Lowland Technology International 2020; 22 (1): 147 - 158
International Association of Lowland Technology (IALT): ISSN 1344-9656
Special Issue on: Engineering Geology and Geotechniques for Developing Countries

Research Paper

Determination of Optimum Strength of Red Soil and Mixed Soil using Soil-Cement (S/C) Mix Ratio

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ARTICLE INFORMATION

Article history:

Received: 14 August, 2019
Received in revised form: 26 April, 2020
Accepted: 27 April, 2020
Publish on: 06 June, 2020

Keywords:

Soft ground
Soil cement (S/C) mix ratio
Unconfined Compressive Strength (UCS)
Ultrasonic pulse velocity (UPV)

ABSTRACT

The research paper is focused on the improvement of the palaeo lateritic red soil, clayey silt of low plasticity (ML) from Ratmate area incorporating mixed with poorly graded sand with gravels (SP) from Helipad area inside the premises of Devghat hydropower station, Nuwakot District, Nepal. With the confirmation of maximum dry density (MDD) and optimum moisture content (OMC), 20% of SP was mixed homogenously with 80% of ML and experimented by adding cements at 3%, 5%, 7% and 10% respectively. Hence ML and mixed soil (H20:R80) have been cured for 7, 14 and 28 days for the determination of undrained strength by UCS and pulse velocity by passing Pundit ultrasonic pulse velocity to check the compactness of specimens. The Pearson's coefficient of correlation between UCS test and UPV revealed the strong positive correlation linear relationship of 0.78. The linear regression model elucidates that for every additional undrained strength determined by UCS, the pulse velocity is expected to be enlarged by an average of 0.5135 m/s. Since, the cement admixture of more than 7% impedes the rapid increase in pulse velocity which was also confirmed by UCS tests due to the presence of high capillary porosity of cement when excess cement was added. The study predicts that the optimum cement content for both soils in this research are best suitable at 7% admixture of cement when cured for 28 days.

1. Introduction

Nepal lies on the pivotal Himalayan region. The geotechnical property of different places is astonishingly different. The products of fragile and complex geological settings bring numerous challenges to develop the sustainable civil infrastructures throughout the nation. To cope with these challenges, geotechnical investigations need to be carried out for understanding geological and engineering geological condition of the terrain and specific solutions should be performed with reference to the detail local surface and sub-surface engineering properties of soil and rock. Ground behaviors deal with the bearing capacity of the rock and soil and its probable failure conditions after surcharging load and seismicity. Bearing capacity of any ground is controlled by the geotechnical properties of existing soils and rocks.

Soft ground contains significant amount of fines and may create several problems of excessive settlement, slope instabilities and bearing capacity failure during

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Note: Discussion on this paper is open until December 2020

construction and/or after the construction phase due to low shear strength and high compressibility. For construction of infrastructures and installation of equipment the investigation of ground condition is an essential task. The expectations of durable infrastructures in soft grounds having significant fines without improving the ground condition may lead to increase the cost of the project. To reduce capital cost of project and make it feasible and sustainable, the application of cement mixed in proper proportion in the soft soil is one of the widely used ground improvement techniques in the world. Soft grounds are highly prone to amplification of seismic velocity and high ground motion during earthquake; the tendency to amplify the effect of ground shaking on civil structures is relatively higher than other ground (Tiwari et al., 2017). The expansive soil also called problematic soil (Seed et al. 1962; Alawaji, 1999; Cokca, 2001; Erguler and Ulusay 2003) which can cause heave problem on foundations of engineering structures that leads to tilting building due to seismic waves and so on.

Improvement of ground by using appropriate proportion of soil and cement ratio (S/C) is widely practiced over many countries; many researchers already proved that this technique is cost effective with compared to other methods. However, this widely accepted ground improvement techniques is still novel in engineering projects and academic researchers in Nepal. Very few academic researchers have carried out researches in this field. In this reference, the study has been performed to understand the soil/cement behaviour with context to Nepal.

The mechanical properties of cement ad-mixed clays have been extensively investigated and provided some conclusions by Terashi et al. (1979), Kawasaki et al. (1981), Kamon and Bergado, (1992), Altabbaa and Evans (2003), Bouassida and Porbaha (2004), Horpibulsuk et al. (2004a, b; 2006), Lorenzo and Bergado (2004), Voottipruex and Jamsawang (2014), Jamsawang, et al., (2017), Manandhar and Karki (2019), etc. Many previous investigations have been focused on the effect of water content of clay and amount of cement content during improvement on the strength (Nagaraj and Miura, 1996; Uddin, 1994; Yin and Lai, 1998). Rawasa et al. (2005) also conducted their research in Oman including expansive clay by using lime and cement together with specific temperatures using cement. It develops a cementeous bond between calcium silicate and aluminate hydration products with soil particles.

The noteworthy research performed by Kennedy et al. (1987) on lime and cement stabilization and Negi et al. (2013) discussed the soil stabilization using lime. Besides, Manandhar et al. (2014) concluded some important findings that the increased in strength treated by cement/lime are owing to governing good dry density near to optimum water content. If gravel contents are increased, the strength will also increase up to some extent. The research results showed that gravel contents in range between 50% to 86% form better strength for short curing time. Choobbasti et al. (2015) published the results of the strength development by using cement and nanosilica to improve in dry density and unconfined compressive strength of the sandy soil. According to Farouk and Shahien (2013), the employment of cement on foundation reduced more than 80% of settlement and significantly improved the values of UCS.

Furthermore, Lee et al. (2005) had been worked in Singapore Clay and compared with Bangkok Clay and Boston Blue Clay and observed the effect of cement on Singapore Clay is not unique. On the other hand, Naveena et al. (2013) predicted strengths developed in stabilized sandy clay. With these references, it is clear that the cement mix noticeably increases the unconfined compressive strength (UCS) as well as the shear strength of soil. In this context, this study has been confined to improve the soil bearing behavior for the construction of good foundation for the solar grid panel installation at Battar Bazaar in Trishuli inside the premises of Devighat Hydropower Station. This study is focused to improve the ground of lateritic clayey silt (red soil) at the Ratmate area treat with cement with addition of sand from the near river terrace at Helipad along the right bank of the Trishuli River (**Fig. 1**).

In order to improve the ground containing clayey silt (ML) from Ratmate soil, two important issues have been incorporated in this research. After determining the suitable proportion of mixing the local poorly graded gravel mixed sand (SP) from Helipad area, treat soil with cement in different proportions and find out series of strengths by curing specimens for 7, 14 and 28 days. Next, obtained soil-cement mixed soil for different curing days are passed through Pundit ultrasonic pulse velocity (UPV) test and correlate the obtained strengths with the pulse velocity for cement treated soils for allotted curing periods.

2. Geotechnical Investigation and materials

The research site is located at Ratmate and Helipad areas of Nuwakot District, Bidur Municipality Ward number-6, Battar Bazar in Trisuli, Provience-3, Central Nepal with the coordinates of 27°53'12.00"N 85° 7'42.00"E and 27°53'8.14"N 85° 7'53.19"E respectively as shown by **Fig. 1**. Geologically, the investigation site belongs to the Central Nepal, Lesser Himalaya. The

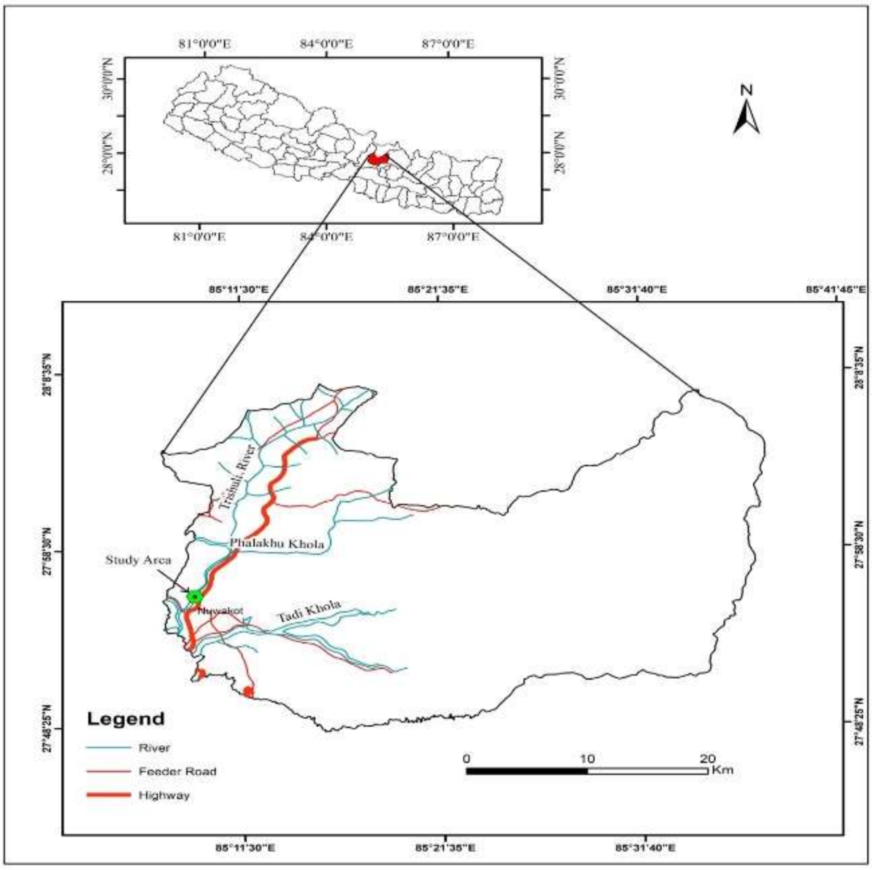

Fig. 1. Location map of the site investigation area.

study area belongs to Kuncha Formation representing low grade metamorphic rocks of phyllite, quartzite, meta-sandstone as the dominant rock type (Stöcklin, 1980; Dhital, 2015). The area belongs to the ancient fluvial deposit of the Trishuli River with 20-25 m thick fine sediments at the top and the fine to coarse sand, pebble, cobble, gravel and boulders followed below the top soil, forming a wide multiple terraces having different levels at the bank towing to seasonal fluctuation of the river.

The geotechnical investigation was conducted to determine the engineering properties of the site and collected samples to determine its in-situ strength in the laboratory. The determination of index properties, strength and pulse velocity by mixing two different types of soil and cement cured for allotted time period are the main task carried out to find the optimum strength of cement treated ground for the foundation of solar grid.

2.1 Materials and methods

2.1.1 Soils and cement

Two types of lateritic red soil (Low plastic clayey silt from Ratmate) and poorly graded gravelly sand (SP) from Helipad area have been carried out to conduct this research. The engineering properties of both soils are presented in **Table 1**. The study area lies on the fluvial deposit plane with the alternating bands of thick and fine sequences of more than 20 m with 1 m - 5 m thick, coarse grained gravel, sand and pebble. The soil samples were extracted from depths of 2 m to 6 m from the site such that top layer organic content would not affect in the test.

The soil properties have been determined in the laboratory following standards given by ASTM and BS. The natural moisture content (NMC) has been determined following the standard ASTM D-2216 (1999) and percentages of soils were determined (**Table 1**) according to ASTM D-1140 (1997) and consistency limits were determined as per BS: 1377-2 (1990) while overall classification of both soils were carried out in accordance with Unified Soil Classification System (USCS). Proceeding, specific gravity was conducted as per ASTM D-854-98 (1999) and compaction test was carried out according to BS: 1377-4 (1990) while UCS test (**Fig. 2**) was experimented as per ASTM D-2166 (1999) respectively.

The cement used for this study was Portland Pozzolana Cement (PPC) of Standard Type - I. It was obtained from Jagadamba Cement Company in Nepal. This cement production is the most widely used for various construction sites in Nepal.

2.1.2 Soil and cement mixing method

The mixed sample of soil and cement properly and accurately, the consistent mixing method was used for all the mixed soil specimen. Generally, Miura et al. (2001) and Horpibulsuk et al. (2005) had recommended time of 10 minutes for mixing to make homogenous paste before transfer to mold. In this methodology, cement and soil were weighted at required proportion and blended well for 5 minutes to make it uniform. At the end, the required amount of water computed from its optimum moisture content was added to the mixture and homogenously blended for additional 5 minutes to make 10 minutes in total. The experimental conditions have been adjusted with cement content by weights of 3%, 5%, 7% and 105 respectively and cured the specimens for 7, 14 and 28 days respectively as shown by **Table 2**. All the soil specimens were adjusted at the optimum water content of soils to get required strength through laboratory experiments.

2.1.3 Ultrasonic pulse velocity (UPV)

The ultrasonic pulse velocity tests were conducted for 18 UCS specimen using Pundit Lab Ultrasonic pulse velocity (UPV) Tester just before the UCS test as per standard of ASTM C-597-02 (2003). The compressional wave (p-wave) velocity was passed from one transducer to another through a soil-cement specimen and the UPV was measured by dividing the distance between the transducer by the arrival time (**Fig. 2b**).

3. Results

3.1 Results of engineering geological investigation site

The site belongs to the areas of Ratmate and Helipad, Battar Bajar, Nuwakot District, Nepal. From the perspectives of engineering geology, both areas form alluvial wide multiple deposits of the Trishuli River. The Helipad area dominantly constituted poorly gradated gravelly sand (SP) with presence of boulders in recent terrace deposit together with the formation of different level of terraces while Ratmate area is red coloured, palaeo deposit lateritic soil of low plastic clayey silt (ML) as shown by **Fig. 3**.

3.2 Results of unconfined compressive strength tests

Specimens for UCS tests performed at the remolded specimen at defined maximum dry density (MDD) and optimum moisture content (OMC) obtained from proctor compaction tests. The samples were prepared and tested at two stages: before treated with cement and after treated with cement. The UCS tests were carried out for Ratmate soil (ML) and Ratmate-Helipad mixed soil at the ratio of H20:R80 before and after the cement treatments. The strength of Ratmate soil before cement treatment was determined to be 207 kPa shown by **Table 3**.

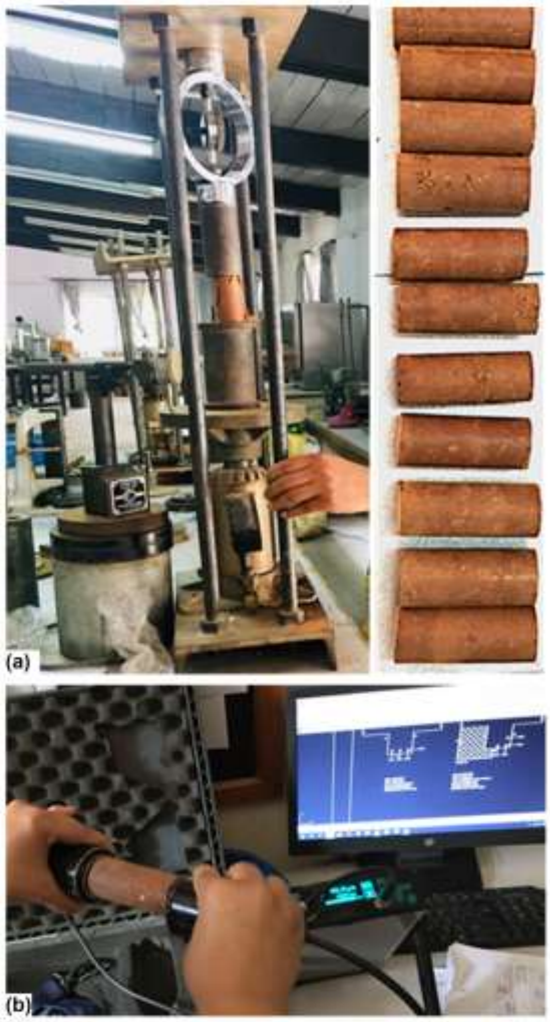

Fig. 2. (a) Represents the experiments of S/C mixed specimens at different curing days and (b) ultrasonic pulse velocity of S/C mixed specimens.

Table 1. Geotechnical properties of soil.

Property of Soil	Soil type		
	Ratmate (R)	Helipad (H)	H20:R80
Specific Gravity	2.48	2.69	2.78
Moisture Content (%)	28	16	17
Gravel (%)		10.3	20.06
Sand (%)	6.61	81.1	56.61
Silt (%)	73	8.22	73.85
Clay (%)	20	20	19.50
USCS	ML	SP	ML
Liquid Limit (%)	36.5		32.4
Plastic Limit (%)	26		28.43
Plasticity Index (%)	10.5		7.97
OMC (%)	17.78	9.5	17
Maximum Dry Density (gm/cc)	1.58	2.15	1.7
UCS (kPa)	207.96		232.8

Table 2. Experimental conditions of Ratmate (ML), mixed soils.

Descriptions	Experimental adjustments
Amount of cement added (%)	3, 5, 7, 10
Allowable mixing time	10 minutes
Atmospheric curing time (Days)	7, 14, 28

Table 3. UCS test results of cement treated soils.

Cement content (%)	UCS (kPa) of Ratmate soil	UCS (kPa) of mixed soil (H20:R80)	Curing period (Days)
	207	283	0 curing
3	480	525	
5	1179	1194	
7	1254	1257	7
10	783	828	
3	526	625	
5	1265	1524	
7	1314	1610	14
10	918	1096	
3	617	677	
5	1506	1651	
7	1651	1871	28
10	1036	1126	

3.2.1 Improvement of UCS values cured for 7 curing days

The improved strength of Ratmate soil after cement treatment with respect to different curing days can be depicted by **Fig. 4**. The maximum UCS value of the red soil bas been obtained as 1254 kPa cured for 7 curing days when treated with adding 7% cement content. Proceeding, the minimum UCS value has been determined to be 480 kPa when treated with adding 3% cement content cured for same 7 days. Also, the UCS value has been increased up to 1179 kPa with 5% cement content but when the cement has been increased up to 10%, UCS was declined to 783 kPa.

The initial UCS of mixed soil in the ratio H20:R80 by weight has been determined as 283 kPa. Afterwards, the maximum UCS value of mixed soil (H20:R80) cured for same seven days has been observed as 1257 kPa and the minimum value has been recorded as 525 kPa. The maximum UCS value has obtained from 7% cement content cured for 28 days. Also, the UCS tests were conducted with 5% and 10% cement contents, which have been recorded as 1194 kPa and 828 kPa respectively. These phenomena demonstrate that the strength is increased as par with the same trend of cement treated red soil as the cement proportion has been increased up to 7%, following the declined trend with further increase in cement content as shown by **Fig. 4** and **Table 3**.

3.2.2 Improvement of UCS value cured for 14 curing days

The maximum UCS value of the red soil has been observed as 1314 kPa cured for 14 curing days when treated with adding 7% cement content. Proceeding, the minimum UCS value has been determined to be 555 kPa when treated with adding 3% cement content for same curing days. Also, the UCS value has been increased up to 1265 kPa with 5% cement content but when cement is increased to 10%, the value of UCS has been declined to 918 kPa as shown by **Fig. 5** and **Table 3**.

On the other hand, the maximum UCS value of mixed (H20:R80) soil cured for 14 days has been determined to be 1610 kPa and minimum value has been recorded as 625 kPa. The maximum UCS value has been obtained at 7% cement content. Also, the UCS tests have been conducted with 5% and 10% cement content and strengths have been determined to be 1524 kPa and 1096 kPa respectively. The results reflected that the strength is increased when the cement content is increased up to 7%, higher the cement content decreased the strength as shown by **Table 3** and **Fig. 5**.

3.2.3 Improvement of UCS value cured for 28 curing days

The test results of 28 curing days seem to be the ultimate result for this research; mostly cement provides its strength within 28 days. The maximum UCS value of red soil has been obtained to be 1651 kPa cured for 28 days when treated with adding 7% cement content. Proceeding, the minimum UCS value has been determined to be 617 kPa when treated with adding 3% cement content cured for same 28 days. Also, the UCS value has been increased up to 1506 kPa with 5% cement content but when cement content was further increased up to 10%, the UCS value has been decreased to 1036 kPa as shown by **Fig. 6** and **Table 3**.

Also, the UCS tests have been conducted at 5% and 10% cement contents, which have been determined to be 1651 kPa and 1126 kPa respectively. It also demonstrates that the strength is increased when the cement content has been increased up to 7%; further increase in the cement content decreased the strength as shown by **Table 3** and **Fig. 6**.

3.3 Results of ultrasonic pulse velocity (UPV)

3.3.1 Results of UPV of Ratmate soil

Table 4 and **Fig. 7** reveal the UPV was drastically varied for cement treated and non-treated specimens. The initial velocity was measured as 150 m/s. When specimens have cured for 7 days, with 3%, 5%, 7% and 10% of cement contents then the velocity increased

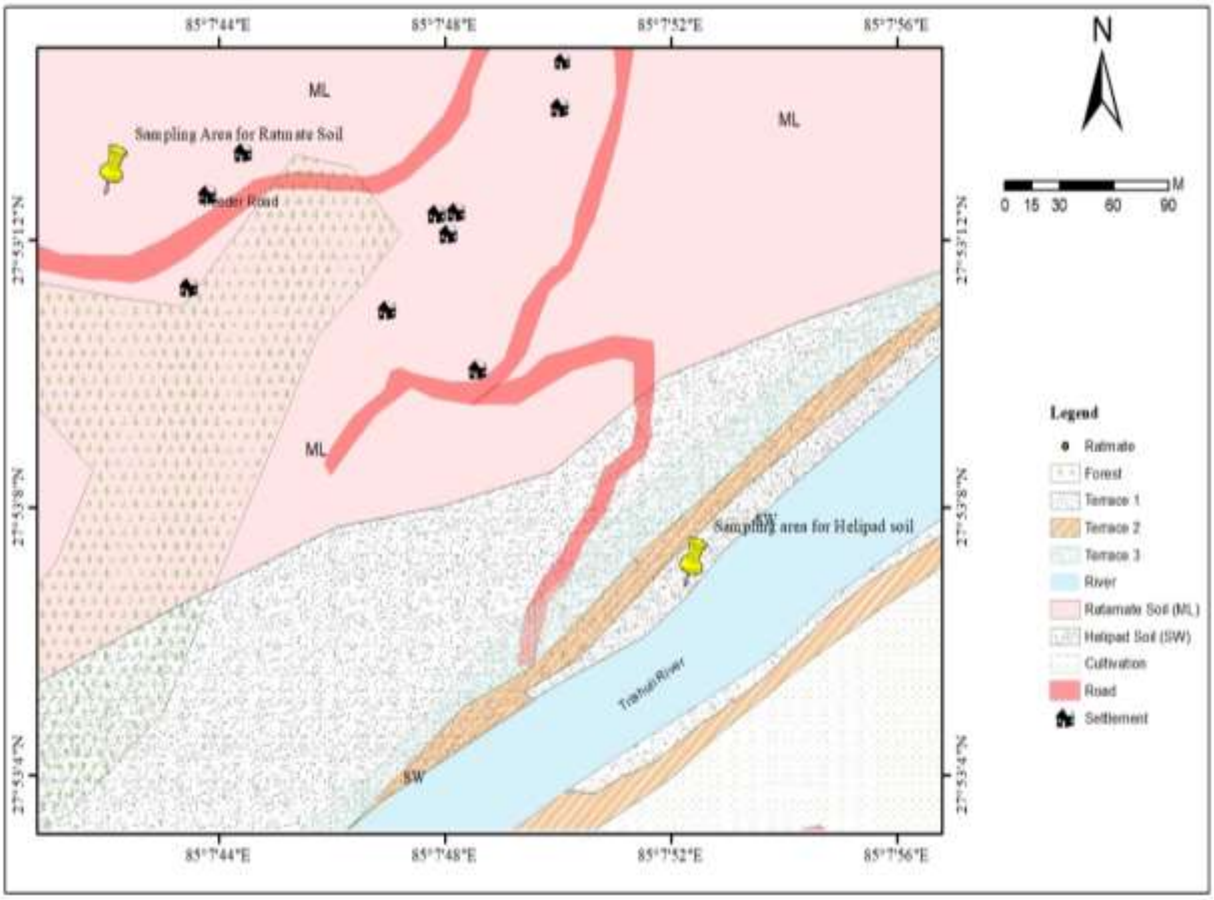

Fig. 3. Engineering geological features of the investigation site.

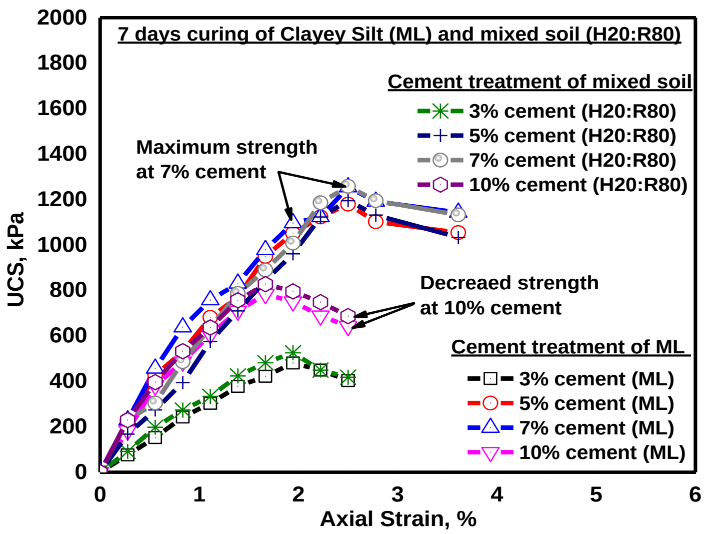

Fig. 4. Improvement of UCS values of clayey silt (ML) from Ratmate and mixed soil (H20:R80) cured for 7 days.

significantly to 970 m/s, 1476 m/s, 1500 m/s, and 1593 m/s respectively. When the amount of Portland cement increases, chemical reactions between soil and cement also increase. The density of cement treated soil, therefore, increases and ultrasonic pulse velocity through the soil mass becomes continuous and travels faster than the untreated soil due to decrease in air voids. Proceeding, the velocity was increased for 14 curing days as 1120 m/s, 1580 m/s, 1702 m/s, and 1732 m/s respectively at same cement contents. Similarly, when velocity was measured for specimens cured for 28 days, the velocities were increased as 1235 m/s, 1660 m/s, 1745 m/s and 1782 m/s respectively. So, the increase in ultrasonic pulse velocity is dependent on cement content

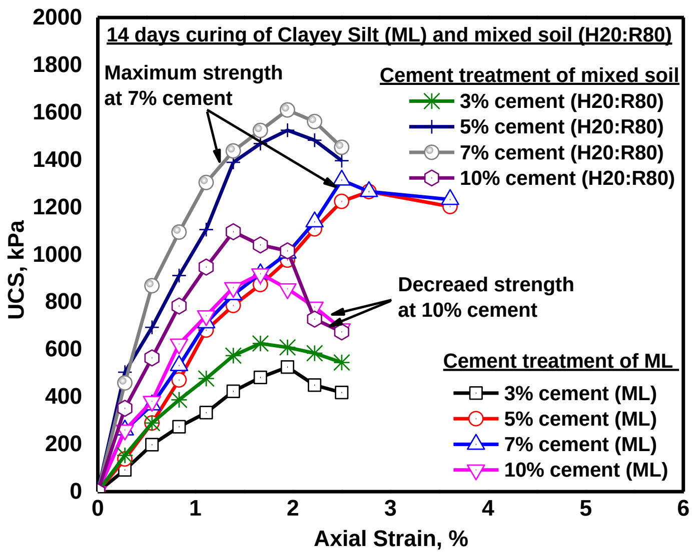

Fig. 5 . Improvement of UCS values of clayey silt (ML) from Ratmate and mixed soil (H20:R80) cured for 14 days.

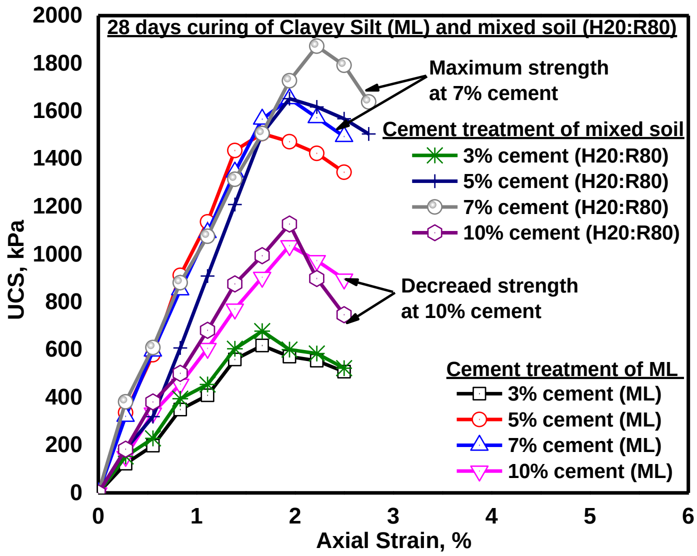

Fig. 6. Improvement of UCS values of clayey silt (ML) from Ratmate and mixed soil (H20:R80) cured for 28 days.

and curing days; although, the obtained result is almost consistent when cement content is increased continuously from 7% to 10% but significant result is obtained with cement content at 7%.

3.3.2 Results of UPV of mixed (H20:R80) soil cured for different periods

The UPV test for mixed soil was also conducted to determine the ultrasonic velocity after cement treated to mixed soil cured for different period having different cement content. After mixing 20% poorly graded gravelly sand (SP) to the Ratmate soil, the effectiveness was observed clearly; the velocity was increased significantly with compared to non-mixed soil. The highest velocity of mixed soil was 1899 m/s and the lowest velocity was 230 m/s before cement treatment. In this mixture, the highest velocity was obtained in 28 curing days with 10% cement content; although, its nearly equal to 7% cement content (**Table 4**). Regarding to curing period, the chemical reaction occurred more complete, the density of treated soil therefore increases significantly over time resulting the increment of ultrasonic pulse velocity as shown by **Fig. 8**.

4. Discussions

Generally, improvement of strength of any soft/problematic ground refers with the treatment of soil by increasing its dry density up to its optimum level; degree of compaction or exploitation of existing voids i.e. the strength of soil at its optimum moisture content level. In this context, the lateritic red soil (ML) from Ratmate area needs to be improved which has more than 36% liquid limit and 26% plastic limit together with 93% fines which incorporating admixture of cement proportion and curing for certain period. The site belongs to palaeo lateritic soil with more than 20 m thick.

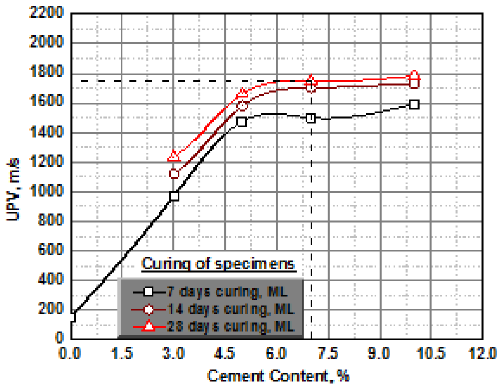

Fig.7. Results of Ultrasonic velocity with different cement content of Ratmate soil (ML)

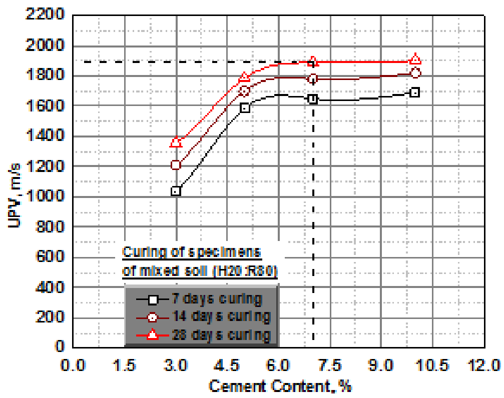

Fig.8. Results of Ultrasonic pulse velocity with different cement content and cutting days of mixed soil (H20 – R80).

Table 4. Results of Ultrasonic Pulse Velocity of Soils

Cement content (%)	UPV (m/s)		Curing period (Days)
	ML	(H20:R80)	
0	150	-	0
3	970	1034	7
5	1476	1586	
7	1500	1650	
10	1593	1690	
3	1120	1210	14
5	1580	1700	
7	1702	1780	
10	1732	1820	
3	1235	1355	28
5	1660	1784	
7	1745	1886	
10	1782	1899	

Besides, poorly graded sand (SP) with gravels were decided to mix in palaeo lateritic soil from the near local resources from Helipad area. The Helipad area constitutes different level of terraces deposited by the major trunk Trishuli River. The compaction test confirmed the suitable mix of SP from Helipad to the ML was at H20:R80 proportion. Hence mixed soil furnished around 36% of undrained strength without cement treatment (**Table 1**).

When cement was blended homogenously mixed to soil of H20:R80 the undrained strength has improved gradually at the controlled moisture content at its respective optimum level obtained by compaction test. The maximum dry density (MDD) of cement treated soils for both ML and H20:R80 are improved from 1.58 g/cm^3 to 2.34 g/cm^3 and 1.78 g/cm^3 to 2.50 g/cm^3 as shown in **Table 5**. With reference to **Figs. 4** to **6**, the undrained strength revealed the maximum strength reached up to 698% increment of red soil only when 7% cement was blended and cured for 28 days. On the other hand, mixed soil revealed the increment of 561% when treated with 7% of cement and cured for same 28 days. Similarly, when checked the values for both red soil and mixed soil treated with 10% cement for same 28 days, only 400% and 298% respectively which is quite lower with compared to 7% cement addition. This strongly supports that the increased in cement contents only unable to depict the strength behaviors of the cement treated ground. The S/C ratios has the optimum level to receive the strength and beyond that limit, the strength further started decreasing. This may be due to the presence of high capillary porosity of cement when excess cement was added (Su and Miao, 2013).

The ultrasonic pulse velocity is directly proportional to the density of the material, more the compactness of the specimen, higher the compressional wave velocity. In this reference, the UPV revealed 1088% of increment of red soil alone when compared with specimen without cement treatment against 10% of cement treated same red soil cured for 28 days. Meanwhile, when compared with 3% cement addition cured for 7 days to red soil and mixed soil (H20:R80) with 7% of cement treated both soils for 28 days, about 83% and 84% pulse velocity have been increased. Further increment in soil up to 10% cured for 28 days revealed only 79% and 82% increment of pulse velocity when compared to same soil at 3% of cement cured for 7 days. This trend has followed with the UCS values. In this reference, coefficient of correlation and linear regression equation have been analyzed between values of UCS and UPV. **Figure 9** explains the coefficient of correlation between these two parameters. Pearson's coefficient of correlation is 0.78 indicating the strong correlation between these two variables representing a strong uphill (positive) linear relationship. Moreover, the regression line equation from the **Fig. 9** can be expressed as follows:

$$y = 994.8 + 0.5135x \quad [1]$$
$$R^2 = 0.6034 \quad [2]$$

The linear regression **Eq. [1]** describes the model for every additional undrained strength determined by UCS, the pulse velocity is expected to be increased by an average of 0.5135 m/s. The densities of cement treated soil increase due to the effect of pozzolanic reaction and air voids reduced, consequently unconfined compressive strengths increase.

Table 5. Improvement of MDD of cement treated soils.

Cement content (%)	Maximum Dry Density, MDD (g/cm^3) ML	Maximum Dry Density, MDD (g/cm^3) H20:R80	Curing Period (Days)
3	1.90	2.19	7
5	1.93	2.11	
7	2.13	2.18	
10	2.20	2.19	
3	2.0	2.20	14
5	2.10	2.25	
7	2.26	2.33	
10	2.20	2.21	
3	2.10	2.31	28
5	2.27	2.35	
7	2.34	2.50	
10	2.00	2.20	

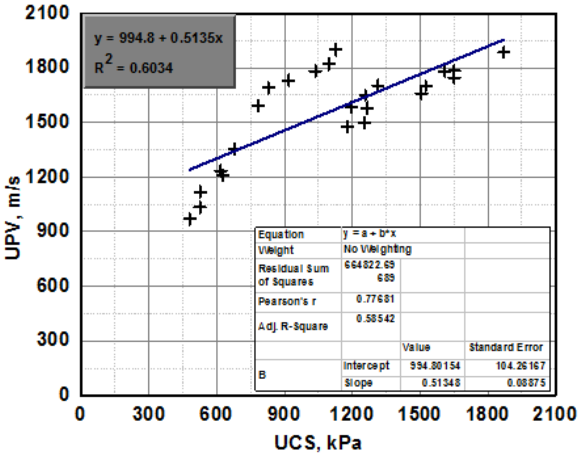

Fig. 9. Results of strength behavior and pulse velocity with references to curing days and cement content in terms of coefficient of correlation.

In the meantime, **Eq. [2]** reveals the coefficient of determination has better model fits in the analysis. Both coefficient of correlation and regression analyses fit the model to interpret the increase in cement content and curing days increase in pulse velocity. The relationship between two variables does not show the perfect correlation because the cement admixture of more than 7% hinders the rapid increase in pulse velocity. This analysis further supports the test results shown by UCS and predicts the optimum cement content for both soils are at 7% for 28 curing days.

5. Conclusions

A comprehensive study has been carried out to improve the ground prior to the cement treatment at an appropriate proportion. Site investigation has confirmed the area belonged to palaeo lateritic red soil of low plastic clayey silt (ML) at Ratmate area inside the premises of Devghat hydropower station, Nuwakot District, Nepal. Portland Pozzolana Cement (PPC) of Standard Type - I has been deployed to improve the red soil which is more than 20 m thick strata. Further, local poorly graded sand (SP) with gravels from the Helipad area from the same premises along the right bank of the Trishuli River was mixed in the red soil to obtain the suitable mixed ratio employing compaction methodology. With the confirmation of MDD and OMC, 20% of SP was mixed in 80% of ML homogenously and experimented by adding cement at 3%, %%, 7% and 10% respectively. Hence homogenously mixed soil (H20:R80) and ML have been cured for 7, 14 and 28 days for the determination of undrained strength by UCS and compressional wave velocity by passing Pundit ultrasonic pulse velocity. Based on experimental results and analysis major conclusions can be drawn as follows:

i. When the undrained strength of cement treated red soil and mixed soil (H20:R80) have compared with the untreated soils, the undrained has gained the maximum strength up to 698% when 7% of cement was admixed in red lateritic soil cured for 28 days. On the other hand, the mixed soil (H20:R80) revealed that the strength has improved to 561% with the same cement content admixture cured for as same periods.
ii. Increment in cement content up to 10% declined the strength for both red soil and mixed soil (H20:R80). The results show 400% and 298% increment of unconfined compressive strength for both ML and H20:R80 soils in comparison to untreated soil which is quite lower than 7% admixture of cement in both soils cured for same 28 days.
iii. The maximum dry density (MDD) of cement treated soils for both ML and H20:R80 have improved from 1.58 g/cm^3 to 2.34 g/cm^3 and 1.78 g/cm^3 to 2.50

g/cm^3 for admixture of 7% cement content cured for 28 days.

iv. The ultrasonic pulse velocity compared with 3% cement addition cured for 7 days in red soil and mixed soil (H20:R80) with 7% of cement treated soils for 28 days improved by 83% and 84%. Further increment of cement content in both soils up to 10% cured for same revealed only 79% and 82% increment with compared to same soils at 3% of cement cured for 7 days. As a result, the perfect correlation was not achieved.

v. The Pearson's coefficient of correlation between UCS and UPV demonstrates the strong correlation uphill (positive) linear relationship of 0.78. The linear regression model illustrates that for every additional undrained strength determined by UCS, the pulse velocity is expected to be increased by an average of 0.5135 m/s. The densities of cement treated soil increase due to the effect of pozzolanic reaction by reducing air voids, consequently unconfined compressive strength and compressional wave velocities increased.

vi. The coefficient of determination model also fits the analysis to confirm the increment of strength and velocity. However, the relationship between two variables does not show the perfect correlation because the cement admixture of more than 7% impedes the rapid increase in pulse velocity due to the presence of high capillary porosity of cement when excess cement was added. This analysis further supports the test results obtained by UCS tests and predicts the optimum cement content for both soils in this research are best suitable at 7% admixture of cement for 28 curing days.

Acknowledgements

Authors would like to express sincere gratitude to International Centre for Geotechnical Services (ICGS) for providing laboratory facilities and financial supports under research and development (R&D) section. I am indebted to Prof. Dr. Lalu Prasad Paudel and faculty members of Central Department of Geology, Tribhuvan University for providing necessary facilities to complete the research work. Meanwhile, authors are very much thankful to Prof. Dennes T. Bargado, Prof. Suksan Horpibulsuk, colleagues for their valuable suggestion and strong supports during the work.

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Symbols and abbreviations

MDD	Maximum Dry Density
ML	Low plastic clayey silt
OMC	Optimum moisture conten
S/C	Soil/Cement
SP	Poorly graded sand
UCS	Unconfined compressive strength
UPV	Ultrasonic pulse wave velocity