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A New Combined Vacuum Preloading with Pneumatic Fracturing Method for Soft Ground Improvement

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Abstract
A combined vacuum preloading with pneumatic fracturing method (VPF) was developed to overcome some shortcomings of the conventional vacuum preloading for soft soil improvement. In this method, high pressure air is injected into the soil before and during vacuum pressure exerting, which causes pneumatically fractures when the air pressure exceeds a critical threshold value. These fractures can increase significantly the soft soil mass permeability and accelerate the pore water pressure dissipating. Hence the VPF method can reduce preloading time and enhance the improvement efficiency of deep soft soil layers. A field project in a highway engineering located in Jiangsu Province of China was conducted to compare the performance of the VPF method and the conventional vacuum preloading. The vacuum degree, pore water pressure, groundwater level, surface settlement and horizontal displacements were monitored during the field test. The effectiveness of soft ground improvement was demonstrated by the comparison of piezocone penetration tests and soil property tests before and after ground improvement. The results showed the high efficiency of the VPF method, especially for deeper soft soil layers. It is a promising method in soft ground improvement engineering practice.

Keywords: pneumatic fracturing, vacuum preloading, soft clay, embankment, settlement

1 Introduction

Vacuum preloading, proposed in early 1950s by Kjellman (1952), has been widely used for soft ground improvement. Due to the limitations of the pumping vacuum equipment, sealing material, and vertical drainage, the method was not successfully used in the early stage (Cognon et al., 1996). In 1970s, since those technical problems were solved, the vacuum preloading method began to be widely used in soft soil engineering. As many engineering practices shown, the vacuum preloading method has some advantages such as no fill material required, shorter construction time, lower cost and environment friendly (Chai et al., 2006). However, some limitations of the vacuum consolidation method were pointed out (Chai et al., 2006): (1) the consolidation time is relatively long for deep soft clay due to their low permeability, which result in the uncertainty of the control post-construction

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settlements; and (2) the vacuum pressure decreases sharply along the depth inducing unsatisfactory efficiency for deeper soft soil.

Several improvements to the vacuum preloading method have been made in the past few years. Drain panels was developed instead of pipes to keep the drain function under high surcharge pressure and to provide better channels for distributing vacuum pressure and discharging water. The vacuum loading combined with surcharge preloading has been researched in laboratory and in numerous engineering projects (Leong et al., 2000; Chai et al., 2006; Rujikiatkamjorn and Indraratna, 2007). Another method combining vacuum preloading with dynamic compaction was developed (Xu et al., 2003). Although these developments have been successfully used in engineering practices, the limitation associated with the improvement efficiency of deep soft soil is still a concern because of the obvious loss of vacuum pressure with the depth and the low permeability of deep soft soil.

A new method, combining the vacuum preloading with pneumatic fracturing and being term as VPF method, was proposed in this study. High pressure air is injected into the soil in this method to generate fractures, then the soft soil mass permeability is increased and the pore pressure dissipation is accelerated significantly. A field test in a highway ground improvement project in Jiangsu Province of China was implemented to validate the performance of the VPF method.

2 Improvement Mechanism of VPF Method

2.1 Pneumatic Fracturing

Pneumatic fracturing is the process of generation or extension of fractures by injecting high pressure air into soils (Alfaro and Wong, 2001; Zhang and Liu, 2008). Since 1990s, the pneumatic fracturing has been developed to increase the mass permeability of soils in environmental engineering and to enhance the bioremediation, biodegradation, which makes contaminant removal and treatment more efficient. The pneumatic fracturing phenomenon has also been observed in geotechnical engineering particularly in ground improvement practices. Larsson et al., (2005) observed a clear pneumatic fracturing phenomenon in process of the installation of deep jet mixing (DJM) columns when the air pressure ranged from 350 kPa to 500 kPa. One to three vertical radial fractures around the column, which were about 10 mm width and 0.5 m long, were observed. Johansson (1999) reported that the maximum excess pore water pressure induced by the installation of DJM lime column was about 1.5 times the static pore pressure when the air jet pressure ranged from 420kPa to 450 kPa. Shen et al. (2003) demonstrated that the rapid consolidation of soft soils through fractures after the installation of DJM columns increases their strength with time. Liu et al. (2008) proposed a combined DJM-PVD method to enhance the quality of DJM column based on the pneumatic fracturing mechanism during the DJM installation. The excess pore water pressure generated by DJM installation is dissipated quickly through networking consisted of PVDs and horizontal pneumatic fractures.

The fracturing mechanism in soils has been identified as shear failure mechanism (Mori and Tamura, 1987) or tensile failure mechanism (Andersen et al., 1994). Shear failure mechanism implies that fracturing in soil occurs when the stress of a soil element intercepts the strength envelope such as Mohr-Coulomb criterion. Tensile failure mechanism means that fracturing occurs when the minor principle stress become negative with the magnitude equal to or greater than the tensile strength of soil. According to the tensile and shear failure mechanisms respectively, Zhang and Liu (2008) proposed the criteria formula for pneumatic fracturing in three dimensional stress state based on the cavity expansion theory.