III-410 HYDRAULIC FRACTURING OF SOIL IN GEOTECHNICAL IN SITU PROBLEMS

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ABSTRACT

In order to clarify the effect of soil fracturing on various geotechnical in situ problems, laboratory hydraulic fracturing test results were compared with the in situ soil fracturing data. Good agreement between those laboratory results and in situ data indicates that hydraulic fracturing formulation on laboratory testing condition fairly can be applied to in situ problems. Thus ultimate hydraulic fracturing pressure related to in field permeability testing was discused.

INTRODUCTION

The effect of soil or rock fracturing has been recognized in many geotechnical in situ problems. Hydraulic fracturing is a technique of great use in augmenting production of tight oil- and gas- bearing rocks as well as in the development of artificial geothermal reservoir.

Another aspect of hydraulic fracturing lies in the area of pressure grouting. Determination of the allowable pressure is an essential factor in the design of a grouting programme. The use of higher excess pressures may weaken the strata by fissuring the soil and rock or by opening fissures in closed joints. Alternatively, if higher excess pressures are used in grouting below a foundation or a concrete cut-off in a dam, the concrete may be lifted from its seat. Such damage would result in the use of an uneconomical amount of grout, with the grout penetrating fissures induced by the grouting process itself at the best. The damage may, of course, be much worse and result in permanent weakening. During the construction of an earth dam, higher grouting pressure may damage the core due to hydraulic fracturing. However, it must also be recognized that the pressure should be kept sufficiently high to minimize the time required to perform the grouting operations.

Also using high pressures for in situ permeability tests, leads to very false results owing to hydraulic fracturing in soil.

The purpose of this paper is comparison between laboratory hydraulic fracturing results in soil and in situ practical data, finaly to introduce a reasonable ultimate value for hydraulic fracturing pressure related to various in situ problems.

HYDRAULIC FRACTURING IN SOIL

The writers have presented in a paper that, hydraulic fracturing initiation in soil is the result of shear failure of soil in the undrained and unconsolidated condition. Assuming elastic behaviour of material, in a hollow cylinder specimen following equation was obtained:

$$P_f-u_o=\frac{b^2(1+\sin\phi_u)}{b^2+a^2\sin\phi_u}(\sigma_h-u_o)+\frac{C_u(b^2-a^2)\cos\phi_u}{b^2+a^2\sin\phi_u} \qquad (1)$$

where:

P_f : Total hydraulic fracturing pressure.
u_o : Excess pore pressure in soil sample.
σ_h : Confining pressure.
ϕ_u : Angle of internal friction. (uu condition)
C_u : Cohesion of soil sample. (uu condition)
a : Internal radius of specimen.
b : External radius of specimen.

Direction of the fractures were vertical and perpendicular to the minimum principal stress plane.

For the in situ hydraulic fracturing problems considering $b\rightarrow\infty$, the expression becomes:

$$P_f-u_o=(1+\sin\phi_u)(\sigma_3-u_o)+C_u\cos\phi_u \qquad (2)$$

or

$$P_f-u_o=(1+\sin\phi_u)\sigma_3'+C_u\cos\phi_u \qquad (3)$$

where:

σ_3 : In situ minimum principal total stress.
σ_3' : In situ minimum principal effective stress.

If we assume that, hydraulic fracturing tests are performed on a portion which is located under ground water level, it can be assumed that the angle of internal friction in uu condition is equal to zero and the Eq.(3) becomes:

$$P_f=\sigma_3'+u_o+C_u \qquad (4)$$

or for the excess hydraulic fracturing pressure:

$$\Delta P_f=\sigma_3'+C_u \qquad (5)$$

considering $p_o'=\gamma' D$, the effective overburden pressure, where γ' =effective unit weight of soil, and D=depth of test point below the ground surface, horizontal effective stress becomes :

$$\sigma_3'=Kp_o' \qquad (6)$$

in which K is ratio of horizontal to vertical effective stress. Substituting Eq.(6) into Eq.(5), it becomes:

$$\Delta P_f=Kp_o'+C_u \qquad (7)$$

Eq.(7) agrees with in situ data which carried out by L. Bjerrum, et al at Fornebu, Oslo in a natural deposit of normally consolidated clay under conditions where the possibility of arching could be eliminated. Fig.1 shows typical results of in situ permeability test carried out at Fornebu, by assuming K=0.7.

IN SITU PERMEABILITY TEST

In situ permeability test is an important tool in soil and rock mechanics site investigations. The out flow test (where a positive excess head is applied) is often preferred to the inflow test, for it may be carried out more quickly. A considerable high value of pressure during the test, will generate hydraulic fracturing in soil and this leads to very false results.

When the test section is located under ground water level, hydraulic fracturing initiation follows the Eq.(7).

If the test points are located over the ground water level, the soil formation is unsaturated and ϕ_u has a considerable effect on hydraulic fracturing pressure. During the test, water through the borehole will penetrate into the soil formation. Considering pore pressure, u, in a point with distance, b, from the center of borehole as shown in Fig.2, and fluid flow satisfying Laplace Equation, hydraulic gradient near the borehole becomes:

$$i_a = \frac{P_f - u}{a \ln\frac{b}{a}} \qquad (8)$$

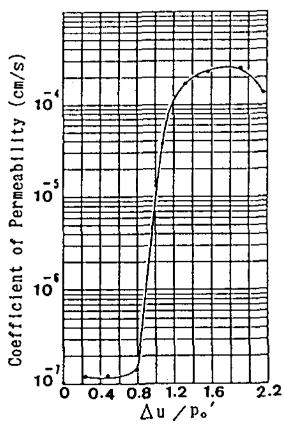

Fig.1. Typical result of in situ permeability test carried out by L. Bjerrum, et al in a deposit of normally consolidated clay at Fornebu, Oslo.(depth 3.1 m., p_o' effective overburden pressure, Δu excess water pressure in piezometer)

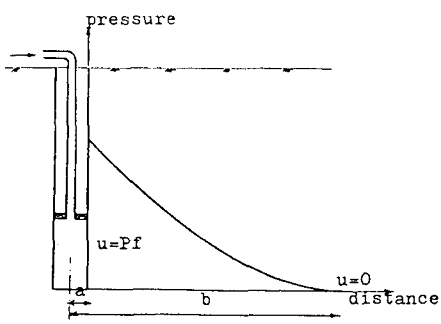

Fig.2. Penetration of water through the borehole into the soil formation.

Substituting Eq.(8) into Eq.(1), and considering u_o=u, following expression can be obtained:

$$P_f = \sigma_h + \frac{(b^2-a^2)(i_a.a.\ln\frac{b}{a} - \sin\phi_u + C_u\cos\phi_u)}{b^2(1+\sin\phi_u)} \qquad (9)$$

For the formation without pore pressure, minimum principal effective stress is equal to minimum principal total stress and equal to σ_h, therefore:

$$P_f = \sigma_3 + \frac{(b^2-a^2)(i_a.a.\ln\frac{b}{a} - \sin\phi_u + C_u\cos\phi_u)}{b^2(1+\sin\phi_u)} \qquad (10)$$

Along the test procedure, water penetration is developed and the value of i_a is decreased by time and finaly after a long time it can be neglected. In this case assuming $b \to \infty$, Eq.(10) becomes:

$$P_f = \sigma_3 + \frac{C_u\cos\phi_u}{1+\sin\phi_u} \qquad (11)$$

According to in situ problems, especially for deeper portions, the value of C_u as compared with σ_3 is small, and the critical state of total hydraulic fracturing pressure for in situ permeability test in any condition as mentioned above, becomes:

$$P_f \leqq \sigma_3 \qquad (12)$$

or for the excess hydraulic fracturing pressure according to overburden pressure:

$$\Delta P_f \leqq K p_o' \qquad (13)$$

In order to obtain an approximate idea of the permeability of strata, packer tests with constant applied head are commonly used. When the length of test section, L, is no less than 10 times the radius, r, of the hole, the following expression may be used for the calculation of the permeability, k:

$$k = \frac{Q}{2\pi LH}\ln\left(\frac{L}{r}\right) \qquad (14)$$

in which Q= the constant rate of flow into the hole, and H= the differential head of water.

The above explanation and Eq.(13) indicates that, the value of H must not exceed the minimum principal effective stress (Kp_o') of the test section. Generally Eq.(13) gives the allowable excess hydraulic fracturing pressure in connection with geotechnical problems.

CONCLUSION

To prevent soil fracturing in different geotechnical problems, it is necessary to keep applied excess pressure as less as horizontal effective ground pressure. Use of higher pressures leads to very false results in permeability tests and may damage foundation or core material of earth dams in pressure grouting.

REFERENCES

1. L. Bjerrum, J.K. T.L. Nash, R.M. Kennard and R.E. Gibson, "Hydraulic Fracturing in Field Permeability Testing" , 1972, Geotechnique 22, No. 2, pp. 319-332.

2. Adam Clive Houlsby, "Engineering of Grout Curtains to Standards" , ASCE, September 1977, pp. 953-970.