Temporary decrease of clay modulus in resonant column test

Diminution temporaire du module des argiles à la colonne résonnante

G. A. ATHANASOPOULOS, Asst. Professor of Civil Engineering, University of Patras, Patras, Greece
R. D. WOODS, Professor of Civil Engineering, University of Michigan, Ann Arbor, Michigan, USA

SYNOPSIS. During resonant column testing of cohesive soil specimens the value of low-amplitude modulus, immediately after tha application of a confining pressure increment,drops below the value it had at the end of duration of previous pressure increment.This drop is temporary and it is recovered after the lapse of a certain regain-time.A preliminary experimental investigation,using resonant column tests on a remolded kaolinite clay,examined the effects of magnitude and duration of the previous confining pressure on the amount of modulus loss and the length of the regain-time.It was found that increased values of the magnitude of previous confining pressure produced lower modulus loss but longer regain-times.Increased values of duration of previous pressure increment produced significantly longer regain-times and made the effects of magnitude of previous confining pressure more pronounced.

INTRODUCTION

The solution to many soil dynamics problems requires the knowledge of the shear modulus,G,of the soil.Values of G are determined either by in-situ or laboratory methods (Richart et al., 1970;Woods,1978).The resonant column testing technique is generally considered as one of the most reliable laboratory methods (Woods,1978). For granular soils the basic parameters affecting the value of G are the average effective confining pressure, $\bar{\sigma}_o$,the void ratio,e,and the amplitude of shearing strain,γ, (Hardin and Drnevich,1972;Richart et al.,1970).For cohesive soils the value of G is also affected by time effects (Afifi and Woods,1971;Anderson and Stokoe,1978;Anderson and Woods,1976;Hardin and Black,1968;Marcuson and Wahls,1972;Richart,1975), of which the most important seems to be the duration of action of the confining pressure,t.The value of G for small values of shearing strain ($\gamma < 10^{-3}$) is termed "low-amplitude shear modulus" and denoted by G_o or G_{max}.

The plot of Fig.1 illustrates typical results of a resonant column test on a cohesive soil specimen for low-amplitude vibrations.This plot indicates that the value of G_{max} is generally increasing with time.In particular two phases of increase can be distinquished : In the first phase the modulus increases mainly in response to the reduction of void ratio during the consolidation process (Anderson and Woods,1976; Hardin and Black,1968).In the second phase the modulus increases linearly with the logarithm of time.The slope of the G_{max} vs.logt straight line is denoted by I_G and termed "rate of secondary increase of G_{max}".It is believed that the normalized rate of secondary increse of G_{max} , which is denoted by N_G and defined in

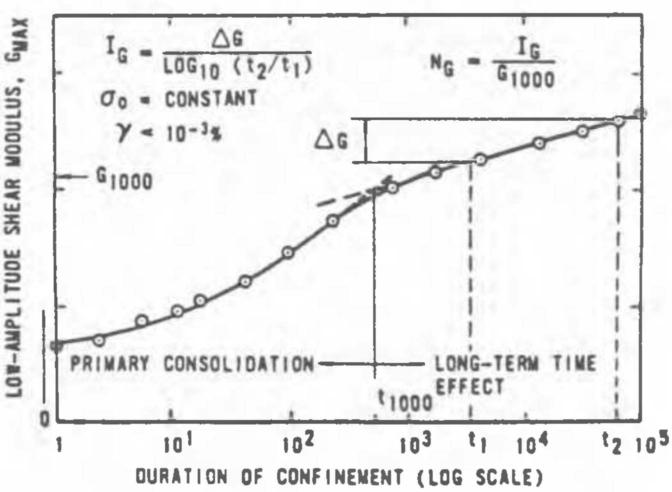

Fig. 1 Typical Results of a Resonant Column Test on a Cohesive Soil Specimen (from Anderson and Stokoe,1978)

Fig.1,is less dependent than I_G on the value of $\bar{\sigma}_o$ (Anderson and Woods,1976;Richart,1975).

The two phases of modulus increase described above seem to correspond to the primary consolidation and secondary compression phases of laboratory consolidation tests.In both these laboratory tests-consolidation and resonant column- a single soil specimen is tested under a sequence of increasing values of confining pressure. Results of resonant column tests,involving sucessive increases of confining pressure,have shown that immediately after tha application of a new confining pressure increment the value of G_{max} drops below the value it had at the end of duration of previous pressure increment (Hardin and Black,1968).This decrease is temporary and the modulus regains its initial value after the lapse of a certain time.It has been suggested that this decrease of modulus is due to the destruction of the stiffness built-up during secondary compression under the previous pressure increment and that modulus drop would increase with increasing magnitude of pressure increment ratio (Hardin and Black,1968).It has also been found that the immediate drop of the value of G_{max} increases with increasing duration of previous pressure increment and that the drop occurs even when only primary consolidation is allowed under the previous pressure increment (Afifi and Woods,1971;Anderson and Woods,1976).It has been recently suggested (Athanasopoulos,1981;Athanasopoulos and Richart 1981,1983) that the fast rates of deformation which are developed immediately after the application of a confining pressure increment(isotropic or anisotropic) are responsible for the immediate decrease of the modulus of cohesive soils.

The information presented above indicates that the duration of confining pressure increments is an important factor to consider when performing resonant column tests on cohesive soil specimens.In this paper the results are reported of a preliminary experimental investigation on the phenomenon of temporary decrease of clay modulus which was described above.In particular,the effects were examined of duration of pressure increment and of consolidation pressure on the amount of low-amplitude modulus loss and on the length of regain-time,of a kaolinite clay.

EXPERIMENTAL PROGRAM

The clay samples used in this investigation were prepared in the laboratory by mixing powdered kaolinite clay (commercially known as Ball Clay) with distilled water and then extruding the mixture from a Vac-Aire extrusion machine (Matlock et al.,1951).Reproducible samples were obtained in this way having W_p= 32, I_p = 39,Activity= 0,46,W_o=45%,e_o= 1.21 and G_s= 2.64.Much evidence has been accumulated indicating that the behavior of these samples is remarkably similar to the behavior of undisturbed samples of natural cohesive soils(Athanasopoulos,1981;Athanasopoulos and Richart, 1981)

The experimental program consisted of testing kaolinite specimens in a Hall-type resonant column device (Richart et al.,1970;Woods,1978) under several values of the effective confining pressure and two different values of duration of each pressure increment: one day and one week.Typical test results for these two durations of confining pressure increments are shown in Fig.2 and Fig.3.Notice that in these plots the shear wave velocity,V_s,instead of G_{max},is plotted vs.the logarithm of time.The two quantities,V_s and G_{max},are interelated via the following equation:

$$G_{max} = \rho . V_s^2 \qquad (1)$$

where ρ= mass density of soil.The initial drop of modulus was determined as the difference in the value of G_{max} at the end of each pressure increment and 1 min after the application of the next pressure increment.The regain-time was determined graphically from the plots as

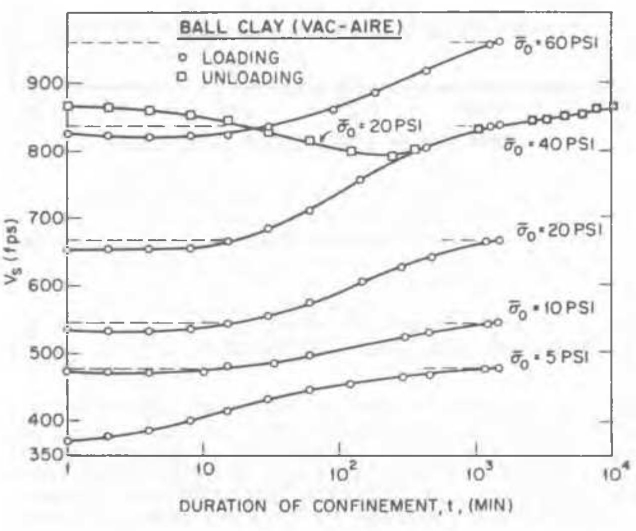

Fig.2 Initial Drop of Shear Wave Velocity After the Application of Pressure Increments: Short Term Tests (1psi = 6.9kPa, 1fps = 0.305 m / sec).

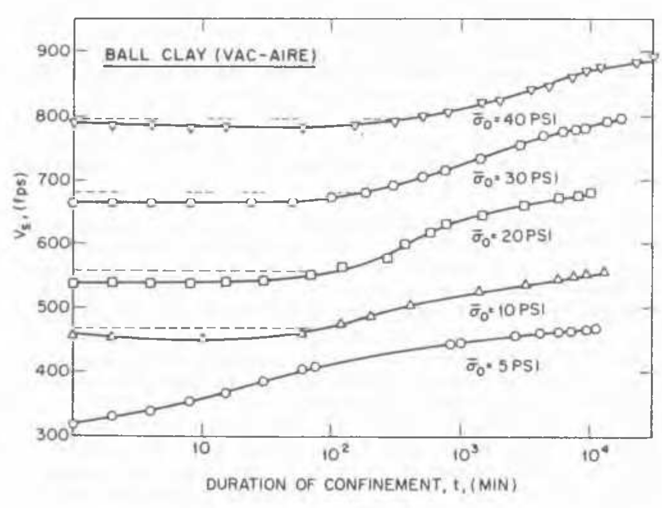

Fig.3. Initial Drop of Shear Wave Velocity After the Application of Pressure Increments: Long Term Tests (1psi = 6.9kPa, 1fps = 0.305 m/sec)

shown in Fig.2 and Fig.3.Notice in Fig.2 that upon unloading from 60 psi (414 kPa) to 20 psi (138 kPa) the value of V_s first undergoes an immediate decrease;the reduction continuous until the value of V_s reaches a minimum value after which it starts increasing establishing again a straight line in the V_s vs. logt plot. This behavior agrees with information reported previously (Anderson and Stokoe,1978,Stokoe et al.,1980).

DISCUSSION OF TEST RESULTS

The test results of the investigation will be discussed by reffering to Fig.4 and Fig. 5.

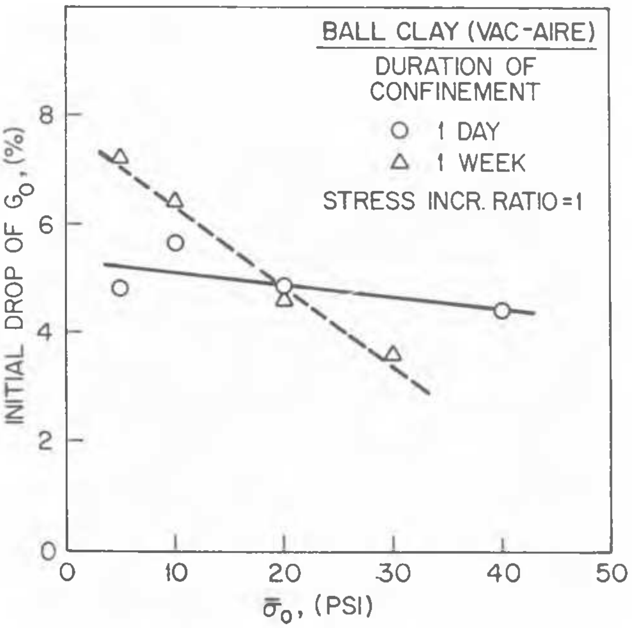

Fig.4 Effect of Magnitude and Duration of Previous Confining Pressure on the Initial Drop of Modulus(1psi =6.9 kPa)

The plot of Fig.4 depicts the effect of magnitude and duration of previous confining pressure on the initial drop of modulus.According to this plot the initial drop pf G_0 decreases approximately linearly with increasing values of confining pressure, $\bar{\sigma}_0$.It is interesting to note that the dependence of initial drop on the value of $\bar{\sigma}_0$ is almost insignificant for the one-day duration of pressure increment whereas it becomes significant for the one week duration. The maximum value of modulus drop observed in this investigation was about 7.5%.

The plot of Fig.5 depicts the effect of magnitude and duration of previous confining pressure on the regain-time measured under the next pressure increment.According to this plot the time required for the regain of the initial drop of modulus increases significantly with increasing values of $\bar{\sigma}_0$ .More striking,however,is the dramatic increase of regain-time when the duration of pressure increment was increased from one day to one week.The results of this investigation indicate that this increase may be of the order of 1230 %! (from 30 min to 400 min).This behavior suggests that the longer a cohesive soil remains under constant effective stress,i.e. the more "aged" is a cohesive soil,the more "sensitive" becomes its structure to the action of subsequent loading.Finally,it should be emphasized that the stress increment ratio was kept equal to 1 in this investigation.For values of this ratio much lower thah 1,the behavior of the cohesive soil could be different than that observed in this investigation.

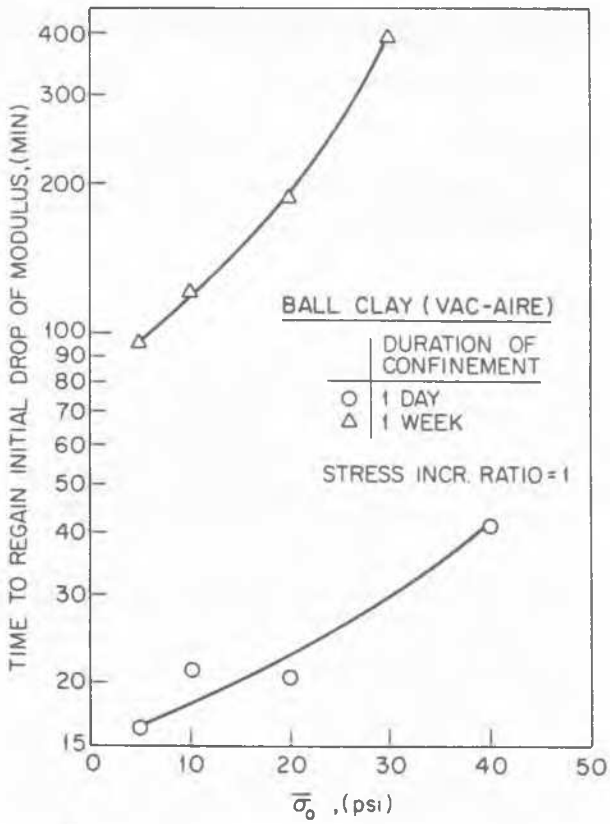

Fig.5. Effect of Magnitude and Duration of Previous Confining Pressure on the Regain-Time of Modulus (1psi = 6.9kPa)

CONCLUSION

The application of each confining pressure increment in resonant column tests on kaolinite clay specimens caused an immediate decrease of the low-amplitude shear modulus with regard to its value just before tha application of the particular increment.The modulus drop decreased with increasing values of confining pressure,the decrease being more pronounced for longer duration of the previous pressure increment.The modulus-drop was recovered after the lapse of a regain-time.This regain-time increased with increasing values of confining pressure and most significantly with increasing duration of the previous pressure increment.

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