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Experimental study on a dredged fill ground improved by a two-stage vacuum preloading method

Jun Wang [a,b,c], Yuanqiang Cai [d], Hongtao Fu [a,b,c,*], Xiuqing Hu [a,b,c], Ying Cai [a], Haizhi Lin [e], Wei Zheng [f]

[a] College of Architecture and Civil Engineering, Wenzhou University, Chashan University Town, Wenzhou, Zhejiang 325035, China
[b] Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation, Wenzhou University, Wenzhou, Zhejiang 325035, China
[c] Innovation Center of Tideland Reclamation and Ecological Protection, Wenzhou University, Wenzhou, Zhejiang 325035, China
[d] College of Civil Engineering and Architecture, Zhejiang University of Technology, Hangzhou 310014, China
[e] Reclamation Construction and Development Limited Company of Dongtou Zhuangyuan South, Wenzhou, Zhejiang 325035, China
[f] Department of Civil and Environment Engineering, Harbin Institute of Technology, Shenzhen Graduate School, Shenzhen 518055, China

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Abstract

The vacuum preloading method has been wisely chosen among many ground-improvement methods considering the time limit of many projects and the characteristics of reclaimed soil. However, the loss in vacuum with soil depth, the clogging around prefabricated vertical drains (PVDs), and the deteriorative consolidation of the deep soil layer, among other factors, create a large challenge to vacuum preloading for dredged marine clay fill. Thus, this study proposes a two-stage vacuum preloading method and focuses on its feasibility and effectiveness. Contrasting laboratory tests are performed in two identical experimental tanks with dredged marine clay fill from the Wenzhou land reclamation site in China. In one tank, the one-stage vacuum preloading method is used to serve as a baseline for this study. In the other tank, use of the two-stage vacuum preloading method is proposed for consolidation; it comprises two stages. In the first stage, the dredged marine clay fill is conditioned by vacuum preloading using half of the PVDs, where the dissipation of the excess pore water pressure tends to be steady. In the second stage, vacuum preloading is activated using all the PVDs. The results show that a better consolidation effect is achieved with the proposed method in terms of the settlement, vacuum pressure, pore water pressure, water content, vane shear strength, and soil particle microstructure after soil consolidation.

Keywords: Dredged fill; Two-stage; Vacuum preloading; Consolidation effect

1. Introduction

The rapidly developing economy and the booming population of coastal cities in China have utilized land reclamation as an attractive approach to overcoming the land crisis. The Wenzhou Oufei Project is the biggest tideland reclamation program in China; its aim is to reclaim a total area of 323.4 km^2 along the Eastern Sea belt of China that is 1.64 times as large as Wenzhou City (Cai et al., 2017a, 2017b; Wang et al., 2016, 2017; Fu et al., 2017). Millions of tons of dredged materials are being removed annually from the sea beds during maintenance work because of the lack of granular fill in Wenzhou and the surrounding regions. These dredged materials are employed as the main fill materials for land reclamation. However, they are typically characterized by high water content and

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* Corresponding author at: College of Architecture and Civil Engineering, Wenzhou University, Chashan University Town, Wenzhou, Zhejiang 325035, China.
E-mail address: fuhongtao2012@163.com (H. Fu).

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compressibility and low undrained shear strength and permeability (Zeng et al., 2016, 2017). Soil possessing these characteristics cannot support construction equipment or be used to build upper structures. Moreover, their disposal has become a troublesome problem. The vacuum preloading method is chosen from among several ground-improvement methods considering the time limit of many projects and the characteristics of reclaimed soil.

The vacuum preloading method has evolved into a mature and efficient technique from its development in the early 1950s (Kjellman, 1952). Since then, it has become an effective soil improvement method for soft clay around the world (Holtan, 1965; Chu et al., 2000; Tang and Shang, 2000; Seah, 2006; Varaksin and Yee, 2007; Miyakashi et al., 2007a, 2007b; Saowapakpiboon et al., 2008; Chu et al., 2009; Indraratna et al., 2011). The conventional vacuum preloading system, referred to as the membrane system, consists of prefabricated vertical drains (PVDs), horizontal pipes embedded in a layer of a sand blanket, membranes, and vacuum pumps (Chu et al., 2004, 2006).

However, different variations in the vacuum preloading system have been used for different specific applications. The membrane system is the most commonly adopted method. The direct vacuum preloading method has been adopted in cases where a coarse granular soil is lacking (Xia and Chen, 2010). In this method, PVDs are tied directly to horizontal pipes to allow the vacuum pressure to be transmitted from the horizontal pipes to the PVDs with the intention of saving the use of a sand blanket as is normally used in the conventional vacuum preloading method (Chu et al., 2000; Yan and Chu, 2005). However, the inadequate consolidation of the deep soil layer is induced by the loss in vacuum along the drainage channel, and the drainage capacity decreases with the drainage channel blockage during soil improvement. Another relatively new method of applying vacuum preloading to dredged fill involves the direct application of vacuum pressure to the PVDs, which are hand-shaped joints and airtight pipes made especially for this purpose. This method is called the closed vacuum preloading method (Wang et al., 2014); it has been employed at land reclamation sites in Wenzhou (Wang et al., 2016). The PVDs were found to have undergone a drastic distortion because of the large soil deformation. A secondary vacuum preloading method (Sun et al., 2011) was used to reduce the PVD deformation and improve the soil reinforcement. However, the difficulty of installing the PVDs for the second time limited its widespread application.

The vacuum preloading technique has brought great progress. However, some limitations for dredged marine clay fill (e.g., vacuum loss with soil depth, clogging around the PVDs caused by a gathering of the soil particles, and non-uniform consolidation (Zhou and Chai, 2016)), and the deteriorative consolidation of the deep soil layer, which create a large challenge to the vacuum preloading of the dredged marine clay fill, still need to be addressed. Therefore, a two-stage vacuum preloading method is proposed herein; it is derived from the closed vacuum preloading method (Wang et al., 2014) and the secondary vacuum preloading method (Sun et al., 2011). In the first stage, the dredged marine clay fill is conditioned by vacuum preloading using half of the PVDs employed to decrease the water content and to increase the shear strength to form some steady drainage channels. In the second stage, the shear strength of the consolidated dredged fill is further increased by vacuum preloading using the remaining PVDs to meet the overall intensity requirements. Contrasting laboratory tests were performed to evaluate the effectiveness of the proposed method. Several key parameters were measured during the test, including the vacuum suction pressure, the pore water pressure, and changes in the water content with different depths. Suggestions for selecting a suitable method in engineering practice were also provided based on the test results of this study.

2. Soil properties

The dredged marine clay fill used in this study was obtained from the Oufei reclamation site in Wenzhou, China (Fig. 1). Wenzhou has a beach area of more than 630 km^2, of which no less than 430 km^2 is available for reclamation. The dredger fill deposit at the land reclamation site has a total thickness of approximately 5 m. The main components of the dredger fill were mud, muddy clay, and muddy silty clay. The sampling depth was 0.5–2 m from the surface of the reclaimed site. Table 1 lists the typical soil properties considered in this study. The soil was extremely soft, with a water content above the liquid limit and virtually no shear strength.

The dredged marine clay fill was measured using a laser particle size analyzer (Mastersizer 2000) produced by Malvin, UK. Fig. 2 shows the curve of the particle size distribution; it illustrates that the soil particle distribution was uniform enough to be aptly used for the ground materials.

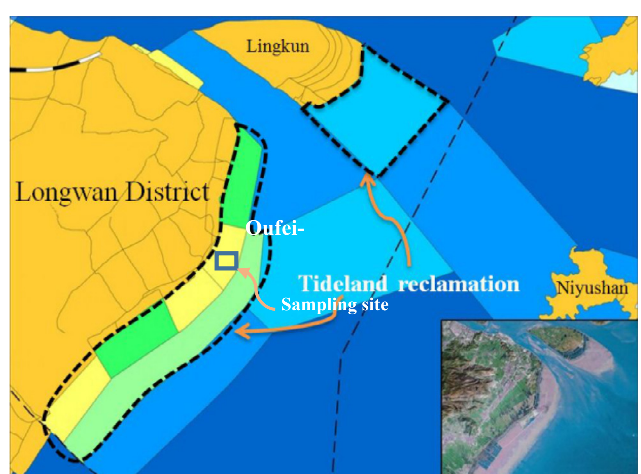

Fig. 1. Aerial view of the Oufei reclamation site in Wenzhou, China.

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