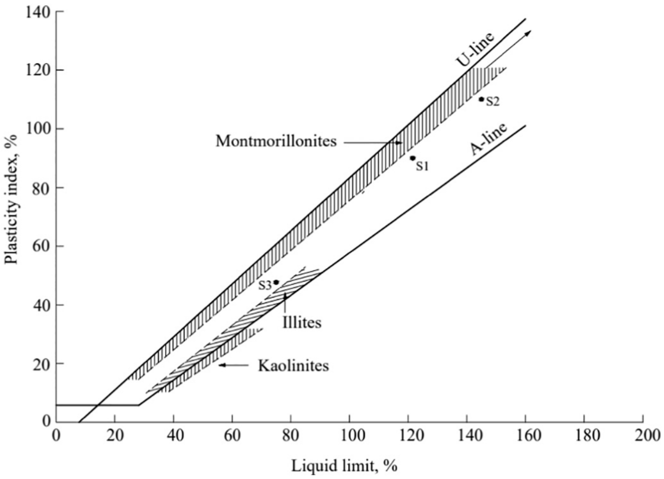

Fig. 1. Location of common clay minerals and the clay samples of current investigation on the Casagrande's plasticity chart.

Since the samples used in this study plot nearly halfway between the A-line and U-line (Fig. 1) and the activity ranges from 0.87 to 1.21 (Table 1), the clay minerals in the samples are predominately illite or, montmorillonite. In addition, the higher liquid limits of clays do not warrant the dominance of kaolinitic minerals (Mitchell and Soga, 2005). Therefore, the samples used in the present study didn't contain kaolinitic minerals. In addition, shear strength test scheme of Shahriar et al. (2018) revealed that samples S1 and S2 are montmorillonite dominant clay and S3 is illite dominant clay.

To characterize the compression behavior, the samples were prepared at three initial moisture contents (w_o) within the moisture content range of 0.54–1.27 times their corresponding liquid limits. Targeted values of initial moisture content for consolidation test were 0.55, 1.00, and 1.25 times their corresponding liquid limits. The preparation of the sample includes the addition of appropriate amount of distilled water to completely dried clay and thoroughly mixing it. Then the moist clay was kept in tightly sealed plastic bags for one day to achieve uniformity of moisture content. As per the recommendation of Mesri and Castro (1987), highly polished stainless-steel rings coated inside with a thin film of silicon grease was used to minimize ring friction. A standard oedometer cell of diameter 63.5 mm and a height of 25.4 mm were used for consolidation test. In the oedometer ring, the samples were put carefully controlling the overall mass. As the initial moisture content is known, the mass of the specimen can be calculated by considering fully saturated condition. The discrepancy between the

Table 1
Engineering properties of the soils considered in the present study (Shahriar et al. 2018).

Sample ID	Location of sample site	Liquid limit (ASTM D4318-17, 2010)	Natural moisture content %	Plastic limit (ASTM D4318-17, 2010)	Plasticity index (ASTM D4318-17, 2010)	Clay fraction < 2 μm (ASTM D422-63, 2007) %	Activity, *A*	Specific gravity (ASTM D854-14, 2014)
S1	Chittagong	122.0	98.2	31.8	90.2	81.08	1.11	2.68
S2	Noakhali	146.0	126.3	35.2	110.8	91.73	1.21	2.69
S3	Rangamati	75.0	61.4	26.8	48.2	55.44	0.87	2.71