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ORIGINAL ARTICLE

Comparison of measured and calculated consolidation settlements of thick underconsolidated clay

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Abstract This study investigates the consolidation settlement of thick deep deposit of underconsolidated clay encountered east of Port Said in Egypt. The foundation soil of the studied area includes a 35 m thick deposit of very soft to medium stiff silty clay. Calculated settlements for a container terminal constructed in this area are compared with two years of field measurements. Consolidation parameters were defined for this site from laboratory and cone penetration tests (CPT). Upper and lower bounds of calculated settlements were calculated using one-dimensional consolidation theory for the range of working container loads. Settlement monitoring was conducted using settlement plates at eight (8) locations. Field measured settlements were compared to calculated settlements to validate the soil properties and evaluate the rationality of the calculated settlements. Field measured settlements fell within the upper and lower bounds of the calculated settlements. The results of this study confirmed that the deep clay deposit is underconsolidated, which poses a geotechnical challenge to potential construction in this area due to expected excessive settlements. In addition, the study showed that applying the one-dimensional consolidation theory using consolidation parameters estimated from CPT and laboratory tests for underconsolidated clays reasonably estimated the magnitude and rate of consolidation settlement.

1. Introduction

East of Port Said is considered an important logistical area due to its location at the northern end of the Suez Canal with high volumes of trade traffic. The area currently includes a large container terminal and is envisaged to grow into a large hub for trade and industry, which entails large infrastructure projects and heavy construction. The foundation soils in the area of the container terminal provide a geotechnical challenge due to the underconsolidated nature of the deep clay deposits that have thicknesses in excess of 35 m. The deep clays have been loaded with dredged soils from an adjacent bypass canal. This

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exposes potential construction activities to challenges of excessive settlements and associated safety and serviceability consequences.

Evaluation of expected settlements depends on the determination of consolidation parameters, which could be evaluated by laboratory tests, field tests, and empirical correlations. Consolidation parameters interpreted from laboratory tests could be subject to inaccuracies resulting from factors such as sample disturbance, sample size, and strain rate [9,16,18]. For field tests, existing correlations are typically used to interpret consolidation parameters. To evaluate inaccuracies in settlement calculations using laboratory and field testing, field settlement monitoring has been conducted at different sites, and was used to compare actual to calculated settlements based on laboratory and field tests [1,2,7,13,17,20].

Several attempts have been made to calculate consolidation settlements using parameters interpreted from in situ cone penetration tests. Oakley and Richard [17] found that calculated settlements using cone penetration test (CPT) data compared well to actual settlements, but the calculated time rates of settlement were within 150% of the actual field measurements. Crawford and Campanella [7] compared measured settlements of earth embankments with settlements calculated from laboratory consolidation tests, in situ Piezocone tests, and dilatometer tests. The authors mentioned that there was good agreement between the settlements calculated using the three methods; however, the actual settlement was approximately 60% greater than the average calculated value.

Liu et al. [13] compared measured settlements at eight embankments sites to calculated settlements based on laboratory tests. The authors found that the calculated settlements based on laboratory tests underestimated the actual settlements in six sites by 13–72%. Abu-Farsakh et al. [2] and Abu-Farsakh and Yu [1] compared calculated settlements based on laboratory tests and Piezocone penetration tests to field measured settlements of instrumented embankments. The authors found that the settlement calculation based on laboratory and Piezocone tests tended to over predict the actual settlement. However, Abu-Farsakh et al. [2] and Abu-Farsakh and Yu [1] reported that values of coefficient of consolidation measured in the laboratory and back-calculated from field measurements showed some scatter but were within the same log cycle. In the first month, the laboratory calculation showed the largest settlement rate; while in the following months, laboratory and field measurements showed almost similar settlement rates. Purzin et al. [20] mentioned that values of coefficient of consolidation may vary by two orders of magnitude from the field values, with the field exhibiting more pervious behavior.

2. Geotechnical data

The site understudy is located near the Mediterranean Sea along the east side of the Port Said East Canal, a side channel east of the Suez Canal referred to as ‘‘Sharq El Tafreea’’ in Port Said, Egypt (Fig. 1). The area surrounding the project was known before the construction of the Suez Canal as ‘‘El-Tinah’’ Plain. Recent silty and clayey materials have been deposited at the area of the site during dredging of the nearby canal. The site covers an approximate area of 184 m by 850 m. Site investigation was conducted in 2010, which included drilling six (6) boreholes from which samples were extracted using 3-inch diameter Shelby tubes for laboratory testing. In addition, six (6) cone penetration tests (CPT) were conducted. Boreholes extended to depths ranging from 40 m to 70 m; and CPTs extended to depths ranging from 30 m to 40 m.

The stratigraphy based on the interpretation of the boring logs, CPTs, and laboratory tests consisted of silty fine sand resulting from dredging nearby canal with thickness ranging from 1.2 m to 6.1 m (Unit 1), followed by very soft to soft silty clay also resulting from dredging with thickness ranging from 4.1 m to 11.9 m (Unit 2). The clay layer is underlain by medium dense to dense silty fine sand with thickness ranging from 0.8 m to 7.3 m (Unit 3), followed by alternating thin layers of silty clay, silt, and silty fine sand with thickness ranging from 3.2 m to 7.0 m (Unit 4). These alternating thin layers are underlain by very soft to medium stiff silty clay with thickness ranging from 34.5 m to 36.8 m (Unit 5). The lower thick clay layer is underlain by very dense sand with thickness ranging from 9.2 m to 13.8 m (Unit 6).

Based on the conducted boreholes and CPTs, it was noted that there is significant spatial variability within the site regarding the thicknesses of the first four (4) units overlying

Figure 1 Location of site under study in Egypt.