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Excess hydrostatic pressure in reinforced retaining wall with cohesive backfill

G.X. LI, Y.X. JIE, Department of Hydraulic Engineering, Tsinghua University, P.R. China
S.H. CHEW, Department of Civil Engineering, National University of Singapore, Singapore

ABSTRACT: Excess hydrostatic pressure may be induced during construction of reinforced retaining walls backfilled with cohesive soil. It may also be induced when surcharge is loaded on the ground surface behind the wall. This kind of excess hydrostatic pressure and its influence on the reinforced retaining wall were studied in the paper. It was found that the excess hydrostatic pressure increases the magnitude of active earth pressure and changes its distribution pattern. The excess hydrostatic pressure also reduces the friction between the backfill and the reinforcement. As a consequence, it leads to longer reinforcement to be used to build the reinforced retaining wall.

1 INTRODUCTION

In practice, cohesive soil is often used as backfill in constructing reinforced retaining walls. Positive excess pore water pressure may be induced in the course of construction. However, when excavation is made in soil nailing structure, there may be negative excess pore water pressure induced in the soil. The distribution of the pore water pressure may be in one-dimensional or in two-dimensional, altering with the drainage condition of the wall's facing. The excess pore water pressure changes the distribution pattern and the magnitude of the earth pressure, to which special attention should be paid.

A simple question on the excess hydrostatic pressure in one-dimensional distribution and its influence on the earth pressure were studied by Motta in 1996 (Motta, E. 1996). In this paper, relatively more complicate factors were considered.

2 PRODUCTION AND DISSIPATION OF EXCESS PORE WATER PRESSURE

Generally, the stress path in the backfill is approximately proportional loading during the construction and surcharge loading of the reinforced retaining wall. The equation proposed by Bishop to determine the excess hydrostatic pressure is

$$\Delta u = \overline{B}\Delta\sigma_1 \tag{1}$$

where

$$\overline{B} = B(A + (1-A)\Delta\sigma_3/\Delta\sigma_1) \tag{2}$$

in which A and B are the pore water pressure coefficients proposed by Skempton (Bishop, 1954); $\overline{B}$ can be directly obtained through the $\Delta\sigma_3/\Delta\sigma_1 = const.$ undrained triaxial test.

The dissipation of the excess hydrostatic pressure, Δu, depending on the drainage condition of the wall's facing. If the facing is impervious, the dissipation of Δu and the consolidation of the backfill may be in one-dimensional. Terzaghi's one-dimensional consolidation theory can be used to calculate the excess pore water pressure at any height in the backfill. However, if the facing is pervious, the consolidation will be in two-dimensional. For this case, we can resolve the two-dimensional consolidation into two one-dimensional consolidations in horizontal and in vertical direction (Carrillo, N. 1942).

For the sake of convenience, here we assumed a simple reinforced retaining wall backfilled with cohesive soil. The height of the wall is assumed to be *H*=5 m. The parameters of the backfill is as follows:

Unit weight γ, 20 kN/m^3
Effective cohesion c', 5 kPa
Effective friction angle φ', 30°
Degree of saturation S_r, 90 %
Seepage coefficient k, 1.0×10^{-6} cm/s
Initial void ratio e_0, 0.5
Compression coefficient a, 0.2 MPa^{-1}

The wall is assumed to be constructed in 10 layers. Each lift thickness is 0.5 m. The time interval between the constructions of each layer is assumed to be 8 hours. A surcharge of 30 kPa is immediately loaded on the ground surface behind the wall after it is finished.

The excess hydrostatic pressure is distributed in one-dimensional if the facing is impervious. While the excess hydrostatic pressure is distributed in two-dimensional if the facing is pervious (see Fig. 1 and Fig. 2).

3 CALCULATION OF EARTH PRESSURE WITH ONE-DIMENSIONAL EXCESS HYDROSTATIC PRESSURE

When the facing of the reinforced retaining wall is impervious, the excess hydrostatic pressure is distributed in one-dimensional. The pore water pressure only varies in the vertical direction, and does not change horizontally. In this case, Rankine's earth pressure theory is still suitable for the calculation of the active earth pressure. The active earth pressure, p_a, at certain depth, z, below the surface is:

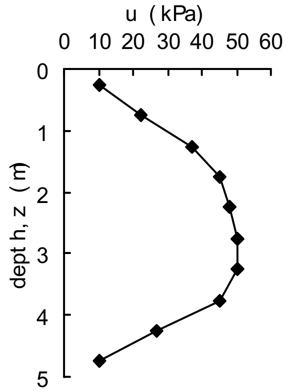
$$\begin{aligned} p_a &= K_a\sigma' - 2c'\sqrt{K_a} \\ &= K_a(\gamma z + q - u) - 2c'\sqrt{K_a} \end{aligned} \tag{3}$$

where $K_a = tg^2(45^\circ - \varphi'/2)$; *u*=excess pore water pressure; c'=effective cohesion; φ'=effective friction angle.

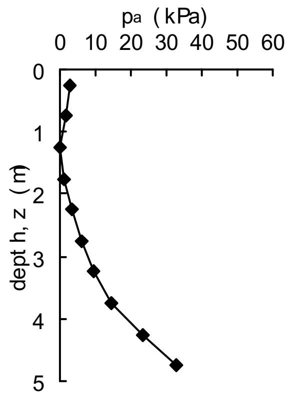
The total resultant pressure on the wall is:

$$\begin{aligned} P &= \int_0^H (p_a + u)dz \\ &= K_a(\frac{\gamma H^2}{2} + qH) + (1-K_a)uH - 2c'H\sqrt{K_a} \end{aligned} \tag{4}$$

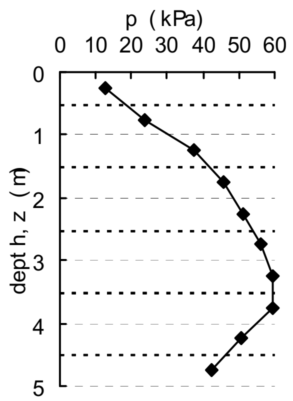
For the above-mentioned retaining wall, the calculation results are presented in Fig. 1. The distributions of the earth pressure and total pressure on the wall are nonlinear. And the



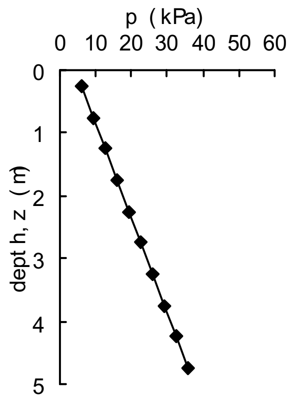
(a) Excess hydrostatic pressure



(b) Active earth pressure



(c) Total pressure



(d) Total pressure at u=0

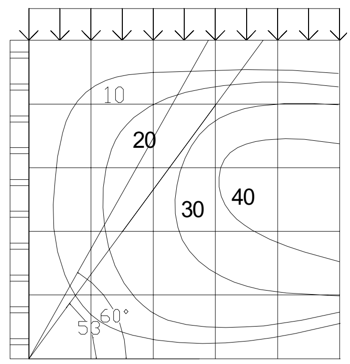
Fig. 1. Pressure at u distributed in one-dimensional

location of the maximum total pressure is higher than the case when the excess hydrostatic pressure, u, is equal to 0. The total resultant pressure is 210 kN/m. While in the case of u=0, the total resultant pressure is 104.5 kN/m.

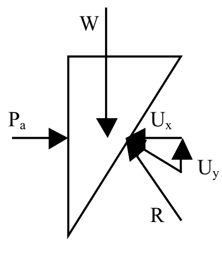
4 CALCULATION OF EARTH PRESSURE WITH TWO-DIMENSIONAL EXCESS HYDROSTATIC PRESSURE

For the above-mentioned retaining wall, if the facing is pervious, the distribution of excess hydrostatic pressure will be in two dimensional, as shown in Fig. 2a. Rankine's earth pressure theory is no longer suitable now, since the effective stress varies in the horizontal direction resulting from the pore water pressure's varying. Here we can use Coulomb's method to solve the question (see Fig. 2b). The result shows that the angle between the horizontal plane and the sliding surface is equal to 53°, instead of $45^\circ + \varphi'/2 = 60^\circ$, indicating that the sliding surface potentially passes through the region with higher pore water pressure.

The total resultant pressure by the calculation is equal to 155 kN/m, 50 percent higher than that (=104.5 kN/m) of the case if the excess hydrostatic pressure, u, is equal to 0.



(a) Distribution of excess hydrostatic pressure



(b) Slide wedge

Fig. 2. Two-dimensional distribution of the excess hydrostatic pressure and the calculation of total resultant pressure by Coulomb' method

The resultant active earth pressure P_a on the wall is

$$P_a = P - U_x \tag{5}$$

where P is the total resultant pressure on the wall; U_x is the horizontal component of the resultant pore water pressure acting on the sliding surface.

Supposing that the active earth pressure at certain depth, z, below the surface is

$$p_a = K_a(\sigma_z - u) - 2c'\sqrt{K_a} \quad (6)$$

where K_a is the coefficient of active earth pressure.

K_a can be determined by solving Eqs. 5 and 6. The distribution of the active earth pressure and the total pressure on the wall can then be obtained after K_a is got (see Fig. 3).

Fig. 3a shows the distribution of the excess hydrostatic pressure. It should be noted that there is no water pressure on the pervious facing of the wall: The distribution of the excess hydrostatic pressure shown in Fig.3a is actually the horizontal component of the seepage force on the slide wedge.

5 TENSILE FORCE AND ANCHORAGE LENGTH OF THE REINFORCEMENT

The total length needed for a certain layer of reinforcement, L_i, can be obtained by

$$L_i = L_{0i} + L_{li} \quad (7)$$

in which L_{0i} is the length of the reinforcement in the active zone, being equal to the distance between the sliding surface and the facing; L_{li} is the reinforcement's anchorage length.

L_{li} can be approximately determined by the following equation

$$2((\gamma z L_{li} + qL_{li} - U)tg\varphi_i' + c_i' L_{li}) = T_i \quad (8)$$

in which $U = \int_0^{l_{li}} u\mathrm{d}x$, u=pore water pressure; φ_i'=effective angle of friction between the reinforcement and the backfill; T_i=tensile force in the reinforcement. T_i can be approximately obtained by the total pressure on the wall.

The existence of the excess hydrostatic pressure induced longer reinforcement needed in design. The influence on the reinforcement can be expressed from the following four aspects:

(a) The excess hydrostatic pressure induces higher total pressure on the wall (see Fig. 1 and Fig. 3).

(b) The excess hydrostatic pressure reduced the effective vertical stress on the interface between the backfill and the reinforcement (see eq. 8).

(c) High tensile force may be induced in the reinforcement at the upper part of the wall by the high total pressure resulting from the existence of the excess hydrostatic pressure, which results in the increase of L_{0i}.

(d) The rise of the location of the reinforcement with the maximum tensile force induces the decline of the vertical geostatic pressure, γz, which leads to the increase of L_{li}.

As shown in Fig. 1c, the reinforcement with maximum tensile force is the 7th layer of reinforcement at the depth of 3.5 m below the surface. However, though the forces in the 1st and 2nd layers of reinforcement are not the biggest, the overburden pressures on them are very small. So they also need longer anchorage length.

6 CONCLUSIONS

Based on the study in this paper, the following main conclusions emerge:

(a) When the reinforced retaining wall is backfilled by cohesive soil with high degree of saturation, excess hydrostatic pressure may be induced in the soil during the construction.

(b) Rankine's earth pressure theory is still feasible if the pore water pressure is in one-dimensional distribution. The total pressure on the wall is the summation of the pore water pressure and the active earth pressure. The distributions of the three are all in nonlinear.

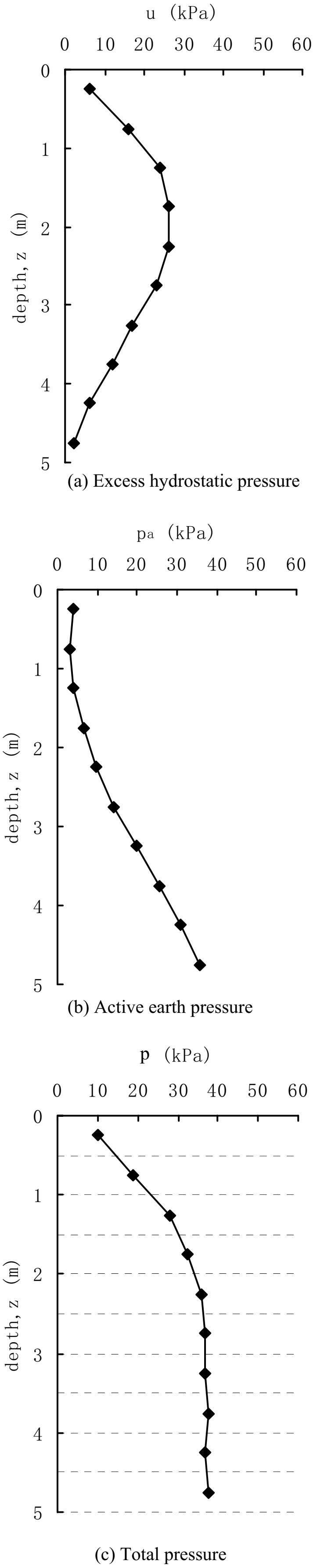


Fig. 3. Pressure at u distributed in two-dimensional

(c) Coulomb's theory is available if the pore water pressure is distributed in two-dimensional. The total resultant pressure can be obtained by graphical analysis. However, the angle between the failure surface and the horizontal plane is no longer equal to $45^{\circ} + \varphi'/2$.

(d) Excess hydrostatic pressure increases the total pressure on the wall, resulting in the increase of tensile force in the reinforcement. The excess hydrostatic pressure also changes the location of the reinforcement with the maximum force, and reduces the friction between the backfill and the reinforcement. As a consequence, it leads to the extension of the reinforcement's length necessary in design.

ACKNOWLEDGEMENT

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