Quick Estimation of Strength Properties of Cement Treated Some Selected Soft Clays of Bangladesh

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ABSTRACT

Soft clays with high water content in Bangladesh are mainly available in the alluvial flood plain deposits, depression deposits and tidal plain deposits. Sometimes, these soft clays are need to stabilize for water front temporary and permanent structures. The paper deals with the development of a phenomenological model to analyze the stress-strain and strength-stiffness related parameters and to predict the expressions for strength, strain and stiffness of cement treated soft clays of Bangladesh. The state of high water contents would simulate the condition realized in deep mixing method. The basic framework for development of model is Horpibulsuk and Miura's proposal. Clay-water/cement ratio, wc/c has been found to be a prime parameter while dealing with both clay and cement as inter acting particular materials. The interrelationship proposed among strength, curing time and wc/c is useful to calculate the strength, strain and stiffness wherein clay-water content varies over a wide range. Based on test results of quick test i.e., unconfined compression test, here it is revealed that the wc/c is the dominant parameter, which governs stress-strain and strength-stiffness characteristics of the cement treated soft clays.

KEYWORDS: Unconfined compression test, water content, clay-water/cement ratio, cementation bond, cement stabilized clay, plasticity of clay, strength.

1. INTRODUCTION

Chemical admixture stabilization has been extensively used both in deep and shallow foundations in order to improve inherent properties of soil such as strength, strain and stiffness behavior by deep mixing method. Moreover, the soft clays being released for the construction works can be made by mixing with cement. Such soft clay formations in Bangladesh, especially when the in-situ water contents are high, unless they are markedly naturally cemented, have large potential for settlement with low inherent axial strength [5]. There are three types of clay in Bangladesh on the basis of plasticity, namely high plastic (C1) clay, medium plastic (C2) clay and low plastic (C3) clay. Preloading on such clay deposits with vertical drains (such as PVD or sand drain) can enhance the inherent shear strength and reduce the compression in a long time consolidation process [5]. An alternative means is to enhance by use of supplementary cementing agents. The resistance to compression and consequent strength development in such a cemented state increase with increasing curing time. It is not practicable to admix a cementing agent with a large volume of in-situ soft clay. Hence, in-situ deep mixing methods have been developed primarily to effect columnar inclusions into the soft ground, transformed to composite grounds. The prediction of strength development of cement treated clays has been presented by [1], [2] and [4]. But most the use of this prediction is limited for the clays at their liquid limit stages. To overcome this limitation in the paper, a factor-wc/c is proposed in this study as the influential parameter for predicting strength and combining the relation by expressions among strength, curing time, clay-water and cement. With this relation, one can calculate the strength from only one set of data. An attempt has been made to predict the equations for strain and stiffness with the relation of strength data.

2. EXPERIMENTAL INVESTIGATION

2.1 Soil sample

Soft clays were collected from various districts of Bangladesh such as C1 clay from Gazipur, C2 from Gopalgonj and C3 clay from Khulna. The samples were collected from a depth of 2-3 m from existing ground level in disturbed and undisturbed states. Its index properties are listed in Table-1. Type I Portland cement was used in this study. Samples were prepared from these clays and cement slurries.

2.2 Methodology of testing

The clay paste was passed through a 2-mm sieve for removal of shell pieces and other bigger size particles. The intentional increase in water content is to simulate the water content increase taking place in the wet method of dispensing cement admixture in deep mixing and the significant in jet grouting. The clay with its water content corresponding to the above simulating levels quantity of cement resulting in clay-water/cement ratio, wc/c of 7.5, 10 and 15 was thoroughly mixed so as to ensure uniform dispersion of the cement. The initial mixing clay-water content (w_i) would be 120%, 150%, 200% and 250%. The tests were also performed with wc/c ratio of 2, 2.5, 4 and 30, with mixing water considered 120% of soft clays. Basic properties of stabilized clays are listed in Table 2. The mixing time was fixed at 10 minutes. Such a uniform paste was transferred to cylindrical moulds of 50 mm diameter × 100 mm height. After 24 hours, the cylindrical samples were wrapped in thick polythene bags and stored in a room of constant temperature and humidity (25 ± 2^0C) until the lapse of various curing periods. Tests were carried out after 1, 2, 4, 12, 24, 52 and 104 weeks of curing.

2.3 Parameters

Horpibulsuk and Miura [1] proposed for given clay-cement mixtures, the strength at any curing time depends on one factor clay-water content/cement ratio, wc/c. As an analogy the parameter that can be identified by Miura et al. [3], is wc/c, which is the ratio of initial mixing water content of the clay, w_i(%) to the cement content, c(%). The cement content, c is the ratio of cement to clay by weight both reckoned in the dry state. To obtain the same value of wc/c, it is possible to vary the water of the clay, or the amount of cement, or both as the case might be. In order to examine to what extent of wc/c and the water of clay are varied over a wide range in this study.

3. STRESS-STRAIN CHARACTERISTICS OF STABILIZED CLAYS

Simply defined that stress is load per unit area and strain is deformation per length. Fig. 1 shows the typical stress ~ strain relationships with different initial water (w_i) contents but at same wc/c ratio, at a curing time of 4 weeks. It reveals that the lower the wc/c (higher the cement content), the greater strength. The stress-strain behaviors and strength characteristics are practically the same as long as the identical wc/c. Such results are confirmed from the study of Miura et al. [3].

Table 1: Characteristics values of the index properties of the base clays.

Properties	Characteristics values		
Type of soil	C1 clay (LL > 50%)	C2 clay (LL =35-50%)	C3 clay (LL < 35%)
Liquid limit, LL, (%)	78	47	33
Plasticity index, PI, (%)	47	22	13
In-situ water content, w_n (%)	70	62	53
Liquidity index, LI	0.83	1.68	2.54
Clay (%)	73	41	32
Silt (%)	23	51	58
Sand (%)	4	8	10
Strength (Peak), q_u (kPa)	50.0	58.5	41.0
Strain (at failure), ε (%)	3.67	3.83	3.65
Dry unit weight, γ_d (kN/m^3)	8.85	9.05	9.44
Specific gravity, G_s	2.680	2.673	2.668
Activity of clays, A_c	0.64	0.35	0.23
Unified Soil classification system	CH	CL	CL

Table 2: Basic properties of stabilized clays at 4 weeks and mixing water content as 120%.

w_i (%)	Clays	wc/c ratio	c (%)	w (%)	γ_d (kN/m^3)	G_s	e	S_r
120%	C1	7.5	16	96.7	6.37	2.661	2.63	97.8
		10	12	103.4	5.94	2.667	2.81	98.1
		15	8	108.9	5.47	2.670	2.95	98.6
	C2	7.5	16	87.4	6.98	2.634	2.47	96.7
		10	12	95.4	6.72	2.653	2.61	96.9
		15	8	103.6	6.43	2.660	2.83	97.3
	C3	7.5	16	74.8	7.52	2.617	2.32	95.3
		10	12	79.3	7.31	2.631	2.41	95.5
		15	8	92.7	6.83	2.644	2.53	96.1

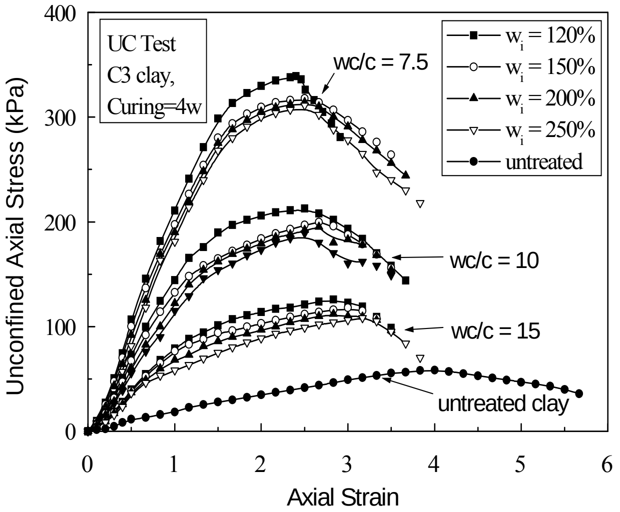

Fig. 1: Typical stress-strain relationships of cement stabilized C3 clay at different wc/c ratio.

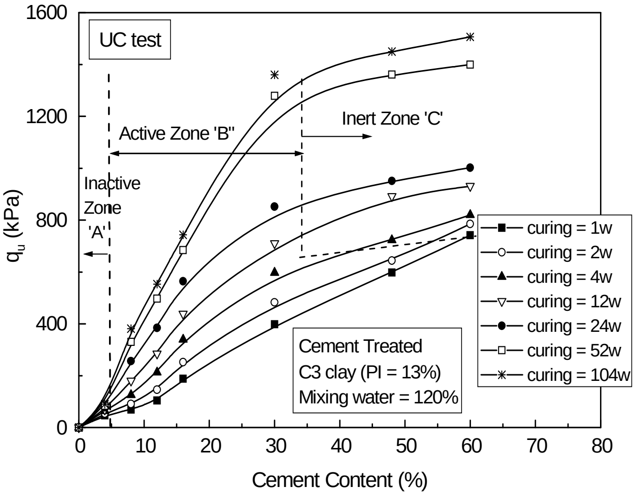

Fig. 2: Typical variation of strength with cement content at different curing time for C3 clay.

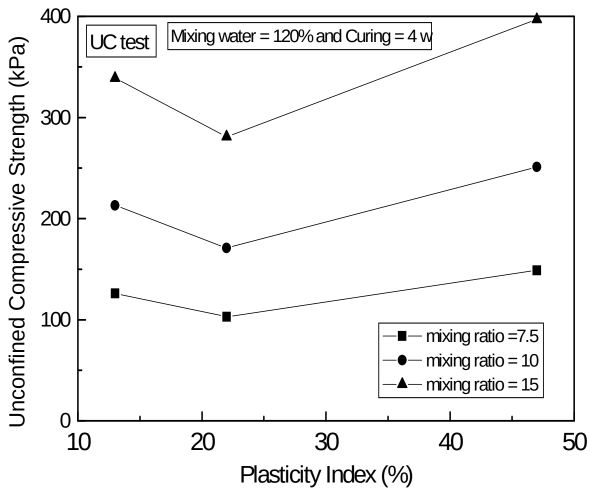

Fig. 3: Variation of strength with plasticity index at different mixing (wc/c) ratio.

4. STRENGTH CHARACTERISTICS OF STABILIZED CLAYS

The strength (q_u) is defined as the maximum stress gained at which the specimen failed during tests. Based on the observation in typical Fig.2, the strength and cement content relationship can be divided into 3 zones: inactive zone, active zone and inert zone. The low marginal improvement of strength is termed as inactive zone. The end result of the complete cementation is to increase the shear strength and this zone is termed as active zone. At this zone, the rate of hydration reaction is very high and thus, the bridging (cementation) effect is very significant and efficient. Hence, the increased amount of cementitious reaction products CSH (calcium silicate hydrate) and CASH (calcium aluminum silicate hydrate) caused a sharp increase in shear strength. Beyond the active zone, the rate of strength reduces and seems to be asymptotic. Such region is referred here as inert zone. This is because of the completion of pozzlolanic reaction and such that no further improvement of strength. The type of clay is chosen on the criterion, the plasticity of soil in Table 1. The variations of strength with plasticity index are shown in Fig. 3 at different mixing water content. It is observed that C2 clay have lowest strength. It is found that C1 clay undergoes better improvement than C3 clay but C3 clay undergoes better improvement than C2 clay. Because C1 clay has more water holding and hardness capacity and the pH values have been measured 8.3, 6.6 and 7.8 for C1, C2 and C3 clays respectively. If pH value exists above 7, soil solution is alkaline and pH value exists below 7, soil solution is acidic in nature. Thus, the C2 clay has a large reserve of potential acidity, so a relatively large amount of cement is needed to first exhaust the reserve acidity, and thereafter, to raise the pH value to the desired value at which the cement-clay reactions are enhanced. Fig. 3 shows that the lower the wc/c, the greater enhancement of the cementation bond strength inducing higher.

5. STRAIN CHARACTERISTICS OF STABILIZED CLAYS

The failure strain of unconfined compression test is defined as the strain at ultimate strength and simply abbreviated as ε_f. From stress-strain characteristics, it is found that the stabilized samples with ductile behavior have higher failure strain but with brittle behavior have lower failure strain. The failure strain reduces significantly as the wc/c ratio decreases or cement content increases as shown in typical Fig. 4. A clear trend can be found initially but beyond wc/c ratio, 13, the failure strain can be found to be stable and reaches an asymptotic value.

6. STIFFNESS CHARACTERISTICS OF STABILIZED CLAYS

Two types of stiffness (modulus), namely initial tangent modulus and secant modulus are considered in the study.

Initial stiffness (Initial tangent modulus, E_i) is defined as the slope of tangent at origin and secant stiffness (Secant modulus, E_{50}) is defined as the slope of straight line passing through the cut point of half-ultimate strength and the origin of non-linear stress-strain curve [2]. For the soil possessing elasto-plastic behavior with a dominating plastic component, the incremental modulus changes continuously with strain. In that case, the initial stiffness does not represent the elastic modulus of the curve and instead of that, the secant stiffness becomes more representative and useful than the initial stiffness. The stiffness was found to be a function of cement content and curing time. Generally, lower cement content (higher wc/c ratio) and lower curing time generate correspond to the smaller values of the modulus in typical Fig. 5. The asymptotic values are attained afterward about wc/c ratio 11 for all clays.

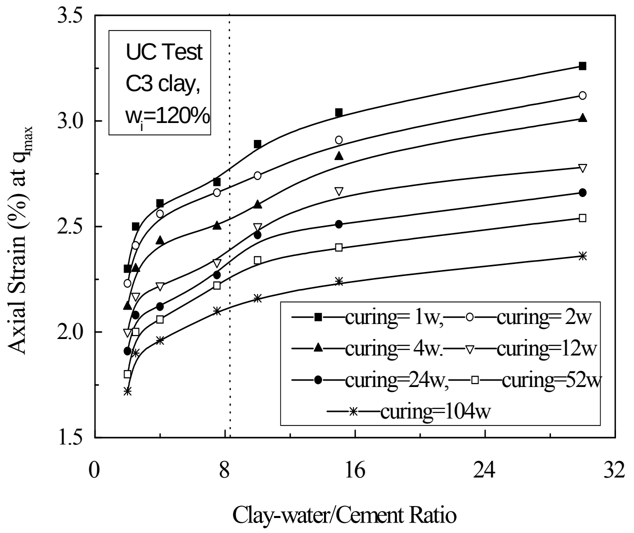

Fig. 4: Typical variation of strain with clay-water/cement ratio at different curing for C3 clay.

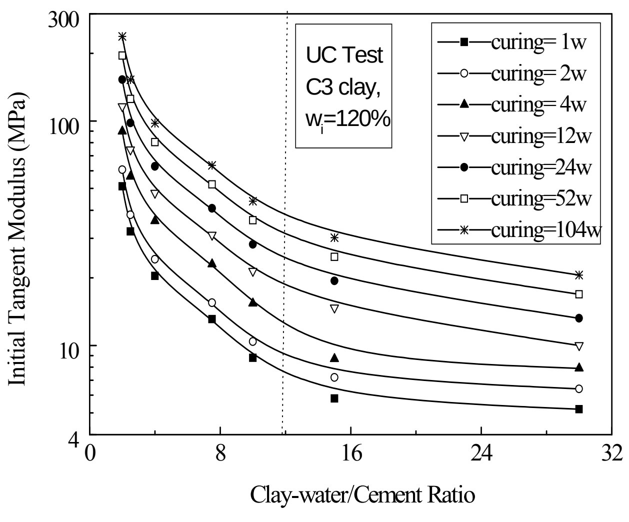

Fig. 5: Typical variation of initial modulus with wc/c ratio at different curing time for C3 clay.

7. STRENGTH ASSESSMENT BASED ON CLAY-WATER/CEMENT RATIO'S CONCEPT

The presence of moisture and cementing agents in the clay gets are transformed into grouping of particles takes place due to physicochemical interactions with clay ~ cement ~ water interactions [3]. No external compaction effort is needed for high water-content mixed. The interacting clay-water system cannot be identified by clay but by water content. According to Horpibulsuk and Miura [1], the relation for strength at any period of curing can be expressed as:

$$q_u = \frac{A}{B^{(wc/c)}} \quad (1)$$

where, q_u is the unconfined compressive strength at a stated age, (wc/c) is the clay-water content/cement ratio, A and B are constant depending on type of clay, cement and curing time.

For the C1 clays having their water contents are equal to and higher than liquid limit and wc/c ranging from 2 to 30, the A-values are 1241, 1562, 1771, 2952 kPa for 1, 4, 12, 52 week-curing, respectively and B-value is 1.24 for all cases of curing which are derived from equation (1). Similarly, for C2 clays, the A-values are 943, 1211, 1395 and 2211 kPa for 1, 4, 12, 52 week-curing time, respectively and B-value is 1.24 for all cases of curing. And for C3 clays (Fig. 6), A-values are 1054, 1354, 1557, 2492 kPa for 1, 4, 12 and 52 week-curing time, respectively and B-value is 1.24. While, Horpibulsuk and Miura [3] found the A-values, 969, 1130 and 1739 kPa for 7, 14 and 28 day-curing time, respectively and the B-value, 1.24. From above prediction, the B-values have been taken as 1.24 for the all cases of Bangladesh (C1, C2 and C3) clays but the A-values are different. For every curing time, the A-values for C1 clay are highest such the C1 clay provide

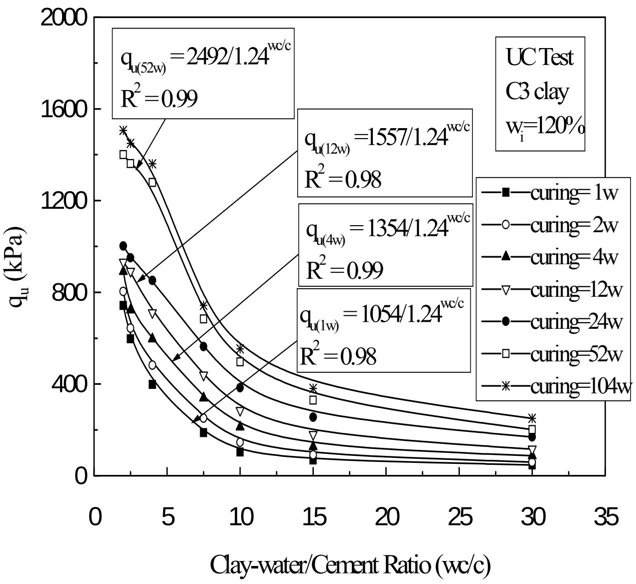

Fig. 6: Strength assessment based on clay-water/cement ratio's concept of cement stabilized clay of Bangladesh (w_i = 120%) for typical C3 clay.

the highest strength. Since B-value is identical for all clays, the same strength ratio at a particular curing time can be obtained as:

$$\left(\frac{S_{(wc/c)_1}}{S_{(wc/c)2}}\right) = 1.24^{\{(wc/c)_2-(wc/c)_1\}} \quad (2)$$

where, $S_{(wc/c)_1}$ is the strength at $(wc/c)_1$ and $S_{(wc/c)_2}$ is the strength at of $(wc/c)_2$. From this prediction, it reveals that the wc/c does not play any role on the strength development with time. As a result, the strength normalization of stabilized clays as shown in Fig. 7 by the 4 weeks- strength as follows:

$$\frac{S_D}{S_{28}} = a + b\ln D \quad (3)$$

where, S_D is the strength after D days of curing, S_{28} is the 28 day-strength, D is the curing time, a and b are constant depending upon the type of clay. It is found that a = - 0.51 and b = 1.07 for clays of Bangladesh. While, a = -0.18 and b = 0.46 for island clays, investigated by Nagaraj et al. [4]. The interrelationship among strength, curing time and wc/c is generalized by equations (2) and (3) as:

$$\left(\frac{S_{(wc/c)1,D}}{S_{(wc/c),28}}\right) = 1.24^{\{(wc/c)28-(wc/c)_{D1}\}}\left(-0.513+1.07\ln D\right) \quad (4)$$

Where, $S_{(wc/c)1,D}$ is strength of stabilized clay to be estimated at $(wc/c)_1$ at D day-curing and $S_{(wc/c),28}$ is strength of stabilized clay at wc/c after 28 day-curing.

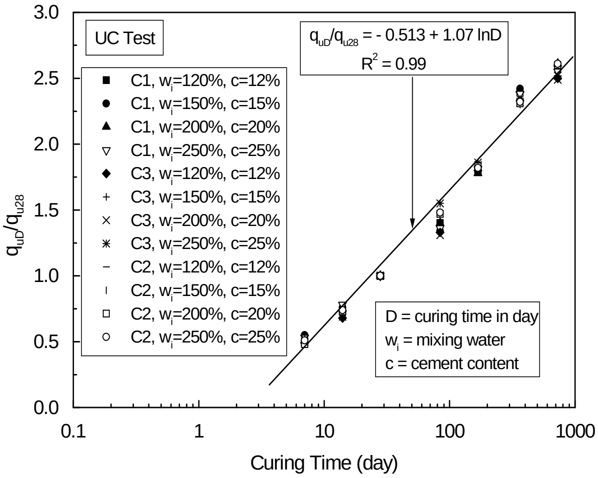

Fig. 7: Strength development with time and its generalization for clays of Bangladesh.

8. STRAIN (AT FAILURE) ASSESSMENT BASED ON STRENGTH FOR CLAY-WATER/CEMENT RATIO'S CONCEPT

Typical Fig. 8 illustrates the relation of ε_f and q_u in an arithmetic plot for C3 clay. Such figures are meaningful to delineate the ductile and brittle behavior of the samples. The relationship has produced a definite trend of reduction of failure strain with incremental values of cement content and curing time. Higher water content (200% to 250%) containing samples have higher strain comparing same cement content of lower water content (120% to 150%). Ductile behavior is associated with low strength and higher failure strain and brittle behavior vice versa. Generally, higher cement and curing time are the main parameters to cause the stabilized mass brittle. The expressions for quick calculation of ε_f (in %) and q_u (in kPa) plot are:

$\varepsilon_f = 2.34 - 7.01 \times q_u / 10^4$ (5a)
for high plastic (C1) clay

$\varepsilon_f = 3.00 - 8.04 \times q_u / 10^4$ (5b)
for medium plastic (C2) and

$\varepsilon_f = 2.83 - 7.60 \times q_u / 10^4$ (5c)
for low plastic (C3) clay

While, Kamaluddin [2] reported that the relationship (ε_f, q_u) for cement stabilized Bangkok clay at low mixing water content, such as $\varepsilon_f = 3.3 - 19 \times q_u / 10^4$.

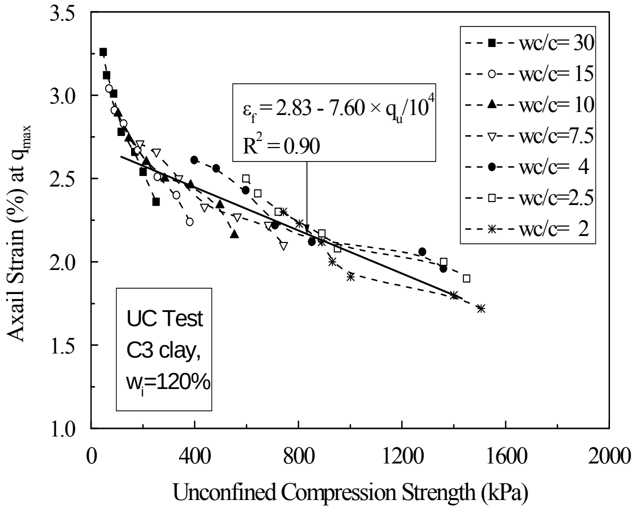

Fig. 8: Typical strain assessment based on Strength in terms of wc/c ratio for C3 clay.

9. STIFFNESS (MODULUS) ASSESSMENT BASED ON STRENGTH FOR CLAY-WATER/CEMENT RATIO'S CONCEPT

Typical Fig. 9 shows that higher stiffness is associated with lower wc/c ratio. The relationship has produced a definite trend of increasing stiffness with incremental values of cement content and curing time. Higher water content (200% to 250%) containing samples have lower stiffness comparing same cement content of lower water content (120% to 150%). Ductile behavior is associated with low strength and stiffness and brittle behavior vice versa. The relations also lie closely on a straight narrow band in such a way that the relationship between E_i and q_u can be approximated to linear. The relations for calculation in between E_i (in mPa) and q_u (in kPa) plot are:

$E_i = 3.02 \times (q_u^{1.5})/10^3$ (6a)
for high plastic (C1) clay

$E_i = 3.35 \times (q_u^{1.5})/10^3$ (6b)
for medium plastic (C2) clay and

$E_i = 3.13 \times (q_u^{1.5})/10^3$ (6c)

for low plastic (C3) clay

While, Kamaluddin [3] reported that relation for stabilized Bangkok clay at low mixing water content, such as $E_i = 6.2 \times (q_u^{1.5})/ 10^3$.

Typical Fig. 10 explains that relationship between secant elastic modulus, E_{50}, and q_u in terms of wc/c ratio for C3 clay. The best fit line for strain and stiffness show a

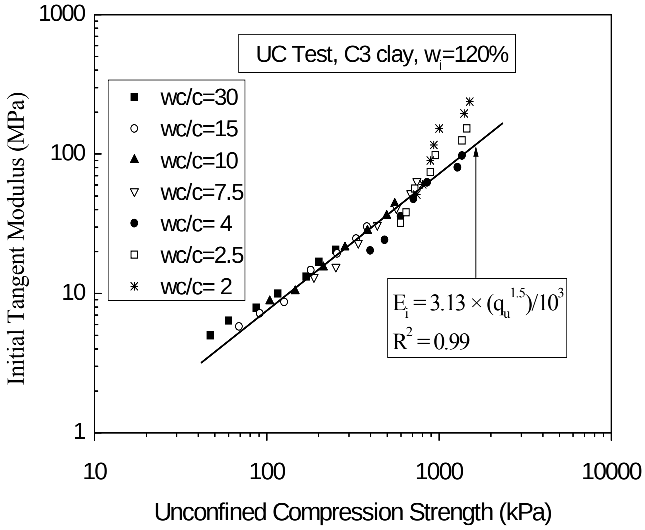

Fig. 9: Typical initial stiffness assessment based on Strength in terms of wc/c ratio for C3 clay.

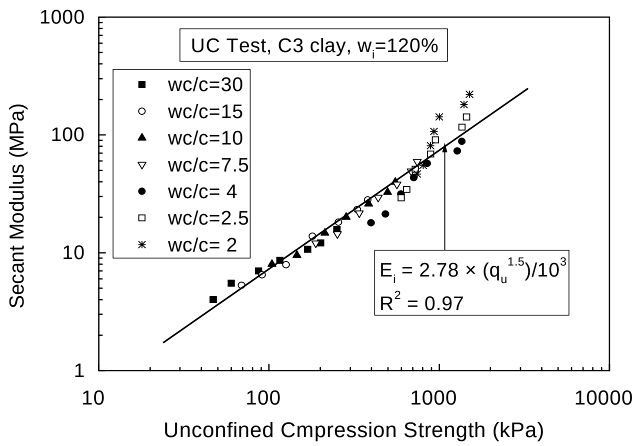

Fig. 10: Typical secant stiffness assessment based on strength in terms of wc/c ratio for C3 clay.

coefficient of correlation greater than 0.90. The relations E_{50} (in mPa) and q_u (in kPa) plot are:

$E_{50} = 2.72 \times (q_u^{1.5})/10^3$ (7a)

for high plastic (C1) clay

$E_{50} = 2.91 \times (q_u^{1.5})/10^3$ (7b)

for medium plastic (C2) clay and

$E_{50} = 2.78 \times (q_u^{1.5})/10^3$ (7c)

for low plastic (C3) clay

While, Kamaluddin [3] reported that the relation (q_u, E_{50}) are $E_{50} = 5.8 \times (q_u^{1.5})/10^3$. It is said that stiffness in study for high mixing water are approximately half times that that of low mixing water.

10. CONCLUSIONS

The following conclusions for cement treated soft clays of Bangladesh are drawn from this study:

(i) The cementation bond strength increases as the clay-water/cement ratio, wc/c decreases. The stress~strains behaviors and strength characteristics are practically the same as long as the identical wc/c. It is found that the wc/c is the influential parameter for the strength and deformation. Samples with a high clay-water (200% to 250%) undergo low stiffness and high strain.

(ii) The cement content of less than 4% does not show any effective improvement of strength and deformation properties of soft clays in Bangladesh at high water content, beyond 4% and up to 40% cement can be envisaged as Active Zone. Beyond 40% cement content is defined as Inert Zone.

(iii) The behavior of stabilized clays is remarkably governed by wc/c, the strength for quick calculation as well as the interrelationship involving strength; wc/c and curing time are proposed as presented in equations

$$\left(\frac{S_{(wc/c)_1}}{S_{(wc/c)2}}\right) = 1.24^{\{(wc/c)_2 - (wc/c)_1\}}$$ and

$$\left(\frac{S_{(wc/c)1,D}}{S_{(wc/c),28}}\right) = 1.24^{\{(wc/c)28-(wc/c)_{,D1}\}}\left(-0.513+1.07\ln D\right)$$

respectively. The implementation of the presented method is to simplify the task of arriving at the cement content and curing time in the laboratory investigations to realize the target values.

(iv) The expressions for quick estimation of strain, ε_f (in %) from q_u (in kPa) plot in terms of wc/c ratio are $\varepsilon_f = 2.34 - 7.01 \times q_u /10^4$, $\varepsilon_f = 3.00 - 8.04 \times q_u /10^4$ and $\varepsilon_f = 2.83 - 7.60 \times q_u /10^4$ for cement stabilized high, medium and low plastic clays respectively.

(v) The expressions for quick estimation of initial stiffness, E_i (in mPa) from q_u (in kPa) plot in terms of wc/c ratio are $E_i = 3.02 \times (q_u^{1.5})/10^3$, $E_i = 3.35 \times (q_u^{1.5})/10^3$ and $E_i = 3.13 \times (q_u^{1.5})/10^3$ for stabilized high, medium and low plastic clays respectively.

(vi) The expressions for quick estimation of secant stiffness, E_{50} (in mPa) from q_u (in kPa) plot in terms of wc/c ratio are $E_{50} = 2.72 \times (q_u^{1.5})/10^3$, $E_{50} = 2.91 \times (q_u^{1.5})/10^3$ and $E_{50} = 2.78 \times (q_u^{1.5})/10^3$ for stabilized high, medium and low plastic clays respectively.

(vii) The high plastic clay undergoes better improvement than low plastic clay but low plastic clay undergoes better improvement than medium plastic clay. The resulting effect of improvement for strength, high plastic clay leads to the formation of more structured for cemented clay at high water.

(viii) This paper reveals that the strength of the stabilized clays strongly depends upon only wc/c. Thus to obtain uniform strength of stabilized clays for engineering works such as deep and shallow foundation, improvement for engineering purposes etc, at construction sites in which water content of clay varies with depth and location, the wc/c of mixture must be controlled. The wc/c ratio's concept, thus, overcomes not only the engineering requirement but also the economical viewpoint.

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