Influence of Curing Stress and Curing Time on Unconfined Compressive Strength behaviour of Cemented Clay

Deepak K. Haritwal[1], Brijesh K. Agarwal[2], Anand V. Reddy[3] and Shailendra Kumar[4]

[1&2] PG Student, Applied Mechanics Department, SVNIT Surat, Surat – 395007
E-mail: *deepakkumarharitiwal@gmail.com; brijeshagarwal251@gmail.com*

[3]*Research Scholar Applied Mechanics Department, SVNIT Surat, Surat – 395 007*
E-mail: vemulaanandreddy@gmail.com

[4]*Assistant Professor, Applied Mechanics Department, SVNIT Surat, Surat – 395007*
E-mail: skumar1863@gmail.com

Abstract. In recent ground improvement techniques to strengthen the weak soils in order to increase the strength characteristics and stiffness of different types of soils, cement stabilization has shown to be very effective. In cement stabilization curing stress and curing time are two important factors. Since previous researchers have mainly focused on importance of the curing time, the present study emphasizes on the combined effect of curing stress and curing time. The aim of present study is to examine the effect of curing time on unconfined compressive strength (UCS) of virgin clayey soil treated with cement under predefined curing stress of 5 kPa. Laboratory test including Atterberg limits, light weight compaction test, and UCS test were conducted. The UCS tests were performed on clayey soil (CH) with the different percentages of cement (i.e.8%, 10% and 12%) for the curing period of 0, 3, 7, 14, 28 and 56 days. The curing stress of 5kpa is being applied along with curing time to check the combined effect of both curing time and curing stress. The results show that the curing time and the curing stress have a significant effect on UCS. The UCS value increases with increasing cement content from 8% to 10% but decreases for further increment in cement content (i.e. from 10% to 12%). The 10% cement content is found to be the optimum. UCS values increases with curing stress and having around 10%-15% high value compared to the curing time condition. The increase in UCS is attributed due to the reduced pore spaces and increased confinement due to the curing stress. This study concluded that applying curing stress leads to have incremental impact on the strength of soil and being very helpful for attaining higher strengths in early days.

Keywords: curing time, curing stress, cement stabilization, UCS.

1. Introduction

Soils having low strength is one of the major problems faced by a geotechnical engineer. Different stabilization techniques are available to overcome this problems. Addition of cement to the soil mixture (CSM) is one of technique to increase the strength of the soil and it is widely used as a ground improvement technique. CSM has reduced permeability, low compressibility and high strength as compared to the untreated soil. (Al-Tabbaa and Evans 1999. Maher et al. 2007; Arulrajah et al.2009); It's necessary to identify the behaviour of CSM so as to use in different environmental conditions and according to the requirements. CSM is widely used in various projects throughout the globe to improve the property of the untreated soil. It was first used in japan (1970) by port and harbour research institute later on it was used to strengthen the embankment of San Francisco's largest potable water reservoir, to stabilize the contaminated sediments in Newark Bay, and to reinforce a slope to maintain its integrity during seismic activities. Typical applications of Cement soil mixture include liquefaction mitigation and foundation stabilization, vibration reduction and excavation support walls. Constructions for high-speed railway tracks and wind turbines engaged the use of CSM to improve soil. (Wooten and Foreman 2005; Barron et al. 2006). Sometimes we come across such soils at project site which cannot be used as a construction material due to their low bearing capacity and shear strength e.g. black cotton soil. In that case we have to improve the soil quality for its further use. This problem leads to development of various ground improvement techniques either using a chemical stabilization or a mechanical stabilization (Yixian et al. 2016). Strengthening of weak soil using chemical additives such as cement, lime, bagasse ash, ground granulated blast furnace slag, fly ash has been suggested by many researchers in past (Kaniraj & Havanagi, 2001 ; Bell, 1996).

In present study only one parameter is used to calculate the mechanical properties of the cement soil mixture i.e. UCS with considering effect of curing time and a combination of both curing time and curing stress. Soil sample is being collected from locally available site and a series of laboratory investigation has been conducted to evaluate the performance of CSM with and without curing stress. A series of unconfined compressive strength (UCS), Atterberg limits, Light weight compaction test are conducted to analyse the performance of the mixture.

Portland pozzolonic cement is used with varying percentage of 8%, 10% and 12% is used in the investigation with special attention given to curing stress and curing time.

A curing stress is being applied along with curing days to check dual effect of both curing time and curing stress. For applying curing stress a special mould is designed to hold the sample of UCS and curing stress is applied above the sample the design standards of the mould is discussed in this study.

2. Materials Used

2.1 Soil

The soil sample is collected from locally available site of Jaypee university solan, H.P. the physical properties of the soil are discussed in table 1 and chemical composition of PPC used in the study is given in table 2.

Table 1 Physical properties of soil used in the study

Property	Value
Specific gravity	2.62
Grain size analysis	
Gravel (%)	0
Sand (%)	15
Silt (%)	20
Clay (%)	65
Consistency limits	
Liquid limit (%)	66
Plastic limit (%)	29
Plasticity index (%)	37
IS classification	CH
Compaction parameters	
OMC of untreated soil (%)	29.42
MDD of untreated soil (g/cc)	1.51
OMC of soil with 8% cement (%)	30.91
OMC of soil with 10% cement (%)	34.06
OMC of soil with 12% cement (%)	34.74
MDD of soil with 8% cement (g/cc)	1.49
MDD of soil with 10% cement (g/cc)	1.47
MDD of soil with 12% cement (g/cc)	1.45
Curing stress (kPa)	5

Table 2 Chemical composition of cement

Oxide	%
CaO	60.99
SiO_2	20.88
Al_2O_3	5.56
Fe_2O_3	3.36
MgO	3.75
SO_3	2.69

3. Experimental program

To study the improved soil behaviour, the soils was treated with Portland cement. According Woodward (2005), the cement content used for cement-soil mixture in utility is found around 10% of dry soil weight. In present study it was decided to use (8%, 10% and 12%) cement content. The water content that is being used for these 3 different cement content is being calculated by the standard proctor test. The purpose of using different cement content is to find the optimum cement content. To check the effect of curing time 0, 3,7,14, 28 and 56 days of curing without applying any curing stress and later with curing stress along with the curing period to analyse their combined effect.

Fig 1 Unconfined compressive test apparatus

All the specimens for the UCS test data is being recorded using a strain rate equal to 1% (equalling 1.25 mm/min), a data acquisition arrangement was made to record the applied load and measured deflection. The test proceeded until failure occurred. The samples were tested according to their designated curing times 0, 3, 7, 14, 28 and 56 days.

A curing stress of 5 kPa is being applied along with curing days to check the dual effect of both curing time and curing stress and test is conducted for 7, 14, 28 and 56 days.

3.1 Mould preparation for curing stress

The apparatus for the curing stress is made with polyvinyl chloride (PVC) pipes which have 55 mm inside diameter and 215 mm height. A base plate of 85mm is taken which consists of an opening for proper holding of the UCS specimen of 50 mm diameter so that during curing stress it does not move from its place. PVC Pipe of 55mm diameter is fixed from bottom with the base plate and sealed with M-seal to avoid leakage of water and maintain proper curing conditions. Base plate and PVC pipe is shown in the figure 2. The sample is placed in the base plate mould and covered with PVC pipe.

Fig 2 Mould and sample preparation for curing stress

Fill the pipe with water up to specimen's height. A disc of diameter less than PVC pipe is taken and is kept on specimen so that stress can be applied above it. A curing stress of 5 kpa is applied with the help of measuring weights. After the completion of curing time the samples were taken out from designed apparatus and were subjected to unconfined compressive tests. The 5 kPa stress is applied with the help of weight that is found out to be around 1 kg.

Calculation of load for the curing stress

STRESS= FORCE/ AREA

5kPA= FORCE APPLIED /AREA OF THE SPECIMEN

AREA OF SAMPLE OF 50mm DIAMETER SAMPLE= $1.96*10^{-3}$ m^2

FORCE = STRESS*AREA

FORCE = $5*10^{3}*1.96*10^{-3}$ = 9.81N

WEIGHT = MASS*G

MASS= WEIGHT/G

MASS=9.81/9.81=1Kg

4. Results and discussions

As explained in previous sections a number of UCS test with varying percentage of cement content is done with and without curing stress to analyse the impact of curing stress. The results are discussed in sub sections.

4.1 Effect of cement content on OMC and MDD of the Soil

The standard proctor test is conducted to find out the optimum moisture content (OMC) and maximum dry density (MDD) of the virgin soil and soil with varying percentage of the cement content. OMC of natural soil is found to be 29.42% and its value increases with cement content due to increase in the demand of water for hydration of the cement. (Chew, S. H et.al 2004). Fig 3 shows that with the increase in cement content the OMC of the sample increases and the MDD of the soil sample decreases. The MDD of the untreated soil is 1.51 gm/cm^3. The OMC and MDD corresponding to 8%, 10% and 12% cement content are 30.91%, 33.06% and 34.74% and 1.49 gm/cm^{3,} 1.47 gm/cm^{3,} 1.45 gm/cm^3 respectively.

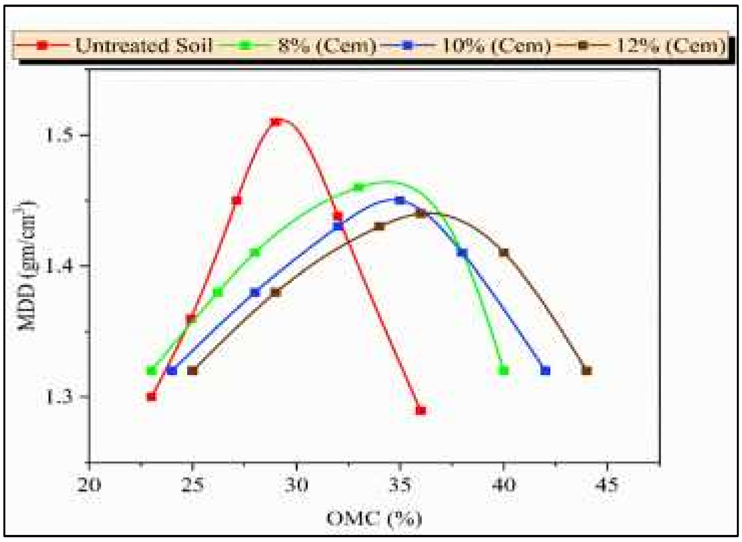

Fig 3 Variation of OMC and MDD

4.2 Stress- strain curves

The stress strain curves are plotted for untreated soil and soil having 8%, 10% and 12% of cement content. The stress values of soil increases with increase in curing days i.e. high values is achieved for 56 days of curing. Fig 4 shows the stress-strain curves for different percentage of cement content. Fig 4 (a), (b) and (c) corresponds to 8%, 10% and 12% cement content stress- strain curves. The stress values increase with time and sample becomes brittle.

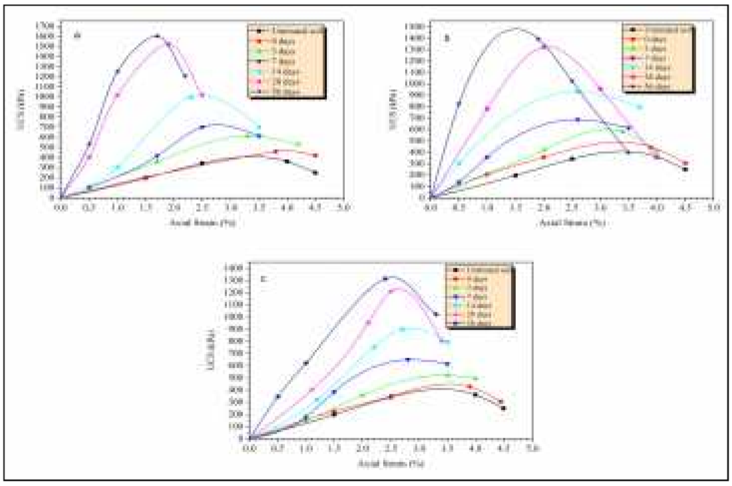

Fig 4 Stress- strain curves 8%, 10% and 12% cement content for different curing days

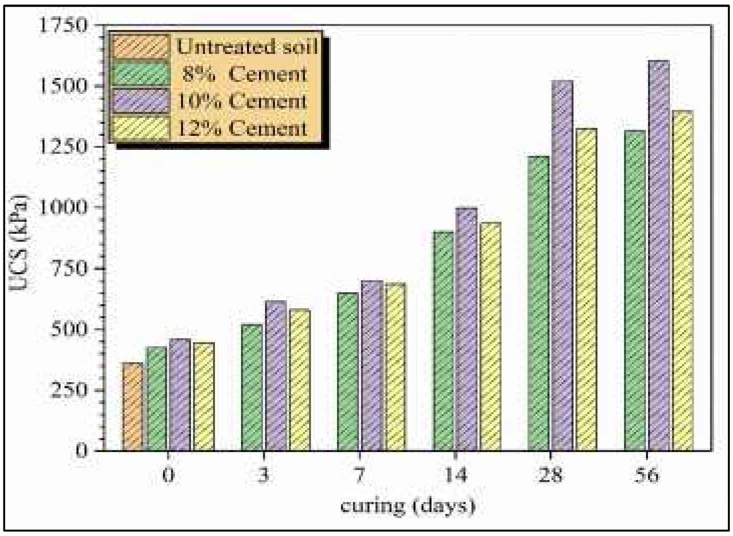

Fig 5 Variation of UCS with cement content and curing time without curing stress

4.3 Variation of UCS with curing days for without curing stress

The unconfined compressive strength (UCS) is being conducted on the untreated soil and soil with 8%, 10% and 12% cement content. Fig 5 shows the variation of UCS with different cement content and for different curing days. The UCS values increases with curing days and high strength is achieved for 56 days curing. The UCS values increases as cement increase from 8% to 10% and decreases after its increases from 10% to 12%. The UCS strength corresponding to 10% cement is found to be optimum for all curing days. The increase in strength is attributed to the hydration products of cement C-S-H gel formation which reduces pore spaces that decreases the compressibility of the soil and leads to the increase in the strength. (Al-Tabbaa and Evans 1999). The high percentage of cement leads to substitution of soil particles by cement which results in lower strength of the soil.

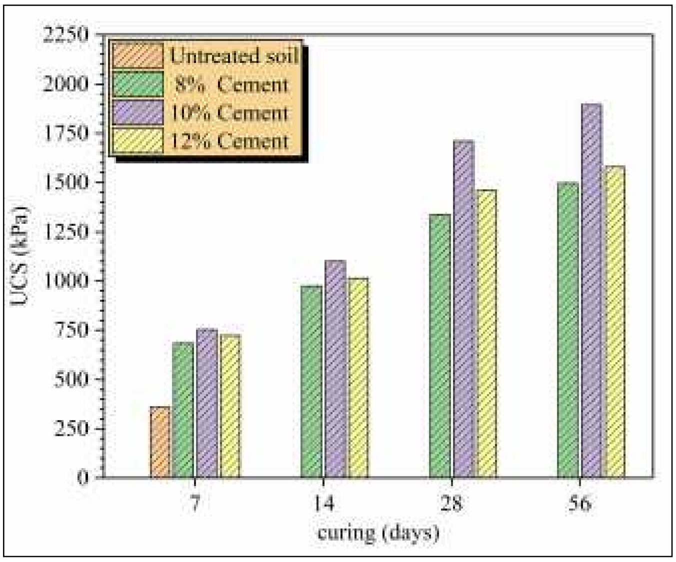

Fig 6 Variation of UCS with cement content and curing time with curing stress.

4.4 Variation of UCS with curing days and with curing stress of 5 kPa

The unconfined compressive strength UCS is being conducted on the virgin soil and soil with different percentage of cement content. The test is conducted for 7, 14 28 and 56 days of curing only due to the limitations of the mould. 5 kPa curing stress is being applied on the sample. The stress is applied with the help of weights used for standard measurement. Fig 6 shows the variation of UCS with curing days and with curing stress of 5 kPa. The UCS values increases with curing days and higher values of UCS is being achieved with curing stress as compared to the sample that are cured without curing stress. The similar trend is observed here and the 10% cement has higher strength as compared to 8% and 12%. The increase is strength is attributed to the increase in confinement pressure from the top that results in decrease in void ratio and porosity of the soil and make the soil more compact.

4.5 Comparison of UCS values of soil with and without curing stress

Soil sample is tested for UCS with different percentage of cement content for with and without curing stress conditions. As discussed earlier higher values of UCS is achieved for 10% cement content as compared to 8% and 12%. The curing stress will increase the UCS values. Fig 7 (a), (b), (c) and (d) shows the variation of UCS values with curing stress as compared to the without curing stress samples for 7 days, 14days, 28days and 56days of curing.

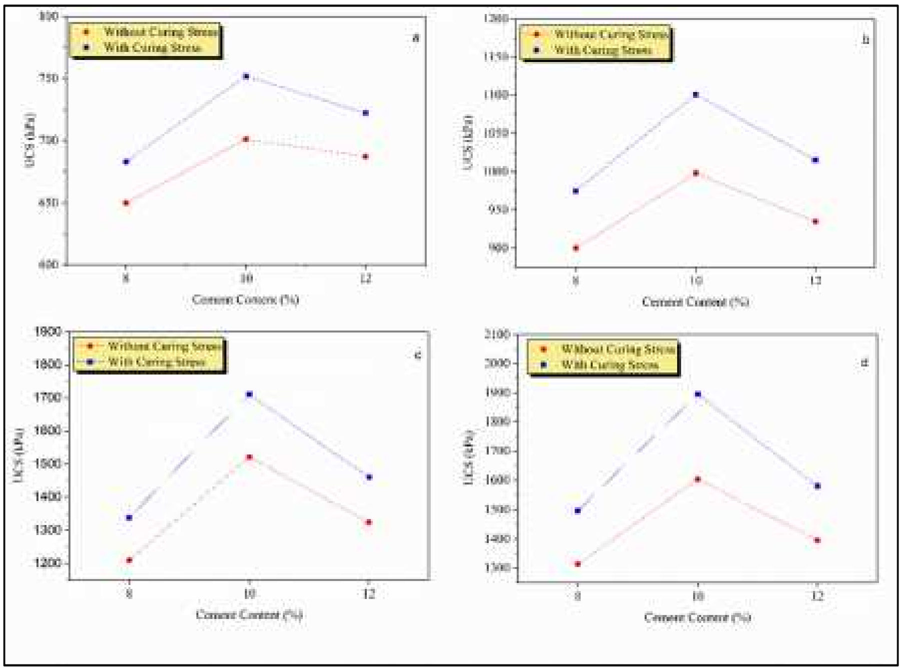

Fig 7 Variation of UCS for 7days, 14days, 28days and 56days of curing for with and without curing stress

5. Conclusions

Based on the laboratory investigations conducted on untreated soil and soil with different percentage of cement content for with and without curing stress following conclusions can be made.

- Effect of cement content on compaction parameters is not so significant however there will be increase in OMC and decreased in MDD of the soil as we increase the cement content.

- The UCS values of soil increases with curing days for same cement content. Higher values of UCS are achieved for 56 days of curing.
- The UCS values increases as we increase the cement content from 8% to 10% but decreases for further increment of the cement content from 10% to 12%.
- The 10% cement content is found to be optimum cement content. The UCS values of the soil increases as we apply the curing stress of 5kPa and it is having high values compared to without curing stress samples. The UCS value increases up to 10-15% as compared to without curing stress conditions.
- The curing time and curing stress both have significant effect on the UCS values of the soil

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