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A SIMPLE MODEL TO SIMULATE THE DEFORMATION-TIME HISTORY OBSERVED IN A ONE-DIMENSIONAL CONSOLIDATION TEST ON A CLAY SOIL

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ABSTRACT: A simple two-parameter model is proposed to represent the time-deformation history of a clay soil observed under a load increment in a one-dimensional consolidation test. It is demonstrated that this model can be used effectively to delineate the entire series of time-deformation history for successive load increments in a one dimensional consolidation test. Further, the model is capable to generate the time-deformation history for any arbitrary load within the applied range of load in the test and thus is particularly helpful in saving time and cost by allowing to reduce load steps in a one-dimensional consolidation test. The nature and magnitude of variation of the model parameters due to change in consolidation pressure level, pressure increment ratio etc. were investigated from one dimensional consolidation tests on a remolded clay.

KEYWORDS: Clay, laboratory test, one-dimensional consolidation, constitutive model, deformation history.

INTRODUCTION

One dimensional consolidation test usually serves to provide two important information. Firstly, the maximum settlement that may occur in an underlying clay layer when subjected to increment in pressure due to construction of a structure and secondly, the rate at which this settlement will take place. Routine laboratory consolidation test, though simple in procedure, involves a long time (about a week) and hence cost. Also, the procedure for determination of the parameters for estimation of total settlement and the rate of settlement is time consuming. After involving such time and effort, the amount of total settlement and the rate of settlement estimated from test data vary significantly from field observations (Duncan, 1993). The reason for such discrepancy lies, among many other factors, on the shortcomings of the conventional consolidation theory, difficulty in assessing proper field drainage conditions (due to existence of sand layers and lenses), error in evaluating field pre-consolidation pressure and also on difficulties in selecting proper values of the coefficient of consolidation, c_v. It is, therefore, envisaged that use of the one-dimensional consolidation test with a pressure increment ratio larger than that used in conventional test (thereby reducing the load steps,

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and time) together with a suitable numerical model may provide the settlement information of a clay layer, without sacrificing much of accuracy, for a lesser time and effort. This will be particularly helpful when a large number of tests are to be carried out within a relatively short period of time. It will also serve as a means of estimating the value of c_v at an intermediate pressure level when time-deformation data are available for some other pressure values. Such a model will also facilitate settlement computations by a computer, taking into considerations of the variation in the values of c_v with small change in consolidation pressure, whereas in usual hand calculation of settlement a constant value of c_v is used for a relatively large pressure increment. Besides, design charts could be developed for consolidation parameters relating the model constants with index properties of clay soils. With these objectives, a simple mathematical function is proposed that can model the void ratio-time relationship (or dial reading-time relation) obtained from a one-dimensional consolidation test on clay soil under a load increment. The model has two independent parameters. The role and physical significance of the parameters are explained and the influence of several factors, such as the magnitude of consolidation pressure, pressure increment ratio, and magnitude of the first pressure increment on the model parameters are presented in this paper.

To verify the effectiveness of the model, consolidation tests were performed on specimens cut out from soil cakes reconstituted in the laboratory under two different vertical pressures (50 kPa and 100 kPa). Tests were performed with pressure increment ratios of 2 (used in conventional tests) and 4. The nature and magnitude of variation of the model parameters were studied from these tests.

VOID RATIO-LOG(TIME) CURVE FOR A SINGLE LOAD INCREMENT

Any mathematical function that can describe the 'time vs. deformation' curve, as observed from a consolidation test, may be used to simulate the relationship. However, a function having two constants is considered here for its simplicity. Konder (1963) first proposed the following hyperbolic equation to represent the nonlinear stress-strain curves of both sand and clay.

$$q = \frac{\varepsilon}{a + b.\varepsilon} \tag{1}$$

where, q = deviator stress; e = axial strain ; a and b are constants whose values may be determined experimentally.

The above hyperbolic equation has also been reported (Tatsuoka and Shibuya, 1991) in a normalized form along with correction factors C_1 and C_2 as follows:

$$y = \frac{x}{\frac{1}{C_1} + \frac{x}{C_2}} \tag{2}$$

where, $y = \frac{q}{q_{\max}}$; $\varepsilon = \frac{\varepsilon}{\varepsilon_r}$; $\varepsilon_r = \frac{q_{\max}}{E_{\max}}$; $C_1 = \frac{1}{a.E_{max}}$; $C_2 = \frac{1}{b.q_{max}}$;

E_{max} = initial tangent modulus and q_{max} = maximum deviator stress.

Eq.(2) when plotted as '*y/x vs. log₁₀(x)*' resembles, in shape, the '*e vs. log₁₀(t)*' plot from a one-dimensional consolidation test under a certain pressure. Thus the following equation was used to represent the 'void ratio vs. time' relationship in a one-dimensional consolidation test for any arbitrary stress increment.

$$e - C_3 = \frac{1}{\frac{1}{C_1} + \frac{t}{C_2}} \tag{3}$$

where, *t* is the elapsed time (in minute) from the application of a load increment and *e* is the void ratio at any time *t*. The constant C_3 is needed to be introduced in Eq.(3), otherwise the void ratio at infinite time (i.e., t = ∝) would have been obtained as zero, which is not desired.

SIGNIFICANCE OF THE MODEL CONSTANTS

Suppose at the instant of application of a load increment i.e., at $t = 0$ (zero), the void ratio of the specimen is e_i. Substitution of $t = 0$ and $e = e_i$. in Eq.(3) produces:

$$e_i = C_1 + C_3 \tag{4}$$

Eq.(4) implies that the constants C_1 and C_3 are not independent. Thus, Eq.(3) can be expressed, with two independent constants, as follows:

$$e = e_i - C_1 + \frac{1}{\frac{1}{C_1} + \frac{t}{C_2}} \tag{5}$$

If Eq.(5) is plotted in a semi-log paper with *e* in arithmetic scale and *t* in log scale, the slope at any time *t* is given by,

$$\frac{de}{d(\log_{10} t)} = -\frac{t.\log_e 10}{C_2(\frac{1}{C_1} + \frac{t}{C_2})^2} \tag{5a}$$

Since C_1 and C_2 are positive non-zero constants and time *t* is always positive, Eq.(5a) ensures that the slope of the plot of Eq.(5) with *e* as ordinate and *log₁₀t* as abscissa is always negative as an actual *e vs. log₁₀t* plot from test data. Also as *t* approaches zero $\frac{de}{d(\log_{10} t)}$ approaches zero. This, together with the condition $e = e_i$ at $t = 0$ implies that the initial portion of the above mentioned plot of Eq.(5) is asymptotic to $e = e_i$ line.

Again, at t = ∝, Eq.(3) produces to $e = e_I - C_1 = C_3$ and Eq.(5a) produces $\frac{de}{d(\log_{10}t)} = 0$. Therefore, the end portion of the *e vs. log₁₀t* plot of Eq.(5a) is asymptotic to $e = e_I - C_1 = C_3$ line. Thus, for any arbitrary load increment, C_3 may be considered to represent the void ratio after a long time when the deformation virtually ceases and C_1 can be interpreted as the total reduction in void ratio (Fig.1a).

Eq.(5) can be rearranged as :

$$\frac{1}{e-(e_i-C_1)} = \frac{1}{C_1} + \frac{t}{C_2} \tag{6}$$

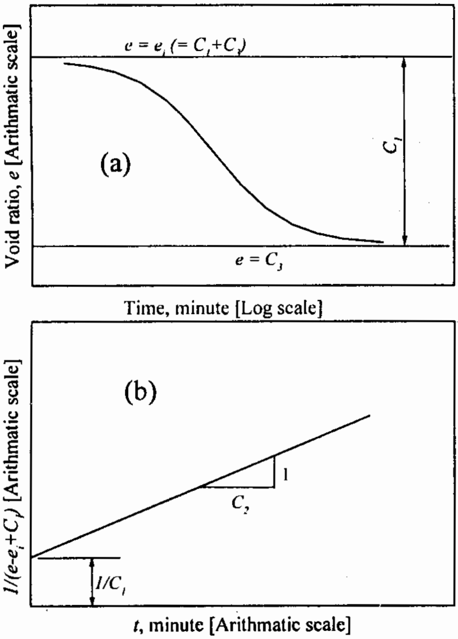

Fig. 1. Physical significance of the model parameters (a) C_1 and C_3, (b) C_2

Equation (6) represents a straight line in '$1/(e - e_i + C_1)$ *vs. t' vs.t'* space as shown in Fig.1b. From this figure, C_1 can be readily visualized as the inverse of the slope of such a straight line. C_2 may be interpreted as having a unit of time. The constant C_2 controls the shape of the '*e vs. log₁₀t*' plot of Eq.(5) in between the end points, which is demonstrated in Fig.2. In this figure, Eq.(5) is plotted with void ratio *e* in arithmetic scale and time *t* in the logarithmic scale, using arbitrary values of initial void ratio e_i, and model constants C_1 and C_2. For each curve in Fig.2, $e_I = 0.87$ and $C_1 = 0.17$ are used whereas, parameter C_2

is different for each curve and ranges from 0.05 to 50. Since C_1 and e_i are not varied, the end points (i.e., at $t = 0$ and $t = \propto$) of all the curves in Fig.2 are same. However, at any given time t, the void ratio e is larger for the curve with a higher value of C_2.

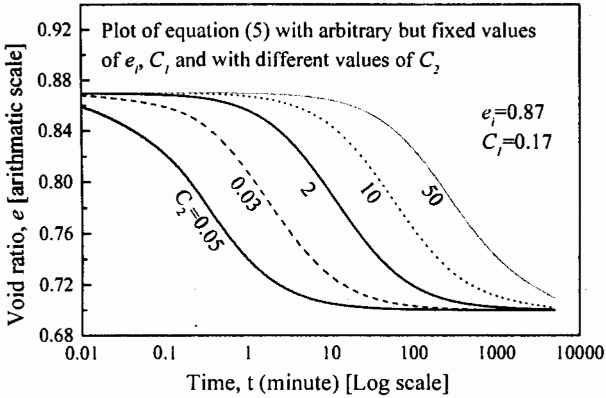

Fig. 2. Role of parameter C_2 on the e – $log_{10}(t)$ curve

The curvature at any time t of the semi-logerithmic plot of Eq.(5) can be computed by differentiating Eq.(5a) with respect to $log_{10}t$, which is:

$$\frac{d^2e}{d(\log_{10}t)^2} = \frac{C_2.(\log_{10})^2.t.(\frac{C_2}{C_1} - t)}{(\frac{C_2}{C_1} + t)^3} \tag{7}$$

for '$t < (C_2/C_1)$' the curvature is negative and for '$t > (C_2/C_1)$' the curvature is positive. At '$t = (C_2/C_1)$', where the curvature is zero, the magnitude of the slope $\frac{de}{d(\log_{10}t)}$ is a maximum.

Substituting $t = (C_2/C_1)$ in Eq.(5a) we get

$$\frac{de}{d(\log_{10}t)} = -\frac{C_1.\log_{10}e}{4} \tag{8}$$

For the curvature to be maximum $\frac{d^3e}{d(\log_{10}t)^3} = 0$. Again differentiating Eq.(7) with respect to $log_{10}t$ and equating to zero we get

$$\frac{C_2.(\log_e 10)^3.t.(t^2 - 4.\frac{C_2}{C_1} + \frac{C_2^2}{C_1^2})}{(\frac{C_2}{C_1} + t)^4} = 0 \qquad (9)$$

Obviously, two roots of Eq.(9) are $t = 0$ and $t = \infty$. For two other roots of Eq.(9), we solve the quadratic equation $t^2 - 4.\frac{C_2}{C_1} + \frac{C_2^2}{C_1^2} = 0$ and obtain $t = 0.268\ (C_2/C_1)$ and $t = 1.732\ (C_2/C_1)$. It may be possible to link the later of this two times to 100 % consolidation stage under the respective load increment, which however has not been attempted here.

REPRESENTATION OF '*e vs. log₁₀(t)*' CURVES OBTAINED FROM A 1-D CONSOLIDATION TEST

Determination of Model Constants for each '*e vs. log₁₀(t)*' Curve

Eq.(5) or Eq.(6) represents the '*e vs. t*' relationship for a single load increment. Whereas, in a consolidation test, there will be several load increments each corresponding to a unique '*e vs. t*' curve. Therefore, it is necessary to distinguish among the values of C_1 or C_2 for the '*e vs. log₁₀(t)*' curves under the different pressure increments. For this purpose Eq.(6) can be re-written as :

$$\frac{1}{e^{\sigma_n} - (e^{\sigma_n}_{t=0} - C_1^{\sigma_n})} = \frac{1}{C_1^{\sigma_n}} + \frac{t^{\sigma_n}}{C_2^{\sigma_n}} \qquad (10)$$

Here the superscript σ_n indicates that the concerned quantity (i.e., void ratio, C_1, C_2, etc.) is for the "*e vs. log₁₀(t)*" curve corresponding to the *n*th load increment and the relevant normal stress is σ_n. The subscript $t = 0$ in the term $e^{\sigma_n}_{t=0}$ indicates that this void ratio is at time $t = 0$ i.e., at the start of the relevant load increment. e^{σ_n} is the void ratio at any time t (in minute) for the *n*th load increment. $C_1^{\sigma_n}$ and $C_2^{\sigma_n}$ may be determined following the steps described below:

1. Consider that the initial void ratio $e^{\sigma_n}_{t=0}$ of the specimen at the instant of application of the *n*th load increment is known. For the first load increment $e^{\sigma_1}_{t=0} = e_0$; e_0 is the initial void ratio of the specimen i.e. the void ratio before any load increment. For the second and subsequent load increments $e^{\sigma_n}_{t=0} = e^{\sigma_{n-1}}_{t=t_f}$, where $e^{\sigma_{n-1}}_{t=t_f}$ is the void ratio of the specimen under previous load increment at $t = t_f$.

2. A straight line parallel to the horizontal axis and asymptotic to the lower right portion of the 'e^{σ_n} vs. $log_{10}(t^{\sigma_n})$' curve is drawn. The intersection of the asymptote with the void ratio axis gives the void ratio $e^{\sigma_n}_{t=\infty}$ for the load increment under consideration.

3. $C_1^{\sigma_n}$ is obtained as $C_1^{\sigma_n} = e^{\sigma_n}_{t=0} - e^{\sigma_n}_{t=\infty}$.

4. Next the quantity $y = \frac{1}{e^{\sigma_n} - e^{\sigma_n}_{t=t_f}}$ is plotted against t^{σ_n} (both in arithmetic scale) and a best-fit straight line passing through the point ($y = 1/C_1^{\sigma_n}$, $t = 0$) is drawn. The slope (say m) of the fitted straight line is determined. Now $C_2^{\sigma_n} = 1/m$. It has been observed that in some cases the above mentioned plot does not represent a straight line which is because of the higher degree of non-linearity of the actual 'e^{σ_n} vs. $log_{10}(t^{\sigma_n})$' relations than represented by Eq.(5). This is a limitation of the proposed model. However, in such a case the value of $C_2^{\sigma_n}$ determined from the slope at the initial portion of the $\frac{1}{e^{\sigma_n} - e^{\sigma_n}_{t=t_f}}$ plot is found to be satisfactory. Alternatively, $C_2^{\sigma_n}$ can be obtained by plotting equation (7) using $e^{\sigma_n}_{t=0}$ (as mentioned in step 1), $C_1^{\sigma_n}$ (as obtained in step 3) and with trial values of $C_2^{\sigma_n}$ and comparing with the '*e vs. log₁₀(t)*' curve (obtained from test data) until a best fit is obtained.

Back Calculation Using the Model

Once the model constants are known for a series of '*e vs. log₁₀(t)*' plots from a one-dimensional consolidation test, the plots can be easily reproduced by using Eq.(7). However, for such a series of curves, the final void ratio for a particular load increment should be the same as the initial void ratio for the subsequent load increment. To achieve this, for the '*e vs. log₁₀(t)*' curves corresponding to the second and subsequent load increment $e^{\sigma_n}_{t=0} = e^{\sigma_{n-1}}_{t=t_f}$ should be used; where $e^{\sigma_n}_{t=0}$ refers to the initial void ratio for the '*e vs. log₁₀(t)*'curve under consideration and $e^{\sigma_{n-1}}_{t=t_f}$ is the void ratio at time $t = t_f$ up to which deformation readings were continued under the previous load increment.

TEST PROGRAM

A series of standard one dimensional-consolidation tests (ASTM, 1986) were performed on laboratory re-constituted soil specimen with the following specific objectives: (1) Determine the variation of the model parameters with the magnitude of consolidation pressure and pre-consolidation pressure; (2) Observe the dependency of the model parameters on the stress increment ratio; and (3) Find the effect of the magnitude of the first consolidation pressure increment on the model parameters.

The specimens were cut out from soil cakes obtained by consolidating soil slurry in a K_0-consolidation cell under two different pressures i.e., 50 kPa and 100 kPa. The method of soil cake preparation is mentioned in detail by Farooque (1995) and Habibullah (2001). The initial pressure and the pressure increment ratio were varied in the tests (Table-1). The grain size distribution of the material used for slurry is shown in Fig.3. More than 98% of the material is finer than #200 sieve (0.075mm). According to MIT soil classification system, majority of the particles is of silt size. The liquid limit and the plastic limits of the material were found to be 49.8% and 27.2%, respectively. On the Plasticity Chart (Unified classification system) the material plots on A-line (i.e. borderline of silt and clay) and is located at the meeting point of regions of CL, ML, CH and MH type of clay.

COMPARISON BETWEEN TEST DATA AND MODEL OUTPUT

Model parameters C_1 and C_2 were determined for each 'e *vs.* $\log_{10}(t)$' plot obtained from tests mentioned in Table 1. Then 'e *vs.* $\log_{10}(t)$' plots from experimental data were compared with those back calculated using the model. Figure 4 is a typical graph showing the effectiveness of the model in delineating the 'e *vs.* $\log_{10}(t)$' relationship. The figure shows a reasonably good agreement between the curve from test data and that reproduced by the model. Also a typical 'e *vs.* $\log_{10}(\sigma)$' plot from test data is compared in Fig.5 with that back calculated using the model, which also shows reasonably good agreement. Such good agreements indicate that C_v values for any intermediate load increment, and C_c and σ_c values for the soil obtained from the model should be close to the corresponding values calculated from test data.

FACTORS AFFECTING THE MODEL PARAMETERS

It was stipulated that C_1 and C_2 are, possibly, functions of soil type, initial void ratio, pressure increment ratio in a consolidation test, magnitude of consolidation pressure, etc. Therefore, the influence of these factors on the model parameters C_1 and C_2 were examined from tests mentioned in Table 1.

Table 1. Consolidation tests performed on samples with various pre-consolidation pressure, initial pressure, pressure increment ratio etc.

Test designation	Pre-consolidation pressure, kPa	Initial void ratio, e_0	Pressure increment ratio	Initial pressure, kPa	Final pressure, kPa
P100T01	100	0.9220	2	12.5	1600
P100T02	100	0.8669	2	12.5	800
P100T03	100	0.8223	2	50	1600
P100T04	100	0.8541	2	25	1600
P100T05	100	0.8439	4	12.5	800
P100T06	100	0.7685	4	12.5	800
P100T07	100	0.7893	4 2	25	800
P100T08	100	0.8271	4 2	25	800
P100T09	100	0.8657	2	25	800
P50T01	50	1.0282	2	12.5	800
P50T02	50	1.0873	2	12.5	800
P50T03	50	0.9396	4	12.5	800
P50T04	50	1.0112	2.5 1.5 2	25	800
P50T05	50	0.9226	2	25	800
P50T06	50	0.9008	2	50	800
P50T07	50	0.9568	2	25	800
P50T08	50	0.8498	2	50	800
P50T09	50	0.9386	4	12.5	800

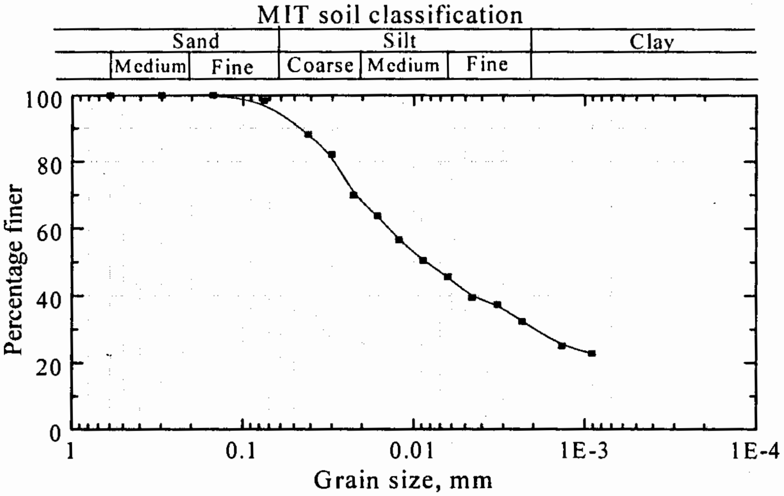

Fig. 3. Grain size distribution

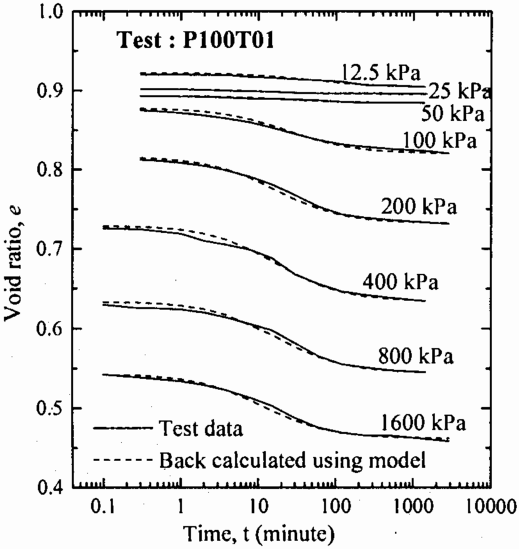

Fig. 4. Comparison between e – $\log_{10}(t)$ relations from test data and those back calculated using model

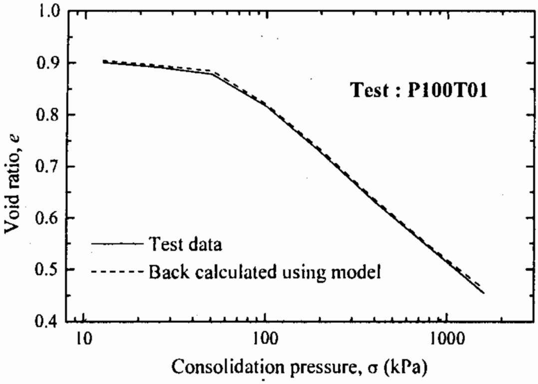

Fig. 5. Comparison between e – $\log_{10}(t)$ curve from test data and that back calculated using model

Variation of Parameter C_1

In Fig. 6 the values of C_1 from tests on specimens with 50 kPa and 100 kPa pre-consolidation pressure and pressure increment ratios of 2 and 4 are plotted against the respective consolidation pressure. For all the tests in this figure, the initial pressure was 12.5 kPa. It is observed from this plot that the value of C_1 for a particular consolidation pressure depends heavily on the pressure increment ratio. The higher the pressure increment ratio the higher is the value of C_I at a particular consolidation pressure. As to the nature of variation of C_I, it is observed from Fig. 6 that, for either of pressure increment ratio of 2 or 4, the value of C_I initially increased with the increase in consolidation pressure, attained a peak and then decreased slightly or remained relatively unchanged. The pre- consolidation pressure (in the present study 50 kPa and 100 kPa) does not appear to have any significant influence on either the magnitude of C_I for a particular pressure or the nature of variation of C_I with consolidation pressure.

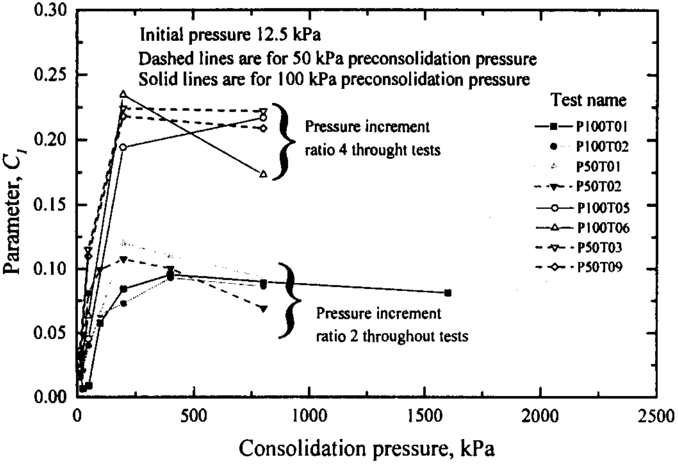

Fig. 6. Effect of pressure increment ratio on parameter C_I

To observe the effect of pressure increment ratio on the values of C_I in a consolidation test, data from three tests (Tests P100T07, P100T08 and P50T04; Table-1), in which the pressure increment ratios were not constant throughout the test, are plotted in Fig. 6(a) along with those plotted in Fig. 6. In tests, P100T07 and P100T08, the pressure increment ratio was 4, for up to 400 kPa consolidation pressure and then a pressure increment ratio of 2 was employed. In these tests the value of C_I gradually increased to around those from tests with constant pressure increment ratio of 4. However, after 400 kPa when the pressure increment ratio was reduced to 2, the value of C_I decreased to the value around those from tests with constant pressure increment ratio of 2. In the test P50T04, in which the pressure increment ratio was varied (first pressure change from 25 to 64 kPa i.e., ratio 2.5, next 64 kPa to 100kPa i.e., ratio 1.5 and then from 100 kPa to 800 kPa with pressure increment ratio of 2) but did not exceed 2.5, the values of C_I were comparable to those in tests in which the pressure increment ratio was 2 throughout. It is to be noted that in the tests P100T07, P100T08 and P50T04 the first consolidation pressure applied was 25 kPa whereas for other tests plotted in Fig. 6(a), the initial pressure increment applied was 12.5 kPa. It is shown later that this variation in the magnitude of the first pressure increment has no effect on the magnitude of C_1 at successive pressure levels.

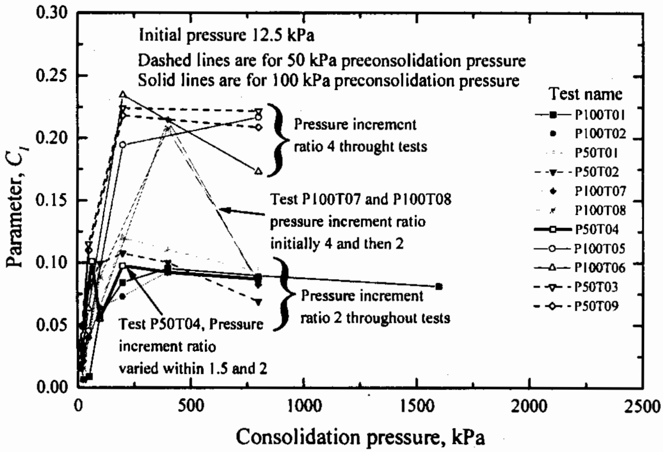

Fig. 6a. Effect of pressure increment ratio on parameter C_1

To investigate the influence of the magnitude of the first pressure increment on the value of C_1, data from different tests on specimens with pre-consolidation pressures of 50 kPa and 100 kPa, in which the magnitudes of the first pressure increment are different, are plotted in Fig.7. In all these tests the pressure increment ratio was 2 throughout. This figure shows that the values of C_1 are rather independent of the variation in the magnitude of the first pressure increment employed. It is to be noted that in all cases the first pressure increment was within the pre-consolidation pressure of the specimen. It can be easily seen that for any magnitude of load increment, without exceeding the pre-consolidation pressure, the specimen undergoes little deformation and thus its effect on the deformation under successive load increments may be considered insignificant.

Attempts were made to obtain a unique relationship between a function of C_1 and the magnitude of consolidation pressure. Several functions were tried. A relatively unique relationship is obtained when C_1/r is plotted against pressure (Fig.8) or logarithm of pressure (Fig.9); r being the pressure increment ratio. It may be that C_1/r vs. consolidation pressure relationship is a unique characteristic of the consolidation behaviour of different types of clay soil. However, further study is needed to confirm this point. It may be possible to develop design charts containing such relationships for different clay soils and relating them to index properties (such as *LL* and *PI*) so that consolidation parameters (C_c and C_v) can be assessed directly if the index properties are known. Such a design chart will facilitate settlement calculations and may also serve as a check for the data from test results.

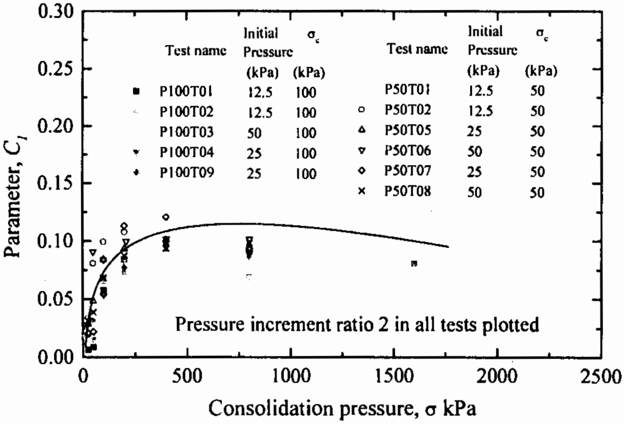

Fig. 7. Effect of the magnitude of first pressure increment on C_1

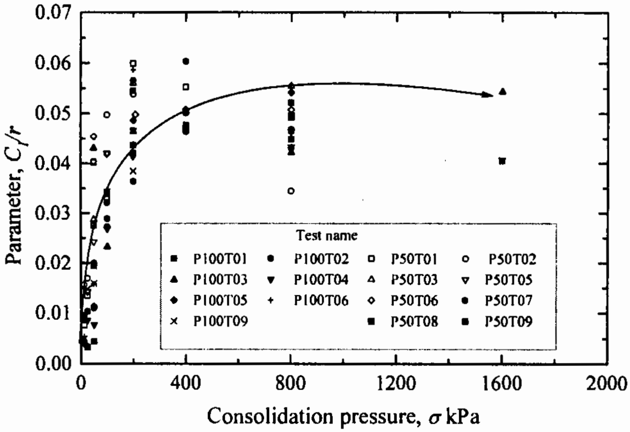

Fig. 8. Normalized values of C_1 versus consolidation pressure (both in arithmetic scale)

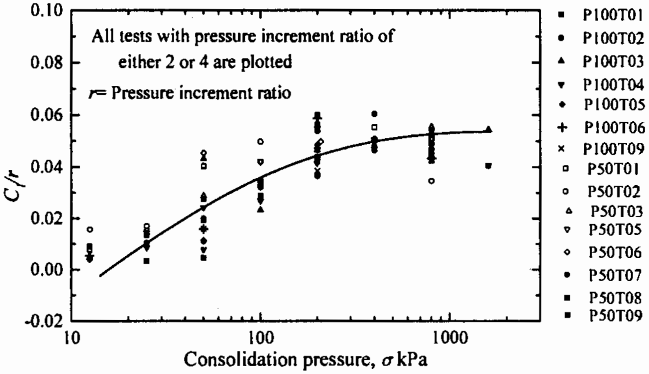

Fig. 9. Normalized values of C_1 versus log of consolidation pressure

Variation of Parameter C_2

Similar to the case of parameter C_1, attempts were made to relate parameter C_2 with the magnitude of consolidation pressure, so that the value of C_2 could be obtained for any desired consolidation pressure level. Figure 10 shows a plot of C_2 against consolidation pressure. No conclusive statement could be made from this figure about the dependency of C_2 on consolidation pressure. Rather, this figure suggests that C_2 is not linked to the magnitude of consolidation pressure. Therefore, attempts were made to explore the dependency of C_2 on other parameters such as 'initial void ratio of the specimen (e_0), void ratio of the specimen before a load increment (e_i), etc.

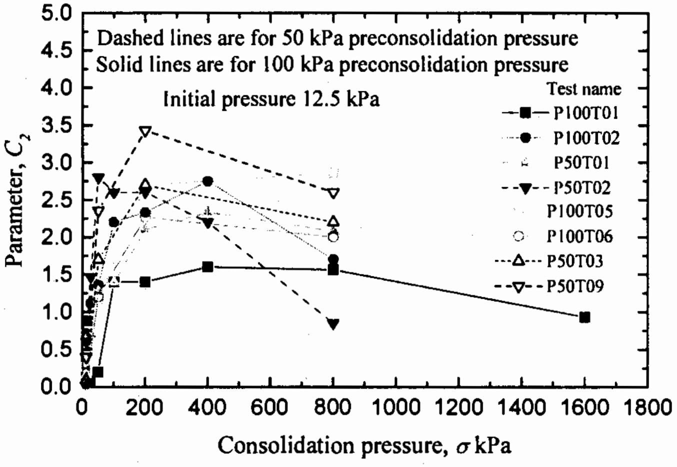

Fig. 10. Parameter C_2 vs. consolidation pressure (both in arithmetic scale)

Of all other parameters investigated e_i showed a consistent variation with the logarithm of C_2. This can be seen from Fig. 11 where logarithm of C_2 is plotted against e_i/e_0. As can be seen from this figure, the value of C_2 initially increases with the decrease of e_i/e_0 and then becomes relatively constant. The void ratio at which the value of C_2 reaches the constant value, appears to correspond to the final void ratio under the pre-consolidation pressure. Thus, a plot similar to Fig.11 may also serve as a supplemental means to check the correctness of the value of pre-consolidation pressure obtained by following some other method such as Casagrande's method.

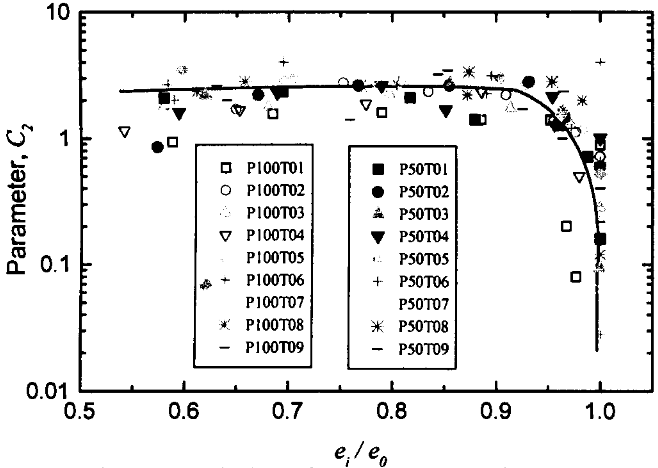

Fig. 11. Variation of Parameter C_2 with e_i/c_o

CONCLUSIONS

A simple two parameter model is presented that can effectively simulate the deformation-time history of a clay soil subjected to a pressure increment in a conventional one-dimensional consolidation test. The magnitude of these parameters and the factors that influence them are discussed based on a series of consolidation tests on specimens prepared from slurry. The initial void ratio of the specimen and the consolidation pressure level are found to be the major factors that influence the value of the parameters. The model allows computation of settlement of a clay layer taking into account the field loading history. It also serves as a rational means to find the coefficient of consolidation C_v at pressure levels other than those employed in a one-dimensional consolidation test.

REFERENCES

ASTM(1986) Annual book of ASTM standards: Part 19, American Society for Testing Materials.

Duncan, M.J.(1993) Limitations of conventional analysis of consolidation settlement, Journal of Geotechnical Engineering, ASCE, Vol.119,No.9,pp.1333-1359.

Farooque,S.M. (1995) Effect of sampling disturbance on engineering behaviour of coastal soils from Chittagong, M.Sc. Thesis, CE Dept., BUET.

Konder, R. L. (1963) Hyperbolic stress-strain response : cohesive soils, Journal of Soil Mechanics and Foundation Engineering Division, ASCE, vol.89, SM1, pp.115-143.

Habibullah, Md. (2001) Modelling of consolidation behaviour of soil, M.Engg.Thesis, CE Dept, BUET.

Tatsuoka, F. and Shibuya, S. (1991) Deformation characteristics of soils and rocks from field and laboratory tests, Keynote lecture for session no.1, Proceedings of the 9th Asian Regional Conference on SMFE, Bangkok, Vol.2, pp.101-170.

NOTATIONS

c_v	coefficient of consolidation
ε	strain
q	deviator stress
e	void ratio
e_i	void ratio of the specimen just before the application of a load increment
e_0	void ratio of the specimen before the application of any consolidation pressure
t	elapsed time in minute from the instant of application of a consolidation pressure
C_1, C_2, C_3	model parameters (constants)
e^{σ_n}, t^{σ_n}, $C_1^{\sigma_n}$, $C_2^{\sigma_n}$ $C_3^{\sigma_n}$	correspond to e, t, C_1, C_2 and C_3 respectively, for the consolidation pressure σ at the nth load increment in a one-dimensional test

$e_{t=0}^{\sigma_n}$ value of e^{σ_n} at $t = 0$, $e_{t=\infty}^{\sigma_n}$ value of e^{σ_n} at $t = \infty$ etc.