APPENDIX B

ASSESSMENT OF DEGREE OF CONSOLIDATION

CONTENTS

APPENDIX B ASSESSMENT OF DEGREE OF CONSOLIDATION

B.1 General

This appendix gives guidance on the principles of calculating the average degree of consolidation for a homogeneous soil stratum with or without vertical drains. When a vertical load is applied, an initial uniform excess pore pressure is assumed generated instantaneously throughout the soil stratum. This excess pore pressure will dissipate gradually or almost instantaneously, depending on the permeability of the soil and the drainage conditions at the boundaries of the stratum, by vertical drainage through the soil to the horizontal boundaries and/or by radial drainage into pre-installed vertical drains. The average degree of consolidation indicates how much of the imposed load is transferred to the effective stress in the soil (with 100% meaning full transfer), defined by:

$$U_t = \frac{u_i - u_t}{u_i} \times 100\% \qquad \text{(B1)}$$

where U_t = Average degree of consolidation of a homogeneous soil stratum at a particular time.

u_i = Initial excess pore pressure upon application of a vertical load.

u_t = Average excess pore pressure at a particular time.

B.2 Consolidation without Vertical Drains

Terzaghi's theory of one-dimensional consolidation predicts the excess pore pressure under vertical drainage alone. Based on Equation B1, Terzaghi's theory gives the following term for the average degree of consolidation due to vertical drainage:

$$U_v = 1 - \sum_{m=0}^{\infty} \frac{2}{M^2} \exp(-M^2 T_v) \qquad \text{(B2)}$$

where U_v = Average degree of consolidation due to vertical drainage alone.

M = $\frac{\pi}{2}(2m+1)$

T_v = $\frac{c_v t}{d^2}$

d = Length of longest drainage path.

t = Time from load application.

c_v = Coefficient of consolidation due to vertical drainage, which can be obtained from laboratory oedometer tests.

The variation of the degree of consolidation with depth is given by:

$$U_{v,z} = 1 - \sum_{m=0}^{\infty} \frac{2}{M} \sin\left(\frac{Mz}{H_{dr}}\right) \exp(-M^2 T_v) \qquad \text{(B2a)}$$

where $U_{v,z}$ = Degree of consolidation due to vertical drainage alone at depth z.
H_{dr} = Length of drainage path.

Reference may also be made to Lee et al (1992) for more accurate assessment of the degree of consolidation for layered deposits.

B.3 Consolidation with Vertical Drains

B.3.1 Consolidation due to Horizontal Drainage

The classical solution is analogous to that described in Section B.2 but flow is horizontal and radially inwards towards each drain. Barron (1948) arrived at the solutions for the excess pore pressure at any radial distance from the drain and at any time during consolidation. Based on Equation B1 and the assumption of equal vertical strain, the following expression can be established for the average degree of consolidation due to horizontal drainage:

$$U_h = 1 - \exp\left[\frac{-8T_h}{F(n)}\right] \qquad \text{(B3)}$$

where T_h = $\frac{c_h t}{D^2}$

c_h = Coefficient of horizontal consolidation.

D = Diameter of equivalent cylinder of soil drained by each vertical drain.

= $1.13 \times$ drain spacing for square grid

= $1.05 \times$ drain spacing for triangular grid

F(n) is a function mainly relating to drain spacing and size, and the extent of soil disturbance due to drain installation (smear effect). It has more than one version as addressed in detail in Barron (1948) and Holtz et al (1991). The basic form of *F(n)* for ideal drains with no smear effect can be expressed as:

$$F(n) = \frac{n^2}{n^2 - 1} \ln n - \frac{3n^2 - 1}{4n^2} \qquad \text{(B4)}$$

where n = D/d'
d' = Drain diameter.
= drain circumference / π

Regarding well resistance, the effect depends on the permeability of the vertical drains and the surrounding undisturbed soil as well as the drain diameter. Different versions of a modified form of Equation B3 that take into account the effect of well resistance (and smear effect) may be found in Hansbo (1981) and Onoue (1992).

B.3.2 Consolidation under Combined Vertical and Horizontal Drainage

The presence of vertical drains does not prevent the vertical drainage of water in the normal way. In reality, both horizontal and vertical drainage take place simultaneously. This can be taken into account using the relationship suggested by Carillo (1942):

$$U_f = U_h + U_v - U_h U_v \qquad \text{(B5)}$$

where U_f is the average degree of consolidation under combined vertical and horizontal drainage.

B.4 References

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