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Vacuum preloading method for land reclamation using hydraulic filled slurry from the sea: A case study in coastal China

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ABSTRACT

This study observed an engineering project, in which the vacuum preloading method incorporated with the vertical drain system was applied to the improvement of the dredged marine clay slurry as the fill as well as the in-situ soft ground for land reclamation. The site conditions, field instrumentation, construction process and partial requirements of the vacuum preloading project are described in this paper. Field monitoring data is presented and analyzed. After the vacuum preloading, the average degree of consolidation achieved was more than 88%, and the bearing capacity of the dredged marine clay slurry was improved from less than 4 kPa to be higher than 50 kPa. Specifications of construction techniques were detailed which would be useful and referenceable to engineers. Three empirical prediction methods for estimating the ultimate settling and consolidation degree are reviewed. Several key parameters and their optimal values in the formulae are discussed and suggested, respectively. Prediction results show that the Asaoka's method is the most preferable for predicting the settling of dredged marine clay slurries with high initial water content improved by vacuum preloading.

1. Introduction

The land reclamation from the sea is one of the most efficient ways to make up the land shortage in some coastal regions of China as available land resources are becoming increasingly scarce due to the rapid economic development and urbanization. According to recent statistics, 5880 km^2 of sea will be reclaimed from the year 2016–2020 (Duan et al., 2016). Meanwhile, about 3×10^8 m^3 of dredged soils are annually yielded from waterways, ports, water conservation, and water environmental engineering projects in China in recent years. In order to fully utilize natural resources, one of the major measures is to use these dredged marine clays as fill materials for land reclamations. The initial reclaimed land which is hydraulically filled with dredged marine clays generally behaves as soup that has very high water content and extremely low bearing capacity such that a small bird cannot stand firm on the "soup" surface. Even weeks after the completion of the hydraulic fulfillment of dredged marine clay deposits, its bearing capacity is still very low. Stabilizing these soft soils before commencing construction is essential for both long term and short term stability. Since they have very low permeability and are usually thick, a long time period is usually needed to achieve the desired primary degree of consolidation (>80%). Engineering measures have to be taken to enhance the bearing capacity.

A system of vacuum preloading incorporated with prefabricated vertical drains (VPPVDs) has become an attractive ground improvement method in terms of both cost and effectiveness (Indraratna, 2010). When it is applied, vertical drains provide a much shorter drainage path in a radial direction which reduce the required preload period significantly and vacuum pressure is used to enhance the efficiency of PVDs. Negative pore pressures (suction) distributed along the drains and on the surface of the ground accelerate consolidation, reduce pore-water pressure, and increase the effective stress. The applications of vacuum preloading drainage method became popular until the 1980s (Qian et al., 1992; Shang et al., 1998). Today, the vacuum preloading combined with PVDs are used more and more in practical ground improvement all over the world (Tang and Shang, 2000; Chai et al., 2006; Zhao et al., 2011; Cui et al., 2012; Mesri et al., 2012; Liu et al., 2014; Kumar et al., 2015; Seah et al., 2016; Zhuang and Cui, 2016; Cai et al., 2017).

There are many efforts on the development of technique and theory of vacuum preloading with prefabricated vertical drains since the vacuum preloading was first proposed by Kjellman (1952). The developments and applications of vacuum preloading techniques was reviewed by Indraratna and Redana (2000), Chu et al. (2008), Griffin and O'Kelly (2014). Several methods based on the vacuum preloading technique have been developed by many researchers, such as the combined vacuum and fill

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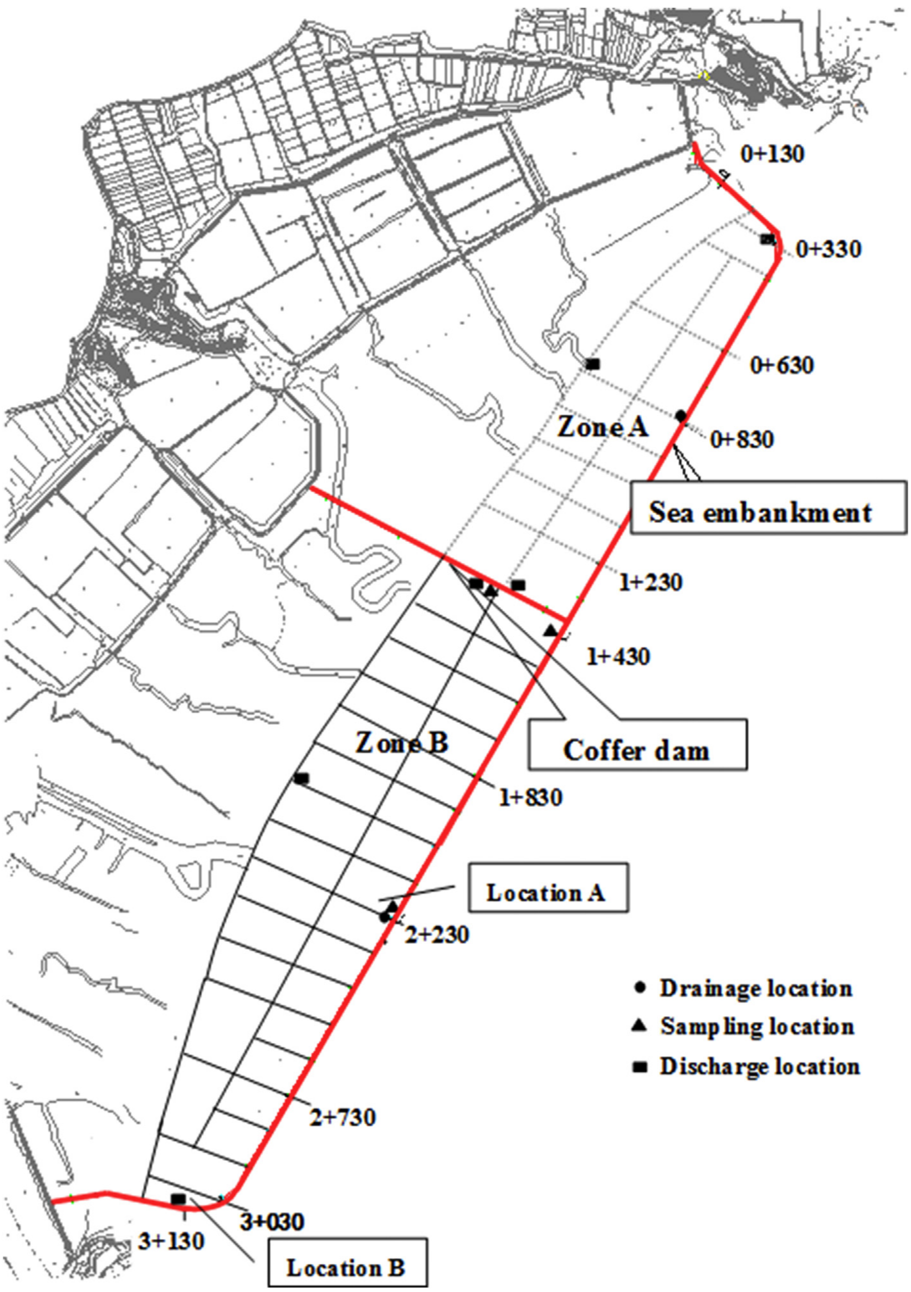

Fig. 1. Land treatment area sketch.

surcharge preloading method (Leong et al., 2000; Yan and Chu, 2005; Saowapakpiboon et al., 2011), the vacuum preloading incorporated with electroosmotic method (Casagrande D.R., 1986; Shang and Lo, 1997; Baotian and Vu, 2010), the combined vacuum preloading and pneumatic fracturing method (Liu et al., 2012, 2016), and the combination of electroosmosis, vacuum and surcharge preloading method (Liu et al., 2014).

Although there are many studies and applications on the vacuum preloading method, further investigations are still necessary for hydraulic filled clay land as their properties aforesaid are quite different than those of natural soft land. The vacuum preloading are not always successfully used for such kinds of ground improvement works, including in China (Tan and Liew, 2000; Gue et al., 2001; Bao et al., 2014). Construction technique optimization and accurate prediction of settlement and consolidation degree are more challengeable (Le at al., 2013; Chung et al., 2014; Zhuang and Cui, 2016; Wang et al., 2016, 2017; Zheng et al., 2017). Because the reclaimed slurry is of high initial water content and high clay content, the consolidation deformation would be large and the settlement would be more complicated. Terzaghi (1925) linear infinitesimal strain consolidation theory is not adapted to predict the ultimate settlement for cases which the deformation or settlement is larger than 15–20% as it concludes a number of simplifying assumptions: the constant permeability and compressibility, infinitesimal strain or deformation, omitted self-weight stress. Gibson (1967) proposed the nonlinear finite strain consolidation theory which removed the Terzaghi's assumptions. Theoretically, this theory may be acceptable for consolidation projects using dredged clay slurry with very high initial water content. However, to obtain analytical solutions from solving these consolidation equations of this theory would be complicated for engineers. Some empirical formulae based on measured data are simple and have a wide range of applications in practical engineering, such as hyperbolic curve method (Tan et al., 1991; Mosleh A. Al-Shamrani, 2003; Yang and Xu, 2014), exponential curve method (Barron et al., 1948; Saowapakpiboon et al., 2010) and Asaoka's method (Asaoka, 1978; Zhuang and Cui, 2016).