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TECHNICAL NOTE

VARIATION IN DIFFERENTIAL PORE WATER PRESSURE AND PARTICLE SIZE AT DIFFERENT CONSTANT RATE OF LOADING IN AN AUTOMATED CONSOLIDATION TESTING SYSTEM

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SYNOPSIS

The paper presents the result of consolidation tests of a typical soil deposit collected from an excavated open pit for a rigid raft foundation, adopting constant rate of loading procedure and using a commercially available computer controlled consolidation testing system. The main objective of the paper, is to study the variation in differential pore water pressure at different rate of loadings and to evaluate compressibility characteristics of soils with tests of short duration to save testing time. The paper also presents the results of grain size analysis at constant rate of loadings.

INTRODUCTION

Consolidation of saturated soil is a process of volume reduction due to expulsion of water from the void space. If the process is slow, it can proceed without the creation of significant pore water pressures, but in case of rapid application of load the compression is inhibited by the inability of the water to drain away quickly enough and this results in a temporary increase in the pore water pressure. The building up and the dissipation of pore water pressures are related to the magnitude and the rate of loading (Crawford, 1964). The conventional oedometer test based on Terzaghi work has been used by the practicing engineers since more than 65 years without major modifications (Terzaghi, 1925; Bjerrum et al 1960 and Wissa et al 1971). Even today most laboratories use standard procedure to interpret the data (Lambe, 1951; ASTM, 1970 and Wissa et al 1971). Usually load increment ratios of unity are applied and each increment is left on for 24 hours and the various soil consolidation characteristics are computed. Using these procedures a consolidation test may take several weeks to complete. This technique presents some disadvantage viz.

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in the e-log σ'_v diagram, the experimental points are widely spaced making it difficult to draw the test curve and estimate the preconsolidation pressure. When the sample is loaded at every 24 hours the amount of secondary compression will vary for each load increment and ultimately the preconsolidation past pressure is poorly defined and the test is time consuming and expensive. Also the variations in determined past pressure have been reported due to changing the duration of loading at each step of loading in the standard and conventional test (Wissa et al 1971; Leroueil et al 1983, 1985; Aboshi et al 1970; Umehara et al 1980). To overcome some of the limitations of the conventional test and to incorporate some of the controls of modern geotechnical laboratory (Wissa et al 1971) a new consolidation cell was developed (Rowe and Barden 1966) where the soil specimen can be saturated at constant volume under a back pressure and loaded with no lateral strain by incremental load or at constant rate of stress or strain or at constant hydraulic gradient. Wissa et al (1971), Smith et al (1969), Umehara et al (1980), Leroueil et al (1983, 1985) and Sridharan et al (1987) have carried out experiments following the constant rate of strain principle. Low et al (1969) have proposed tests at controlled hydraulic gradients and Aboshi et al (1970) have proposed tests at constant rate of loading. Sinha et al (1990) also studied the effect of constant rate of loading for a typical soil sample and evaluated compressibility characteristics of soil. These tests require automation. Aboshi et al (1970) suggested that in the proposed method a total testing time of upto 3 hrs. for the maximum pressure of upto 1000 kPa on a sample of 20 mm thickness, giving a rate of loading 300 kPa per hour would be sufficient to evaluate the consolidation characteristics of soil whereas Irwin (1975) suggested a test of 80 hrs. duration for a 150 mm diameter Rowe cell sample loaded upto 500kPa giving a rate of loading 6 kPa per hour (Head 1986). Burghignoli (1979) showed that by using various rate of loading the secondary deformation could be separated from elastic deformations. The most suitable rate of loading is probably related to the coefficient of consolidation value* but this is to be derived from the test data and there seems to be no published guidance (Head 1986). It would therefore be necessary to determine a suitable rate of loading for a particular clay by trial in order to be within the extreme value.

Rowe and Barden (1966) have developed new consolidation cell for samples ranging from 75mm–500mm diameter and proved to give satisfactory results

$$* \; C_v = \frac{3 \times 10^{-5} \times \Delta\sigma'_a \times \bar{H}^2}{\Delta_t \times \Delta_u} \quad m^2/sec$$

for vertical consolidation of undisturbed, remoulded or compacted samples of saturated or partially saturated clay with or without a back pressure.

The authors undertook an experimental programme to study consolidation characteristics of a typical regional soil deposit in the country, collected from a construction site at about 23 m depth. The undisturbed tube soil sample of 100 mm diameter collected from the open excavated pit made for the purpose of rigid raft foundation. The consolidation tests following constant rate of loading at 40, 120 and 360 kPa per hour using commercially available automated computer controlled consolidation testing system (Menzies 1984, 1987) were carried out to evaluate the variation in differential pore water pressure at various rate of loadings. The particle size distribution before testing for three different sections made out from a specimen of 76 mm diameter and 20 mm height and after conducting consolidation tests were determined. This was done using commercially available automated laser particle size analyser available in the institute to study the particle migration at various hydraulic gradients.

SOIL SAMPLE AND EXPERIMENTAL PROGRAMMES

An undisturbed tube soil sample of 100 mm diameter was collected from an open excavated pit to carry out consolidation test adopting constant rate of loading procedure using commercially available computer controlled consolidation testing system (Fig. 1) at 40, 120 and 360 kPa per hour loading rate. The soil sample used for consolidation test revealed liquid limit (WL) in the range of 22–25 percent and plasticity index in the range of 5–8 percent. The soil contained 89 percent silt and 11 percent clay. This could be determined by using Laser Particle Size Analyser (Fig. 2). The consolidation tests were carried out at selected rate of loading viz 40, 120 and

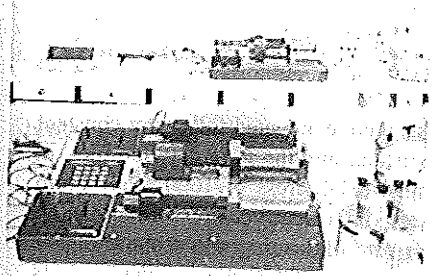

Fig. 1 Geotechnical Digital Consolidation Testing System

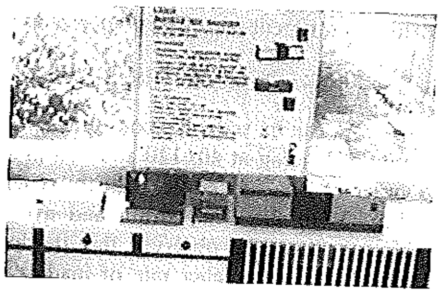

Fig. 2 Laser Particle Size Analyser

360 kPa per hour and tests actually lasted for 21.1, 7.1 and 2.4 hours at 1000 kPa terminal axial stress. Initially the target axial stress and back pressure applied-were 150 kPa and 100 kPa respectively. On termination of consolidation tests the soil sample were taken out from the ring and the samples were divided into three equal parts and designated as top, middle and bottom sections. Then representative soil specimens were taken and particle size distributions were determined separately for each section using the Laser Particle Size Analyser. For comparison the particle size distribution of untested soil sample were also carried out, only for the sample size of 76 mm diameter and 19 mm height at various rate of loading.

EXPERIMENTAL RESULTS

Consolidation Test :

On the basis of experiments conducted, the various computer plots viz axial strain v. average axial effective stress *; volume change v. square root time; volume compressibility (Mv) v. average axial effective stress; Janbu modulus (1/Mv) v. average axial effective stress; differential pore water pressure vrs axial stress; differential pore water pressure v. time and hydraulic gradient v. time were developed to evaluate variation in porewater pressure due to various rate of loadings (Fig 3, a-g) (Menzies 1984).

Grain Size Analysis :

On the basis of experimental results the comparative particle size distribution curve for 40, 120 and 360 kPa per hour constant rate of loading alongwith original untested soil sample were also plotted and are shown in Fig. 4 (a-c). The grain size at passing 90 percent, 50 percent and at 10 percent were also worked out to examine the variation in particle size distributions due to application of load at different rate. The grain size as worked out are tabulated in Table–1.

DISCUSSION ON RESULTS

As can be seen, the consolidation tests were conducted following constant rate of loading at 40, 120 and 360 kPa per hour and the total duration took in order of 21.1, 7.1 and 2.4 hours at terminal axial stress of 1000 kPa. From Fig. 3 (a) the axial strain and average axial effective stress relationship curves, it can be observed that the lower rate of loading could show higher strain than the higher rate of loading. As far as past pressure calculation is

* $\sigma'_a = [\sigma_a - u_o - 0.7 \times \Delta_u]$ kPa

VARRIATION IN DIFFERENTIAL PORE

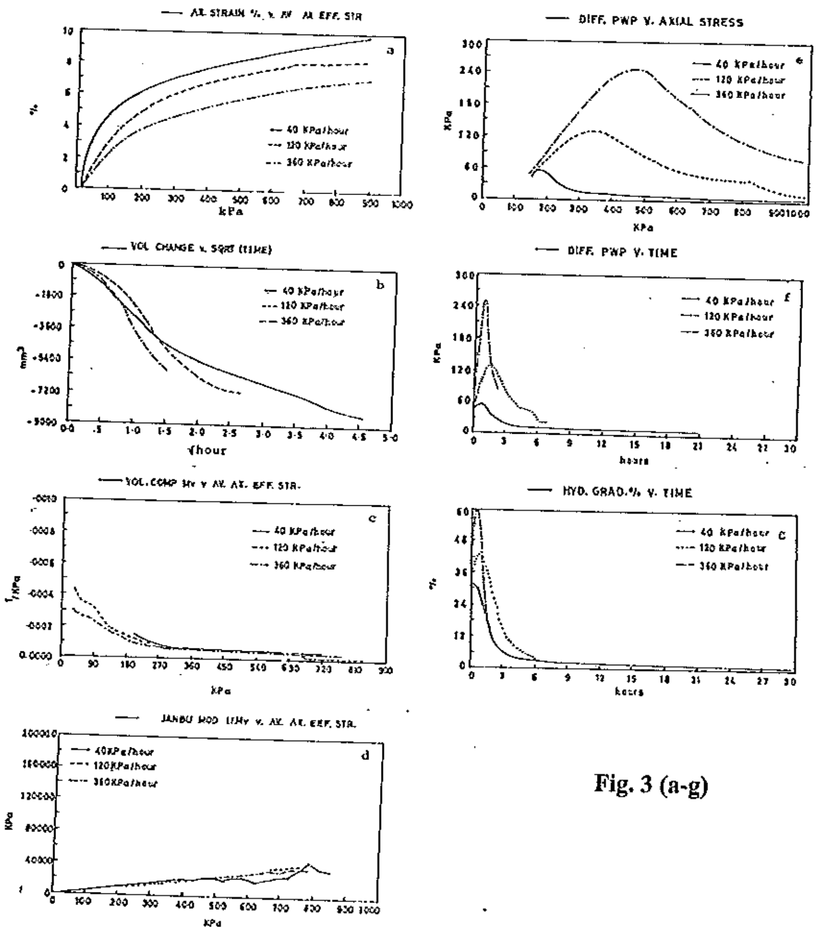

Fig. 3 (a-g)

concerned it works out to 165, 190 and 195 kPa and reveals low variation and also similar compressibility indices of value $C_c = 0.05$. In the same way the change in volume for different rates of loading Fig. 3 (b) reveal a marked change at higher rates and could reveal higher coefficient of consolidation ($C_v = 31 \times 10^{-9}$ m^2 / sec). This indicates that at higher rates of loading the dissipation of pore water pressure is not rapid in comparison to $C_v = 17 \times 10^{-9}$ m^2 / sec as obtained at low rates of loading. The volume compressibility characteristics (M_v) Fig. 3 (c) beyond 270 kPa average axial effective stress are almost found unchanged. Similarly the Janbu modulus is also unchanged and the rates of loading have no effect Fig. 3 (d). It can be seen Fig. 3 (e-g) that a marked variation in differential pore water pressure and hydraulic gradient occurs at different rates of loading. Therefore the dissipation of pore water pressure is not rapid and for slow rates of loading i.e. at 40 kPa per hour the variation in differential pore water pressure became negligible after 4 hours of test duration Fig. 3 (g). The same trend could be observed for the hydraulic gradient. The study reveals

Table 1 Variation in grain size at different constant rate of loading

Constant Rate of Loading (CRL)	Grain Size Finer Than (in microns) At 90 %	50 %	10 %
40 kPa / hour			
Tested Soil			
Top Section	35.6	8.8	2.5
Middle Section	35.2	8.8	2.6
Bottom Section	34.4	9.5	2.8
120 kPa / hour			
Tested Soil			
Top Section	37.8	9.2	2.5
Middle Section	27.0	8.3	2.6
Bottom Section	33.6	9.2	2.7
360 kPa / hour			
Tested Soil			
Top Section	38.0	8.3	2.2
Middle Section	35.3	7.9	2.1
Bottom Section	38.1	7.8	2.0
Untested Soil	32.1	7.0	1.5

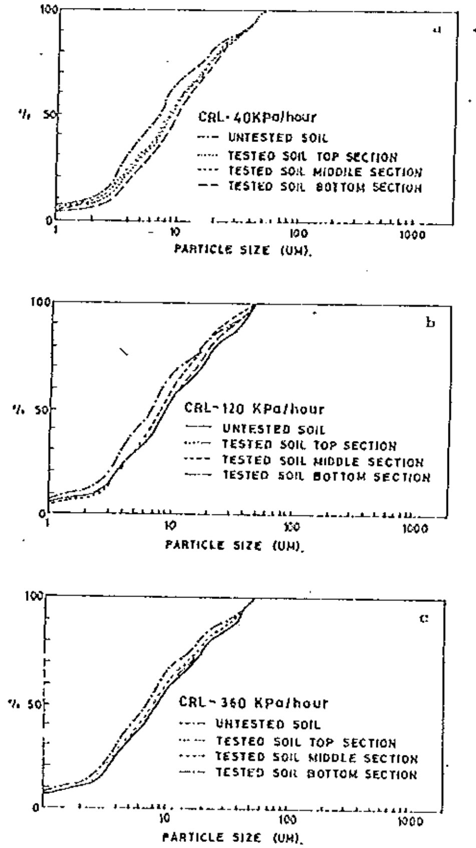

Fig. 4 (a-c)

that a drastic reduction in testing time is possible by adopting even the lower rate of loading at about 450 kPa in comparison to time consuming standard conventional test. It is suggested that the constant rate of loading test is adopted for quick evaluation of consolidation characteristics.

The grain size analysis after carrying out the consolidation tests at various selected rates of loading were determined using a commercially available laser particle size analyser. The particle size distribution plots for different sample sections alongwith original untested soil samples were compared in Fig. 4 (a-c). A marked change in grain size is apparent and observed that the rate of loading has influenced the change in grain size. Fig. 4 (a-c) also reveals that the migration of grain at various hydraulic gradients seems to be possible. The results tabulated in Table–1 indicate that different rates of loading influence the grain size distribution as a result of the hydraulic gradient.

CONCLUDING REMARKS

– The laboratory investigations carried out at different loading rates reveal a variation in differential pore water pressure. The higher loading rates indicate higher change in differential pore water pressure.

– Similarly the variation in differential pore water pressure at various constant rates of loading with time indicates that the generation of pore water pressure is slow for slow rates of loading in comparison to the higher rates of loading.

– A Similar trend in the variation in hydraulic gradient with time is observed.

– For very low variation in differential pore water pressure the application of a low rate of loading can reduce the testing time.

– The influence of loading rate of the variation in grain size distribution due to the effect of hydraulic gradient on the migration of grains.

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NOTATION USED :

Cv = Coefficient of consolidation
Cc = Compressibility Index
Mv = Volume compressibility
e = Void ratio
σ'_v = Effective vertical stress
σ'_a = Effective axial stress
σ_a = Axial stress
$\Delta\sigma'_a$ = Change in effective axial stress
Δ_t = Change in time
H = Mean length of the specimen
u_o = Back pressure
Δ_u = Change in porewater pressure measured at the base of specimen
m = meter
W_L = Liquid Limit