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Performance of PVD improved soft ground using vacuum consolidation methods with and without airtight membrane

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ABSTRACT

In order to investigate the performance behavior of soft ground improvement using different vacuum consolidation methods (VCM) and different PVD thicknesses, four trial sections namely C1, C2, D1, and D2 were constructed. VCM without airtight membrane using cap drains and direct tubing system (VCM-DT) were used for the first two sections with PVD thickness of 3 mm and 7 mm for C1 and C2, respectively. VCM with airtight membrane and band drains (VCM-MB) were applied for the last two sections for D1 and D2with PVD thickness of 3 mm and 7 mm, respectively. The soil conditions, construction procedures, instrumentation program, and monitored results of the above trial sections are presented in this paper. The results confirmed that the effective vacuum pressure in PVD mainly depends on vacuum consolidation methods and the assumption of uniform distribution of vacuum pressures along the PVD depth which can be suggested for practical design. For VCM-MB using PVD thickness of 3 mm arranged in triangular pattern of 0.9 m spacing, the degree of consolidation of more than 90% can be achieved in less than 8 months of vacuum pumping. However, for VCM-DT, further investigation is needed for preventing air leakage in vacuum system particularly for the case of thick soft clay deposits with large deformations during the preloading.

1. Introduction

Soft clay deposits are wide spread in Mekong River Delta (MRD) and Saigon-Dong Nai River lower plain (SDR) including Ho Chi Minh city(HCMC) in Southern Vietnam. The low shear strength and the high compressibility of these soft clays have challenged the wit of the geotechnical design engineers in solving problems related to the stability condition during embankment construction as well as to the post construction settlements. Residual settlements including differential settlements during operation period constitute major problem of most highway projects constructed on soft ground in MRD and SDR. Preloading soft clay deposits for increasing stability and controlling the post construction settlements using PVD with embankment surcharge and vacuum pumping has been extensively applied (Bergado et al., 1998; Chu et al., 2000; Yan and Chu, 2005; Kelly and Wong, 2009; Rujikiatkamjornand and Indraratna, 2007, 2009, 2013; Indraratna et al., 2005, 2011, 2012; Artidteang et al., 2011; Geng et al., 2012; Long et al., 2013; Chai et al., 2013a, 2013b; Voottipruex et al., 2014). In Viet Nam, the first application of surcharge combined vacuum consolidation for soft ground improvement under expressway embankment was proposed for the North-South Expressway (NSEW) connecting HCMC and Dong Nai province. In order to evaluate the performance behavior including vacuum pumping techniques and the influence of PVD thickness on vacuum pressure distribution as well as other assumptions to be used in design calculations for this project, four trial sections, namely: Sections C1, C2, D1, and D2 were conducted using different vacuum consolidation methods (VCM) and different PVD thicknesses. VCM without airtight membrane using cap drains and direct tubing system (VCM-DT) were used for Sections C1 and C2 with PVD thickness of 3 mm and 7 mm, respectively. VCM with airtight membrane and band drains (VCM-MB) were applied for Sections D1 and D2 with PVD thickness of 3 mm and 7 mm, respectively. Site conditions, construction procedures, instrumentation program and monitored results as well as analyses and discussions on the

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List of notations

a	thickness of prefabricated vertical drain
L_d	length of prefabricated vertical drain
C_c	compression index
c_v	coefficient of consolidation in vertical direction
e_0	void ratio
H	embankment height
p_c	pre-consolidation pressure of improved soil
p_{fill}	pressure at the base of embankment due to the self weight of embankment fill
p_{vac}	effective vacuum pressure inside the vertical drain
p_{w0}	pore water pressure inside the vertical drain before vacuum pumping
p_{wt}	pore water pressure inside the vertical drain at time t
t	time
u_0	initial excess pore water pressure at a depth z
u_z	excess pore water pressure at a depth z at time t
U_z	degree of consolidation at a depth z
z	depth from ground surface to a considered point
γ	total unit weight of soil
$\Delta\sigma_v$	increase of total vertical stress at a depth z due to the self weight of embankment fill
$\Delta\sigma'_{vt}$	increase of effective vertical stress at a depth z at time t
$\Delta\sigma'_{vf}$	increase of effective vertical stress at a depth z when excess pore water pressure is fully dissipated
σ'_{v0}	effective overburden stress of natural soil at a depth z

performance behavior of the above trial sections are presented in following sections.

2. Soil conditions

The project site was located at Nhon Trach District in Saigon-Dong Nai River delta (SDR), about 25 km to the east of HCMC. The site area is quite flat with natural ground surface at elevation (EL) of +0.5 m to +0.70 m. The ground water table in rainy season is near the ground surface at EL of about +0.5 m and it is about 0.5 m–1.0 m lower in dry season. The soil profile along the center line of trial sections is presented in Fig. 1, consisting of following sub-soil layers:

- Current fill: Fine sand fill with thickness of about 0.5 m–1.0 m.
- Layer 1a: Very soft clay of around 6–10 m thick with some organic matters, average values of water content are of 90.3%, plastic limit of 45%, liquid limit of 95%, unit weight of 14.5 kN/m^3, and SPT-N values from 0 to 1.
- Layer 1b: Underlying layer 1a to the depth of about 11 m to 23 m, soft clay with some organic matters, average values of water content are of 72.2%, plastic limit of 44%, liquid limit of 81%, unit weight of 1.51 kN/m^3, and SPT-N values from 1 to 3.
- Layer 2: Underlying layer 1b to the depth of about 15 m to 28 m, firm to stiff clay with some organic matters, average values of water content are of 34.2%, plastic limit of 30%, liquid limit of 72%, unit weight of 1.89 kN/m^3, and SPT-N values from 10 to 22. Sand lenses (L2-1) were found in this soil layer.
- Layer 3: Underlying layer 2 to the depth beyond the bottom of borehole is medium dense, fine to medium sand with SPT-N values from 10 to 34.

The basic properties of foundation soils consisted of wet unit weight, γ_w, natural water content, ω, and initial void ratio, e_0, from 4 boreholes along the center line of the trial embankments are plotted together in Fig. 2. The soil parameters from laboratory oedometer tests for the geotechnical parameters along the expressway including the trial sections are represented in Fig. 3, in

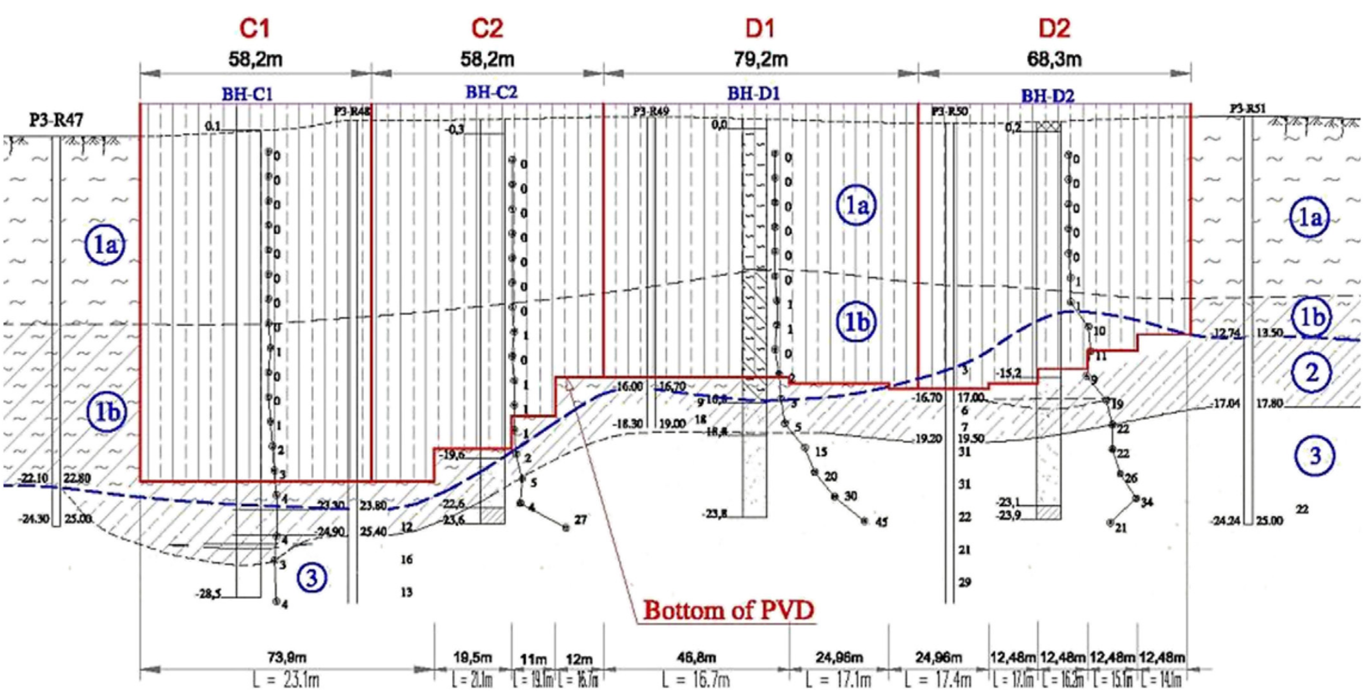

Fig. 1. Soil profile along the Trial Sections C1, C2, D1 and D2.