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Soft peaty clay stabilization in Sri Lanka: sustainability through utilizing secondary raw materials

Stabilisation de l'argile tourbée molle au Sri Lanka: durabilité grâce à l'utilisation de matières premières secondaires

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ABSTRACT: In situ deep mixing of soft peaty clay with a binder such as cement can improve strength and compressibility characteristics significantly in a short period of time. However, due to the higher cost and environmental impact of cement as the binder, reducing the cement content using secondary raw materials such as Calcium carbide residue (CCR) and Fly ash (FA) is needed and is focused on this study. Improvements in strength for various proportions of CCR, FA and cement were assessed by conducting unconsolidated undrained triaxial tests for short-term (28 days) and long-term (90 days) curing. Further, behaviour of compressibility was investigated by conducting loading, unloading, and preloading one-dimensional consolidation test on oedometer. Adding only cement has the best improvement while 10% CCR, 15% FA with 5% cement mixture showed the best results among alternative mixtures. The CCR fixation point was 30% and was independent from time. Further, having similar proportions for FA with CCR & cement mixtures provided better results. However, permitting pozzolanic reaction under an overburden stress can noticeably improve the strength & stiffness of peaty clay.

RÉSUMÉ : Le mélange profond in situ d'argile de tourbe molle avec un liant tel que le ciment peut améliorer considérablement les caractéristiques de résistance et de compressibilité en peu de temps. Cependant, en raison du coût plus élevé et de l'impact environnemental du ciment en tant que liant, la réduction de la teneur en ciment à l'aide de matières premières secondaires telles que les résidus de carbure de calcium (CCR) et les cendres volantes (FA) est nécessaire et se concentre sur cette étude. Les améliorations de la résistance pour diverses proportions de CCR, FA et ciment ont été évaluées en effectuant des essais triaxiaux non consolidés non drainés pour une cure à court terme (28 jours) et à long terme (90 jours). De plus, le comportement de la compressibilité a été étudié en effectuant des tests de consolidation unidimensionnels de chargement, de déchargement et de préchargement sur un œdomètre. L'ajout uniquement de ciment a la meilleure amélioration tandis que 10 % de CCR, 15 % de FA avec un mélange de ciment à 5 % ont montré les meilleurs résultats parmi les mélanges alternatifs. Le point de fixation du CCR était de 30 % et était indépendant du temps. De plus, le fait d'avoir des proportions similaires pour l'AF avec des mélanges de CCR et de ciment a donné de meilleurs résultats. Cependant, permettre une réaction pouzzolanique sous une contrainte de mort-terrain peut sensiblement améliorer la résistance et la rigidité de l'argile tourbeuse.

KEYWORDS: calcium carbide residues, compressibility, fly ash, shear strength, soft peaty clay

1 INTRODUCTION

Rapid development in the construction industry has compelled the geotechnical engineers to utilize lands underlain by weak soils forcing to improve strength and compressibility characteristics of the soil. Lands underlain by thick layers of peaty clay were often encountered in many new highway projects spanning across flood plains in the country forcing a viable solution for soil improvement.

Peaty clays encountered in flood plains of Sri Lanka have undergone complete degradation (classified as amorphous granular or H10 (Hobbs 1986)) are mixed with alluvial deposits. As such, the organic contents are in the order of 30-40%. They are characterised by a very high-water contents (over 300%) and therefore of a very high compressibility and very low shear strength (as low as 2 kN/m^2). Peaty clays possess very high secondary consolidation settlements with the highest secondary compression index to compression index ratio (C_α/C_c) for all geo-materials (Mesri 1997).

Therefore, to prevent possible shear failures, high road embankments constructed on sites underlain by peaty clays should be done in stages (or sufficiently slowly) allowing for strength gain with consolidation. The embankments are to be preloaded during the construction to ensure that the settlements in service are within acceptable limits.

In Southern Expressway and Colombo Katunayake Expressway projects, different techniques such as pre-consolidation with preloading; pre-consolidation with vacuum consolidation and heavy tamping followed by preloading; sand compaction piles and crushed stone piles; and excavation and removal have been used to enhance stiffness and shear strength of peaty clays (Kulathilaka 2015). These techniques involve consolidation of the peaty clay or transfer of loads to a stronger intrusion (granular columns). These additional steps in ground preparation leads to an extension of the duration of projects specially when it involves high embankments.

Since the speed of construction is a major concern of current development projects, geotechnical engineers must look for rapid methods which are sustainable. Deep mixing with cement, lime or with a mix of other industrial binders in-situ is a technique that can be adopted to improve the engineering properties of soft peaty clay in a short period of time.

1.1 *Deep mixing with cement*

The deep mixing process is beneficial over other techniques because when peaty clay is deep mixed in-situ with a binder like cement, a hydration process (refer to Eq. 1) will occur followed by a subsequent pozzolanic reaction which increases strength and consolidation characteristics in a short period of time (around 28 days).

$$\text{Cement} + \text{water} \rightarrow CSH + CAH + CASH + Ca(OH)_2 \quad (1)$$

In the cement hydration process, hydrated calcium silicates (CSH), hydrated calcium aluminates (CAH), hydrated calcium aluminium silicates (CASH), hydrated lime [$Ca(OH)_2$] are the main products (formation of primary cementitious materials). There is an increase in pH value of the medium due to the dissociation of $Ca(OH)_2$ which let the silica and alumina from the soil to be dissolved (as an acid dissolves in a strong base). The hydrous silica and hydrous alumina then gradually react with Ca^{2+} ions to form secondary cementitious materials. Formation of cementitious materials which get hardened with time and dissipation of pore water for the hydration process make the peaty clay to be stabilized rapidly (Horpibulsuk et al. 2012).

Dry cement powder (dry mixing) is used for improvement of organic clays of high initial water content in the field mixing process. The deep mixing is conducted in the form of columns (20 to 30 m depth) in a designed grid arrangement where these columns may be overlapped to create walls or blocks. Alternatively, the complete mass of peat also can be stabilized over a shallow depth according to the availability of machinery (Porbha, Tanaka and Kobayaska 1998).

Simple machineries were developed in Sweden by modifying a crawler mounted crane and mass stabilization of thick peat layers were carried out successfully for the construction of highways and railways (Jelisic 2004). Machinery of this type can be developed locally, and the process of deep mixing would be practically viable. As such, mixing with cement or lime could be a plausible method for improvement of soft peaty clay layers encountered in Sri Lankan Road projects.

However, laboratory studies done at University of Moratuwa, Sri Lanka have shown that a cement content of the order of 20-25% is required to achieve a desired level of improvement in organic clay with properties ranging between 260 – 600% of moisture content, 20 – 40% organic content, 3 – 4 pH value and 1.5 to 2.1 specific gravity (Vitharana 2019). This is comparable with the cement weights of 200-250 kg per cubic meter of organic clay reported in literature (Kulathilaka 2015). Hence, using cement is not economically and environmentally feasible for Sri Lankan organic clay stabilization. Hence, the use of secondary raw materials for full/partial replacement for cement to reduce the environmental impact and higher costs is essential

1.2 *Deep mixing with Fly ash (FA) and Calcium Carbide Residues (CCR)*

Fly ash (FA) is one such conventional secondary raw material produced at coal power plants and is successfully used as a cementitious material in many countries. FA mainly includes SiO_2, Al_2O_3, and Fe_2O_3 which makes FA a pozzolanic material. However, Sri Lanka has class "F" FA which is low in calcium (~6%) (Vitharana 2019). Therefore, Sri Lankan FA needs to be mixed with a high calcium additive such as Calcium Carbide Residues (CCR) to generate better pozzolanic reactions.

CCR is a by-product of acetylene gas production factories, and it is a waste product in the industry derived as shown in Eq. 2.

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \quad (2)$$

$Ca(OH)_2$ is disposed in slurry form and after being sun dried it becomes dry form which is known as CCR. 64 g of calcium carbide (CaC_2) provides 26 g of Acetylene gas (C_2H_2) and 74 g of CCR, in terms of $Ca(OH)_2$ that is an abundance as a raw material (Horpibulsuk et al. 2012). There is an increasing demand to find a way to dispose CCR since it is challenging to dispose to the nature being a highly basic material. Therefore, utilization of CCR as a secondary raw material for stabilization of peaty clay will be a sustainable solution.

Horpibulsuk et al. (2012), studied the change in index properties of the CCR stabilized silty clay from Thailand and observed a considerable increase in the plastic limit and a smaller reduction in liquid limit when the CCR content is increased in the clay samples. Hence, increase CCR content caused a reduction of the plasticity index which caused by the adsorption of Ca^{+2} ions from the cation exchange process indicating the flocculation of clay particles. However, Horpibulsuk et al. (2012) noticed that the plasticity index reduction is marginal at a certain CCR content (7% for Thai silty clay) and denoted this point as the *CCR fixation point* which implies the maximum adsorption capacity of Ca^{+2} ions by the soil.

The strength improvement in peaty clay with CCR can be classified into three zones: active, inert, and deterioration (Horpibulsuk et al. 2012). In the *active zone,* strength increases with the CCR input and ends with CCR fixation point. Then the *inert zone* starts with a slower strength development due to the lack of natural pozzolanic materials in the soil to react with excess amount of CCR input. Adding another pozzolanic material rich source like FA, in this zone can accelerate the process again. In the *deterioration zone* strength decreases due to the loss of pozzolanic materials and unsoundness caused by excess free lime (Kampala & Horpibulsuk, 2013). Hence, using CCR and FA together should provide better strength improvement in peaty clay. Vitharana (2019) studied the use of CCR with FA for stabilization of peaty clay and the results are shown in the Figure 1. However, according to the figure, the improvement of strength of the stabilized soil samples were not sufficient for the field applications. Hence, Vitharana (2019) proposed to use a smaller amount of cement with CCR and FA to improve soft peaty clay as a partial replacement rather than the full replacement of cement.

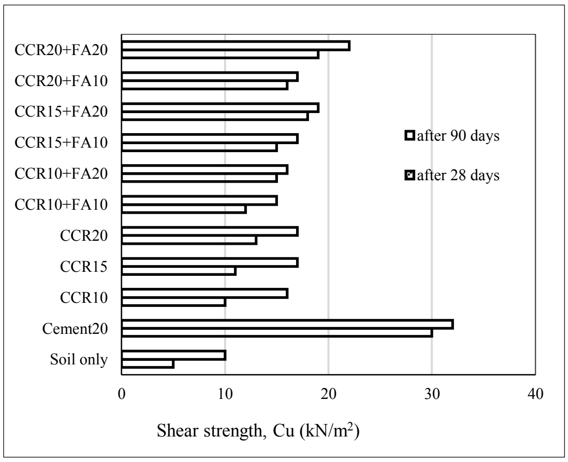


Figure 1. Strength of peaty clay samples after 28 days of curing (Vitharana 2019)

Thus, the main objective of this study was to investigate the applicability of CCR and FA as a partial replacement of cement during dry mixing to improve the shear strength of soft peaty clay.

2 METHODOLOGY

2.1 *Materials*

Peaty clay samples were extracted from the Outer Circular Expressway at Kerawalapitiya, Sri Lanka. Debris were removed and a homogeneous sample was prepared. The basic properties of peaty clay are presented in Table 1. Soil samples were mixed with CCR (from Ovin Gas (pvt.) Ltd, Homagama) and FA (from Lakvijay Power Plant, Norochcholai) on a wet weight basis as in Table 2. The chemical composition of FA and CCR used are in Table 3 and the particle size distribution curves are shown in Figure 2. The moisture content of CCR was 42.14% (CCR was air-dried before use) and the specific gravity was 1.875. The moisture content of FA was 0.15% while the specific gravity was 2.270. The total additive percentage was kept at 30%. Five percent cement content was selected as a fixed amount and remaining 25% was replaced with CCR and FA. Further, three samples were prepared with 15%, 30% and 45% of CCR to investigate the CCR fixation point of the soil.

Table 1. Basic Properties of Peaty clay

Basic Property	*Value*
Moisture Content (%)	614.12
Bulk Density (kN/m^3)	10.75
Specific Gravity (Gs)	1.514
pH Value	6.0
Organic Content (%)	39.64
Fibre Content (%)	27
Ash Content (%)	59.5
Initial Void Ratio	5.44

Table 2. Mix Proportions

Combination	*Additives % by weight*		
	CCR	*FA*	*Cement*
Peat only	-	-	-
Peat + Cement	-	-	30
Peat + CCR + FA + Cement	20	5	5
	15	10	5
	10	15	5
	5	20	5
Peat + CCR + FA	15	15	
Peat + CCR	15, 30, 45		

Table 3. Chemical Composition of FA and CCR

Material	*Composition in FA (%)*	*Composition in CCR (%)*
SiO_2	45	6.49
Al_2O_3	31.8	2.55
Fe_2O_3	4.4	3.25
CaO	9	70.78
MgO	1.1	0.69
K_2O	-	7.93
SO_3	0.5	0.66
LOI	3.7	1.35

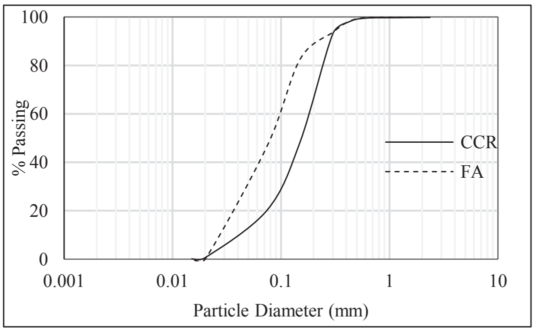


Figure 2. Particle Size Distribution of FA and CCR

2.2 *Laboratory Simulation of the deep mixing process*

The process of complete liquefaction of the in-situ soil and mixing with stabilizers was simulated in the laboratory by mixing the soil with dry stabilizers with the help of a mixing tool.

Peaty clay was mixed with cement, CCR and FA according to different mix proportions by weight (Table 2). The mixing percentages are the percentage weight of each additive out of the weight of the peaty clay used for the sample. Mixing was done with an aid of a mechanical mixer (Figure 3) to simulate the process of complete liquefaction of the in-situ soil and mixing with dry stabilizers. Prepared samples were kept in buckets and a surcharge of 10 kN/m^2 was applied to simulate the hardening of the soil mix under its own weight in the field (Figure 4). The samples were cured for 28 days and 90 days separately for short-term and long-term stabilization respectively.

After curing, undisturbed samples were obtained and Unconsolidated Undrained Triaxial test was conducted according to ASTM D2850 standards under 50 kPa, 100 kPa and 150 kPa cell pressures to investigate shear strength parameters of stabilized peaty clay samples.

One-Dimensional Consolidation test was carried out to evaluate the improvements achieved in the compressibility characteristics. The Oedometer apparatus was used to conduct the experiment according to the ASTM – D 2435 standard test method. The test was done with both loading, unloading and reloading stages on the undisturbed samples extruded from the buckets. In the loading stage, started from 5 kN/m^2 stress and increasing to 10, 20, 40, 80 kN/m^2 stresses respectively. Then unloading was done for stress levels of 40, 20 and up to 10 kN/m^2. After that reloading was started from 20 to 160 kN/m^2. The loading duration was one day for all stages. Stress levels of these magnitudes were selected because these soft peaty clay layers are encountered near the surface levels and are of maximum thicknesses in the range of 10-12 m.

Figure 3. Mechanical mixer

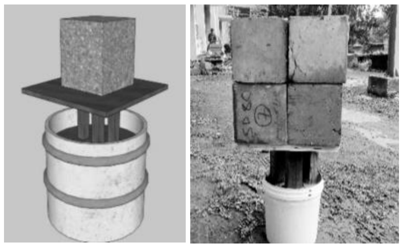


Figure 4. Loading Mechanism

3 RESULTS AND DISCUSSIONS

3.1 *Optimum CCR content*

Similar to the observations by Horpibulsuk et al. (2012) for Thai silty clay, it was be interesting to check the behaviour of CCR for Sri Lankan peaty clays. However, O'Kelly (2015) concluded that the Atterberg limits of peat are not reliable indicators of its consistency and natural water content, organic content, fibre content and degree of humification of peat are more suitable for assessing its likely engineering behaviour. Hence, for this study, the water content and the organic content of the peaty clay samples were used for investigating the optimum CCR content. Here, water and organic content of both short-term (28 days) and long-term (90 days) curing were used for comparison and are shown in Figure 5.

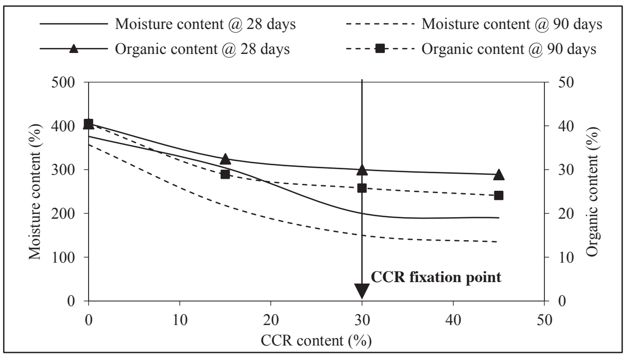


Figure 5. Moisture content and organic content of the treated peaty clay samples

According to the Figure 5, the optimum CCR content where the maximum adsorption of Ca^{+2} ions to the peaty clay occurs when CCR content is 30%. Because, both moisture content and the organic content of the treated peaty clay samples has minimal changes after 30% of CCR content. Interestingly, this CCR fixation point does not change with time as both 28 days curing, and 90 days curing indicates similar behaviour. Hence, it concludes that the CCR fixation point is independent from the curing time. However, this observation should be confirmed with more experiments.

Strength behaviour of the short-term and long-term stabilized samples is represented in Figure 6. The graphs were extended using best fit ($R^2 > 0.99$) polynomial trend lines to clearly observe the inert and the deterioration zones. Similar to the findings in literature, shear strength of peaty clay has improved rapidly at the beginning. Because initially, pozzolanic reaction occurs rapidly and makes the cementitious material, which densify the peaty clay by filling pores in it. Next, an inert region is displayed, where increment slows down as the pozzolanic material in peaty clay gets depleted. However, further increase in CCR%, caused the shear strength to decline due to the excess lime created.

Compared to short-term, long-term curing exhibits around 3.5% increment in shear strength of peaty clay samples. In addition, the active region of both short-term and long-term curing falls up to 30% CCR. Conversely, long-term curing displays a longer inert region (30% - 60%) while that for short-term curing is comparatively shorter (30% - 45%). These results indicate that long-term curing allows more room for the flocculation of peaty clay particles to densify the soil matrix. Therefore, in field application, we can expect higher strength improvement in peaty clay with time. However, a similar optimum CCR content of 30% was observed for both short-term and long-term curing similar to the results of CCR fixation point in Figure 5, indicating that the maximum adsorption capacity of Ca^{2+} ions by soft peaty clay will not change with time for curing.

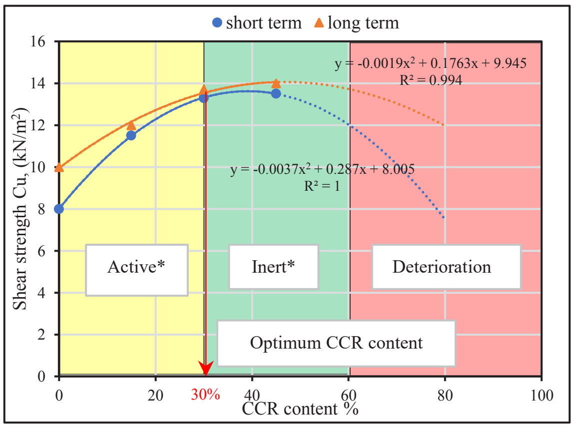


Figure 6. Shear Strength variation with CCR (*shaded areas show the different stages of strength variation for long-term curing)

3.2 *Strength behaviour of peaty clay with CCR, FA and cement*

Second objective was to investigate the best mixture of CCR and FA as a partial replacement of cement which gives the maximum improvement in shear strength of soft peaty clay samples and the shear strength behaviour of the soil samples are shown in Figure 7.

According to Figure 7, maximum improvement is achieved when 30% cement is added to the peaty clay. Among the other additive combinations, CCR 10%, FA 15% and 5% cement gave the highest shear strength. However, it is almost half of the shear strength obtained for 30% cement. In addition, when the curing period extends, all the soil samples showed an increment ranging from 18% to 40% which is much higher than with only CCR. This explains the potential to improve the strength of the peaty clay with time when FA and/or cement is available which provides additional pozzolanic material for the excess lime generated by CCR to react.

This can be further explained by the shear strength increment with the FA content of the sample with 15% CCR and 15% FA. Addition of 15% FA has increased the shear strength by around 6% and 14% in 28 days and in 90 days consequently compared to only 15% CCR sample. This observation further confirms the importance of having rich aluminosilicates as secondary raw materials in the binder for continuation of pozzolanic reactions for longer-durations.

Further, the strength has been increased with the increasing FA content up to 15% and then has reduced for 20% of FA when 5% cement is added to the samples. For 20% FA, there is only 5% cement and 5% CCR and the amount was not sufficient to generate enough pozzolanic reactions to strengthen the soil matrix. The maximum strength additive combination has an equal amount of FA (15%) and CCR (10%) with cement (5%). Further, only this combination was able to surpass the 30% CCR strength value during short-term curing (refer to Figure 7). However, addition of 5 to 15% of FA to the mixture could exceed the 30% CCR strength value after 90 days curing. This observation suggests using an equal amount of FA with CCR and cement mixtures for better results in short-term.

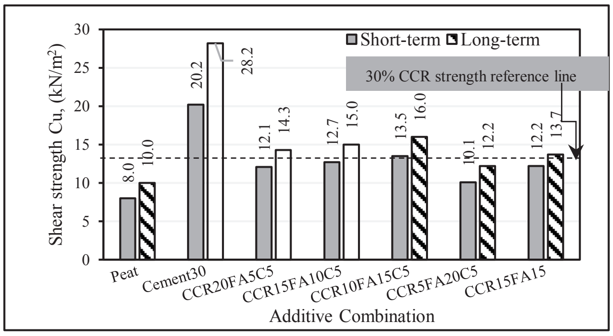


Figure 7. Strength variation of soil samples with CCR, FA and cement

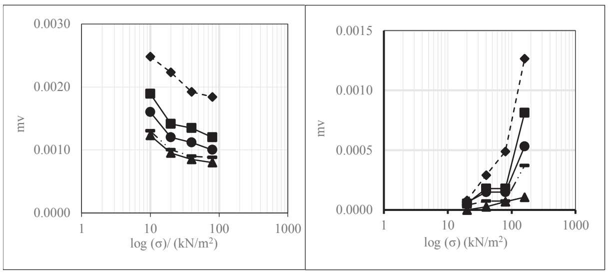
In addition, Horpibulsuk et al. (2012) observed that addition of FA for silty clay stabilization was more effective when FA is added excess to the CCR fixation point. However, this observation was not applicable for the present study as the CCR fixation point was 30% and the total additive mixture was maintained at 30% considering the field application which warrants future studies.

3.3 *Compressibility of peaty clay with secondary raw materials*

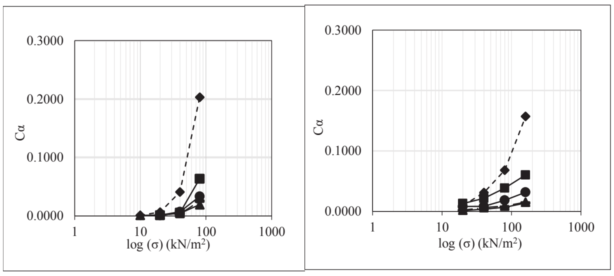
The preloading process was simulated by conducting Oedometer tests with loading, unloading and reloading increments. The specimen in the reloading increments resembles a preloaded soil (at a stress level of 80 kN/m^2). The coefficient of volume compressibility (m) and the coefficient of secondary consolidation (C_α) were evaluated in all the loading and reloading increments. The values of compression index (Cc) and recompression index (Cr) were also evaluated using the e vs log σ plot.

3.3.1 *Compressibility of peaty clay with CCR*

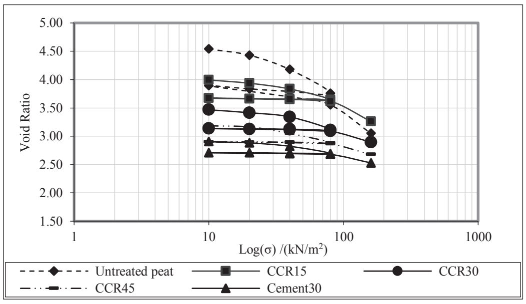
Figure 8 shows the compressibility behaviour of peaty clay after addition of CCR and 30% cement. According to the figure, addition of CCR has improved both primary and secondary consolidation of peaty clay for all the CCR contents. However, 30% cement shows the best improvement similar to the observations in shear strength probably due to the availability of higher aluminosilicates in the media to develop more cementitious products. Interestingly, still CCR could provide a better improvement than the preloaded natural peaty clay (refer to the gradients of natural peat in Figure 8(a), (b), (c) and (d)).



(a) m_v vs log σ during loading (b) m_v vs log σ during reloading



(c) Cα vs log σ during loading (d) Cα vs log σ during reloading



(e) e vs log σ

Figure 8. Compressibility behaviour of CCR treated peaty clay

3.3.2 *Compressibility of peaty clay with CCR, FA and cement*

Table 4 summarises the compression and recompression index obtained after 28 days and 90 days curing of treated peaty clay samples. As observed before, 30% cement provides the best improvement among all the combinations. However, when equal percentages of FA with CCR and cement is used (15% FA+10% CCR+5% cement), the improvement is higher than the improvement by the preloading on natural peaty clay. Nevertheless, all the additives could improve the compressibility characteristics of peaty clay and this performance turns better with time for all cases.

In addition, the Cα values of the treated peaty clay were much lower (all were less than 0.01) than the values reported for naturally occurring peaty clay layers in Sri Lanka (which are in the order of 0.02 – 0.06, Karunawardena (2000)) (refer to Figure 9). Further, like strength behaviour, higher improvement in compressibility can be observed when equal amounts of CCR and cement with FA are mixed compared to the compressibility of soft peaty clay with optimum CCR content (Figure 9). Comparatively, more significant improvements are visible for secondary consolidations and is important for long-term stability of highway embankments built on soft peaty clays (refer to Figure 8 and 9).

Table 4. Compression and recompression index

Sample	*$Cc/(1+e_o)$*		*$Cr/(1+e_o)$*	
	28 days	*90 days*	*28 days*	*90 days*
Peaty clay	0.627	0.328	0.091	0.065
CCR 15%	0.048	0.035	0.012	0.009
CCR 30%	0.041	0.032	0.007	0.006
CCR 45%	0.039	0.021	0.005	0.004
CCR 20% + FA 5% + cement 5%	0.197	0.196	0.005	0.004
CCR 15% + FA 10% + cement 5%	0.192	0.094	0.005	0.004
CCR 10% + FA 15% + cement 5%	0.074	0.049	0.003	0.002
CCR 5% + FA 20% + cement 5%	0.293	0.218	0.007	0.006
CCR 15% + FA 15%	0.192	0.139	0.006	0.0003
Cement 30%	0.038	0.001	0.003	0.0003

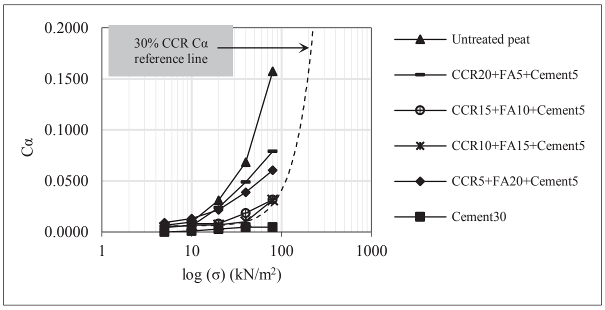


Figure 9. Cα vs log σ during reloading for treated peaty clay with CCR, FA and Cement

3.4 *Changes in the microstructure*

Microstructure of the stabilized samples were investigated through scanning electron microscope (SEM) and are shown in Figure 10. Irregular shape of peaty clay particles and the voids among particles are clearly depicted in the figure. When the cement or CCR is mixed with soil, a rod-shaped structure (Ettringite) can be observed which makes a more aggregated and bonded structure hence increases the shear strength. The spherical shape of FA allows peaty clay to densify more than the CCR with proper packing. Due to the high specific gravity of FA, it allows peaty clay to be well compact and thus in-crease the shear strength. However, the soil matrix with 30% cement is more densified and has higher ettringite formations compared to other mixtures. Hence, a higher cement percentage than 5% should be added for better improvement.

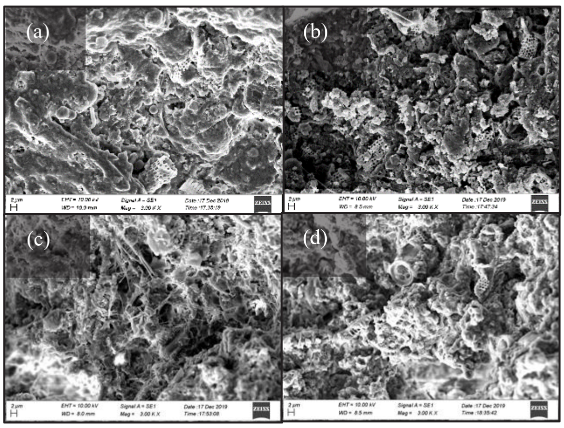


Figure 10. SEM images of (a) peaty clay, (b) peaty clay with 10% CCR 15% FA and 5% cement, (c) 30% cement and (d) 30% CCR (magnification of 3k and voltage of 10 kV)

4 COMPARISON WITH PREVIOUS STUDIES

Results of the present study were compared with Vitharana (2019) who have used CCR, FA and cement as stabilizers with a surcharge of 10 kN/m^2 and are shown in Table 5. Both studies have similar organic content whereas, moisture content of present study's soil is twice as for Vitharana (2019)'s study. When peaty clay is treated only with cement, present study has around 34% lesser strength improvement despite using 10% higher cement for mixing. Thus, it further confirms the previous observation of the moisture content playing a vital role in the increment of the shear strength of peaty clay. Furthermore, CCR fixation point follows a similar pattern as for moisture content where the value is doubled in the present research. 15% CCR addition provides similar strength for both soils in short-term. Whereas the long-term improvement of strength is hindered in present study as the Ca^{+2} ions absorption levels are still halfway (optimum CCR content is 30%) and/or lack of aluminosilicates in soil compared to Vitharana (2019)'s study.

However, present study shows a higher improvement for longer durations when cement is added compared to the previous study. For example, case (i) & case (ii) shows around 12% higher increment in strength from 28 days to 90 days compared to the previous study. We can conclude that adding cement provides more pozzolanic materials to continue the strengthening in the long run. Further, when comparing the effect of cement on compressibility characteristics of peaty clay, Figure 11 reveals the positive influence of cement when added to the same CCR and FA mixture by improving the compressibility characteristics of soil. Hence, partial replacement of cement has more advantages than for the full replacement with secondary raw materials for peaty clay. However, the strength improvement observed here are still lower than some of the records in literature (Jelisic 2002, Kulathilaka 2015) with cement/lime. Hence, a reasonable overburden stress should be provided with the Pozzolanic reaction for higher improvements in strength and stiffness.

Table 5. Comparison with previous studies

Reference				Vitharana (2019)		Present Study	
Properties of Peaty clay		Moisture%		300%		614%	
		Organic%		40.5%		39.6%	
		G_s		1.8		1.5	
Shear Strength (kN/m^2)	Soil only			4.5		8	
	Additive combination (%)	Cement (C)		20		30	
				S-30	L-32	S-20	L-28.2
		CCR /FA	(i)	CCR15+FA10		CCR15+FA10+C5	
				S-15	L-17	S-12	L-15
			(ii)	CCR10+FA20		CCR10+FA15+C5	
				S-15	L-16	S-13.5	L-16
			(iii)	CCR15		CCR15	
				S-11	L-17	S-11.5	L-12
CCR Fixation point				15%		30%	

S – Short-term (28 days); L – Long-term (90 days)

5 CONCLUSIONS & RECOMMENDATIONS

- Partial replacement of cement with CCR and FA combination has shown considerable development in strength and stiffness and can be increased by application of higher overburden stress on peaty clay.
- The strength is increased with time, whereas CCR fixation point is independent of time.
- Variation of moisture content plays a main role in the stabilisation of peaty clay.
- For better improvements, using similar proportions of FA with CCR and cement mixtures is suggested.

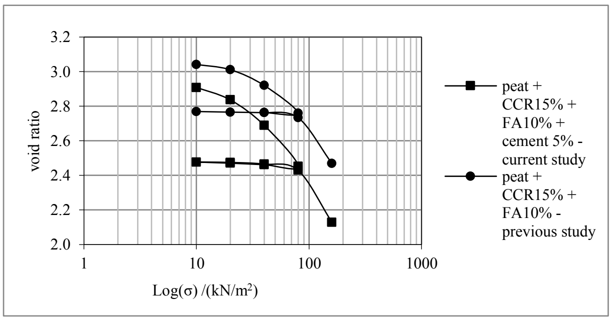


Figure 11. Comparison of the effect of cement on soft peaty clay improvement with present study and Elpitiya (2019)

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