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Technical Note

An approach to shorten the construction period of high embankment on soft soil improved with PVD

A.K. Sinha*, V.G. Havanagi, S. Mathur

Geotechnical Engineering Division, Central Road Research Institute, Delhi-Mathura Road, New Delhi 110020, India

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ABSTRACT

Prefabricated Vertical Drains (PVDs) are being used to accelerate the consolidation of subsoil for construction of high embankment on soft ground. The construction is carried out in stages and height of the first stage construction depends on in-situ undrained shear strength. Each subsequent stage construction is carried out after completion of either 90% primary consolidation or percent consolidation at inflection point. The height of subsequent stages depends upon the gain in undrained strength of subsoil. In this paper, the authors have advocated an approach to shorten the construction period for high embankments. In this approach, the first stage construction would be carried out based on the in-situ undrained shear strength of subsoil. Instead of waiting for 90% primary consolidation or percent consolidation at inflection point, the embankment is raised in layers of 0.2 m thickness. Based on the time required to gain strength with the construction of the 0.2 m layer, the waiting period is determined for each subsequent layers. The waiting period depends on soil parameters such as subsoil thickness, C_r/C_v ratio and different PVD factors viz. smear, drain spacing and well resistance, pattern of laying of PVD, etc. Using this approach, there would be increase in the consolidation rate and overall reduction in the construction period. A typical practical example has been solved to demonstrate the usefulness of this approach over the two conventional methods. For a 4.5 m high embankment, it is observed that waiting period is reduced by 77% and 43% as compared to the 90% primary consolidation method and inflection point method respectively.

1. Introduction

The use of vertical drains and surcharge to accelerate the consolidation of thick deposit of soft clay for soil improvement is well established and there have been a number of recent papers on this topic (Abuel-Naga et al., 2006; Abuel-Naga and Bouazza, in press; Chai et al., 2006, 2008; Chu et al., 2006; Rowe and Li, 2005; Rowe and Taechakumthorn, 2008). The significant concern for embankment construction on soft soil is to reduce the time required for consolidation of soft ground and to accelerate the rate of construction. For this purpose, PVDs are often used and several cases have been reported (e.g. Bergado et al., 1993a,b; Hansbo, 2005; Holtz, 1987; Indraratna et al., 2005; Shen et al., 2005; Tan, 1994). Analytical solutions developed by Barron (1948) and Hansbo (1981) are widely used.

Generally, construction of high embankment is carried out in stages on soft ground. Height of the first stage construction depends on in-situ undrained strength and target factor of safety. Ladd (1991) and Bergado et al. (2002) studied this aspect and analysed the stability and gain in strength of subsoil due to surcharge loading in multistage construction. Nicholson and Jardine (1981) carried out multistage loading analysis based on the assumption that consolidated undrained strength (C_U) would grow in proportion to their maximum effective vertical stress (σ'_v). An overall ratio (C_U/σ'_v) of 0.25 was selected after considering the likely effects of change to plain strain condition, anisotropy and strain rate dependence. Ladd and Foot (1974) have given SHANSEP (Stress History and Normalized Soil Engineering Properties) procedures for estimation of in-situ undrained strength. The increase in subsoil strength is estimated by carrying out vane shear and static cone penetration tests before and after the surcharge loading. Li and Rowe (2002) studied the effect of construction rates on rate sensitive soils.

The next stage of loading i.e. incremental height of embankment is taken up after completion of 90% primary consolidation (IS 15284, part 2, 2004) or at inflection point consolidation (Sinha et al., 2007). The waiting period to achieve 90% consolidation or at inflection point for soft soils may vary from few weeks to several

* Corresponding author. Tel.: +91 011 26842612; fax: +91 011 26845943.
E-mail address: sinha.crri@nic.in (A.K. Sinha).

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Nomenclature

b	Width of PVD
C_c	Compression index
C_r	Coefficient of consolidation in radial direction
C_u	Undrained shear strength of subsoil
C_v	Coefficient of consolidation in vertical direction
d	Equivalent diameter of PVD
d_s	Diameter of smear zone
D_e	Effective drain spacing
e_0	Initial void ratio
F	Factor of safety
h_1	Height of first stage embankment
h_2	Height of second stage embankment
H	Thickness of clay layer
k_r	Coefficient of permeability in radial direction
k'_r	Coefficient of permeability in smear zone (radial direction)
k_v	Coefficient of permeability in vertical direction
l	Drainage length of PVD
M	Slope of degree of consolidation with log time, $100 \times dU\%/d \log t$
M_r	Coefficient of volume change
n	Drain spacing ratio, D_e/d
N_c	Terzaghi's bearing capacity factor
P_s	Drain spacing for a square pattern
q_w	Discharge capacity of PVD
s	Smear ratio, d_s/d
S_p	Center to center spacing of PVD
S	Ultimate primary settlement
t	Time
t_b	Thickness of PVD
t_w	Waiting period in day
T_r	Time factor in radial direction
T_v	Time factor in vertical direction
U	Degree of consolidation
U_r	Degree of consolidation in radial direction
U_v	Degree of consolidation in vertical direction
Greek symbols	
γ_s	Density of subsoil
γ	Dry density of embankment material
C_U	Undrained strength of in-situ subsoil
∇C_{U1}	Gain in undrained strength due to first stage construction
∇C_{U2}	Required gain in undrained strength for second stage construction
$\nabla \sigma$	Incremental over burden pressure
σ_o	Effective over burden pressure
σ'_v	Effective vertical stress

months. This period depends upon the subsoil condition, water table, spacing of PVDs and loading imposed due to embankment construction. The long waiting period not only leads to idling of man and machinery but delays the various project activities. The contractors obviously add the cost of all these delays in the project. In order to reduce the waiting period/idling time, Indraratna et al. (1992, 2005) studied the effect of loading rate of a 4 m high embankment on PVD stabilized soft clay. The rate of construction varied from 0.4 m/week to 0.1 m/week. It was concluded that slow rate of construction would allow the soft soil to gain sufficient strength supporting the stability of embankment.

In the present paper, a new approach has been proposed for incremental loading of the embankment. It has been suggested to raise the embankment in small increments of 0.2 m. Based on the time required to gain strength with construction of 0.2 m, the waiting period is determined for each subsequent layer. The method for calculating gain in undrained strength due to loading; degree of consolidation required for second and subsequent stage of loading, etc. has been explicitly explained in the paper and is supported with a solved example. It has been found that the method of small incremental loading is far more effective than the conventional approach as it not only reduce the total construction period but also reduces the idling of man and machinery.

2. Proposed construction method

The proposed construction method for high embankment has been given step wise as below.

Step 1 Height of first stage embankment construction.

The height of first stage (h_1) construction should be based on undrained shear strength of in-situ (virgin) subsoil as below.

$$h_1 = \frac{C_U N_c}{\gamma F} \tag{1}$$

where C_U = undrained strength of in-situ subsoil in kN/m^2, $N_c = 5.7$ (Terzaghi's bearing capacity factor), h_1 = height of the first stage embankment, γ = dry density of embankment material, $F = 1.25$ (IS 15284, part 2, 2004).

Step 2 Gain in undrained strength of subsoil due to first stage construction.

The gain in strength of in-situ subsoil due to first stage construction at 90% degree of consolidation is estimated using equation (2) (Nicholson and Jardine, 1981; Almeida et al., 2000).

$$\frac{\nabla C_{U1}}{\gamma h_1} = 0.25$$

$$\nabla C_{U1} = 0.25 \times \gamma h_1 \tag{2}$$

where ∇C_{U1} = gain in undrained strength of subsoil in kN/m^2 due to first stage construction, γ = dry density of embankment soil, h_1 = height of the first stage construction.

Step 3 Required gain in undrained strength of subsoil for second stage embankment construction.

According to MORTH (2001), the height of each compacted layer of embankment should be 0.2 m. For 0.2 m layers of embankment as second stage construction (h_2), required gain in undrained strength (∇C_{U2}) of subsoil is estimated by equation (4).

$$h_1 + h_2 = \frac{(C_U + \nabla C_{U2}) N_c}{\gamma F} \tag{3}$$

$$\nabla C_{U2} = (h_1 + h_2)\frac{F \times \gamma}{N_C} - C_U \tag{4}$$

Step 4 Degree of consolidation required for construction of second stage.