III-501 ALLOWABLE GROUTING PRESSURE IN COHESIONLESS SOIL FOUNDATIONS

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ABSTRACT

In order to clarify the relationship between grouting pressure and pressurizing time in a pressure grouting programme, theoretical interpretation based on the hydraulic fracturing study in cohesionless soils was developed. It was found that the pressurizing time is exponential function of excess grouting pressure. Derived equations are helpful for estimating allowable grouting pressure and pressurizing time in pressure grouting applied to cohesionless soil foundations.

INTRODUCTION

Limiting the applied pressure in the pressure grouting does not seem to be explicitly mentioned in the geotechnical literature. It is obvious, of course, that in a layered soil under artesian pressure that too great a head will cause the ground surface to heave when $\Delta P_i/P_o' > 1$ where P_o' is the effective overburden pressure and ΔP_i is the excess injection pressure.

The grouting world was similarly conscious of hydraulic fracturing and Creager, et al. (1945) give the same rule of thumb for a safe grouting pressure. Others (Grundy, 1955, Lippold, 1958) give higher allowable grouting pressures. In order to estimate allowable grouting pressure, Morgenstern and Vaughan (1963) analysed hydraulic fracturing in terms of the excess pore pressure required to displace the effective stress circle until it touches the Mohr-Coulomb failure envelope.

Houlsby, A. H. (1977), to standardize of grout curtain in dam foundation, based upon the grouting experiences of many individuals, gives a range of permissible grouting pressure for different types of rock.

During the construction of earth dams, if grouting is applied from grouting gallery, additional attention is needed to keep the grouting pressure as less as minimum principal effective stress of core, near the foundation.

According to writers investigation for hydraulic fracturing in cohesionless soils, in this study theoretical equations for the maximum grouting pressure in cohesionless soils were derived. This equations are the function of pressurizing time which is an important factor on the grouting programme.

HEAVING BY GROUTING PRESSURE

It was found by experimental study that even for the higher injection pressures, hydraulic fracturing does not initiate in cohesionless soils, but if higher excess pressures are used in grouting below a foundation or concrete platform in a dam, the platform may be lifted from its seat. Concrete platform on the grouting surface commonly is used in pressure grouting. An important advantage of using concrete platform is repressing the ground material, if excess injection pressure exceeds P_o' effective overburden pressure near the borehole.

MAXIMUM INJECTION PRESSURE RELATED TO HEAVING CONDITION

Let us consider a grouting problem in which the grouting pressure is applied in a depth of h as shown in Fig.1. A concrete slab with radius R and thickness t is located on the surface of the ground. According to the penetration of grout material, the potential distribution is logaritmic in the grouting portion and this is shown in Fig.2. We consider the potential function of following form:

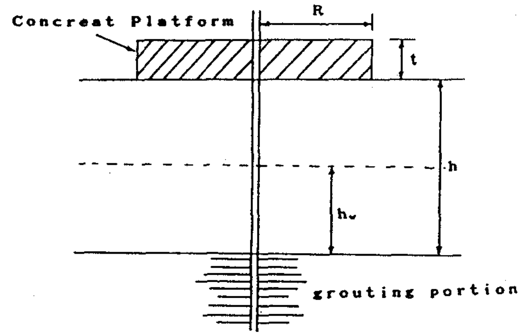

Fig.1. Grouting problem in which grouting pressure is applied in depth of h.

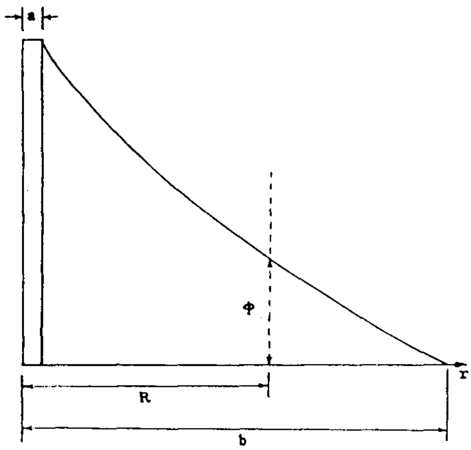

Fig.2. Distribution of potential in the grouting problem.

$$\Phi = \Delta P_i \frac{\ln(b/r)}{\gamma_g \ln(b/a)} \tag{1}$$

$$\Delta P_i = P_i - u_o \tag{2}$$

where P_i = total injection pressure, u_o = excess pore water pressure, ΔP_i = excess injection pressure, a = radius of the borehole, b = distance from the center in which injection pressure drops to u_o, and γ_g = unit weight of grout material.

Neglecting the effect of borehole, vertical effective overburden force acting under concrete slab as a cylinder with radius R, can be calculated in following form:

$$S_1' = \pi R^2(t\gamma_c + h\gamma_t - h_w\gamma_w) \quad (3)$$

where γ_c and γ_t are the unit weight of concrete and ground soil respectively. The excess uplift force which is the result of excess injection pressure into the borehole and acting under the slab, can be computed in following form:

$$S_2' = 2\pi\gamma_g \int_a^R \Phi r dr \quad (4)$$

substituting Eq.(1) into Eq.(4) and integrating the resulting equation, it becomes

$$S_2' = \frac{\pi \Delta P_i}{\ln(b/a)}[R^2(\ln b/R + 1/2) - a^2(\ln b/a + 1/2)] \quad (5)$$

For the equilibrium of the forces, when the heaving occurs, S_1' must be equated to S_2' and the resulting equation becomes:

$$\Delta P_i[R^2(\ln b/R+1/2)-a^2(\ln b/a+1/2)]- -R^2(t\gamma_c+h\gamma_t-h_w\gamma_w)=0 \quad (6)$$

Considering k_g permeability coefficient of the ground with respect to the grout material and γ_g unit weight of the grout material, velocity can be calculated from Eq.(1) and has following form:

$$V_r = \frac{k_g \Delta P_i}{r\gamma_g \ln(b/a)} \quad (7)$$

The time t_g which is the time of arriving grout material to the point b, can be computed from the following equation:

$$t_g = \int_a^b dr/V_r \quad (8)$$

integrating Eq.(8) it becomes:

$$t_g = \frac{\gamma_g(b^2-a^2)\ln(b/a)}{2k_g \Delta P_i} \quad (9)$$

where k_g is the permeability coefficient with respect to the grout and equal to $k_o(\gamma_w/\mu)$ in which k_o is the permeability coefficient of ground for water, γ_w is the unit weight of water and μ is the viscosity of the grout material.

Unknown factors in Eqs.(6) and (9) are ΔP_i, b and t_g, where ΔP_i and t_g are excess injection pressure and pressurizing time respectively. Therefore if the injection pressure is kept constant, the pressurizing time can be calculated and reversely, if the pressurizing time is kept constant, allowable grouting pressure can be calculated.

MAXIMUM GROUTING PRESSURE RELATED TO INITIAL FAILURE

It is known from the behaviour of the cohesionless material that when the injection pressure exceeds confining pressure in a portion, the material initially will fail in this portion. Thus if in a grouting problem the radius of this portion exceeds an allowable distance, the ground under the slab will fail and the grout material will appear on the ground surface around the concrete slab. The result will be more dangerous if the injection is performed from the grouting gallery in earth dams, because the grout material can penetrate into the core, thus the core may fail by the hydraulic fracturing due to the grouting pressure.

Let us consider that the damage happens if the excess grouting pressure exceeds σ_h' effective horizontal ground pressure at the distance R. Substituting this condition ($\sigma_h' = \gamma_g\Phi$) into the potential equation (Eq.(1)) gives:

$$b = \exp\left[\frac{\Delta P_i \ln R - \sigma_h' \ln a}{\Delta P_i - \sigma_h'}\right] \quad (10)$$

again substituting Eq.(10) into Eq.(9) gives:

$$t_g = \frac{\gamma_g \ln(R/a)}{2k_g(\Delta P_i - \sigma_h')} \cdot \left[\exp\left(\frac{2\Delta P_i \ln R - 2\sigma_h' \ln a}{\Delta P_i - \sigma_h'}\right) - a^2\right] \quad (11)$$

Eq.(11) is the direct relationship between injection pressure and pressurizing time, therfore considering one as constant, the other can be calculated. The minimum value of ΔP_i or t_g computed from Eqs.(6), (9), and (11) must be considered in the application of pressure grouting in any cohessionless soil.

CONCLUSIONS

1. In cohesionless soil foundation grouting, permissible grouting pressure and pressurizing time are the function of each other. Increasing one, the other will decrease.

2. Hydraulic fracturing does not initiate in cohesionless soils but the concrete platform may be lifted from its seat due to the injection pressure or the grout material may penetrate into the core of earth dams due to the increase of failed portion.

3. Using Eqs.(6),(9), and (11), allowable injection pressure and pressurizing time can be estimated in a pressure grouting programme.

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