Load - settlement and strength characteristics of marine clay using deep cementitious technique

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Overview

- Introduction
- Objectives
- Test conducted
- Methodology
- Results
- Conclusions
- References

Introduction

- Marine clay, one of the problematic soil which cause excess settlement and low in bearing capacity
- Deep mixing method (DMM) - ground improvement method which describe a variety of soil mixing techniques to improve the soils in-situ
- Based on the Federal Highway Administration has suggested the technique classified as method of additive injection & method of which additives is mixed

Introduction(Contd…)

- In Deep mixing method, soft soil is stabilized in situ with binder without compaction
- Deep mixed columns can provided by single and compounded in order to load transferring and settlement analysis
- Typically triangular & rectangular pattern used for reducing the settlement and improving the bearing capacity

Major findings from the literature

- By providing deep mixing to the weak soil can improve the stability and bearing capacity
- Various parameters such as soil type, amount of binder, mixing time, curing period, water content
- Mechanism of biocementation involves precipitation of calcite or carbonate

Major findings from the literature

- For a specific soil, the lower the water content, wt, and the higher the content of binder, aw, the greater the strength, qu
- A minimum amount of cement of about 5% is necessary irrespective of curing period to obtain an improvement effect for this particular soil
- Basic mechanism involves hydration, flocculation, pozzolonoc reaction, carbonation

Objective

- To determine load settlement characteristics of marine clay
- To determine load settlement characteristics of marine clay using deep cement mixing
- To determine the strength characteristics of cementitious clay by using unconfined compression test

Material used

- Marine clay
- Cement
- Calcium carbonate

Fig 1 Marine clay - Collected from Kundaloor, Cochin

Tests conducted

- Unconfined compression test
- Plate load test

Methodology

- Index properties of marine clay
- Specific gravity(IS 2720 (Part -3)-1980)
- Sieve analysis (IS 2720 (Part 4) – 1985)
- Atterberg limit: liquid limit, plastic limit, shrinkage limit (IS 2720 (Part -5): 1985)
- Standard proctor compaction test (IS 2720 (Part 7):1980)

Methodology- model box and footing

- Tank dimensions 0.5m×0.5m in plan and 0.5m in depth
- The load was applied by means of a hydraulic jack over which proving ring is connected in order to measure the applied load
- A dial gauge is provided for the measurement of corresponding settlements.
- A 10 mm thick steel square footing plate of size 100 mm x 100 mm was used.

Methodology

- The plate load test for uncemented marine clay was conducted
- Marine clay bed prepared by using the obtained maximum dry density and optimum moisture content of 32% from the proctor compaction test.
- Clay filled in the tank with 3 layers of equal weight and being compaction should be done

Methodology (Contd…)

- After filling the clay at particular depth square footing was placed.
- Then the loading is provided by means of a hydraulic jack placed over the footing with a support of loading plate
- The load was applied in small increment until the failure happen. The settlement of the footing was measured using dial gauges
- An experimental program was carried out to study the behavior of deep cement mixing on marine clay

Fig 2 Test tank

Fig 3 Loading by Mechanical Jack on Footing

Plate load test for deep cement mixed column

- For mixing and pumping the cement grout, a grouting chamber is necessarily required
- Grouting setup requires a grout chamber with agitator, an air pump and a grouting nozzle.
- Grout is poured into the chamber through the inlet and when switched ON the motor agitates the grout, which rotates the blades attached to the shaft.

Plate load test for deep cement mixed column

- After the required pressure attained the outlet valve is released.
- Cement grout was pumped under a constant pressure of 1 kg/cm^2 (100 kPa).
- Cement grout filled in a 38mm diameter pipe with required density at a Water cement ratio of 0.45

Fig 4 Grout Pouring Through Inlet

Fig 5 Pipe Inserted and Leveled

Results

Table 1 Index properties of marine clay

Property	**Obtained value**
Specific gravity	2.38
Organic content(%)	7
Liquid limit (%)	74
Plastic limit (%)	34
Shrinkage limit (%)	18
Plastic index(%)	40
Clay (%)	36
Silt (%)	46
Sand (%)	18

Table 1 Index properties of marine clay(Contd…)

Property	**Obtained value**
Maximum dry density (g/cc)	1.37
Optimum moisture content (%)	32
Soil classification	CH

Grain size distribution of marine clay

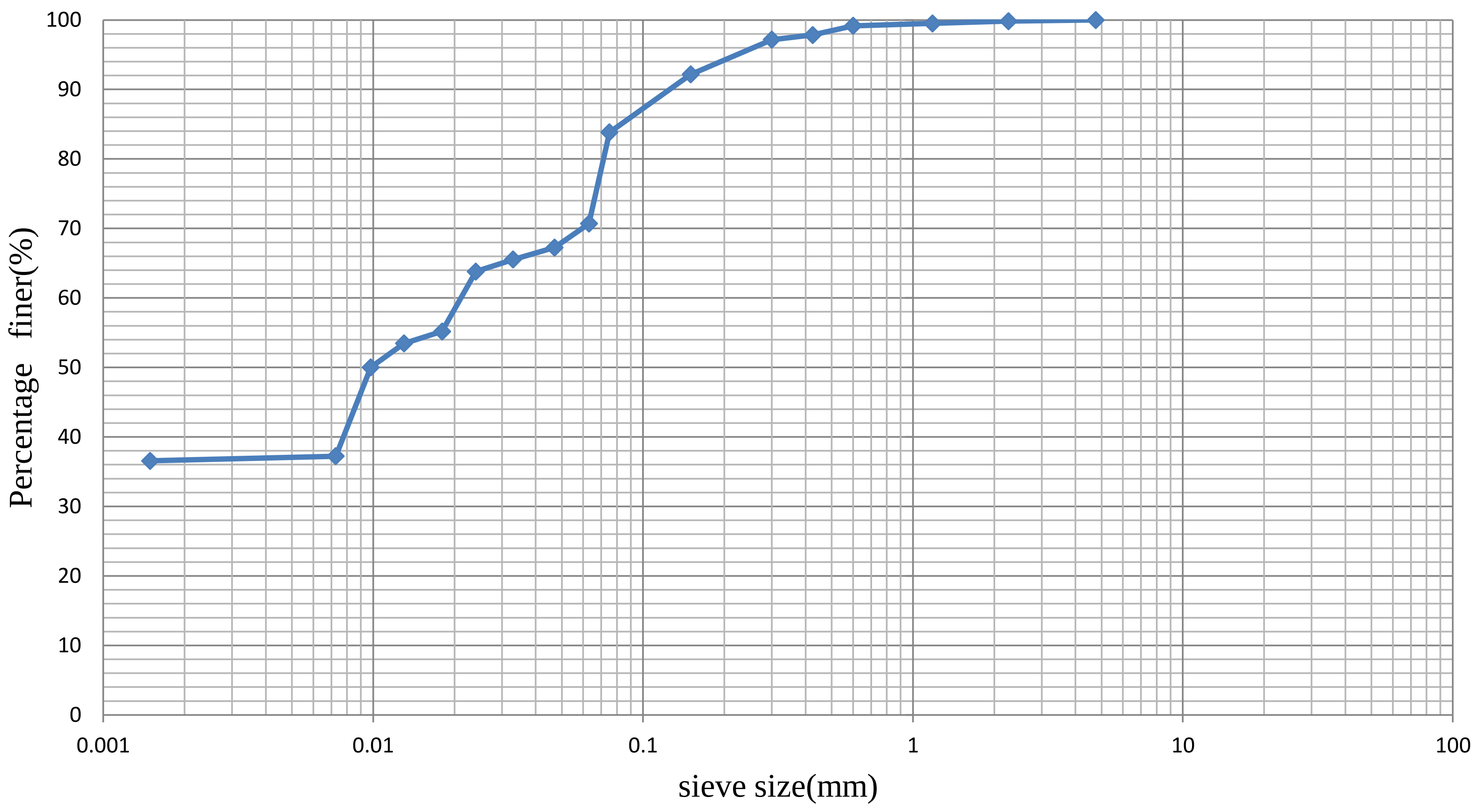

Fig 6 grain size distribution curve

Compaction curve

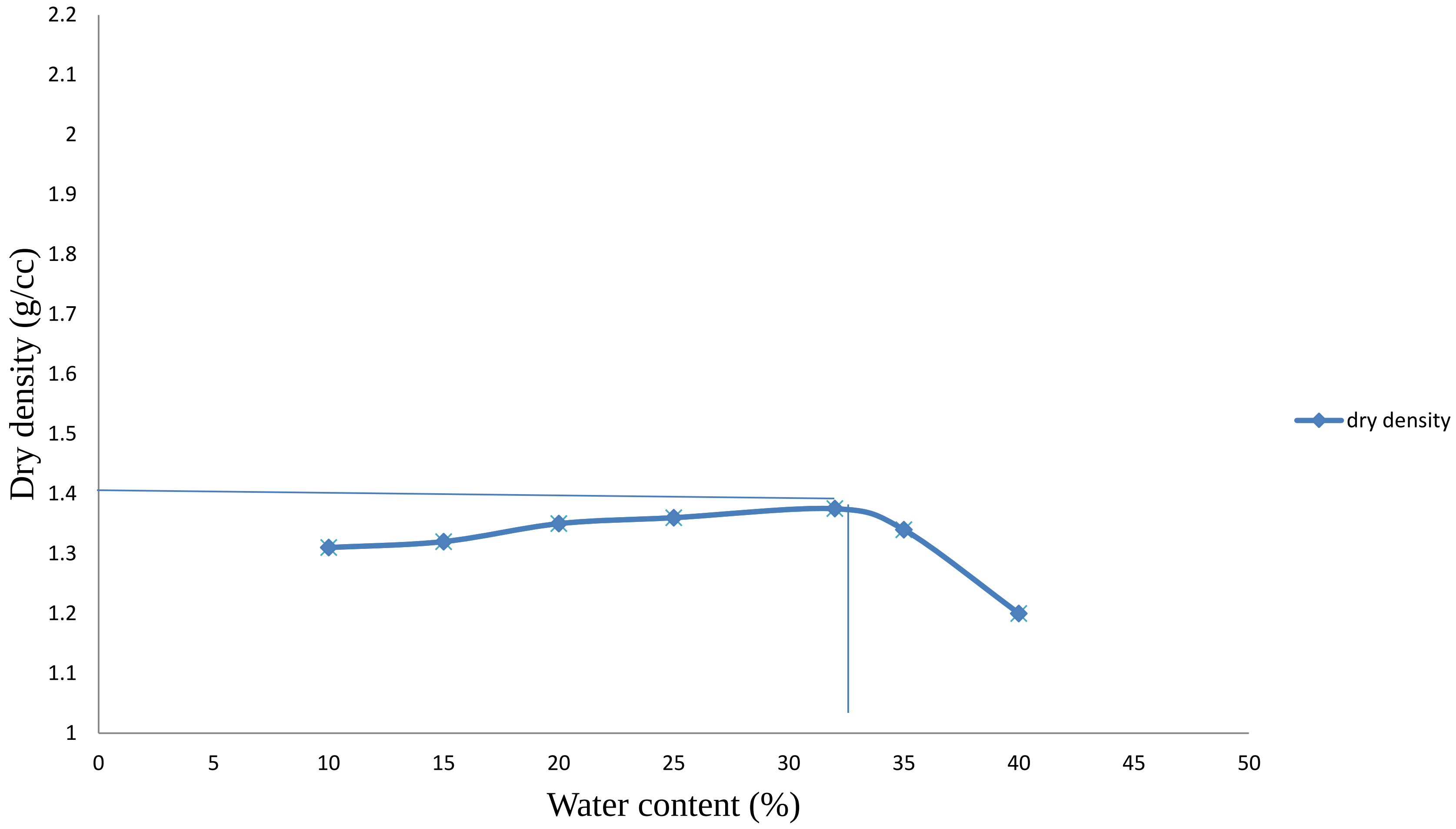

Fig 7 compaction curve

Plasticity chart

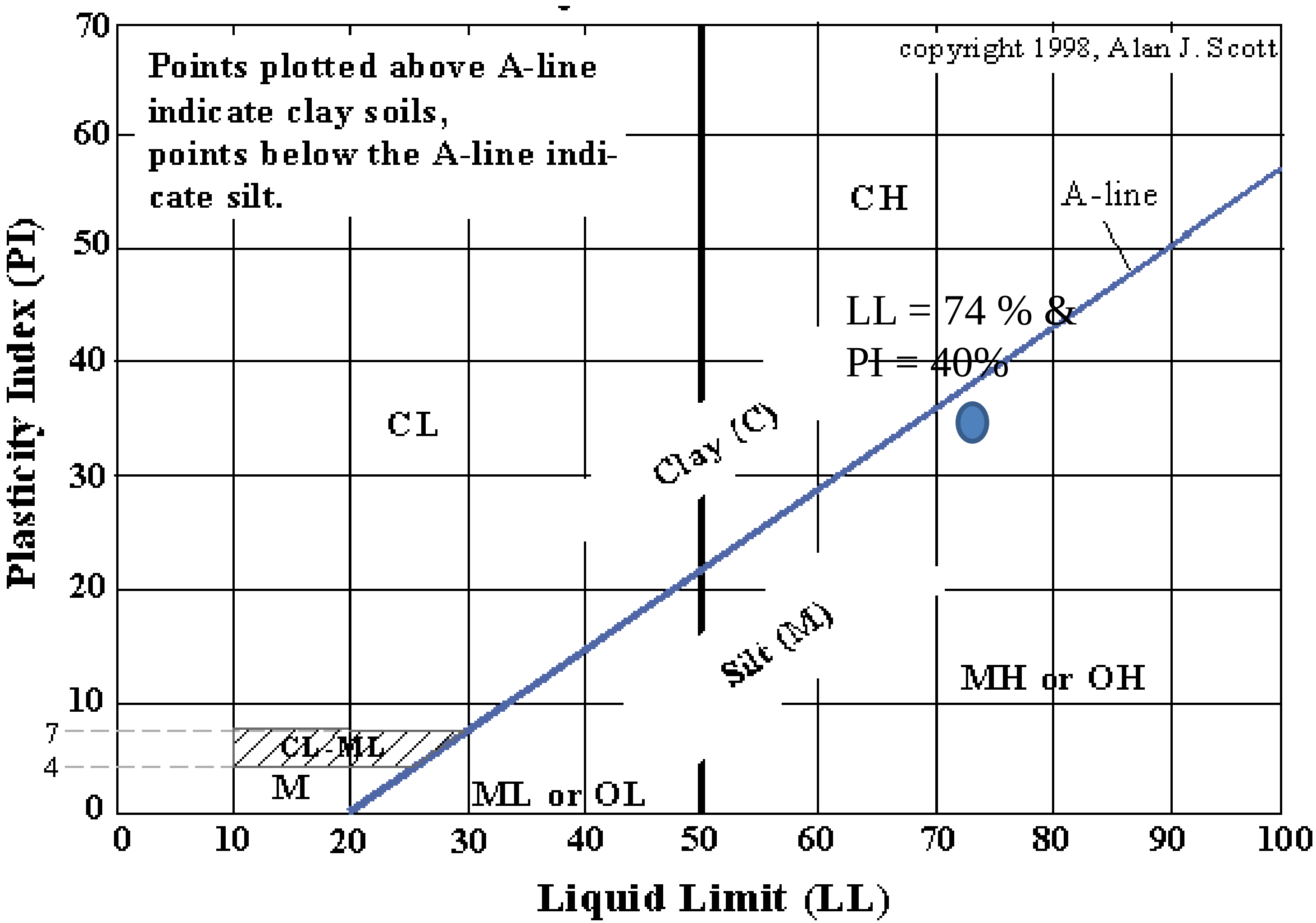

Fig 8 plasticity chart

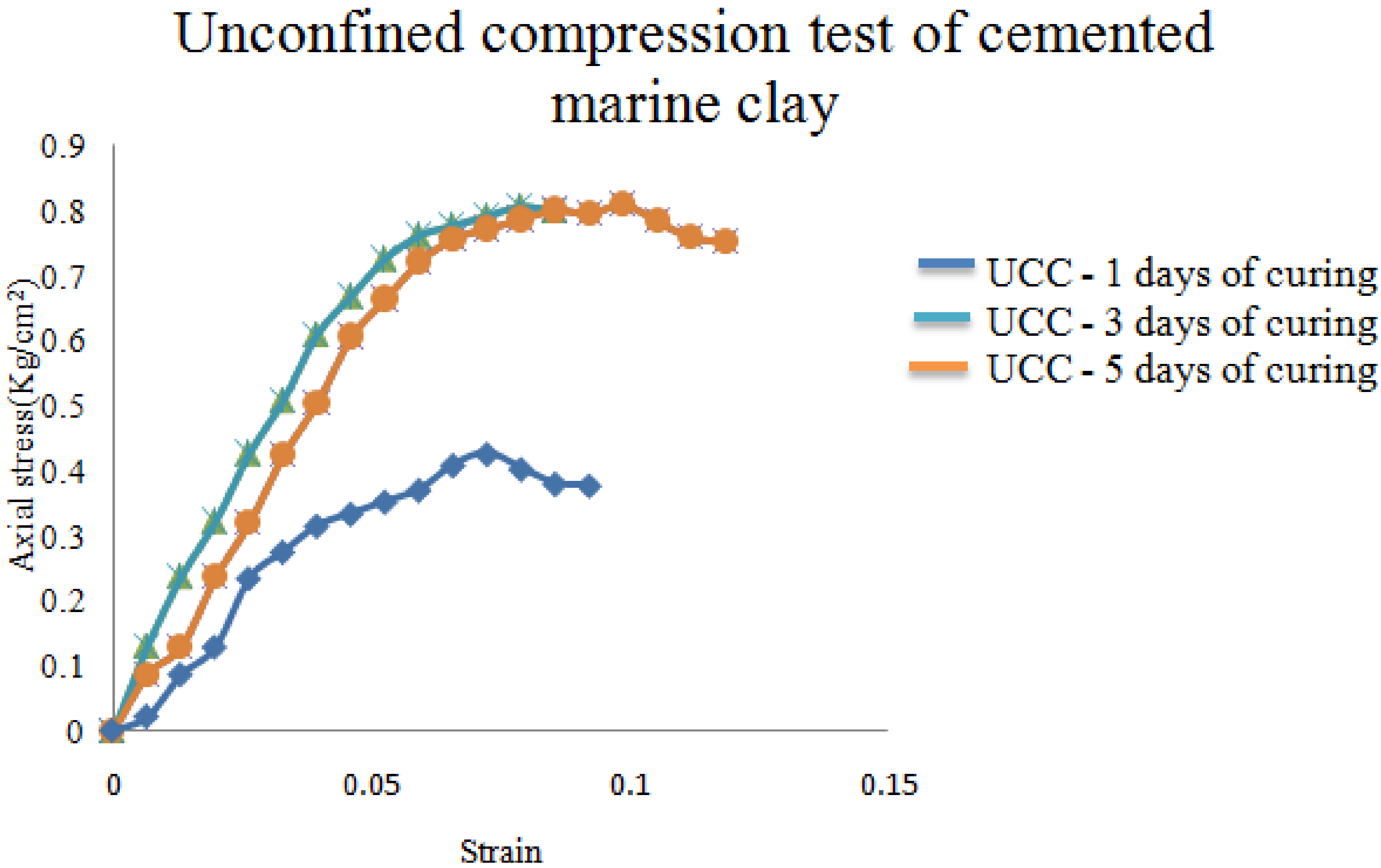

Fig 9 Unconfined compression test of different days of curing

Contd…

- Unconfined compression test conducted on marine clay by using cement content of 5%
- Curing was done for 1, 3 and 5 days respectively
- The maximum value obtained as 0.810kg/cm^2 at 5 days of curing and for 1 day of curing, it is 0.46kg/cm^2
- By increasing curing period from 1 to 5days, the percentage increase is obtained as 76%

Unconfined compression test $CaCO_3$ precipitated specimen

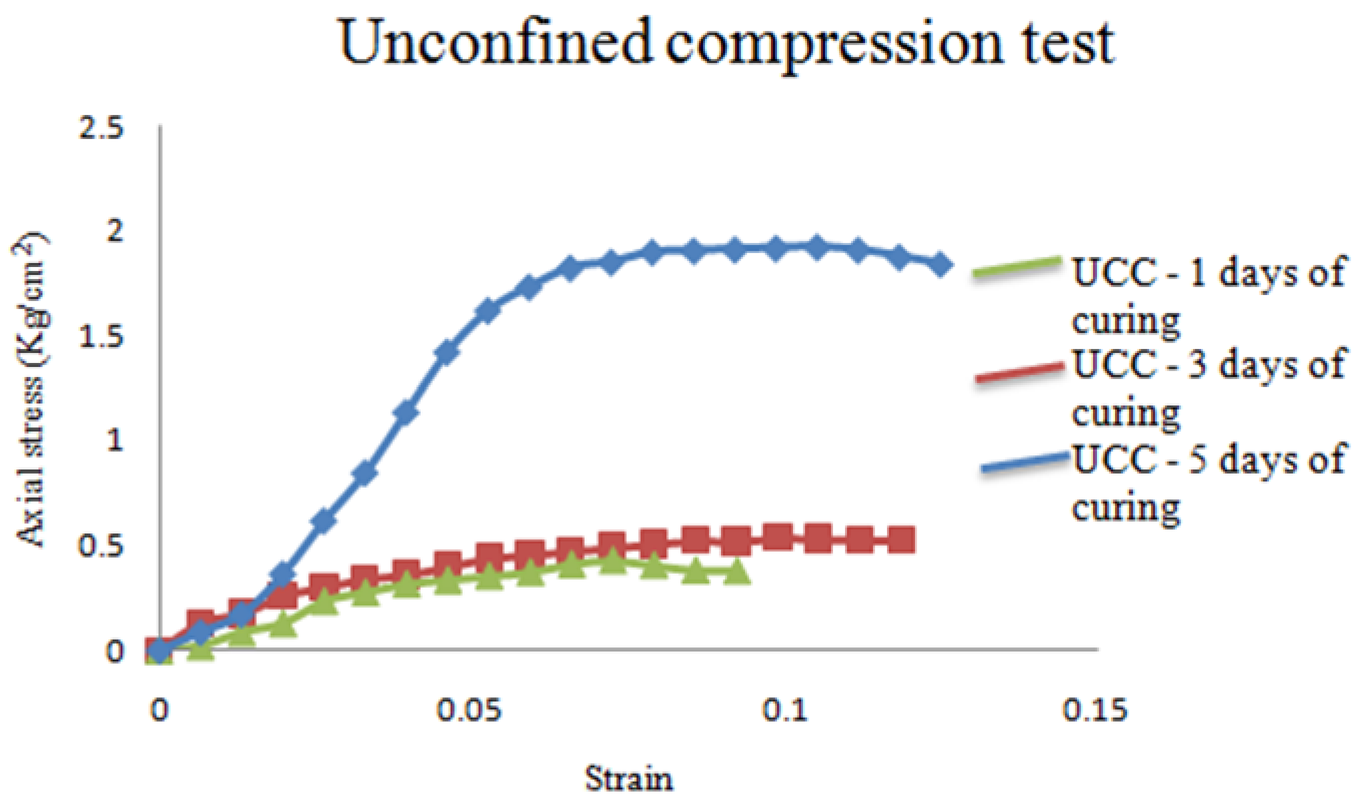

Fig 10 Unconfined compression test of different days of curing

Contd…

- Unconfined compression test conducted on marine clay by using calcium carbonate content of 5%
- Curing was done for 1, 3 and 5 days respectively
- The strength increases from 0.53 to 1.9 kg/cm^2 from 1 to 5 days of curing for $CaCO_3$ precipitated specimen. As curing increases unconfined compression strength increases.
- By increasing curing period from 1 to 5days, the percentage increase is obtained as 258%

Load settlement curve of cemented marine clay at different W/C ratio

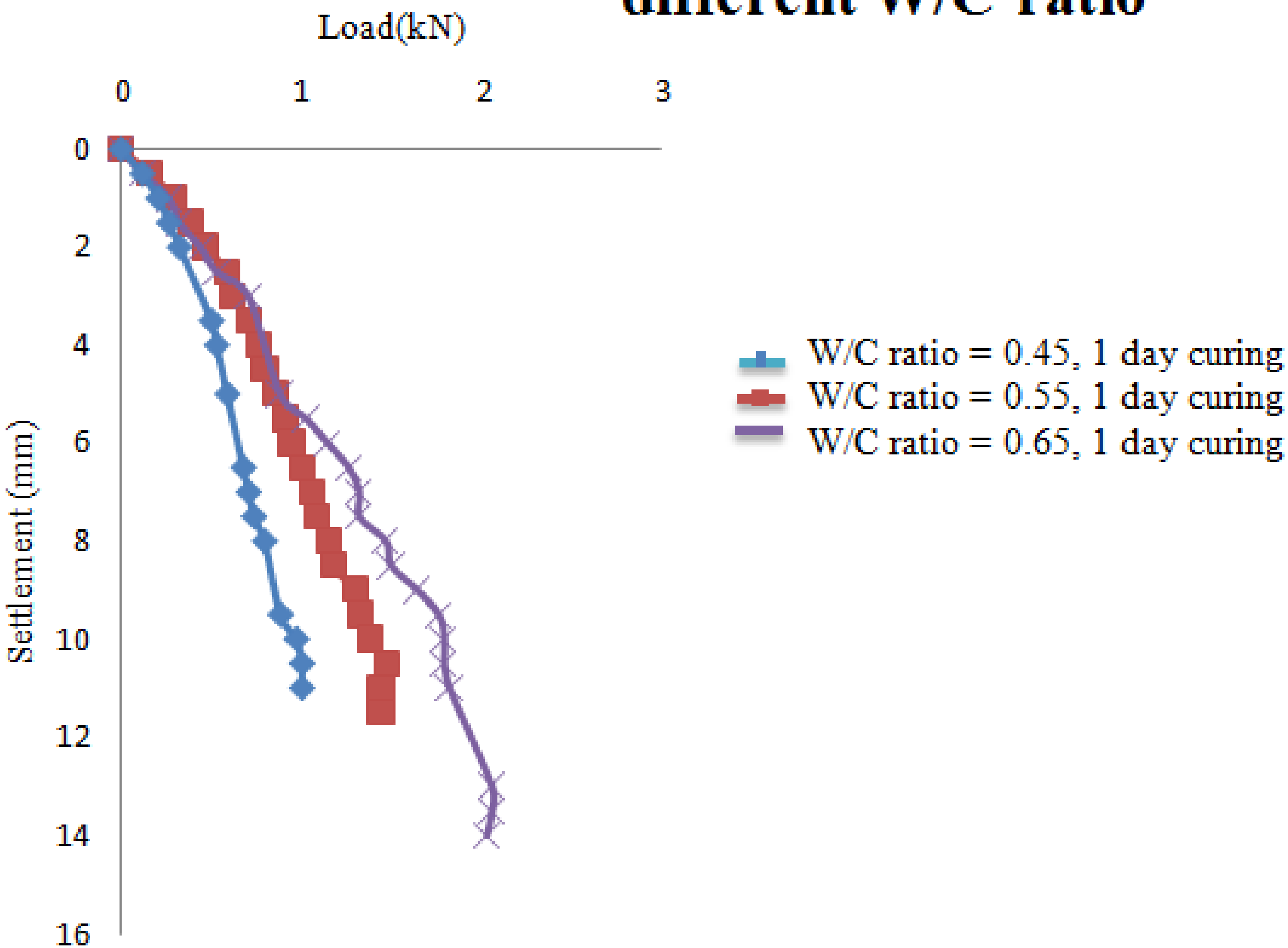

Fig 11 Load settlement curve of cemented marine clay at different W/C ratio

Contd…

- Plate load test conducted at different W/C ratio of 0.45,0.55 and 0.65 respectively at 1 day of curing
- The maximum load carrying capacity obtained at 2.05 kN at a settlement of 13mm for 0.65 W/C ratio
- For 0.45 & 0.55 W/C ratio the load carrying capacity is obtained as 0.8kN & 1 kN respectively
- The increase in load obtained as 1.56 for 0.65 W/C ratio

Load settlement curve of different pattern cemented marine clay

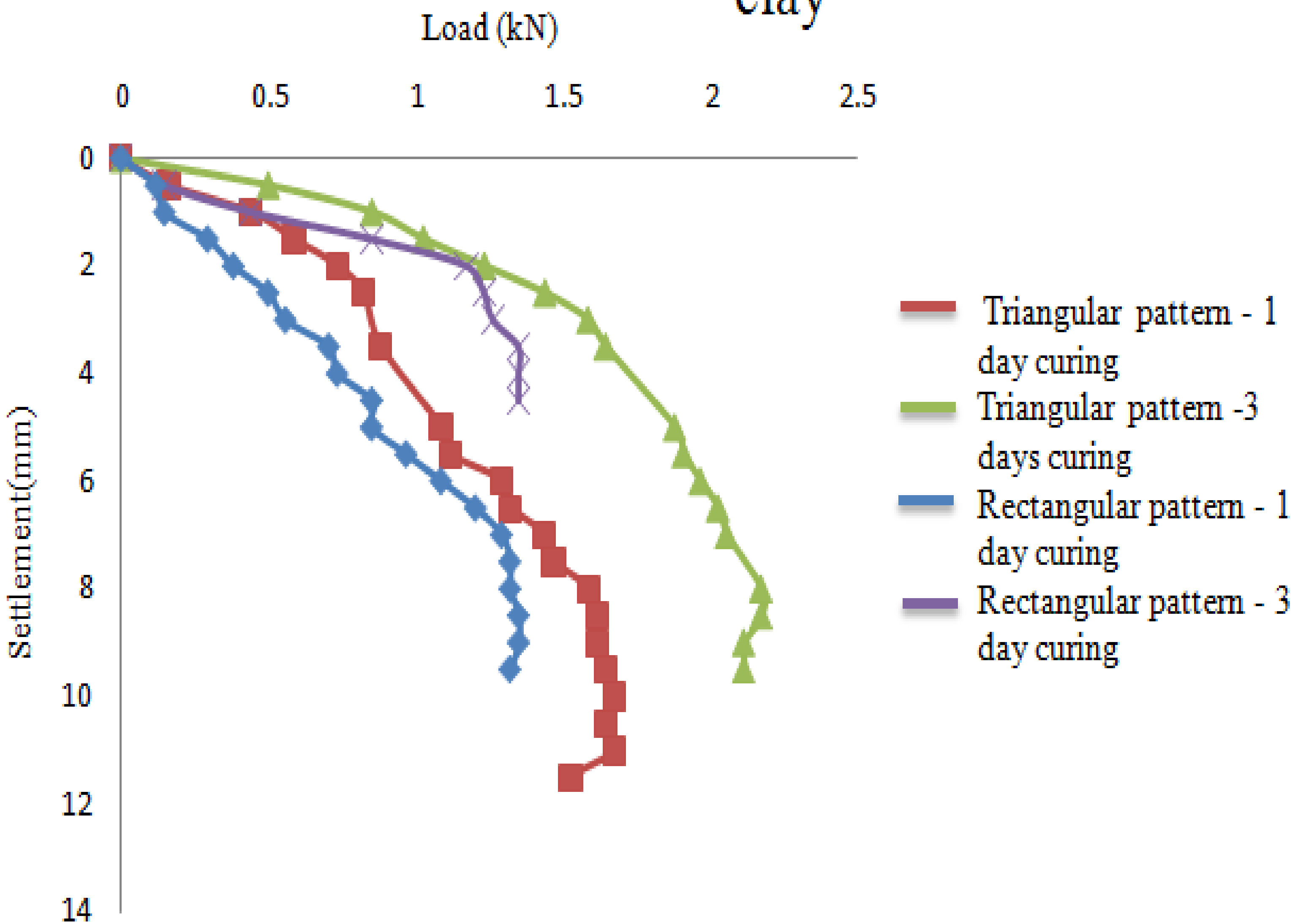

Fig 12 load settlement curve for different pattern

Contd…

- Plate load test conducted at triangular and rectangular pattern at different curing period of 1 and 3 days respectively
- The maximum load carrying capacity obtained at 2.17 kN at a settlement of 8mm for triangular pattern at 3 days of curing
- The maximum load carrying capacity obtained at 1.4 kN at a settlement of 5 mm for rectangular pattern at 3 days of curing

Conclusions

- The maximum value obtained as 0.810kg/cm^2 at 5 days of curing and for 1 day of curing, it is 0.46kg/cm^2
- By increasing curing period from 1 to 5 days, the percentage increase is obtained as 76%
- The strength increases from 0.53 to 1.9 kg/cm^2 from 1 to 5 days of curing for $CaCO_3$ precipitated specimen
- By increasing curing period from 1 to 5days, the percentage increase is obtained as 258%
- As curing increases unconfined compression strength increases.

Conclusions (contd…)

- Installation of deep cemented technique on marine clay improves the load carrying capacity
- By comparing three water cement ratio, the maximum load carrying capacity obtained at 2.05 kN at a settlement of 13mm for 0.65 W/C ratio
- For 0.45 & 0.55 W/C ratio the load carrying capacity is obtained as 0.8kN & 1 kN respectively
- The increase in load obtained as 1.56 for 0.65 W/C ratio

Conclusions (contd…)

- The maximum load carrying capacity obtained at 2.17 kN at a settlement of 8mm for triangular pattern at 3 days of curing
- The maximum load carrying capacity obtained at 1.4 kN at a settlement of 5 mm for rectangular pattern at 3 days of curing
- From results, load carrying capacity is more for triangular pattern than rectangular pattern but settlement reduction is for rectangular pattern

Work to be done

- Unconfined compression test at different remolding water content
- To determine the effect of pattern in by using calcium carbonate precipitation
- To compare the load settlement characteristics by using cemented as well as calcium carbonate precipitation

References

- Duraisamy Y., and Airey D. W., (2015). “Performance of biocemented sydney sand using ex situ mixing technique.” *The journal of deep foundation institute* , vol 9(1), 48-55.
- Ng Wei Soon et al (2014). “ Factors affecting improvements in engineering properties of residual soil through Microbial – Induced Calcite Precipitation.” *ASCE Geotech. Geoenviron. Engineering*, 1 -9.

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- Shahidul Islam Md., and Rosian Hashim (2009). “Bearing capacity of stabilised tropical peat by deep mixing method." *Australian Journal of basic and applied sciences*, 3(2), 682-688
- Woo- Sik Kim., Nguyen Minh Tam., and Du-Hwoe Jung and (2005). “Experimental study on strength of cement stabilized clay." *J. of engineering, design and technology*, Vol 3(2), 116-126.

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- Ivanov V., etal. (2013). “Strengthening of soft marine clay using bioencapsulation.” *Marine geosources & geotechnology*, 33, 325-329.
- Wei- Soon Ng., Min-Lee Lee, and Siew-Ling Hill (2012). “An overview of the factors affecting Microbial-Induced Calcite Precipitation and its Potential application in soil improvement." *International scientific reasearch & innovation*, 6(2), 02-22

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- Yin J. H., and Fang Z. (2006). “Physical modelling of consolidation behaviour of a composite foundation consisting of a cement- mixed soil column and untrated soft marine clay.” *Geotechnique*, 56(1), 63-68.
- Masum Shaikh et al (2014). “Soft soil improvement by cement column." *international journal of advanced structures and geotechnical engineering*, Vol. 3(4), 31.-315.

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- Jacobson J.R. et al (2005). “Factors affecting strength of lime- cement columns based on a laboratory study of three organic soil.”, *Deep mixing* Vol 3(2), 87-94.
- Chen K.B. et al (2015). “Effect of reagents concentration on biocementation of tropical residual soil.” *Soft soil engineering international conference* , 3(2), 1-6.

Thank u

Aim	Materials used & Tests conducted	Parameters varied	Major findings
1. Duraisamy Y., and Airey D. W., (2015). "Performance of biocemented sydney sand using ex situ mixing technique." *The journal of deep foundation institute* , vol 9(1), 48-55.			
• To improve the strength & stiffness of loose sand •To investigate the effect of ex situ mixing to create cemented soil column •To determine the bearing capacity of gypsum cemented column, biocemented column, test without column	• Sydney sand •Cement •Calcium chloride ($CaCl_2$) •Urea and bacteria •Unconfined compression test •Triaxial test •Plate load test		•Cemented column increase the stiffness of the foundation response compared to uncemented soil

Aim	Materials used & Tests conducted	Parameters varied	Major findings
2. Ng Wei Soon et al (2014). " Factors affecting improvements in engineering properties of residual soil through Microbial – Induced Calcite Precipitation." *ASCE Geotech. Geoenviron. Engineering*, 1 -9.			
• To determine effect of cemented sand •To determine effect of bacteria concentration •To evaluate the effect of curing condition on MICP treated sample	•Fine sand •Urea •Calcium chloride •Unconfined compression test	•reagent concentration •treatment duration	•Improvement in shear strength and reduction in hydraulic conductivity •A minimum calcite content 1% is required to measure the improvement in shear strength

Aim	Materials used & Tests conducted	Parameters varied	Major findings
3. Shahidul Islam Md., and Rosian Hashim (2009). “Bearing capacity of stabilised tropical peat by deep mixing method." *Australian Journal of basic and applied sciences*, 3(2), 682-688.			
•To investigate physical properties of peat soil •To determine bearing capacity of tropical peat •To measure the bearing capacity of stabilized column	•Peat soil •Ordinary Portland Cement • Sand •Bentonite •$CaCl_2$ •Cone penetration test	•Different mix design •Curing period	•Bearing capacity of peat soil is very negligible and high settlement value •Peat soil stabilized by soil column very effective, soil can stabilized in short time

Aim	Materials used & Tests conducted	Parameters varied	Major findings
4. Woo- Sik Kim., Nguyen Minh Tam., and Du-Hwoe Jung and (2005). “Experimental study on strength of cement stabilized clay." *J. of engineering, design and technology*, Vol 3(2), 116-126.			
•To determine the effect on strength characteristic of cement treated clay	•Soft clay •Cement •Unconfined compression test	•Soil type •Sample preparation method •Mixing method •Curing time •Dry weight ratio of cement to clay •Water- clay to cement	•Soil- cement sample with higher cement content showed more brittle failure •Unconfined compressive strength of dry mixing method greater than wet mixing method •Modulus of elasticity increase with increasing unconfined compressive strength •By increasing cement content increase unconfined compressive strength

Aim	Materials used & Tests conducted	Parameters varied	Major findings
5. Ivanov V., etal. (2013). "Strengthening of soft marine clay using bioencapsulation." *Marine geosources & geotechnology*, 33, 325-329.			
•To investigate physical properties of peat soil •To determine bearing capacity of tropical peat •To measure the bearing capacity of stabilized column	•Marine clay •Urease producing bacteria •$CaCl_2$ •Unconfined compression strength test	•Water content •Clay aggregate size	•Soft clay can strengthened through encapsulation of clay

Aim	Materials used & Tests conducted	Parameters varied	Major findings
6. Yin J. H., and Fang Z. (2006). "Physical modelling of consolidation behaviour of a composite foundation consisting of a cement- mixed soil column and untrated soft marine clay." *Geotechnique*, 56(1), 63-68.			
•To understand the consolidation behaviour of the composite foundation by physical model test	•Marine clay •Cement •Model test	•Radial distance	•Partial radial drainage was observed along the DCM column • Permeability of the DCM column higher than untreated soft clay

Aim	Materials used & Tests conducted	Parameters varied	Major findings
7. Wei- Soon Ng., Min-Lee Lee, and Siew-Ling Hill (2012). "An overview of the factors affecting Microbial-Induced Calcite Precipitation and its Potential application in soil improvement." *International scientific reasearch & innovation*, 6(2), 02-22			
•To provide an overview factors affecting the MICP in soil •To investigate the shear strength & impermeability	•Residual soil •Bacteria •Unconfined compression test	• Different densities	•The improvement increases with increase in soil density •The study was done with optimum conditions (reagent concentration and treatment duration)

Aim	Materials used & Tests conducted	Parameters varied	Major findings
8. Duraisamy Y., and Airey D. W., (2012). "Strength and stiffness of biocemented liquefiable sand soil." *international conference on ground improvement and ground control*, 1-6			
•Effects of biocementation on the mechanical properties	•Quarts sand •Carbonate sand •Triaxial test		•Measurement of shear wave velocity can provide an indication of degree of cementation •Share wave velocity increase to a peak value and reduces

Aim	Materials used & Tests conducted	Parameters varied	Major findings
9. Masum Shaikh et al (2014). "Soft soil improvement by cement column." *international journal of advanced structures and geotechnical engineering*, Vol. 3(4), 31.-315.			
•To determine the effect of cement column in improving the soft soils •To check the degree of improvement in cement column	•Clay •Cement •Plate load test •Unconfined compressive strength test		•Bearing capacity of cement column increased at a minimum percentage of cement

Aim	Materials used & Tests conducted	Parameters varied	Major findings
10. Jacobson J.R. et al (2005). “Factors affecting strength of lime- cement columns based on a laboratory study of three organic soil.”, 3(2), 87-94.			
•Comparing the strength of lime-cement column by different organic silty soil	• organic silt •Lime •Cement •Unconfined compressive strength test	•Curing temperature •Dosage rate •Method of mixing •Cement type •Lime type	•Increasing in curing temperature increase in mixture strength •Drying and rehydrating cause drastic decrease in mixture strength •Increase in soil water content produce in the mixture strength •Strength of cement soil without lime decreases with increasing water to cement content

Aim	Materials used & Tests conducted	Parameters varied	Major findings
11. Chen K.B. et al (2015). "Effect of reagents concentration on biocementation of tropical residual soil." *Soft soil engineering international conference* , 3(2), 1-6.			
•To investigate the effect of cementation reagents concentration on MICP treatment •Determine effectiveness &feasibility of Bacillus subtilis in this MICP treatment for tropical residual soil	•Residual soil •Bacteria •Urea •Nutrient broth •$CaCl_2$ •Unconfined compressive strength	•Reagent concentration	•Unconfined compressive strength of the treated soil improved with increased concentration of cementation reagent and reached optimum at 0.25M of cementation reagent

Aim	Materials used & Tests conducted	Parameters varied	Major findings
12. Morteza Esmaeili, and Hamid Khajehei (2016). "Mechanical behaviour of embankments overlying on loose subgrade stabilized by deep mixed columns." Journal of rock mechanics and geotechnical engineering, 1-9.			
•To investigate the behaviour of embankment lying on the loose sandy subgrade •To investigate the effect of the performance of square and triangular pattern	•Sand •Clayey sand •Cement •Plate load test	• Various load cell •Square & triangular pattern	•DMCs in triangular pattern and square pattern in the reinforced models were able to increase the bearing capacity of the embankment

Aim	Materials used & Tests conducted	Parameters varied	Major findings
13. Atefeh Zamani, Brina M., etal (2016). “Permeability reduction due to microbial induced calicite precipitation.” *Geo Chicago conference* , 269.			
•To determine change permeability from MICP cementation •	•Fine sand •Bacteria •Urea •$CaCl_2$ •Permeability test •Shear wave velocity	•Cementation concentration	•Fine sand specimen were cemented with MICP to varying level of cementation, assessed using shear wave velocity •Permeability decreases with increases in cementation level

Aim	Materials used & Tests conducted	Parameters varied	Major findings
14. Song- Yu Liu etal (2012). "Field investigation on performance of T- shaped deep mixed cement column supported embankments over soft ground." *J. Geotech.Geoenviron. Eng.*, 138(6), 718-727.			
•To reduce the settlement of soft clayey soil under embankment loading •Comparing the conventional deep mixed column and T shaped mixed column	•Clay •Cement •Insitu plate load test •Unconfined compressive strength		•TDM column have less cement compared to conventional deep cement column

Aim	Materials used & Tests conducted	Parameters varied	Major findings
15 Al-Tabbaa A., Evans C. W., (1998). "Pilot in situ auger mixing treatment of a contaminated site part 1: treatability study." *Proc.Instn Civ. Engrs Geotech. Engng*, 52-59.			
•To develop soil- grout mixes appropriate for sites on low cement content and grout content	•Man made •Sand and gravel •Cement •Pulverized fly ash •Lime •Bentonite •Unconfined compressive strength	• Mix design	Treatability study indicate suitabity of the treatment methodology for site

Aim	Materials used & Tests conducted	Parameters varied	Major findings
16. Shahidul Islam Md., and Rosian Hashim (2016). "Stabilization of peat soil by soil-column techniques and settlement of th group columns." *international journal of the physical science*, 1-9.			
•To enhance the bearing capacity and strength of peat soil of group column and single column •Compare the load – settlement between computer modelling and field test data	•Peat soil •Pulverised fuel ash •Cement •Sand •Calcium chloride •Load test •PLAXIS 8.2	•Type of mixing	•Group column will give a higher value than single column •Settlement value of group column by prebored premixed method gives more good results than auger mixing •A deviation in settlement founded by comparing the field testing and computer modelling

Aim	Materials used & Tests conducted	Parameters varied	Major findings
17. Samuel Jonah Abbey, Samson Ngambi, and Barisua Ebenezer Ngekpe(2015) "Understanding the performance of deep mixed column improved soils _ A review." *Int. J. of civil engineering and technology* , Vol 6(3), 97-117.			
•To enhance the engineering properties of weak soils to provide sufficient stability and bearing capacity	•clay •Cement •Plate load test •Unconfined compressive strength test	•Cement content •Effect of mixing •Curing period	•Amount of binder depend upon the initial moisture content •Unconfined compression strength of weak soil increases with increase in cement content

Aim	Materials used & Tests conducted	Parameters varied	Major findings
18. Qian Zhao and Chi Li etal (2014). "Factors affecting improvements of engineering properties of MICP- treated soil catalyzed by bacteria and urease." *J. Mater. Civ. Eng*, 1-9.			
•To determine the engineering properties of soil	•Sand •Bacteria •Urease •Unconfined compression strength	•Type of sand • Cementation media •Curing conditions •Bacteria concentration •Reaction time	•Unconfined compression strength and $CaCO_3$ content increase with increasing concentration

Aim	Materials used & Tests conducted	Parameters varied	Major findings
19. Yan Jiang, Jie Han and Gang Zheng (2013). "Numerical analysis of consolidation of soft soils fully pentrated by deep mixing." *KSCE Journals of civil engineering*, vol17(1), 96-105.			
•To study mechanically and hydraulically coupled 3D models for the analysis of consolidation	• Finite element software ABAQUS	• stress concentration ratio •Area replacement ratio •Modulus ratio •Permeability ratio •Consolidation	•The stress concentration ratio increase with the column modulus and time •The settlement of deep mixed column foundation decreases with increase in column modulus and area replacement ratio

Aim	Materials used & Tests conducted	Parameters varied	Major findings
20. Glen A. L. and Dennes T.B. (2006). "Fundamental characteristics of cement admixed clay in deep mixing ." Journal of rock mechanics and geotechnical engineering, 1-9.			
•Compressibity and strength charctesics of high water content cement-admixed clay	•Clay •Cement •Unconfined compression test •Oedometer test •Consolidated triaxial compression	•Clay water content •Cement content	• Stress- strain response indicated that the cement –treated clay behaved as less brittle