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Research Paper

Characteristics of Cement Treated Soil: A Case Study from Soft Bangkok Clay and Red Soil of Nepal

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ABSTRACT

Soft Bangkok Clay from Thailand and clayey silt of red soil, Nepal have been incorporated for the research as a case study in order to understand the characteristics. Highly plastic soft Bangkok Clay and low plastic clayey silt have been confirmed as non-swelling soils through XRD analyses. The peak intensities of red soil from Nepal is more than two times higher than the intensity of soft Bangkok Clay. Higher water content and warm temperature form lower intensities in the soft Bangkok Clay resembling the amorphous state with compared to red soil of Nepal. As a result, the amount of admixture of cement in clay varies significantly to enhance the adequate strength. Hence, the research has delineated through determining undrained strengths treated with cement in different proportions at different curing time and checked the stiffness by passing through ultrasonic wave velocity. The specimens were extracted from the depths of 3.0 m and 12.0 m soil-cement column formed by dry method in Thailand and in-situ clayey silt from Nepal was treated with cement. Besides, 20% local poorly graded soil was added in the clayey silt and all treated specimens were cured for 7, 14 and 28 days. The results confirmed that the Bangkok Clay received the highest strength at 13.89% of cement addition for 3.0 m depth core and 11.11% of cement treatment received the maximum strength for 12.0 m core cured for 28 days. Conversely, clayey silt from Nepal received the maximum strengths at 7% cement treatment cured for 28 days.

1. Introduction

Construction practices on soft ground with low strength and unstable soil require treatment to improve the strength, increase bearing capacity and reduce the settlement of foundation before initiating any construction works by stabilizing the ground. Amidst several techniques to improve the ground, the improvement of ground using appropriate proportion of cement/lime into soil is widely practiced in several countries as one of the easiest and cost effective methods.

Generally, lime and cement are incorporated to apply for the improvement of soft ground; in the case of lime, two different terms are applied whether the required ground is to be applied for soil stabilization or for solidification. According to Miura et al. (1986) and Kitazume et al. (2008) the strength improvement using lime lasts for long-term when applying deep mixing method without decreasing the strength for 27 years which is further added by Hino et al. (2012) in order to improve the workability and trafficability. Although, the lime treated soil was observed to be quicker in terms of deterioration under sea water when with compared with normal ground (Hara et al., 2010). Manandhar et al. (2014) has extensively worked for the treatment of mine waste products utilizing lime treatment in along with

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mixing gravel contents to understand the strength parameter and bearing behaviour. Horpibulsuk et al. (2004a, b) further noticed that the effects of lime or cement in fine-grained soils had minor changes to their stress and environmental factors.

Overall, the strength of soil cement column depends on various factors such as soil type, cement content, curing time, water content and other factors (Kitazume, 2013). The mechanical properties of cement ad-mixed clays have been extensively researched and concluded by pioneer researchers (Terashi et al., 1979; Kawasaki et al., 1981; Kamon and Bergado, 1992). There are several soil stabilization methodologies applied successfully to improve the ground. Among them soil-cement column is one of the widely accepted ground improvement technology. The soil-cement column method is generated by mixing the strengthening material such as lime, cement and fly ash in the natural soil in order to increase the stiffness of the soil (Broms, 1998, and Bruce, 2001). Furthermore, the use of this technology is highly durable, economically very liable and construction process is rapid with compared to other technics (Chen et al., 2013; Dehghanbanadaki et al., 2013; and Kitazume and Terashi, 2013).

Rawasa et al. (2005) also conducted their research in Oman including expansive clay by using lime and cement together with specific temperatures using cement. Similarly, Fook-Hou Lee (2005) had been worked his research on Singapore Clay and compared with Bangkok Clay and Boston Blue Clay and mentioned noticeable improvement in strengths. Besides, Pandey and Rabbani (2017) determined that with the increasing consistency limit the quantity of cement should be increased to get optimum UCS and cement stabilization is the best option for coarse grained soil containing clay contents.

In this study, several soil/cement characteristics adopted from Thailand and Nepal have been incorporated in order to understand the trend of improvement using different techniques. There exists a huge research gap between Thailand and Nepal in the field of ground improvement techniques especially in soil/cement treated ground. Thailand has extensively applying the soil/cement treatment techniques in soft ground to improve the strength of the ground. In contrast, Nepal has very limited academic researches soil/cement treatment and almost it is novel in the field of engineering practices. This comparative study allows academic researchers and professional to quickly understand the behaviour of soft soils and will become easier to decide the necessary parameters to improve the strength of the ground which gives extensive ideas to apply directly in the engineering projects. In this reverence, samples from Bangkok Clay have drawn from the pull out soil cement column and determined the required strength parameters in the laboratory. In the case of red soil from Nepal, red soil was collected directly from the site from certain depth and treated with cement in the laboratory. The obtained results will offer the knowledge and characteristics of different types of soils and provide some basic trend with reference to soil improvement. In this context, the researches have been carried out in soil-cement column and soil/cement admixtures blended with poorly graded sand and clayey silt from the part of Bangkok Clay and Nepal.

2. Materials and methods

2.1 Materials

Bangkok Clay was adopted to carry out experiment from the soil cement column of different depths cured with different cement contents. Similarly, two type of soils were incorporated from Nepal and a Bangkok Clay was adopted to conduct this research. Red lateritic soil of low plastic clayey silt and poorly graded gravelly sand were collected from Nepal. The site belongs to the fluvial deposit sequence with presence of thick fine sequences of more than 20 m alternated with 1 m - 5 m thick coarser soil of gravel, sand and pebbles. The main objective of this research is to enhance the strength of red soil by mixing cement alone and adding poorly graded gravelly sand in red soil along with different weight percent of cement. The properties of both soils from Nepal and Bangkok Clay are outlined **Table 1**. The admixtures were then cured for 7, 14 and 28 days respectively to obtain the improved strength of soil cement and soil cement mixed poorly graded gravelly sand from Nepal and Bangkok Clay respectively (**Table 2**).

2.2 Methods

The methodologies to determine the percent of oxides of soils from Bangkok Clay and red soil of Nepal have been determined by the non-destructive analytical technique to determine the elemental composition using X-ray fluorescence (XRF) analyses. **Table 3** shows the elemental composition with reference to their respective oxides. Further, the non-destructive laboratory tests of soils have been carried out using X-ray diffraction (XRD) in order to confirm the availability of clay minerals to confirm whether the soils are expansive. Afterwards, the cylindrical-shaped column has been formed using rotary

Table 1. Properties of soils from Thailand and Nepal.

Properties	Bangkok Clay, Thailand		Nepal		
	3.0 m	12.0 m	Clayey silt (Red soil), Nepal	Sand, Nepal	0.8ML:0.2SP
Specific gravity			2.48	2.69	2.78
Moisture content (%)	89.5	94.6	28	16.0	17.0
Gravel (%)				10.32	0.04
Sand (%)			6.61	81.15	6.61
Silt (%)	99.9	99.9	73	8.2	73.85
Clay (%)			20		19.50
USCS (Soil classification)	CH	CH	ML	SP	ML
Liquid limit (%)	56.8	65.3	36.5		32.4
Plastic limit (%)	27.9	32.2	26		28.43
Plasticity index (%)	28.9	33.1	10.5		7.97
Optimum moisture content (OMC, %)			17.78		17.0
Maximum dry density (g/cm^3)			1.56	2.48	1.78
Unit weight (g/cm^3)	1.43	1.45			

Table 2. Experimental conditions of soils from Thailand and Nepal.

Descriptions	Experiment adjustment	
	Bangkok Clay, Thailand	Clayey silt (Red soil), Nepal
Adjusted initial water contents (%)	89.5 (3.0 m), 94.6 (12.0 m)	17.7
Amount of cement (%)	8.9, 9.71, 11.11, 13.89	3, 5, 7, 10
Atmosphere curing time (Days)	7, 14, 28	7, 14, 28

Table 3. Qualitative XRF analyses and percentages of oxides from Nepal and Thailand.

Compounds	Oxides, (%)	
	Red soil, Nepal	Bangkok Clay, Thailand
SiO_2	49.874	47.796
Al_2O_3	22.958	13.858
CO2	11.077	10.805
FeO	6.881	3.598
Fe_2O_4	7.647	3.998
Fe_3O_4	-	3.865
K_2O	3.121	1.744
MgO	0.824	1.925
CaO	0.178	9.402
Na_2O	0.161	0.827
MnO	0.095	0.065
P_2O_5	0.066	0.072
TiO_2	0.614	0.425
NiO	0.012	0.008
ZnO	0.010	0.0082
ZrO_2	0.038	0.026

drilling machine which has the facility to inject cement into the weak soil layer during rotation in order to create the stiff soil cement column. Moreover, the strength of soil cement column depends on various factors such as soil type, cement content, curing time, water content and other factors (Kitazume, 2013). In the current practice, the soil-cement construction processes have been adopted by two different construction methods of wet process and dry process in which moisture content of soil plays a vital role to control the ground behaviour. In the wet process, the soil cement column is produced by rotating mixing machine into the natural soil to break up the soil fabrics during the down stroke and the up stroke formed a stiff soil cement column. The slurry cement is injected by air pressure and blended in the soil in this method. On the other hand, dry reagent such as cement, lime or a combination of both, is pneumatically injected and blended with the natural soil in the dry process. The strength of dry process is higher than the strength of wet process at the same binder dosage as well as more economic.

In the dry process, the SCG Portland cement Type -1 was thoroughly mixed to natural soil at the ratio of 200 kg:1 m^3. The 12 m length of the soil-cement column at the construction site was bored and the mixing machine was utilized by rotating down the hole with the down stroke until it had approached to the tip of soil. Afterwards, the cement was injected into the natural soil during the up stroke process. **Figure 1** (**a** to **c**) describes the steps of dry mixing process at the construction site.

Then the quality of cement mixing process was checked in two parts. The laboratory tests confirmed the index and mechanical properties of soils at the construction site. Soil samples were extracted from the depths of 3.0 m, 6.0 m, 9.0 m and 12.0 m respectively and the specimens were treated with cement at 150 kg/m^3, 175 kg/m^3, 200 kg/m^3 and 250 kg/m^3 which are equivalent to 8.3, 9.71, 11.11 and 13.89% respectively. Hence obtained specimens are cured for 3, 7, 14 and 28 days and subjected to unconfined compressive test (**Fig. 1d**).

On the other hand, the suitable mixing ratio between cement and natural soil from laboratory test were mixed to obtain soil-cement column at the construction site. There are following controlling parameters need to be outlined during the construction.

- The diameter of soil-cement column should not be less than 95% of the designed diameter.
- The undrained shear strength should not be less than the design.
- The inclination of soil-cement should not be more than 1%.
- The distance between the soil-cement column is not more than 10 cm.

Following these controlling factors at the construction site, the soil-cement column was pulled by means of pull out test randomly in every 3,000 soil-cement columns in order to verify the shape, diameter and uniformity of soil cement-column (corresponding photograph of **Fig. 1c**). Afterwards, coring was performed to check the unconfined compressive strength in the laboratory as shown by **Fig. 1d**. In this research the soil-cement column at the depths from 3 m and 12 m were carried out from pull out test for the determination of undrained strength followed with the cement proportions of 8.3, 9.71, 11.11 and 13.89% and cured for 7, 14 and 28 days in order to determine the strengths.

On the other hand, the Portland Pozzolana Cement (PPC) of Standard Type - I from Jagadamba Cement Company was used to carry out the experiments in Nepal. In order to prepare mixed sample of soil and cement properly and accurately, the consistent mixing method is used for all soil specimens. At first, cement and soil were weighted at required proportion and then mixed well for 5 minutes. Afterwards, the required amount of water calculated from optimum moisture content was added and homogeneously mixed for 5 minutes. Besides, different portions of poorly graded gravelly sand (SP) were mixed in dry red soil and determined the maximum density and optimum water content at different proportions. The experimental results furnished the most suitable mixture of red soil and gravelly sand be at the proportions of 0.8ML:0.2SP through compaction test. Hence obtained mixed soil as well as red soil (ML) were treated with cement at 3, 5, 7 and 10% and cured for 7, 14, and 28 days in air and in water and determined the undrained strength of individual specimen respectively (**Fig. 1d**).

The ultrasonic pulse velocity tests were conducted for UCS specimen using Pundit Lab Ultrasonic Pulse Velocity (UPV) Tester just before the UCS test for both soils from Thailand and Nepal.

3. Results

3.1 Results of XRD

The XRF and XRD analyses have been incorporate to understand the basic clay mineralogy found in Bangkok Clay and red soil from Nepal. **Table 1** shows the percentage of oxides obtained by XRF analysis of both soils in order to determine the primary compositions of SiO_2, Al_2O_3 and Fe_2O_3 respectively. Among these primary oxides, SiO_2 reveals almost equal proportions. The chief differences are found in Al_2O_3 and Fe_2O_3. The measurement shows that about 23% and 13.9% of Al_2O_3 are found in red soil and Bangkok Clay while 7.6% and 4% of Fe_2O_3 are found in both soils respectively. The chief differences in distribution of aluminum oxides and ferric oxides demonstrate some principal occurrences of clay minerals. In order to confirm the types of clay minerals, results of XRD of Bangkok Clay and red soil from Nepal in **Figs. 1** and **2** scanned with a 2θ value ranging from 2° to 70°explain the presence of principal clay minerals. Both soils contain clay minerals of kaolinite, quartz and muscovite as a common clay mineral forming non-swelling clay representing both countries. The principal difference is recorded with the presence of illite clay mineral in Bangkok Clay and halloysite clay mineral in red soil of Nepal.

In **Fig. 2,** the basal spacing of Bangkok Clay for kaolinite mineral represents 50 a.u. (23°- 47.5°) followed by muscovite minerals 175 a.u. - 150 a.u. (18.1°- 29.5°), illite mineral 200 a.u. (34°) - 100 a.u. (55°) and quartz mineral 260 a.u. (21°) - 100 a.u. (68.8°) respectively. Proceeding, **Fig. 3** measures the basal spacing of red soil (ML) of Nepal. The kaolinite mineral is ranged from

Fig. 1. Sketch and corresponding photographs from **(a)** to **(c)** describe the methods of dry process, cement inject and pull out of soil-cement column by means of pull out test and, **(d)** represents the preparations of cores extracted from the pull out test and laboratory undrained strength tests.

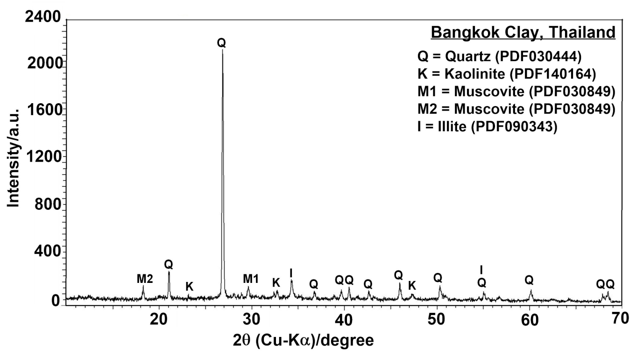

Fig. 2. Representation of XRD results of soft Bangkok Clay, Thailand.

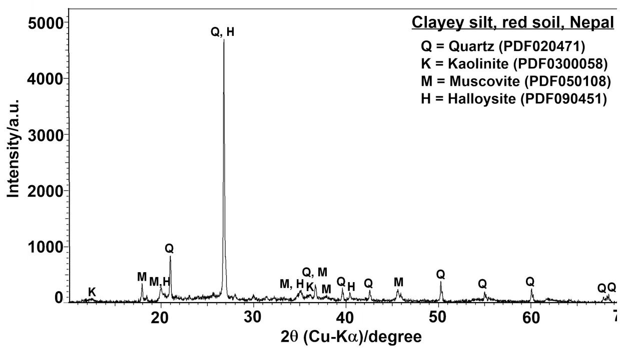

Fig. 3. Representation of XRD results of red soil (ML),Nepal

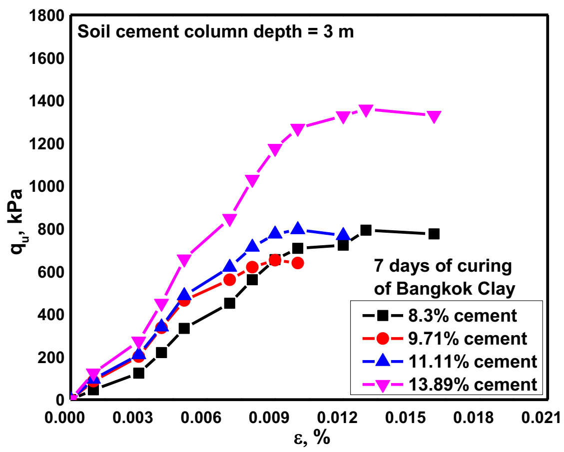

Fig. 4. Undrained strength of treated Bangkok Clay (7 days curing).

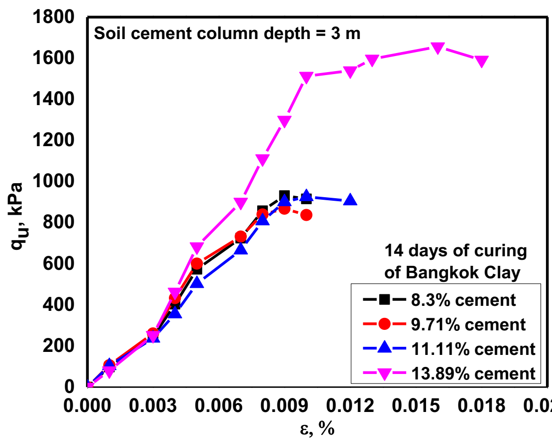

Fig. 5. Undrained strength of treated Bangkok Clay (14 days curing).

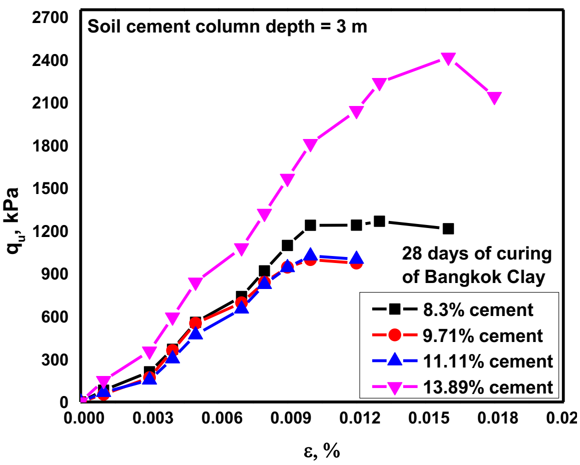

Fig. 6. Results of undrained strength of cement treated Bangkok Clay of 28 days curing.

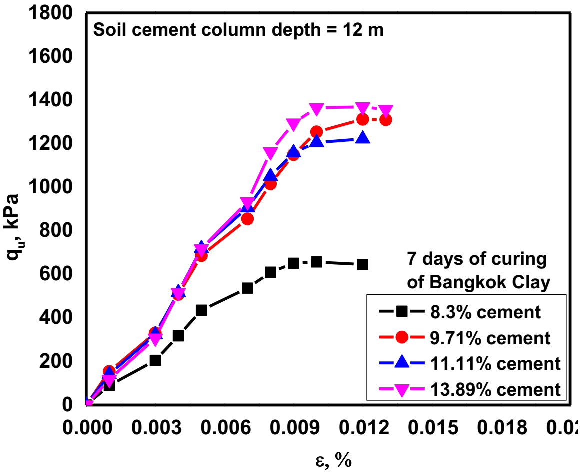

Fig. 7. Results of undrained strength of cement treated Bangkok Clay of 7 days curing at 12.0 m depth.

90 a.u. (12.5°) - 300 a.u. (37.9°) followed by muscovite mineral is ranged from 450 a.u. (18°) - 200 a.u. (45.8°), halloysite mineral is ranged from 290 a.u. (20°) - 200 a.u. (41.5°) and quartz mineral is ranged from 850 a.u. (21°) - 100 a.u. (68.5°) respectively.

3.2 Results of UCS of Bangkok Clay

Usually, the soft Bangkok Clay governs with high water content of more than 90% with lower undrained shear strengths ranging 4-10 kPa (Yoobanpot et al., 2017). With addition of cement content up to 10% yielded 449 kPa in clay-water/cement ratio hypothesis studied by Horpibulsuk et al. (2011). In this context, it revealed the importance to treat the soft soil with more cement proportion and cured for several days. The Bangkok Clay is generally mixed with 150-200 kg/m^3 high cement contents for deep cement mixing (DCM) column applications to improve the quality of the ground (Lai et al., 2006; Horpibulsuk et al., 2011a, b 2012a, b; Jamsawang et al., 2011, 2015; Voottipruex et al., 2011a, b). Hence, this section treats the results of undrained strength of soil-cement column at the depth of 3.0 m and 12.0 m respectively. Three specimens from the same depth were tested in the laboratory and averaged the obtained undrained strength. Hence, the soil-cement column of Bangkok Clay was treated for 7, 14 and 28 days and the results have been studied. **Figure 4** shows the strength received by the specimen extracted from 3.0 m depth. The maximum strengths of 792.9 kPa, 652.5 kPa, 795.4 kPa and 1359.4 kPa have been determined when cured for 7 days at cement contents of 8.3, 9.71, 11.11 and 13.89% respectively. The improvement in strengths can further be noticed in **Fig. 5** when cured for 14 days and the obtained values are observed as 931.3 kPa, 867.9 kPa, 925.7 kPa and1656 kPa respectively. Similarly, **Fig. 6** reveals the maximum strengths received as 1266.9 kPa, 997.4 kPa, 1024.1 kPa and 2416.5 kPa respectively when cured for 28 days.

Meanwhile, the undrained strengths were checked for soil cement column extracted from 12.0 m depth**. Figure 7** represents the maximum strengths obtained as 656.6 kPa, 1311.8 kPa, 1221.7 kPa and 1369.1 kPa respectively when cured for 7 days treated with the same cement contents. Additionally, the increase in strengths are measured for 14 days curing and values are acquired to be 745.6 kPa, 1568.6 kPa, 1431 kPa and 1208.3 kPa respectively as shown by **Fig. 8**. With continuation in the process, **Fig. 9** reproduces the maximum strengths as 1171.1 kPa, 1593.6 kPa, 1583 kPa and 1489 kPa respectively when cured for 28 days.

3.3 Results of UCS of from Red Soil and Mixed Soil from Nepal

This section includes the results of undrained strength of low plastic clayey silt (ML) of red soil from Nepal. **Figure 10** shows the strength governed by clayey silt and mixed poorly graded gravelly sand (SP) in ML at certain proportion. In the clayey silt 20% SP was mixed properly and experimented before cement treatment. Initially, red soil revealed the maximum strength of 352.3 kPa while the mixed soil demonstrated the maximum strength of 247.4 kPa which is quite lower than unmixed red soil.

Although red soil governed higher strength in the laboratory but it's suitability in foundation design would be lower due to its compressibility when natural water content increases. With this understanding, the project requires ground improvement using cement stabilization method. In this context, the undrained strength is further determined with cement treatment for both soils. At first, different proportions of cements (3, 5, 7 and 10%) have blended in clayey silt (ML), cured for 7, 14 and 28 days and determined the strength. In **Fig. 11**, the maximum strengths determined to be 480.5 kPa, 1179.7

kPa ,1254.3 kPa and 783.2 kPa respectively at 3, 5, 7 and 10% cement cured for 7 days. The same soil when cured for 14 days with the same cement content, the strengths have increased to be 525.6 kPa, 1265.7 kPa, 1314 kPa and 918.7 kPa respectively (**Fig. 12**). Further improvement has been observed when cured for 28 days and the maximum strengths as per **Fig. 13** measured as 617.5 kPa, 1506.1 kPa, 1652 kPa and 1036.2 kPa respectively.

After determined the improved strength, the red soil was further mixed with 20% poorly graded sand at the appropriate proportion of 0.8ML:0.2SP and experimented in detail. The proportion have been decided after determining maximum dry density and optimum moisture content by compaction method in the laboratory. **Figure 14** demonstrates the obtained maximum strengths are 525.4 kPa, 1194.6 kPa, 1257.7 kPa and 827.7 kPa at 3, 5, 7 and 10% cement treatments cured for 7 days. The improvement in strengths can be noticed when cured for 14 days with the measured results of 625 kPa, 1524.3 kPa, 1610.2 kPa and 1096.5 kPa respectively (**Fig. 15**). Similarly, 28 days of curing shows the gradual increment of strengths as 677.7 kPa, 1652 kPa, 1872 kPa and 1126.4 kPa respectively (**Fig. 16**).

3.4 Results of Ultrasonic Pulse Velocity

In general, the ultrasonic pulse velocity is used to measure the strength of concrete. Higher strengths of concrete increase pulse velocity. In this study, authors measure soil/cement specimens to understand whether the patterns of increasing strength can be understood by passing pulse velocity following the similar pattern of increment. In this reference, the ultrasonic pulse velocity of Bangkok Clay cured for 14 days at 13.89% cement content was checked from 1.0 m, 6.0 m and 12.0 m depths. The velocity has increased for shallow depth soil-cement column as shown by **Fig. 17**. Similarly, pulse velocity was measured for red soil (ML) and mixed soil (0.8ML:0.2SP) from Nepal. The results showed that increase the cement contents increase velocity and higher for 28 curing days.

4. Discussions

A case study on soil cement treatment from Bangkok and Nepal have been carried out in order to understand the basic strength parameters of soils. Investigation through both XRF and XRD analyses reveal non-expansive clays containing common clay minerals kaolinite, quartz and muscovite. Illite clay mineral is present in Bangkok Clay while halloysite clay mineral is present in clayey silt of red soil from Nepal as an additional clay mineral to differentiate the clay mineralogy behaviour hereby expressed strength of both soils on the basis of obtained water content and percent of fines. The XRD results from **Figs. 2** and **3** reveal the highest intensity of quartz minerals for both soils from Thailand and Nepal. The peak intensities measured for red soil of Nepal is more than two times the intensity measured for soft Bangkok Clay for 2θ value ranging from 2° to 25°. The peak intensity of quartz Q_{Nep} is measured to be 4,650 a.u. for red soil from Nepal while the peak intensity of quartz Q_{BKK} is measured to be 2,120 a.u. respectively. Similar patterns hold for remaining common clay minerals for all values of 2θ ranged from 2° to 70°. Both soils present common clay minerals of muscovite and kaolinite respectively. In this reference, the qualitative study is performed by normalizing the peak intensities of common clay minerals. In general, higher intensity values of clay minerals describe the state of crystalline state. Based on analyses, red soil (ML) deposit from Nepal shows the soil deposit belongs to crystalline state with compared to soft Bangkok Clay. Therefore, crystalline clay mineral from red soil is adopted as the base line to compare the intensities of remaining common clay minerals of soft Bangkok Clay. In this reference, the normalized equation is proposed as follows:

$$Q_{Nep} = \alpha.\ Q_{BKK} \quad [1]$$

Where, α is a normalized coefficient factor.

The normalized coefficient factor obtained using **Eq. [1]** is referred to determine the peak intensities of normalized clay mineral of soft Bangkok Clay $(NCM)_{BKK}$ using the following equation.

$$(NCM)_{BKK} = \alpha.\ (CM)_{BKK} \quad [2]$$

The results of normalized intensities of muscovite $(M1)_{BKK}$ and $(M2)_{BKK}$ and kaolinite $(K)_{BKK}$ were computed using **Eq. [2]** and present in **Table 4**. The normalized clay minerals with respect to clay minerals of red soil from Nepal is plotted against peak intensities of Bangkok Clay as shown by **Fig. 18**. The analysis shows that the normalized muscovite (M1 and M2) and kaolinite are in the range of 9.67%, 16.98% and 21% respectively which is under ± 25% of 1:1 slope and indicates quite similar proportions when normalized. From this analysis, it can be confirmed that the deposited red soil from Nepal is more crystalline with compared to Bangkok Clay. Therefore, the common non-swelling clay minerals are formed in both soils. The variation of intensities may be

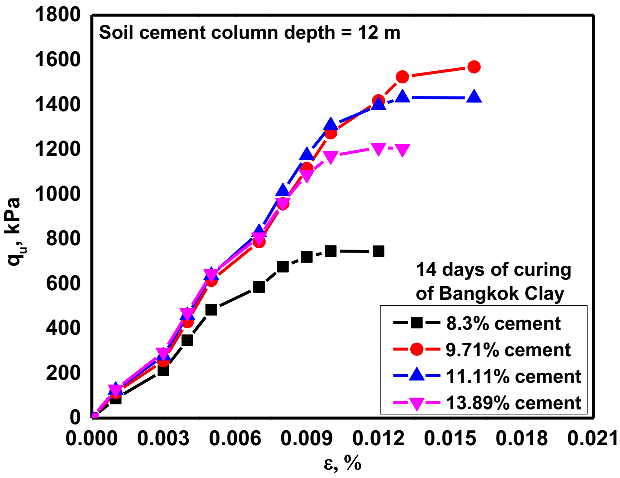

Fig. 8. Undrained strength of cement treated Bangkok Clay, days curing at 12.0 m depth.

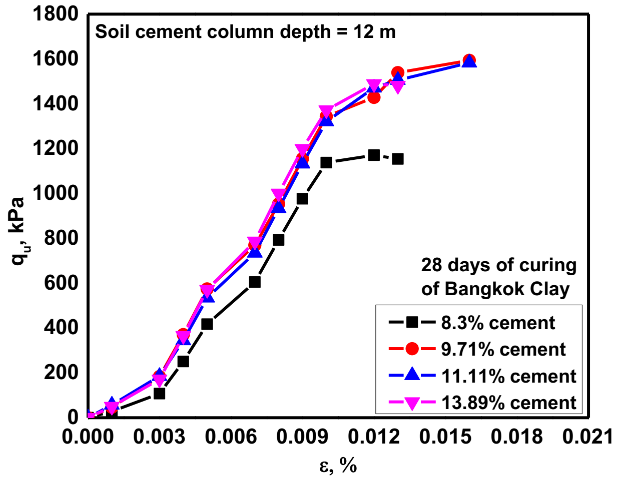

Fig. 9. Undrained strength of cement treated Bangkok Clay, 28 14 days curing at 12.0 m depth.

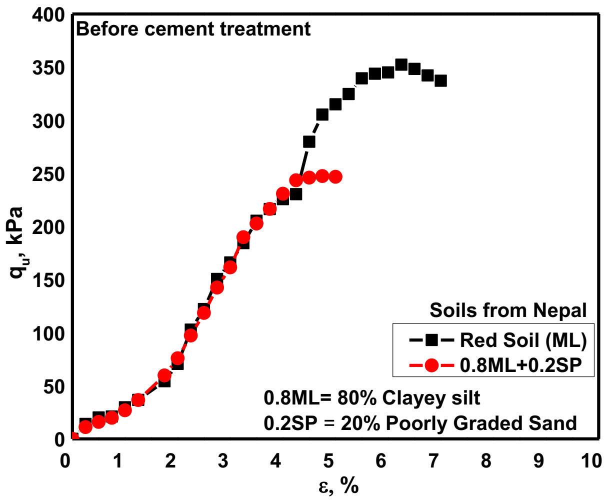

Fig. 10. Undrained strength of red soil and mixed with poorly graded soil.

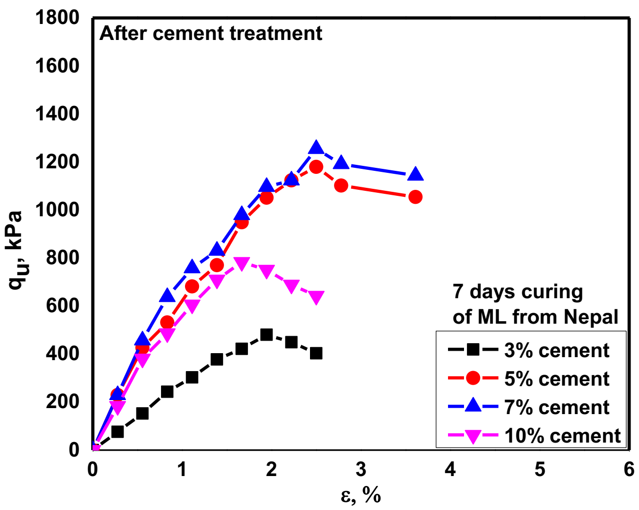

Fig. 11. Undrained strength of cement treated red soil, 7 days curing.

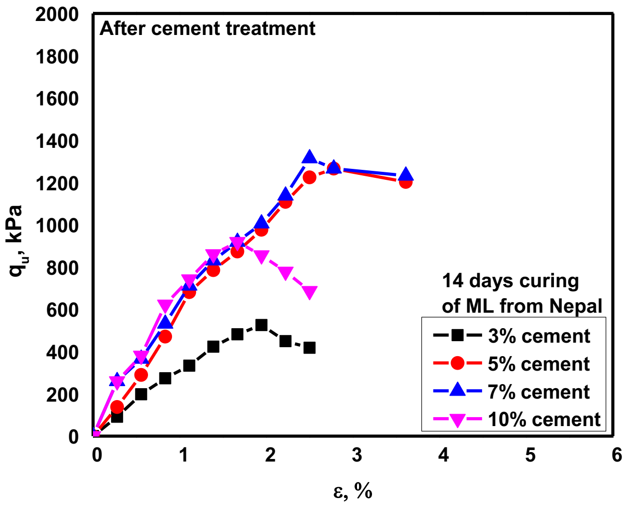

Fig. 12. Undrained strength of cement treated red soil, 14 days days curing.

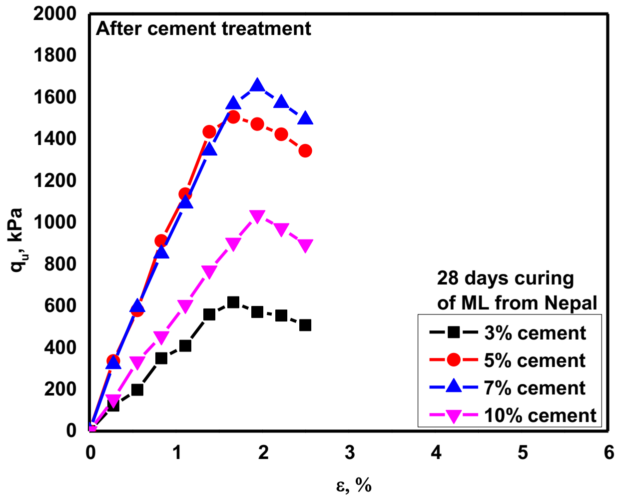

Fig. 13. Undrained strength of cement treated red soil,14 curing.

Table 4. Peak intensities, normalized coefficient factor and normalized intensities of clay minerals.

Normalized Equation	Peak intensities	Normalized intensities (up to 2θ =20°)
$\alpha = Q_{Nep}/ Q_{BKK}$ = 4650/2120 = 2.1934	Q_{Nep} = 4,650 a.u. (**Fig. 2**) Q_{BKK} = 2,120 a.u. (**Fig. 1**) M_{Nep} = 300 a.u. (up to 2θ = 20°) (**Fig. 2**) K_{Nep} = 90 a.u. (up to 2θ = 20°) (**Fig. 2**)	$(M1)_{BKK}$ = 329.01 a.u. $(M2)_{BKK}$ = 350.944 a.u.
$(NCM)_{BKK} = \alpha.\ (CM)_{BKK}$ (from **Eq. [2]**) Where, CM refers to Clay Mineral		K_{BKK} = 109.67 a.u.

Note: Here subscripts of 'Nep' and 'BKK' refers to soils from Nepal and Bangkok Clay respectively.

due to the formation of soils in different temperatures and groundwater resources. In context to Nepal, the ground using **Eq. [2]** and present in **Table 4**. The normalized clay minerals with respect to clay minerals of red soil from Nepal is plotted against peak intensities of Bangkok Clay as shown by **Fig. 18**. The analysis shows that the normalized muscovite (M1 and M2) and kaolinite are in the range of 9.67%, 16.98% and 21% respectively which is under ± 25% of 1:1 slope and indicates quite similar proportions when normalized. From this analysis, it can be confirmed that the deposited red soil from Nepal is more crystalline with compared to Bangkok Clay. Therefore, the common non-swelling clay minerals are formed in both soils. The variation of intensities may be due to the formation of soils in different temperatures and groundwater resources. In context to Nepal, the ground water level is quite lower governing lower water content while the soft Bangkok Clay generally encounters through water table hence by govern higher water content of more than 80%. As a consequence, the warmer temperature of Bangkok Clay together with higher natural water content form amorphous state. From this perspectives, the admixture of higher cement content would be expected than usual which is further discussed below with reference to strength parameters.

The Bangkok Clay contains high water content and the overall stratum belongs to soft and highly compressible with presence of highly plastic clay (CH) containing liquid limits of 56.8% and 65.3% and plastic limits of 27.9% and 32.2% with higher water contents of 89.5% and 94.6% at depths of core from 3.0 m and 12.0 m respectively. These highly plastic clay On the other hand, the red soil from Nepal constitutes more than 36% liquid limit, 26% plastic limit and 93% fines and formed low plastic clayey silt (ML). In this reference, the treatment of both soils require different proportions of cement to improve the strength of soil. Since, Bangkok has been adequately utilizing ground improvement technique using cement slurry in assistance with dry mixing process, higher amount of cement has been widely used in the treatment of sub-surface by installing firmed and stiff soil-cement column. The Bangkok Clay has adopted admixtures of cement from 150 kg/m^3, 175 kg/m^3, 200 kg/m^3 and 250 kg/m^3 which is equivalent to 8.3%, 9.71%, 11.11% and 13.89% by percent respectively. The cement treated Bangkok Clay at the depth of 3.0 m showed distinct strength improvement with increased cement content as explained above by Figures 4 to 7 when cured for 7, 14 and 28 days. Among them, 13.89% cement treated soil-cement column through dry mixing method has demonstrated the highest undrained strength. Alternatively, results from 12.0 m depth showed almost same strengths when cement content is added 9.71% onwards. There are no such significant changes in increasing cement proportions. Since, the Bangkok Clay is compressible and contains higher water content, excessive cement addition up to 13.89% would govern better performances. Higher the water content more treatment requires. On the other hand, since the specimens are non-expansive clay and dry method of injecting are applied to prepare soil-cement column resulting that the cement admixture shortens the deformation.

The red soil (ML) from Nepal shows the significant increase in strengths are mostly revealed with the cement treatment of 7% by weight percent. When UCS values are compared to red soil and 20% admixture of poorly graded sand in the red soil before cement treatment, strength of mixing soil (0.8ML:0.2SP) received significantly lower strength. When both soils subjected to cement treatments as demonstrated in **Figs. 10** to **14** the undrained strength determined to be higher for both soils when cured for 7, 14 and 28 days. The red soil (ML) received 356%, 384% and 469% of increment of strength while 0.8ML:0.2SP mixed soil received 508%, 651% and 757% of increment of strength at 7% cement treatment cured for 28 days respectively. Although the red soil (ML) improved the strength with cement treatment, the mixed soil (0.8ML:0.2SP) has received more strengths with compared to the red soil alone. In the meantime, increase in cement content of 10% does not significantly increase the UCS value. **Figure 19** represents plots of

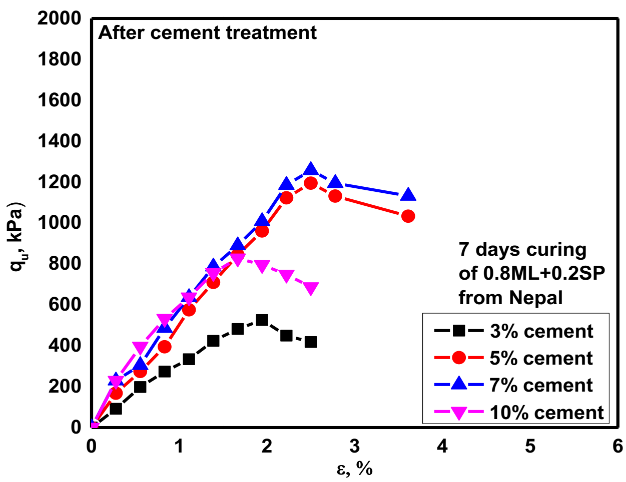

Fig. 14. Undrained strength of cement treated red soil mixed with poorly graded gravelly sand, 7 days curing.

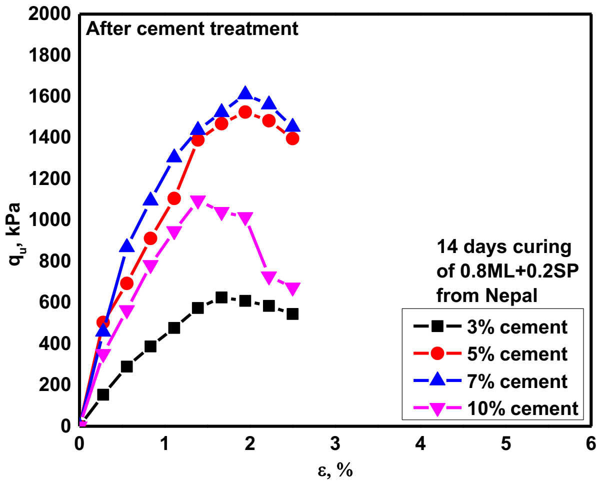

Fig. 15. Undrained strength of cement treated red soil mixed, with poorly graded gravelly sand, 14 days curing.

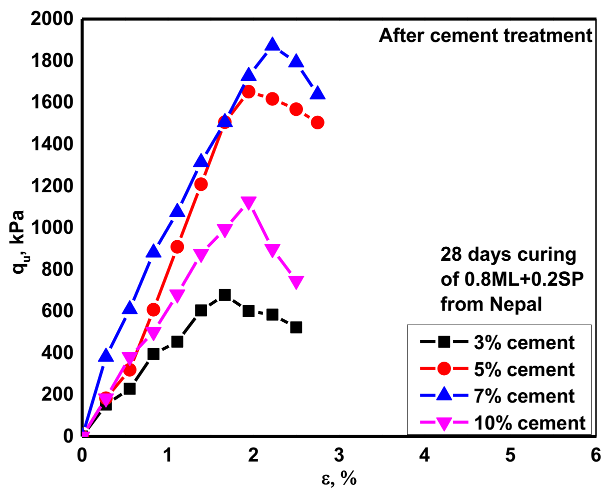

Fig. 16. Undrained strength of cement treated red soil mixed with poorly graded gravelly sand, 28 days curing.

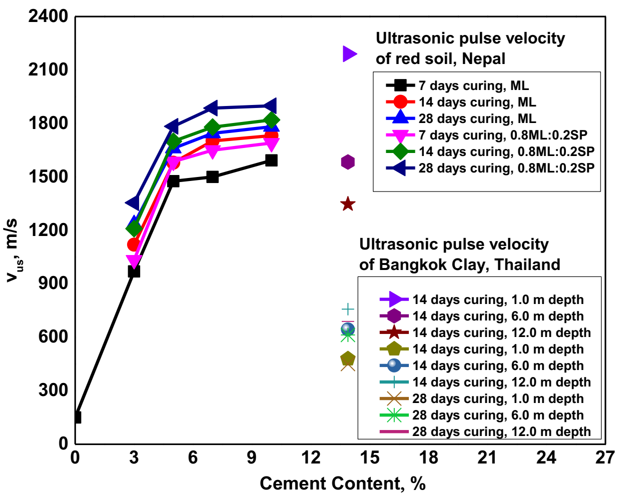

Fig. 17. ultrasonic pulse velocity versus cement content of Bangkok Clay and mixed soil from Nepal.

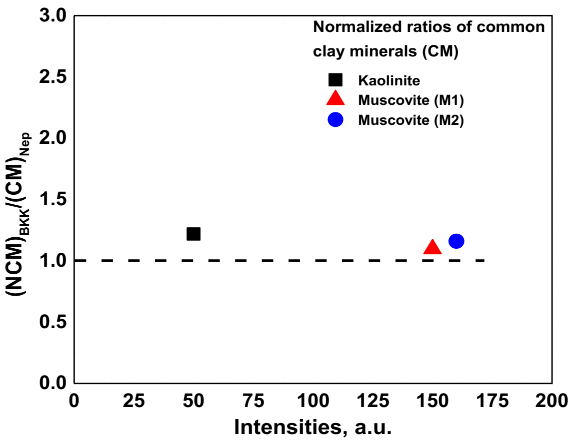

Fig. 18. Normalized clay minerals of soft Bangkok Clay with reference to clay mineral from red soil of Nepal.

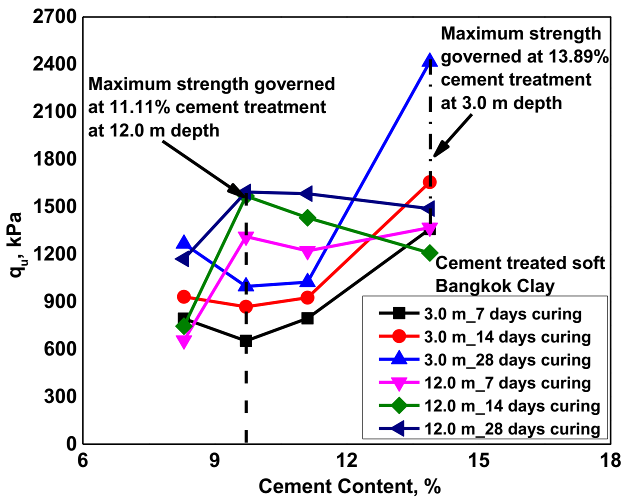

Fig. 19. Representation of maximum strengths received after curing soft Bangkok Clay of Thailand.

maximum strengths received at different cement treatment to the soil for different curing days. Soils from Nepal delineate the maximum strength governed at 7% cement treatment. Further increase in the cement content decreases the strengths. With reference to Su and Miao (2002), excessive increase of cement abates the strength values due to increment of the capillary porosity. On the other hand, the soft Bangkok Clay reveals the maximum strength at 13.89% cement treatment for 28 days of curing when core was extracted from the depth of 3.0 m as shown by **Fig. 20**. The strengths from this depth shows the enhancement of UCS values with respect to increase in cement contents. In contrast, the measurements of the core extracted from the depth of 12.0 m reveal the slight decrease in strengths at 13.89% of cement treatment. The graph depicts the maximum strength has received at 11.11% of cement treatment.

The ultrasonic velocity measurement in **Fig. 16** revealed higher the cement content increased the velocity in the specimen. In this context, Bangkok Clay treated with 13.89% cement showed increase of velocity up to 2190.7 m/s. This phenomenon is more clear in red soil and mixed soil from Nepal. Cement content binds the soil to make it stiffer and reduces voids so as to make it easier to travel the velocity. The velocity has increased gradually by 1500 m/s, 1702 m/s and 1745 m/s for ML and 1650 m/s, 1780 m/s and 1886 m/s for 0.8ML:0.2SP soil up to 7% cement added all curing days. While cement content was increased up to 10%, increment of velocity is insignificant. In this reference, the ultrasonic velocity has supported to decide 7% cement addition is quite enough to treat the ground especially when cured for 28 days.

5. Conclusions

The research paper is focused on understanding the behaviours of soils experimented as case studies from soft Bangkok Clay and red soil from Nepal as a case study. The soft Bangkok Clay has been researched extensively and treatment of ground has been widely applied in Bangkok to improve ground/sub-surface. Soil-cement columns were installed to reduce the differential settlements occurred in developing road/highway network. This paper has incorporated the strength behaviours applying dry method of forming soil-cement columns. The extracted cores were experimented to understand the way of strength developments from depths of 3.0 m and 12.0 m respectively. The unconfined compressive strengths were checked in these depths with the treated soil-cement column and for different during time. On the other hand, ground treatment using cement in soil is very

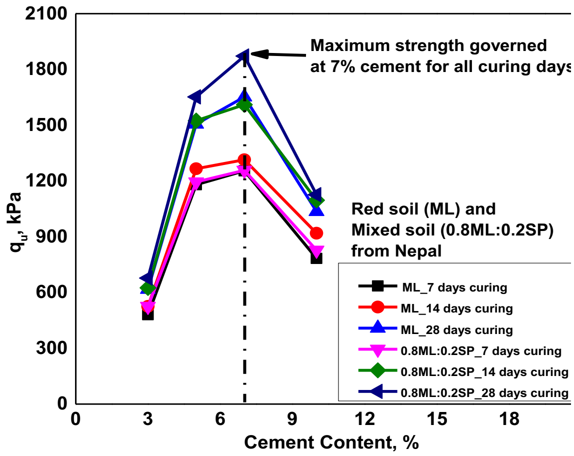

Fig. 20. Representation of maximum strengths received after curing red soil of Nepal.

limited in researches together with very rare in engineering project applications. In this reference, red soil of clayey silt has been considered for the research and subjected to the treatment with addition of 20% of local poorly graded soil along with cement treatment as a case study. Both researches have been treated by curing specimens for 7, 14 and 28 days respectively. Based on these behaviours following important conclusions can be drawn.

1. The red soil from Nepal is a clayey silt (ML) having low plasticity. When 20% of poorly graded soil (SP) from local site has been added, the maximum dry density of ML 1.58 gm/cm^3 1.78 g/cm^3. The optimum water content for ML and SP was measured to be 17.8% and 17% respectively.
2. XRF analyses shows both Bangkok Clay and red soil of Nepal constitute primary compositions of SiO_2, Al_2O_3 and Fe_2O_3, representing almost similar proportions of SiO_2 concentrations by weight percent. The results revealed some significant differences in Al_2O_3 and Fe_2O_3 in both soils. Bangkok Clay represents nearly two times in weight percent compared with red soil (ML) of Nepal. Consequently, XRD results confirm the presence of illite clay mineral in Bangkok Clay and halloysite clay mineral in red soil of Nepal as a principal difference. Both soils have recorded same clay minerals of kaolinite, quartz, and muscovite representing non-swelling clay.
3. The peak intensities measured for red soil of Nepal is more than two times higher than the intensity measured for soft Bangkok Clay for 2θ (2° to 25°). The peak intensity of quartz is determined as 4,650 a.u. for red soil from Nepal while the peak intensity of quartz is measured to be 2,120 a.u. respectively which holds the similar pattern for remaining common clay minerals.

4. The normalized intensities of muscovite (M1 and M2) and kaolinite are diagnosed in the range of 9.67%, 16.98% and 21% respectively which is under ± 25% of 1:1 slope and indicates quite similar proportions. This confirms that the deposited red soil from Nepal is more crystalline environment with compared to the soft Bangkok Clay.
5. The peak intensities may be varied due to the formation of soils in different environment. The environment of red soil of Nepal delineates low ground water condition with compared to the soft Bangkok Clay which is generally encountered with water table and always administer higher water content of more than 80%. Significantly, the warmer temperature of Bangkok Clay together with higher natural water content form amorphous state and expects higher admixture of cement content than usual which is further confirmed by determining undrained strengths.
6. The UCS values measured from the 3.0 m depth of soil-cement column revealed maximum strength of 2416.5 kPa when 13.89% (250 kg/m^3) cement was added and cured for 28 days. At this depth all specimen results confirmed the higher cement content of 13.89% achieved higher strengths for all curing days. In contrast, the core from the depth of 12.0 m soil-cement column achieved 1593.6 kPa at 11.11% (175 kg/m^3) cement addition for 28 days curing. On the other hand, red soil alone achieved 1652 kPa strength at 7% of cement treatment for 28 days curing. Besides addition of 20% of poorly graded soil in red soil also achieved highest strength of 1872 kPa for same cement content treated for same curing period. In this reference, it has been found that the strength increased up to 469% while compared to untreated red soil. Further, the strength has been enhanced up to 757% when 20% of poorly graded soil was added in red soil of Nepal. Cement treated soil from Nepal also significantly showed the decrease in strengths when further cement content was added and measured the strength at 10% for all curing days. The reason is due to the reason of increase of capillary porosity with increase of cement content.
7. It is noteworthy to receive the higher strength when specimens were prepared at its maximum dry density and optimum water content in the case of red soil, Nepal. In the case of soft Bangkok Clay, initial water content is higher so that more cement treatment requires to reduce the water content to achieve the higher strengths.
8. The ultrasonic pulse wave velocity also confirms the increase of velocity with increase in strength for soil-cement treated specimens for both soils from Thailand and Nepal. The velocity was measured to be highest for 13.89% cement content core cured for 28 days when extracted from 3.0 m depth in Bangkok Clay. Similar phenomena were observed in clayey silt and mixed soil from Nepal. The velocity was measured to be highest at 7% cement treatment as 1745 m/s and 1886 m/s respectively for 28 days curing. Higher cement content of 10% decreased the velocity. Increase in velocity up to optimum level decreases the void ratio in the specimen along with enhancement of strengths. But further increase in cement supports the increase in the capillary so that both velocity and strength decrease as per experimental results for both countries.

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Symbols and abbreviations

ML	Low plastic clayey silt
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
SCG	Siam Cement Group
SP	Poorly graded sand
UCS	Unconfined Compressive Strength
UPV	Ultrasonic pulse velocity
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
$(CM)_{BKK}$	Clay mineral of soft Bangkok Clay
$(K)_{BKK}$	Normalized intensity of kaolinite of soft Bangkok Clay
$(K)_{Nep}$	Normalized intensity of kaolinite of red soil (Nepal)
$(M1)_{BKK}$	Normalized intensities of muscovite_M1 of soft Bangkok Clay
$(M2)_{BKK}$	Normalized intensities of muscovite_M2 of soft Bangkok Clay
$(M)_{Nep}$	Normalized intensities of muscovite of red soil (Nepal)
$(NCM)_{BKK}$	Normalized clay mineral of soft Bangkok Clay
Q_{BKK}	Peak intensity of quartz of soft Bangkok Clay
Q_{Nep}	Peak intensity of quartz of red soil (Nepal)
α	Normalized coefficient factor