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PROJECT REPORT

ANALYTICALLY EVALUATING THE EFFECTIVENESS OF SOIL STABILIZATION WITH CEMENT KILN DUST

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

SUBMITTED BY

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NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

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(2020)

This is to certify that the

BE Civil Engineering Project entitled

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Has been accepted towards the partial fulfilment of the requirements

BE Civil Engineering Degree

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Dr. Abdul Waheed, Ph D
Syndicate Advisor

Dedication

Special dedication to my parents

My supervisor, my beloved friends

And all faculty members.

For all support, encouragement and believe in me.

Thank you so much.

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In the name of Allah who is the most merciful and the most beneficent, it is a matter of great honor for us to present our civil engineering knowledge. We are highly obliged to our Project Advisor Dr. Abdul Waheed who kept on guiding us through his lifelong and extensive innovative experience in the Geo Technical Engineering domain of the recognized international engineering organizations. This work is a clear reflection of the dedicated hard work and profound interest of my group members in the Geo Technical Engineering field of Civil Engineering. At last, a very special thanks to our parents for their best wishes and lifelong struggles for our success and betterment. May Allah bless them and bestows His countless blessings and bounties on them.

Thank you.

All Syndicate members

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ABSTRACT

The world is expanding day by day; demanding manifold development in communication and building infrastructure. The network of road in those part of the world where there are deserts. Soil are mostly of low strength for roads as well as building foundations. The roads built in those areas are expensive due to weak subgrade soils.

- An analytical study was conducted to evaluate effectiveness of soil stabilization by adding waste materials with these natural soils to enhance the characteristics of the subgrade of these soils. Almost 30 research papers were analyzed. The byproduct of Cement Kiln's Dust (CKD) was used to enhance the properties of soil. Study encompass soils from different part of world and checked with percentages of CKD such as 5%, 10%, 15%, 20%, 25% and 30% cured for 7-28 days depending upon the site condition. The percentages depend upon the chemical composition of CKD and hygroscopic moisture content of that area. The mixtures were tested for basic soil properties i.e. Atterberg limit, Dry Density, Specific gravity, pH, and Optimum Moisture Content (OMC) to improve engineering properties such as California Bearing Ratio (CBR), cohesion, Angle of internal friction, permeability and compressibility. The results of these tests showed enhancement in the engineering properties of soil. By adding 0 to 20% CKD in dam's embankments Direct Shear strength increased from 270 to 450KPa. Void ratio decreased from 1.25 to 1.01%. Hydraulic conductivity decreases from 9.123 to 6.124 cm/s. In foundations with 2.5 to 7.5% CKD. The shear strength increases from 13 to 54 KPa. Cohesion increases from 4 to 10 KPa. Penetration decreases from 18 to 11.3mm. Slope stability with 10 to 30% CKD. CBR increased from 7.3% to 30%. Cohesion increased 0.12 to 1.04 KPa. Angle of internal friction increased from 13 to 16. For roads with 5-25% CKD OMC decreases from 18% to 15% and increase MDD from 1.68 to 1.78g/cc. UCS increases from 1.691 to 5.24Kg/cm2. The CBR increases from 2.26 to 8.32%.
-

CHAPTER 1

INTRODUCTION

1.1 General

Geo-Technical engineer usually find the soil that he is using for different projects in some particular area unsuitable for his work. He can use different alternatives:-

- Acceptance to soil just as it exists, but considering its poor qualities realistically for the design in question.
- Elimination or avoidance of unsatisfactory material replacing it with a more suitable one.
- Modification of soil properties so that it can meet the design requirements.

The last alternative leads to soil stabilization techniques. There are several methods that could be used for improving soil properties to make them suitable for their use, the most common methods are:-

- Stabilization by physical means; by blending/ mixing soils.
- Stabilization by mechanical means; by compacting soils.
- Stabilization by chemical means; by using additives, lime, cement and CKD etc.

On account of great variability in the composition of soils, each method can be applied to different types of soil. The use of the optimum procedure for each soil type is out of question. The soil properties most often requiring improvement by stabilization are:

- Volumetric stability.
- Strength (UCS, DS, CBR).
- Permeability.
- Compressibility.
- Durability.

The areas that are studied have the soil that are mostly unsuitable for any civil engineering works as regards to its engineering properties and is required to be treated by a suitable method such as addition of stabilizing agent, which must improve the desired engineering properties of soil to undertake any significant civil engineering works. Hence the need of finding out some low cost addictive for soil stabilization will help in development of infrastructure. Soil modification or stabilization by CKD for SP, SM, SP-SM, SC and CL soils are the most suitable techniques.

During production of cement the CKD is produced at the rate of 6 to 7 percent per bag out of which 2.5 to 3 percent is discharged in atmosphere and remaining is collected and removed from kiln. The amount removed is approximately 3 to 4 percent by weight per bag of cement which is treated as industrial waste material. The CKD stabilizes the soil in the similar manner as that of cement but a little higher percentage by weight is required as compared to cement. The CKD is available at throw away price and cost involved is of its transportation from factory to construction site.

The evaluation of research work was done to check suitability of additive for these soils in different areas. It is aimed at determining the best suitable percentage by weight of CKD to achieve the desired engineering properties for pavement sub-grades or even for roads, embankments, slopes and foundations by enhancing in-situ soil the engineering properties for the design. CKD starting from 5 percent to 30 percent by weight was mixed with soil and tested in laboratory, which gave satisfactory results.

1.2 PROBLEM STATEMENT

The sand of the areas like deserts mostly are unstable due to its properties and the structures like roads were unable to construct due to soil behavior. The foundations of the buildings were not feasible on such area and they collapse due to its strength. In such areas the slopes are very difficult to construct, the negligible cohesion of the soil and strength are the main factors. Due to water shortage in these areas dams are to be constructed so the main factor was permeability. Such soils have been stabilized by addition of PVC powder, rubber, paper and fly ash. CKD is one of the additive which can improve the requisite engineering properties of such soils.

The application of this research is the improvement in the strength and other engineering properties of soil. The use of CKD was very cost effective and it is also helpful in utilizing environmentally hazardous waste material.

The problem calls that to use local waste material for the need of research however using CKD in civil engineering works. In this study soils of different areas were tested for varying percentage of CKD by weight which can give satisfactory results for slope stability, foundations and road embankments sub-grades and sub-bases for light traffic. The specimens were tested for gradation analyses, determination of in-situ and laboratory moisture content, determination of specific gravity, compaction testing by standard proctor method, California Bearing Ratio testing, direct shear and UCS testing.

1.3 SCOPE

The research work was primarily an analytical study of soil modification by CKD, where the soil samples were tested for soil classification by sieve analysis (AASHTO Classification), in situ and lab density, specific gravity, permeability, moisture content, compaction testing by standard proctor method, CBR testing and unconfined compressive strength by varying weight of CKD by percentage.

1.4 OBJECTIVES

Following objectives were aimed at:

- Characterization of different soils to establish their existing basic/engineering properties.
- Adding CKD in different percentages for optimization /enhancement of engineering properties of soils.
- Evaluating effectiveness of soil stabilization by adding CKD.

1.5 Methodology of Research

The lab work conducted by the researchers was divided into three parts as under:-

1.5.1 Soil Characterization

The soil was categorized according to matrix shown in Table 1.1.

Ser	Journal	Author	Soil type (USCS)						Soil properties (Basic/Engg)							
			SP	SM	SC	SC-SM	CL	M	LL	PL	PI	OMC	MDD	UCS	CBR	K
1																
2																
3																
4																
5																

1.5.2 Soil Stabilization

The soil was stabilized by adding different percentages of CKD and performing different tests.

Ser	Journal	Author	Stabilization Methodology Adopted - % CKD (lab & field tests)				
			OMC	MDD	UCS	CBR	K
1							
2							
3							
4							
5							

1.5.3 Effect of Soil Stabilization

The effect of soil stabilization was checked and recorded in the template as shown in table below

Ser	Journal	Author	Improved Soil properties						
			OMC	MDD	UCS	CBR	K	etc	etc
1									
2									
3									
4									
5									

1.6 Literature review

The previous studies conducted on the subject were thoroughly evaluated and cited as literature review in chap 2.

1.7 Lab Test Program

Lab test program is covered in the Chap 3 covering 1.5.1 to 1.5.3. Methods or procedures adopted in soil characterization, stabilization were covered along with ASTM.

1.8 Result Analysis

The result inferred from soil stabilization for each application of stabilized soil are discussed in Chap 4.

1.9 Conclusions and Recommendations

The efforts are presented in Chap 5.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

This part includes many research articles, projects and publications on the soil stabilization with waste product of cement, cement kiln dust (CKD). The researches on this topic clearly tells our choice of the project. CKD is environmentally hazardous but its use in some good manner could reduce its effect. The soils of different parts of world were studied and tells us that different properties were improved and it is beneficial than non-stabilization techniques.

The section is divided into different parts according to the use of soil in different fields. The parts are:-

- Stabilization of soils for pavement construction.
- Stabilization of soils for foundation construction.
- Stabilization of soils for slope stability.
- Stabilization of soil for constructing dams.

Different types of soils are there in the world that are unsuitable for construction that could be made suitable for construction. Their properties are enhanced and modified according to the requirement of the project. Soils are characterized and the properties are then tested according to their type.

2.2 Stabilization of soils for pavement construction

The most common example of the use of CKD to stabilize soils is in pavement construction. CKD is mostly used to stabilize the subgrade and sub base according to the traffic of that area.

2.2.1 CL Soils

Clayey soil mostly have swelling problem due to less strength and settlement. Thus by use of CKD in soil with the 5%, 10%, 15%, 20% and 25% improves the soil. Observation was that as CKD increases the soil strength increased and became useful for pavement construction(B. Kumar & Puri, 2013).

Black cotton soil that according to USCS classification is clay material. The strength was improved by adding 5, 6, 8 and 10% of CKD. The CBR test was conducted and the bearing capacity was improved(A Salahudeen & Akiije, 2014).

The grey color soil named as Black cotton soil was tested with 5%, 10%, 15%, 20% and 25% CKD of weight of soil. It was used in application of stabilized soil in waste contaminated area(Manisha Meena, 2018).

Due to advancement in technology the presence of manmade chemicals in the soil causes the land contamination. They change the properties of soil. Soil stabilization of such soil improves its properties. The soil was stabilized with 1%, 2%, 4%, 6%, 8% and 10 % of CKD(Gupta, Pandey, & Srivastava, 2015).

CKD is the waste material that is produced in excess during cement production. It has harmful effect on the environment. Its use in soil stabilization increases the risk and increase the properties of soil. CKD with 2.5%, 5%, 7.5% and 10% of soil was used. Laboratory tests were conducted to check the soil properties with or without addition of CKD(Rimal, Poudel, & Gautam, 2019).

Lab tests were carried out to observe the use of CKD as soil stabilizer. The CKD was used in 5%, 10%, 15%, 20%, 25% and 30% of soil. Soil properties were tested with increasing amount of CKD. LL and PL increased. Addition of CKD also improves the permeability of clay soil(Alawi, 2016).

Lab test were carried on black cotton soil with CKD of 0%- 16% soil used. Soil tests carried out to check the eligibility of soil to be used as a pavement material(GK Moses & Saminu, 2012).

Pavement constructed on good properties of subgrade reduces initial cost and maintenance. The poor subgrades are stabilized with some waste material such

as CKD. In this project CKD of 5% - 30% of soil was tested and the properties were tested. The results showed that adding CKD of 20% cured for 14 days increases CBR (Mosa, Taher, & Al-Jaberi, 2017).

The soil in the Nile delta was studied and its properties were improved by adding the 5%, 10% and 20 % of CKD. The test results showed great improvement in the properties(Ismail & Belal, 2016).

The clayey soil was stabilized to construct pavement. The subgrade soil was treated with 0.5%, 1%, 1.5%, 2% and 2.5% of CKD and it was noted that 2% CKD achieved the targeted rate of 25% of CBR(Jasim & Mohammed, 2019).

In this research project two test sections were constructed that were stabilized with CKD in Detroit. CKD was used in 6, 8 and 10% of the soil. Test results showed that CKD stabilized both test sections. Test results of Dynamic cone penetrometer showed increase in subgrade strength(Bandara & Grazioli, 2010).

In this project two samples of CKD were used one fresh one and the other was 12 years old. CKD was added in 8%, 15% and 25% of the soil. The results were improved and the soil gain more strength in fresh CKD samples due to the presence of lime in it(Sreekrishnavilasam & Santagata, 2006).

2.2.2 SP Soils

The paper shows the research done on soil stabilization with different waste materials. Lab tests of soil with 10% to 50% CKD were done. CBR and UCS tests were performed. The results showed improvement in the soil properties(Michael, Singh, & Kumar, 2016).

Dune sand of Iraq was studied and it was characterized as SP. The dune sand was stabilized with percentages of 2.5%, 5% and 7.5% of CKD and 28 days curing was done. Soil properties of strength, cohesion and penetration were improved. Thus it was an economical solution to stabilize it(Rammal & Jubair, 2015).

In this project there is review on the applications of CKD in different fields. CKD was tested with 25% - 30% of CKD. The study results tells us the benefits of use of CKD (Elbaz, Aboulfotoh, Dohdoh, & Wahba, 2019).

In this project CKD was mixed with red mud and both were mixed to stabilize the SP soil. Both of them are waste material and annually dumped at a large scale. So CKD was mixed from 0 % - 25% and the properties were improved(Rana & Gupta, 2019).

This research gives a review on use of CKD for soil stabilization and waste stabilization. CKD was used 0%-50% and cured for 14 days. Results showed that 34% of CKD increases pH above 10 which is sufficient to stabilize(Rahman, Rehman, & Al-Amoudi, 2011).

In this paper the soil of Egypt was treated with10%, 20% and 30% of CKD and then the compressive strength was tested with OMC. Soil was stabilized for roads subgrade(Abdel Aziz, Altohamy, & Towfeek, 2010).

The CKD from cement factory in Riyadh was taken and tested on SP soil. CKD was used in 4%, 10% and 16% of the soil. Results showed that CKD reduces plasticity, increases pH and OMC(Al-Refeai & Al-Suhaibani, 2009).

In this project high dosage of CKD was used from 0% - 100% of soil and cured for 0 – 28 days. Tests of UCS, Direct shear and permeability were done. The properties of soil were increased as the CKD content increases(Mohamed Y Al-Aghbari & Dutta, 2009).

The tests were carried out on the soil of USCS classification SP. The CKD was mixed with soil in 0%, 2.5%, 5%, 7.5% and 10%. The UCS test were carried out and it shows UCS increases with percentage of CKD(Rimal et al., 2019).

2.2.3 SC soil

In the project SC soil was treated with CKD of 0% - 12%. All the properties OMC, hydraulic conductivity and permeability were tested. The results showed the improved properties(G Moses & Afolayan, 2011).

In the country like Nigeria that is still developing the material cost is reduced by using waste material and increasing the soil properties. The CKD was added and tested for subgrade and subbase material. 0%-24% of CKD was used in tests. Compaction, strength of soil and consistency limits were checked. The 24% CKD showed the most improved CBR and UCS(Andrew, 2012).

2.2.4 SW soil

In this project SW soil was treated with CKD from 0%-24% of the soil. The soil properties were improved such as compaction, permeability, CBR and UCS(Okafor & Egbe, 2013).

2.3 Stabilization of soils for foundation construction

The use of CKD to stabilize soil is also applicable in foundation construction. The soil was stabilized to increase its bearing capacity and strength.

2.3.1 CL soils

The soil in the Nile delta was studied and its properties were improved by adding the 5%, 10% and 20 % of CKD. The test results showed great improvement in the properties. The MDD decreases and OMC increases as percentage of CKD increases. The soil properties showed great improvement for foundation construction(Ismail & Belal, 2016).

In the research it showed that the poor soil conditions result in poor strength and bearing capacity. In this project soil was stabilizes with 0% to 30% of CKD. Soil properties like compaction, atterberg's limit, CBR and permeability was tested. The properties were increased by addition of CKD(A. Kumar & Singh, 2017).

The Black cotton soil in India have moisture content variation and due to it causes damage to super structures and foundations. CKD was used to improve its properties. CKD with 0%-25% of soil weight was used. The CKD showed improvement in soaked CBR and UCS(Singh, Jain, Singh, & Jain, 2015).

The research was conducted to check the feasibility of use of CKD for soil stabilization. Two soils were tested with CKD. Strength, unconfined compression

and permeability was checked. Strength of soil was improved and coefficient of permeability was reduced(Al-hassani, Kadhim, & Fattah, 2015).

2.3.2 SP soils

The research was carried out to check percentage of CKD for dune sand stabilization and check the chances of resting shallow foundation on it. CKD causes decrease in LL of soil and CKD mixture. There was increase in φ and (c). The CKD was mixed in 0%, 4%, 8% and 12%. The samples were cured for 14 days(Albusoda, Salem, & Salem, 2012).

Dune sand of Iraq was studied and it was characterized as SP. The dune sand was stabilized with percentages of 2.5%, 5% and 7.5% of CKD and 28 days curing. Properties of strength, cohesion and penetration were improved. Thus it was an economical solution to stabilize it(Rammal & Jubair, 2015).

The soil of desert areas of Oman have soil of SP classification. This causes many problems in construction of infrastructure. The bearing capacity was very less and structure collapse on wetting of soil. The CKD was added in percentages of 2%, 4%, 8%, 10% and 12%(Mohammed Y Al-Aghbari, Mohamedzein, & Taha, 2009).

2.4 Stabilization of soils for slope stability

Slopes in some areas are of quite importance because they are needed for regular flow of water in case of canals, for making the embankments etc. The soil of some areas is not stable enough to remain in shape and collapse. CKD is used as an additive to stabilize it and increase its strength and cohesion.

2.4.1 SP soil

In Egypt the irrigation system originates from the River Nile. The canals and branches coming out from the river are made on sandy soil. There are many chances of collapsing and slope stability is main problem. So CKD was used in 10%, 15% and 30% of soil used. Three models were built of canal embankment to check slope stability. The results showed great increased in soil stability(ElMashad & Hashad, 2013).

2.4.2 CL soil

The soil was stabilizes with CKD of 0.5%. 1%, 1.5%, 2%, 2.5% of the soil. The main purpose was to increase the CBR of the soil. It was noted that 2% CKD was able to achieve 25% of CBR rate. The soil was applicable in shoulders and slopes of culverts(Jasim & Mohammed, 2019).

2.5 Stabilization of soil for constructing dams

The retention structures that could be made are natural or built dams. The stability of upstream tailing dams was investigated using additives. Tests were conducted to show any improvement with use of non-traditional additives such as mixture of Cement, CKD and Gypsum. Soil parameters were taken to make finite element model using PLAXIES 2D to imitate soil behavior that is improved when tailing dam is built. The model showed improvement in overall stability of tailing impoundments. It was found very essential to construct dams(Alsharedah, 2015).

Soil stabilization by addition of CKD, covers wide variety of soils along with its practical applications in the field of civil/geotechnical engineering as mentioned above showed a suitable alternative for soil modification.

CHAPTER 3
MATERIALS AND METHODOLOGY

In the project the data was collected from different research papers. All the research papers were having different soil classification and properties according to their area. Different methodologies were adopted for each research papers according to the properties which were to be improved and the purpose for which the soil was being stabilized. Here common soils, basic properties, engineering properties and methods/procedures adopted would be discussed.

3.1 MATERIALS

The materials that are used are:-

3.1.1 SOIL

The soil characteristics and properties depend upon the type of the soil, in which area it is located and under which condition it is being used. The soils used were mostly SP, CL, SM and SC according to the USCS classification. The moisture content and other properties of soil vary with respect to area.

3.1.2 CKD

CKD is a fine powder like substance. It consists of CO_2 that is a reactive compound. It depends upon that what type of material is used and how it is collected. It is a by-product of cement clinker. It contains different amounts of alkali, sulfates and lime. The CKD from taken from different factories from different part of world have different classification and composition. So its result upon the properties of soil would be different.

3.2 METHODOLOGY

Different methods have been adopted for the stabilization of soil with CKD as per the desired engineering properties of soils and the nature of the project. The ASTM used for the project are:-

- Grain size analysis. **ASTM D6913 / D6913M - 17**
- Determination of Moisture Content of Dune Sand. **ASTM D4944/D4959**
- Determination of Specific Gravity of Dune Sand. **ASTM D 7172**
- Relationship between Dry Density and Moisture Content. **ASTM D2216 - 19**
- California Bearing Ratio Test. **ASTM D1883 - 16**
- Unconfined Compressive Strength Test. **ASTM D2166 / D2166M - 16**

3.2.1 Methodology for the Stabilization of soils for pavement construction

MDD test done to check suitable compaction. Then CBR test is done to check the thickness of the layer of the layer. Then the UCS test is done to observe UCS of soil. Different percentages CKD were checked against different types of soil and results were checked (Andrew, 2012; B. Kumar & Puri, 2013; Manisha Meena, 2018; GK Moses & Saminu, 2012; Okafor & Egbe, 2013; AB Salahudeen, Eberemu, & Osinubi, 2014).

In these papers firstly the soil was classified. Then OMC test conducted to check OMC. Then MDD test was carried out to check the suitable compaction and in the end CBR. These test on simple then on treated soil was carried out to check the trend of improvement (Gupta et al., 2015; Rahman et al., 2011; Rimal et al., 2019)

In these paper firstly grain size distribution was done and soils were classified as SP soils. OMC test carried out to note moisture. MDD was also done. UCS was done to check strength of soil which is main parameter. Permeability of soil was also check before and after addition of the CKD(Mohamed Y Al-Aghbari & Dutta, 2009; Alawi, 2016).

In these paper the soil was first classified according to USCS. Then the OMC of the soil was checked. Then MDD and CBR of the soil was checked without and with CKD in the sample (Elbaz et al., 2019; G Moses & Afolayan, 2011; A Salahudeen & Akiije, 2014).

In this papers the soil is classified. Then the CBR test is performed to check the strength and thickness of the layer. Then swell pressure of soil is checked (Mosa et al., 2017).

In this papers the soil is tested with methods such as OMC, MDD, CBR and UCS. Another method that is direct shear method that is also applied(Mohamed Y Al-Aghbari & Dutta, 2009; Michael et al., 2016).

3.2.2 Methodology for Stabilization of soils for foundation construction

In these projects OMC and MDD was checked and the percentage of CKD was added and tested again. CBR and UCS were done on the samples to observe strength. Direct shear test was done to check shear strength. Triaxial test was done to check the properties and deformability of soils (Mohammed Y Al-Aghbari et al., 2009; Al-hassani et al., 2015; Albusoda et al., 2012; Singh et al., 2015).

In these research papers the SP soil was treated. The Direct shear test was done to check the shear strength. Then the penetration test and bearing test was done to check the soil improvement (Abdulabbas, 2017; Rammal & Jubair, 2015).

In these research projects the soils was classified as CL soil. Its Atterberg's limit was checked. It was tested with OMC and MDD. Their CBR value was found to check its strength after the addition of the CKD. (Ismail & Belal, 2016).

In this paper the soil was classified according to USCS. The Atterberg's limit was checked. The MDD and OMC was also checked. CBR of the soil was noticed strength of the soil. Then the permeability of the soil was checked (A. Kumar & Singh, 2017).

In this research project grain size distribution was done to classify according to USCS. OMC and MDD was done to check the moisture. The UCS test was

conducted to check strength of soil. Hydraulic conductivity and volume shrinkage was also tested (Oriola & Moses, 2011).

3.2.3 Methodology for Stabilization of soils for slope stability

In this research paper the soil was classified as per USCS classification. The MDD and OMC of soil and stabilized sample was checked and compared. The CBR and UCS test conducted to check strength. The permeability of the soil was also checked (ElMashad & Hashad, 2013).

In this project the grain size distribution was done. The Atterberg's limit was tested. The OMC of sample was checked. MDD of the mixture was also tested. UCS test tells the strength of the mix(Jasim & Mohammed, 2019).

3.2.4 Methodology for Stabilization of soil for constructing dams

In this paper the soil was classified according to USCS. The OMC and MDD was noted for soil before and after stabilization. The CBR test was done to check soil strength. Hydraulic conductivity of the soil was tested. Volumetric shrinkage strain was also checked. Soil modification parameters were used to make finite element model using PLAXIES 2D to simulate behavior of soil(Alsharedah, 2015).

CHAPTER 4

ANALYSIS OF RESULTS AND DISCUSSION

Different tests were conducted on the soils of different areas with different soil properties. The results were checked for the improvement in soil properties for the purpose soil is being stabilized. Different soil papers were studied and their test results were analyzed for CKD utilization. The results are analyzed and categorized on the basis of methodology used and the purpose of the stabilization.

4.1 Results for the Stabilization of soils for pavement construction

- In this project clay was tested with 0 to 25%of CKD. The results are of compaction are:-

Table 4.1 Characteristics of Soil with CKD

SAMPLE	OMC (%)	MDD(g/cc)
Soil + 5% CKD	19.1	1.68
Soil + 10% CKD	18.8	1.69
Soil + 15% CKD	18.4	1.74
Soil + 20% CKD	15	1.77
Soil + 25% CKD	16.4	1.74

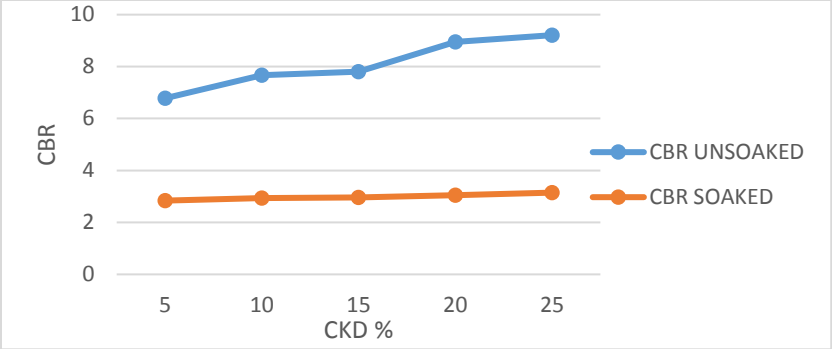

Figure 4.1 CBR values vs CKD percentages

Table 4.2 Values of UCS and Undrained Shear strength for CKD %

SAMPLE	UCS (Kg/cm^2)	Undrained Shear Strength (Kg/cm^2)
Soil	1.69	0.84
Soil + 5% CKD	5.25	2.62
Soil + 10% CKD	5.51	2.75
Soil + 15% CKD	5.63	2.81
Soil + 20% CKD	5.78	2.89
Soil + 25% CKD	5.68	2.84

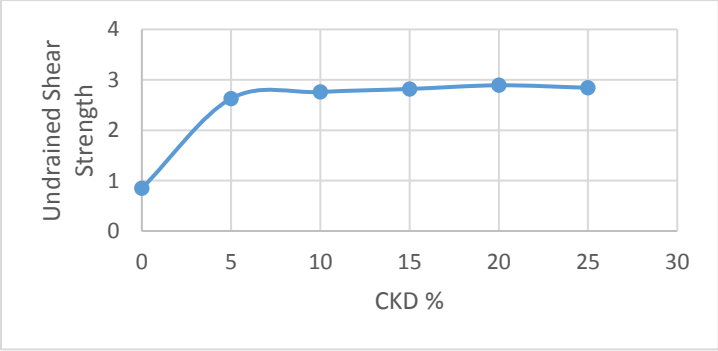

Figure 4.2 Undrained Shear Strength vs CKD %

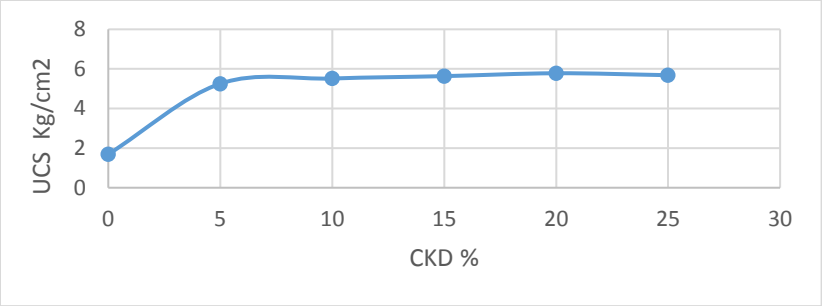

Figure 4.3 UCS vs CKD %

For the Clay OMC and MDD was 17% and 1.7 g/cc. The OMC ranges from 18.9 to 16% and MDD from 1.6 to 1.7g/cc. Thus the compaction energy increases. It was noticed as CKD % increases OMC decreases and MDD increases. The CBR in both soaked and unsoaked condition increases from 6.78 to 9.2 and 2.8 to 3.147. The UCS and Undrained shear strength increases with increasing CKD % up to 20%. More addition decreases the values of q_u and C_u (B. Kumar & Puri, 2013).

- In this project different soils were stabilized with 4%, 10% and 16% of CKD and different soil properties were tested.

Table 4.3 Engineering properties of different Soils

PROPERTIES	SOILS		
	1	2	3
USCS CLASSIFICATION	SM	SC	CL
LL	19.1	25.5	26.5
PI	1	8	7.5
SPECIFIC GRAVITY	2.69	2.81	2.81
MDD	20.9	20.5	17.4
OMC	7.4	8.6	17.2

Classification of soil as SM, SC and CL. The Atterberg's limit was tested and there was an increases in PL and LL and there was decrease in PI with addition of CKD. Soil workability increases. The pH also increases. The pH increases above 12. The soil acidic reactions are reduced. The soil was having low CBR value. The addition of CBR increases the CBR from 6.7 to 20.2 for 2% CKD. The addition of 10% CKD increases CBR to 800% which was dramatic. The permeability of the soil decreases with 4%. With 10% the permeability of CKD was decreased a little bit (Al-Refeai & Al-Suhaibani, 2009).

- In this paper the soil was stabilized with CKD % of 5, 10, 15 and 20.

Table 4.4 Engineering Properties of CKD Soil mix

Properties	CKD%				
	0	5	10	15	20
LL %	67.4	65.2	70.4	67	62
PL %	20.7	20.5	19.3	17.8	14.2
PI %	46.5	44.8	51	49	47.5
SG	2.35	2.36	2.38	2.37	2.64
OMC%	24	23	22.5	18.6	17.5
MDD Mg/cm^3	1.4	1.5	1.55	1.65	1.7

PL, LL and PI decreases with CKD percentage. The MDD increases, OMC decreases as the CKD increases. The UCS value was increased a little from 0 days to 7 days. From 7 to 14 days UCS value showed less improvement but on 28 days the value showed a major increase(Manisha Meena, 2018).

- In this research paper the soil was stabilized with CKD % of 2, 4, 6 8 and 10. The soil classification, Atterberg limits and other soil properties were tested.

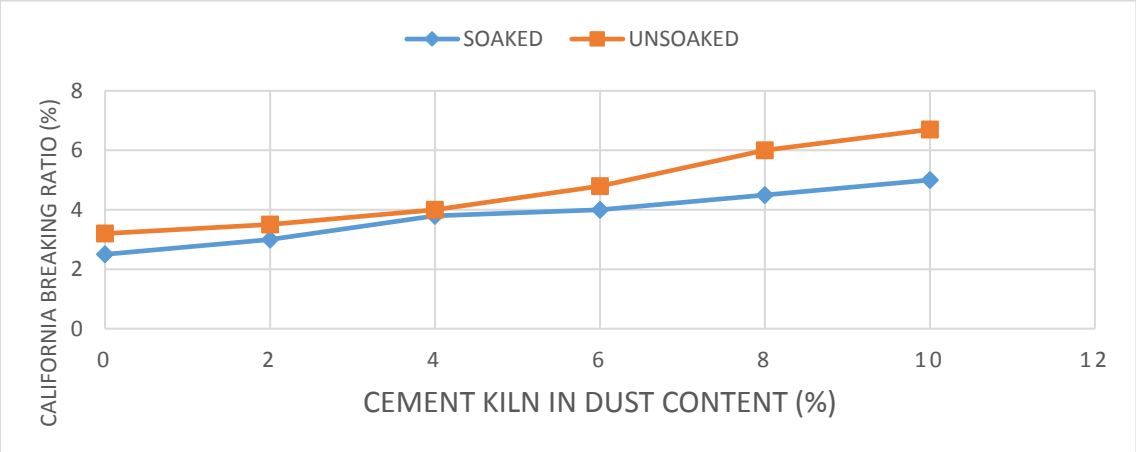

Figure 4.4 CBR vs CKD% of Soil

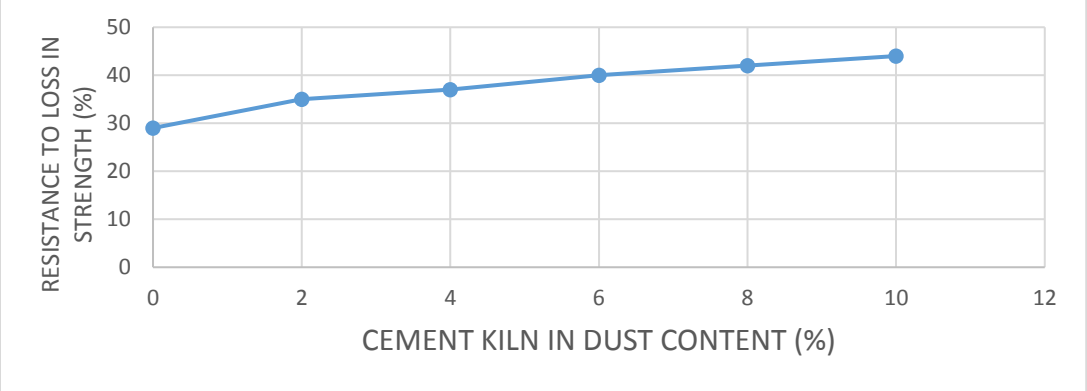

Figure 4.5 Loss in Strength vs CKD% of Soil

The MDD of the soil increases till 6% and then decreases. OMC increased till 6% of CKD and then started decreasing. The compaction increases and suitable compaction can be gained. As shown from the fig 4.10 the UCS increases with CKD but strength decreases with curing time. CBR value also show increment but not suitable for the subbase CBR. The loss of strength

resistance increases with CKD % increases. 7 days soaking of 10% CKD gives results that show it could be used in construction of subbase.

- In this paper the soil was stabilized using the CKD from 0%-24%.

  The soil was SC.The results showed that the Liquid Limit decreases up to 12% CKD and then increases with more addition. The results of PL was same as LL. There was decrease in plastic index from 14.5% to 11.1%. The clay content decreases. The results showed that MDD increased from 1.8 to 2.6 Mg/m^3 by adding 0 to12% CKD. There was decrease in MDD after 12% CKD due to brittle nature of soil. The OMC increased with the increase of CKD %. The unsoaked CBR increased from 22% to 80%. The soaked CBR trend was similar with less values. UCS increased with addition of CKD for 7, 14 and 28 days(Andrew, 2012).

- The research paper showed that the soil was stabilized with 0% to 25% of CKD. The results are:-

Table 4.5 Soil Properties of natural soil

PROPERTIES	RESULTS
LL %	41
PL%	27
PI %	14
MDD (Kg/m^3)	1820
UCS (KN/m^2)	390
OMC %	12
CBR %	2.1

MDD increased from 0% to 12% of CKD and then decreases. The more compaction can be achieved. The LL decrease with CKD till 12% and then increase slightly. Trend of PL is same of LL. The CBR value increased with

CKD. Results show increase in UCS value for 0 - 28 days. The UCS value increase with addition of CKD. The values of UCS for 7, 14 and 28 days are 1360 KN/m^2, 1450KN/m^2 and 1480 KN/m^2 (Okafor & Egbe, 2013).

- In this paper the soil was stabilized with 0-16% of CKD. The samples compacted using the energies of Western African Standard (WAS) and British Standard Light (BSL).

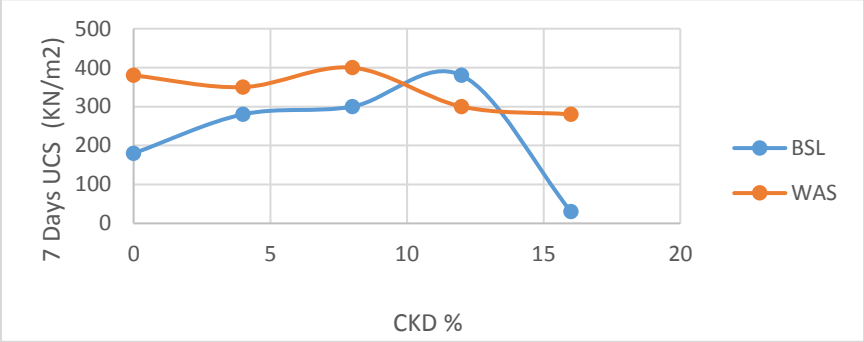

Figure 4.6 7 Days UCS vs CKD%

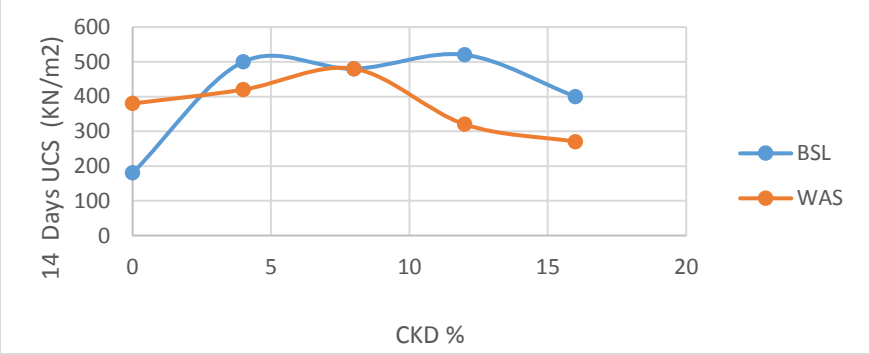

Figure 4.7 14 Days UCS vs CKD%

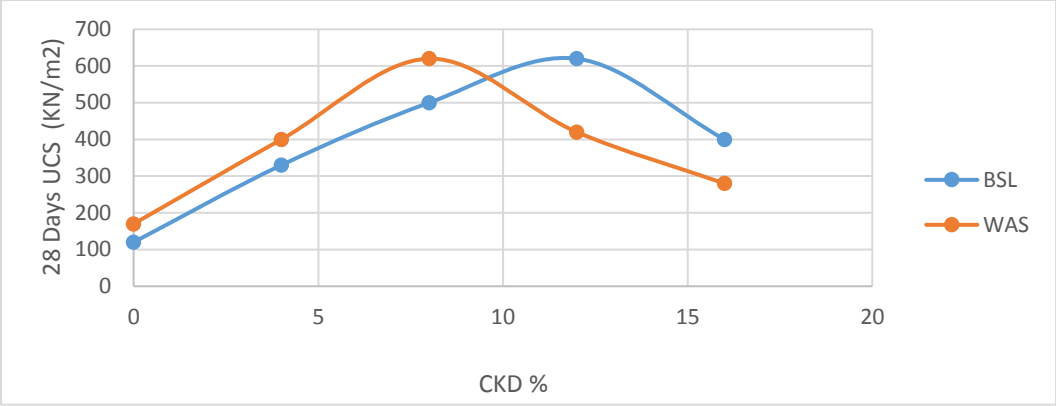

Figure 4.8 28 Days UCs vs CKD %

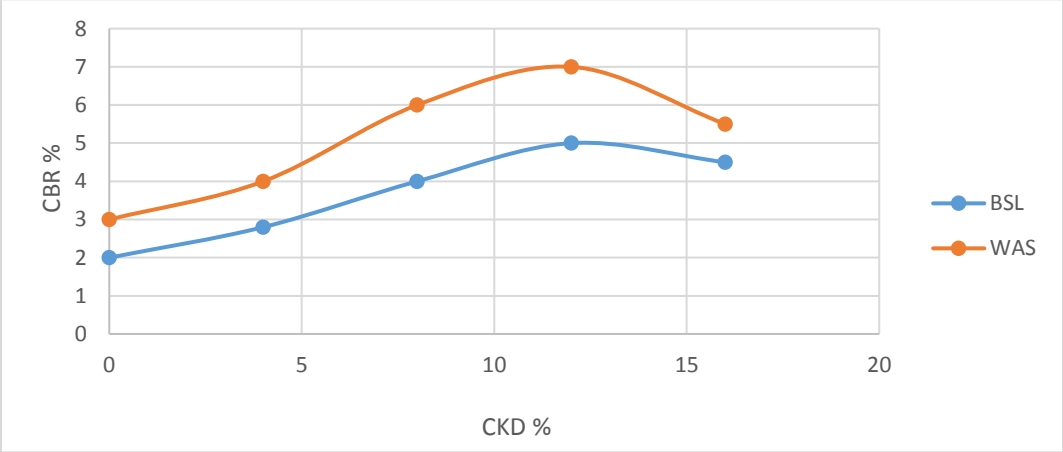

Figure 4.9 CBR% vs CKD%

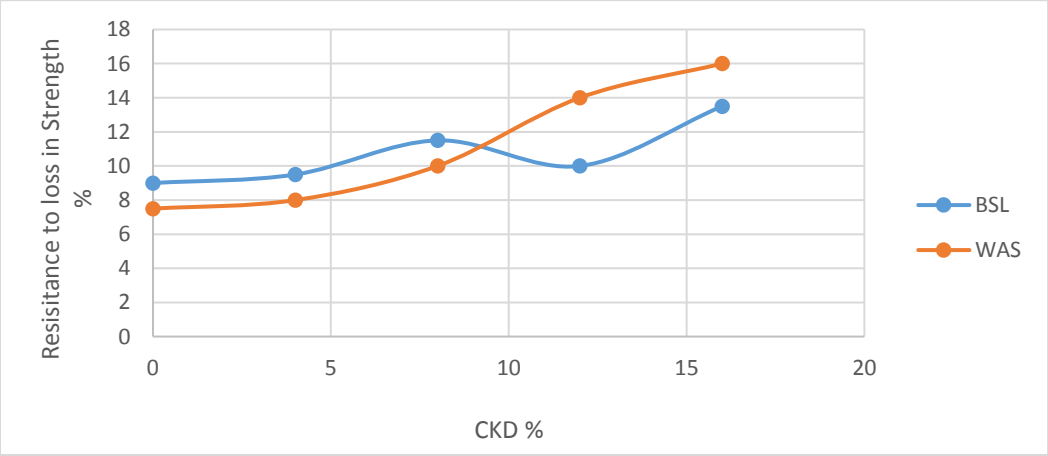

Figure 4.10 Resistance to loss in Strength vs CKD%

The soil was CL as per USCS classification. UCS values were 178 and 381KN/m^2 at energy levels of BSL and WAS. The 7 days UCS value for stabilized soil gave values of 394 and 420KN/m^2 at 12.5% and 8.5% CKD. These values fail the range of 787 – 1373 KN/m^2 which is requirement of subbase material. The CBR resulted in increase in strength of 2% and 3% from the soil for BSL and WAS. The peak value of CBR was 12% at 12% CKD for BSL and 16% at 12% CKD for WAS. It does not meet the minimum value required for subbase CBR that is 30%. The resistance to loss in strength peak values were 1.2 and 16.1% at 16% CKD for BSL and WAS(GK Moses & Saminu, 2012).

- In this paper two soils were stabilized using the CKD ranging from 0% to 50%. The results of the soil individually are:-

  For SABKHA, MDD decreased from 1.92 to 1.7g/cm^3 for CKD 0% to 50%. The OMC increased from 9.5% to 14.5% for 0% to 50% CKD. The UCS for unsealed samples increased from 680 to 3870 kPa for 0% to 50% CKD. MDD decreased from 1.77 to 1.55 g/cm^3 for 0% to 50%. OMC showed increment from 17 to 22.5% for 0 to 30% CKD. The strength of unsealed samples increased from 2700 to 4550 kPa. The improvement was 1.69 times 169%(Rahman et al., 2011).

- In this project the expansive soil was stabilized with CKD of 0% to 10%.
  The results noticed are:-

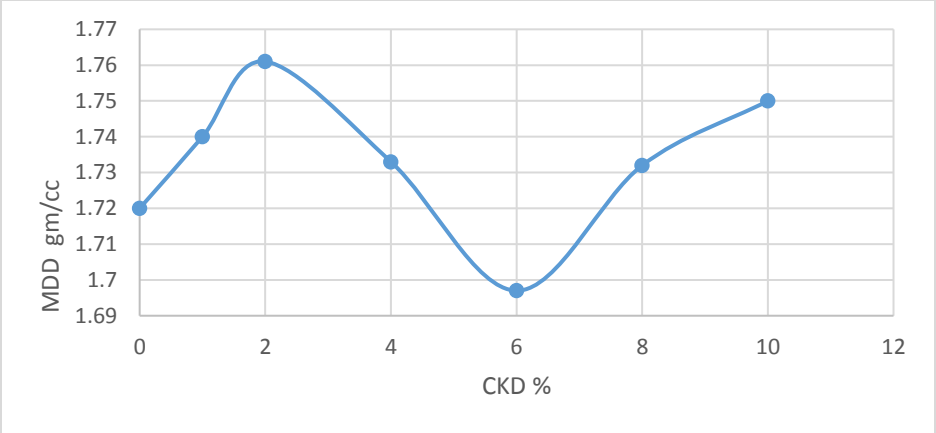

Figure 4.11 Max Dry Density vs CKD %

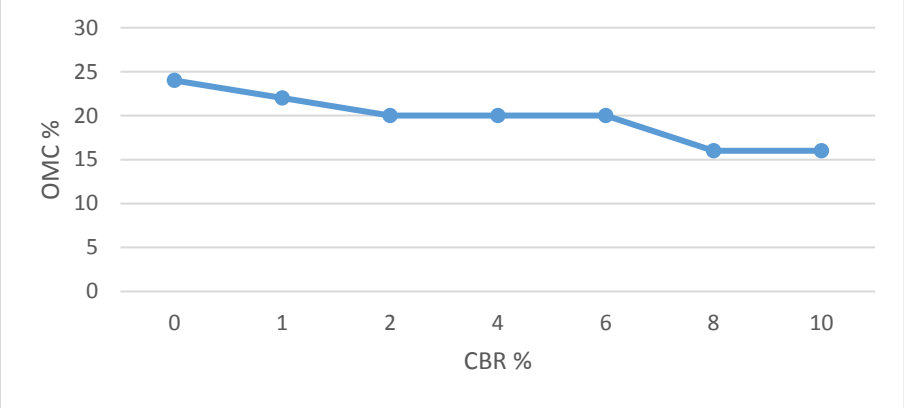

Figure 4.12 OMC % vs CKD%

Soil was CL. It was noticed, OMC and MDD decrease CKD. The compaction could not be easily achieved. Fig shows that OMC highest value is of natural soil. The UCS decreased at start if addition of CKD but CKD content increases the UCS value increases. The results shows that at 8% CKD soil is stabilized(Gupta et al., 2015).

- In this paper CKD % of 0% to 10% was taken to stabilize the soil. Test results are:-

Table 4.6 Unconfined Compressive Strength vs CKD%

DAYS	CKD %				
	0%	2.5%	5%	7.5%	10%
1 DAY	0.31	0.69	0.98	1.23	1.59
7 DAYS	0.58	2	2.5	3.4	5.2
14 DAYS	1	2.9	3.5	5.1	7.5
28 DAYS	1.5	5.6	7	9	10.1

Soil was classified as CL.The MDD and OMC increased with CKD content. The Compaction thus soil stability increases. UCS of soil increases CKD content. 28 days curing gives the most efficient results(Rimal et al., 2019).

- In this project the soil was classified as CL and the soil was stabilized with CKD of 10%, 15%, 20% and 30%.

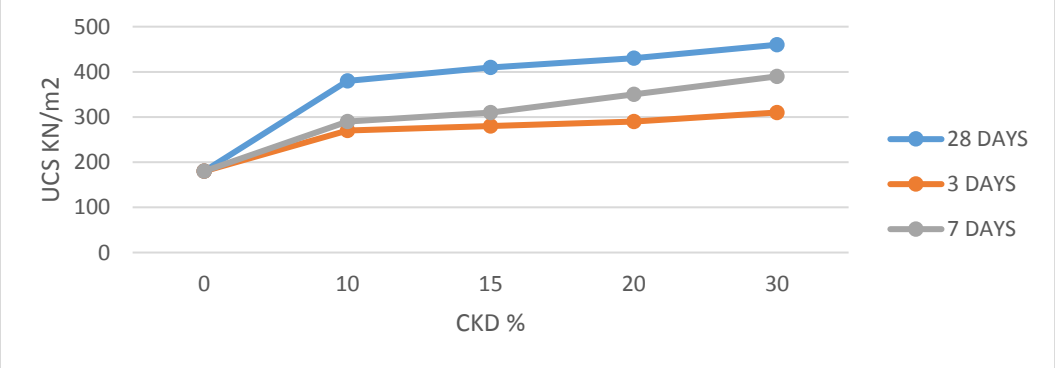

Figure 4.13 UCS vs CKD %

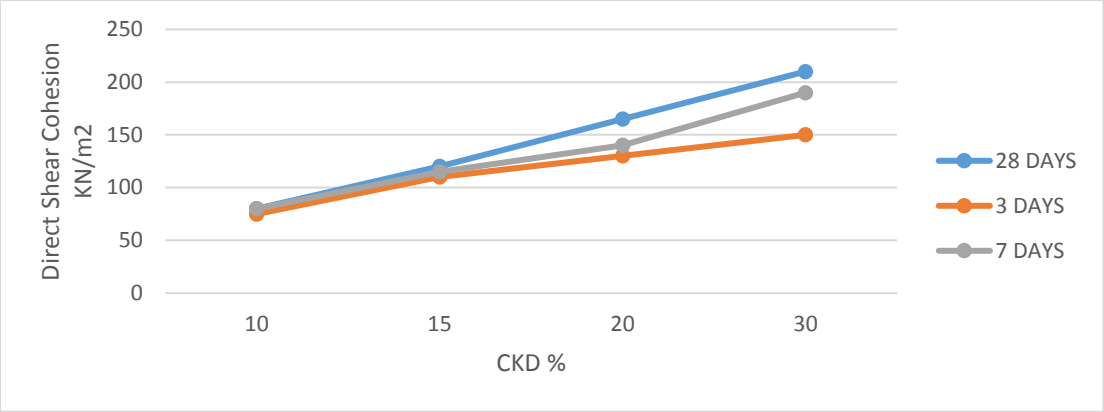

Figure 4.14 Direct Shear Cohesion vs CKD %

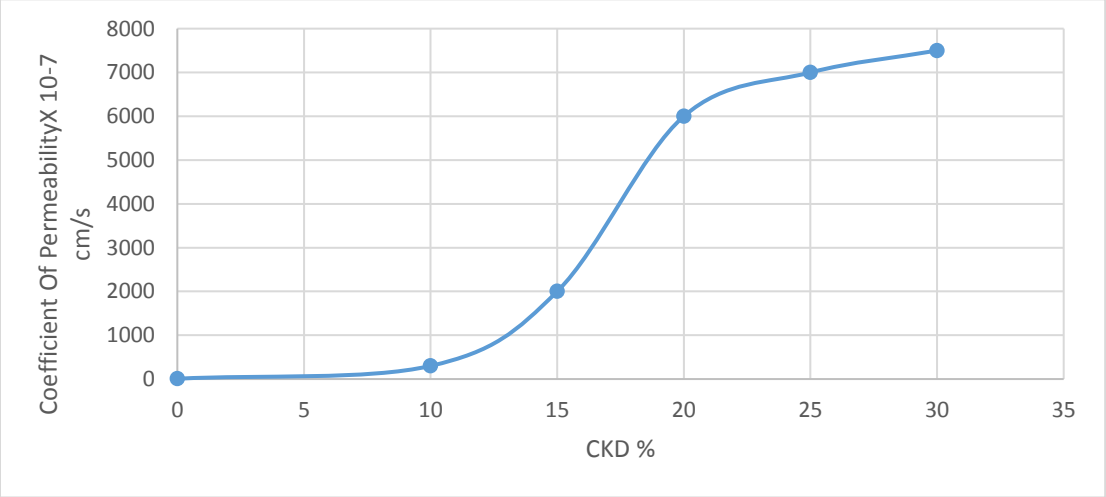

Figure 4.15 Coefficient of Permeability vs CKD%

Soil was CL according to USCS. Liquid limit increases 2.7% with increase in 5% of CKD. The PL also increase with 1.8% with similar trend as of LL. From Fig UCS increases with curing time. Increase of UCS 52, 66 and 100 % of 3, 7 and 28 days for 10% CKD. The similar trend was for other percentages of CKD. The permeability value decreases(Alawi, 2016).

- In this paper the soil treated with 25 to 30% CKD. The analysis of results are:-

  The SP soil was taken. There was decrease in void ratio. Thus soil stability increases. Hence, strength was increased and plasticity indices decreases. The swell potential decreases, raw clay from 9% to 0% when treated with 25%

CKD. Shear strength was increased and hydraulic conductivity was decreased to 10^{-9} m/s(Elbaz et al., 2019).

- In this paper the CKD % of 0, 2, 4, 6, 8 and 10% were used to stabilize the soil.

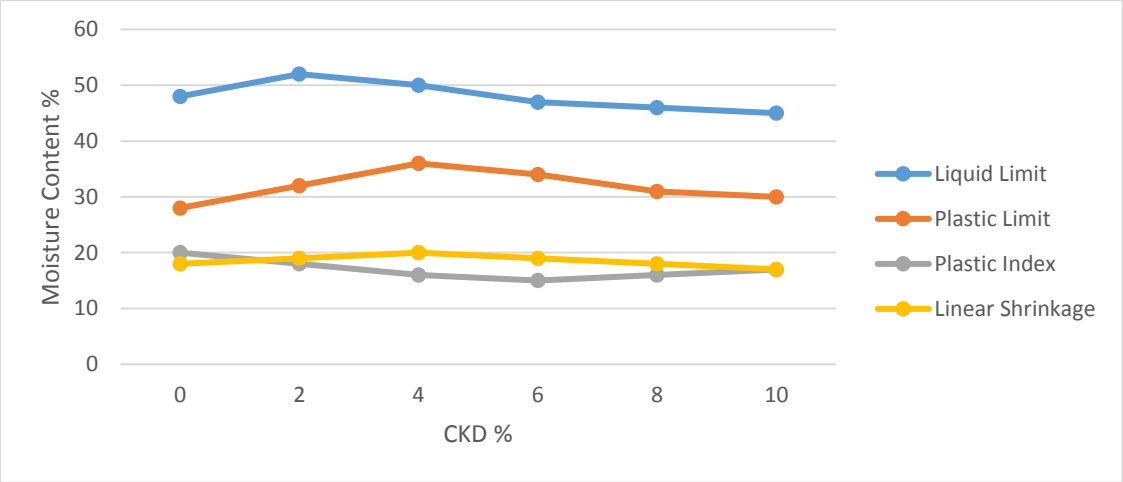

Figure 4.16 Moisture Content vs CKD%

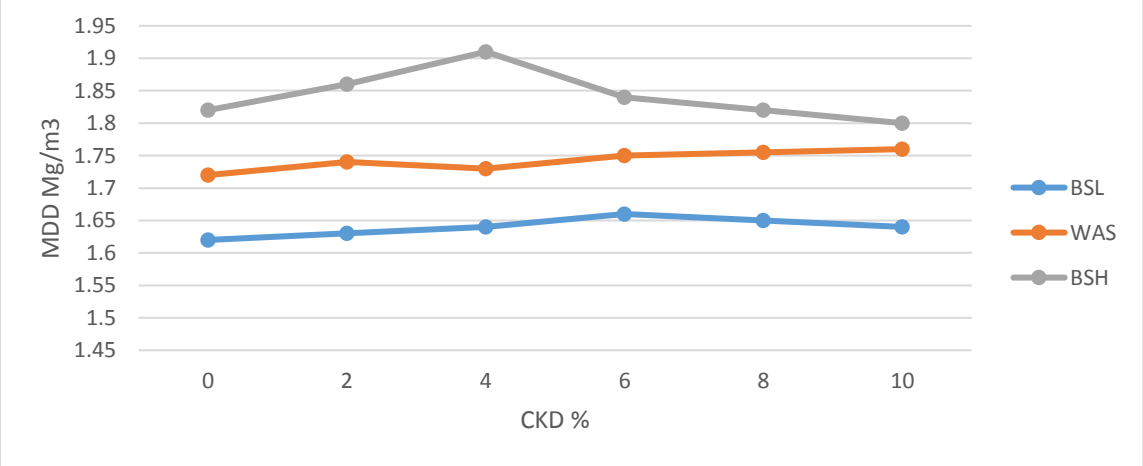

Figure 4.17 MDD vs CKD%

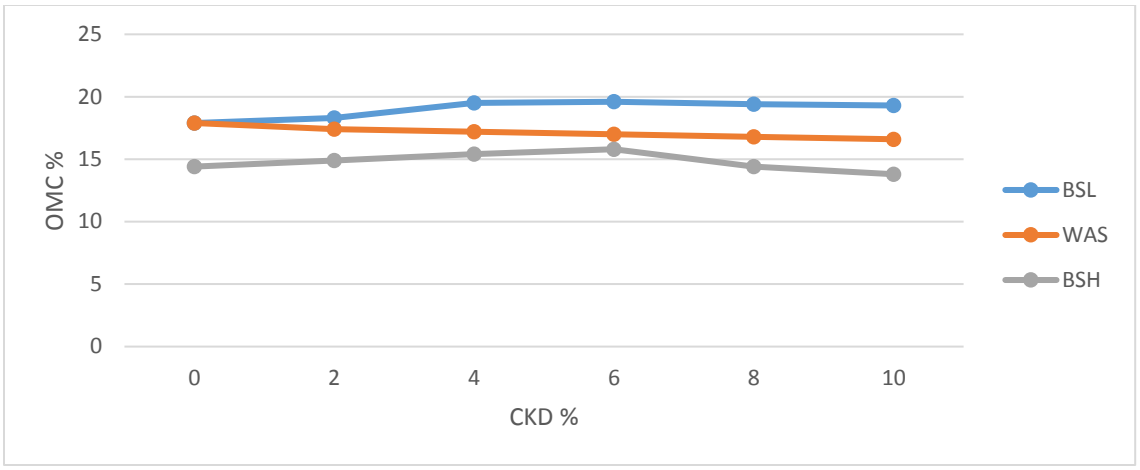

Figure 4.18 OMC vs CKD%

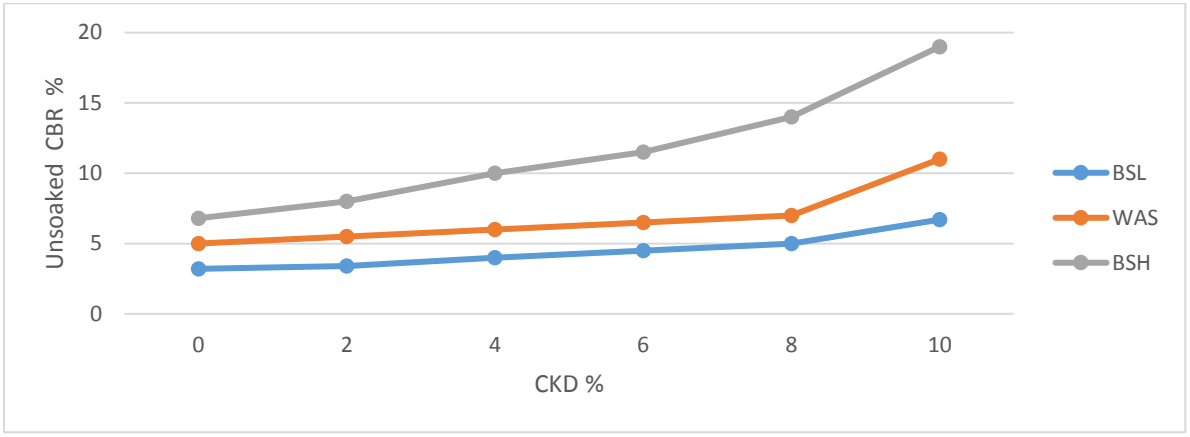

Figure 4.19 Unsoaked CBR vs CKD%

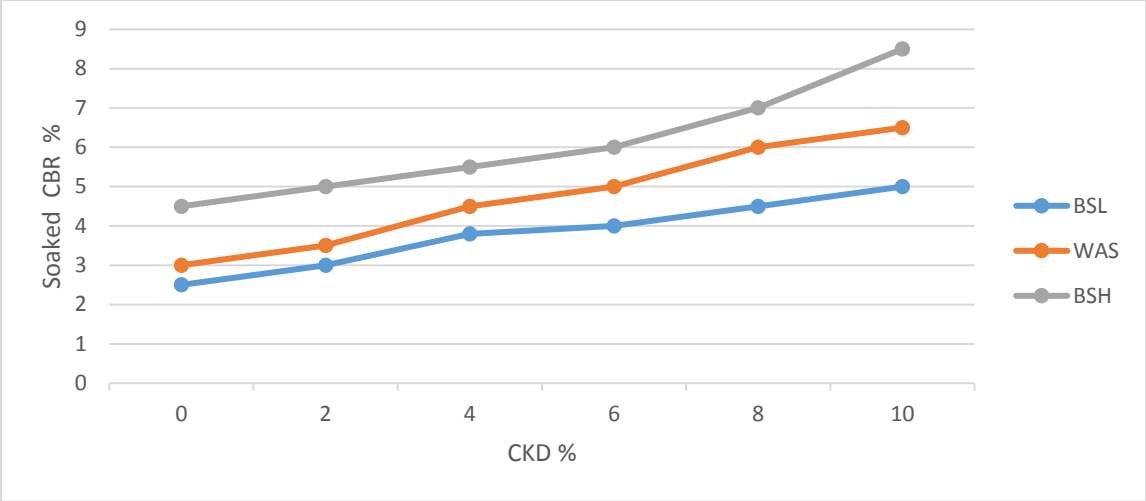

Figure 4.20 Soaked CBR vs CKD%

The soil was classified as CL. The liquid limit increases till 2% CKD. At 4% CKD the Plastic limit and linear shrinkage showed peak and then decreased. For BSH and BSL compactions the value of MDD increases from 1.6 and1.82 Mg/m^3 for soil to 1.66 and 1.9 Mg/m^3 at 4% and 6%. The WAS compaction decreases OMC as MDD increases. The values of CBR both soaked and un soaked increases with CKD percentage(A Salahudeen & Akiije, 2014).

- In the research soil was stabilized with 0%, 4%, 8% and 12% CKD. The soil was stabilized with BSL, BSH and WAS compactive effort. The results are:-

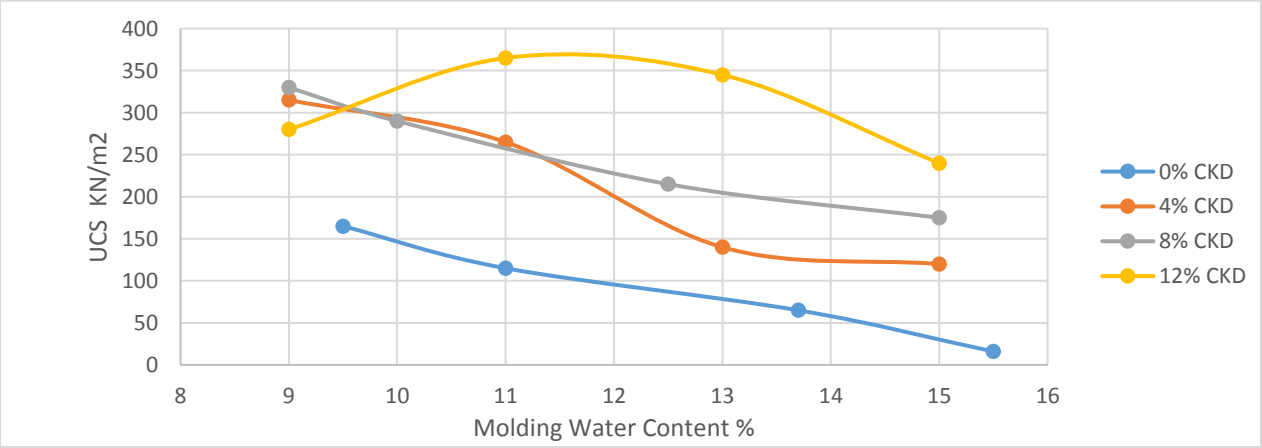

Figure 4.21 Water Content effect on UCS for BSL compactive effort.

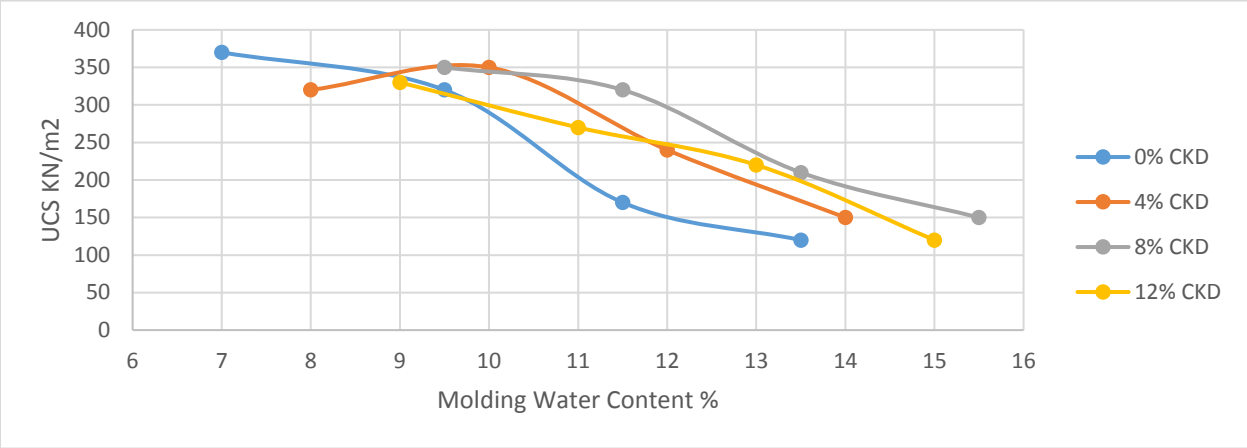

Figure 4.22 Water Content effect on UCS for WAS compactive effort

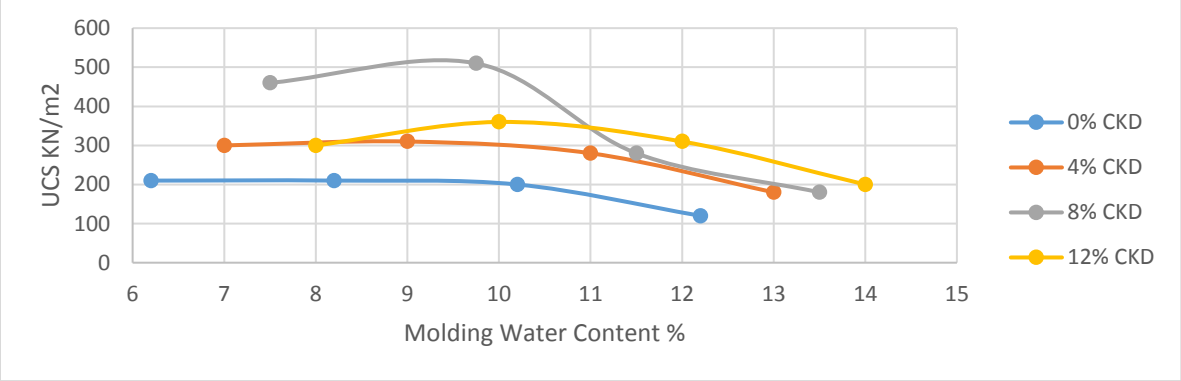

Figure 4.23 Water Content effect on UCS for BSH compactive effort

The MDD of BSH, BSL and WAS compactive effort decreases with increase in CKD. There OMC values showed increase for WAS and BSH compactive efforts and decrease for BSL compactive effort. The UCS of soil decreases with increasing water used in molding(G Moses & Afolayan, 2011).

- In this research project the soil was stabilized with 0 to 30% CKD value.

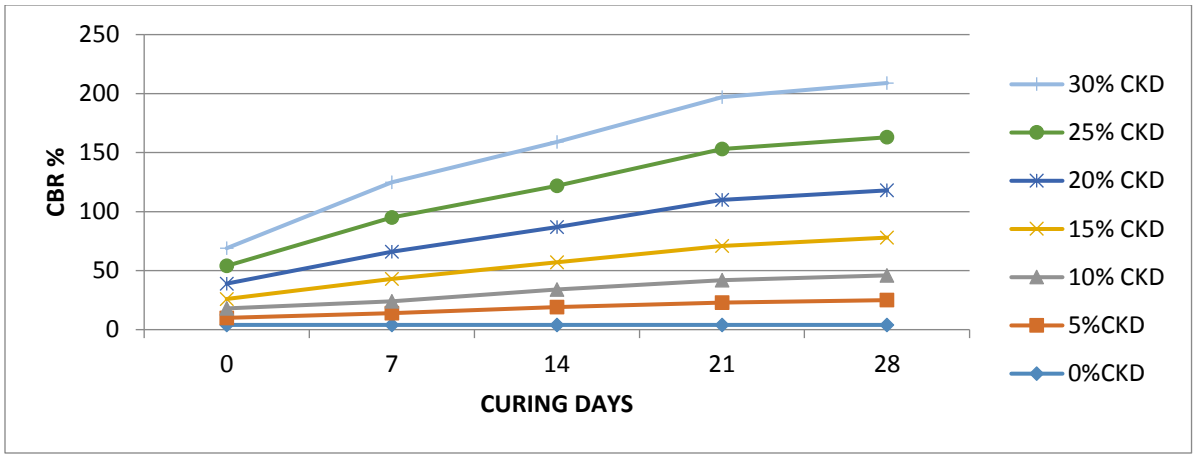

Figure 4.24 CBR vs Curing Days for Different CKD %

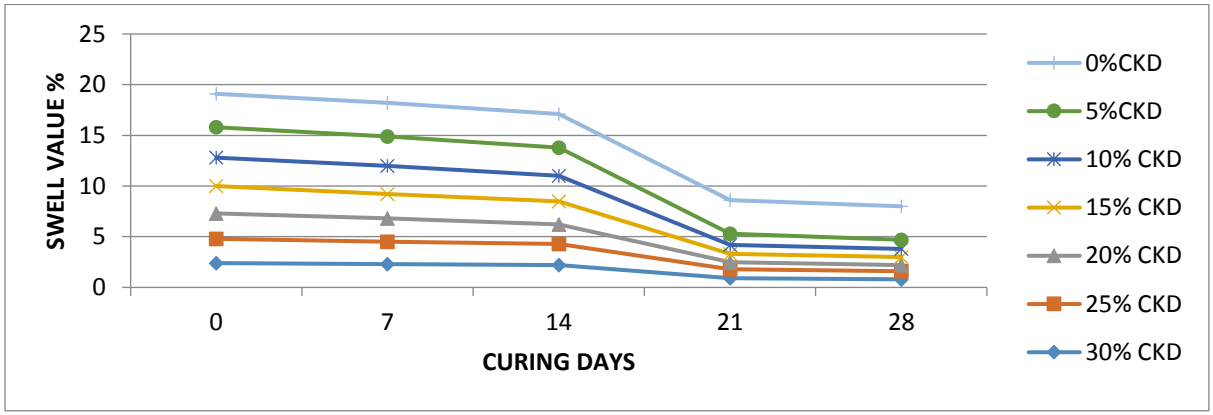

Figure 4.25 Swell Value vs Curing Days for Different CKD%

CL soil was treated. The values of CBR increases CKD and curing days. CBR values for 28 days and 14 days are insignificant. Thus, optimum curing time is 14 days. The swelling ratios decreases with increase in CKD. The 20% of CKD produced high CBR value and low swell ratio(Mosa et al., 2017).

- In this paper soil was stabilized with CKD 0% to 25% and the results showed that are:-

The soil was classified as SP. The values of soaked CBR and UCS increase with CKD content. DFS of the soil reduced from 30% to 5%. As the result of compaction it showed that MDD value increased and OMC reduced. Permeability also increases $4.8x10^{-4}$ to $1.43x10^{-3}$ cm/s(Michael et al., 2016).

- In this paper the soil was stabilized with CKD and the CBR and strength was checked and the results are:-

  The soil was SP and CL. DCP test shows a trend of increase in subgrade strength through stabilization with CKD. The increase in strength was 885%. CBR of the soil also increase with CKD content(Bandara & Grazioli, 2010).

4.2 Results for the Stabilization of soils for Foundation construction

- In this research paper the soil was stabilized with 4, 8 and 12% CKD and the results are:-

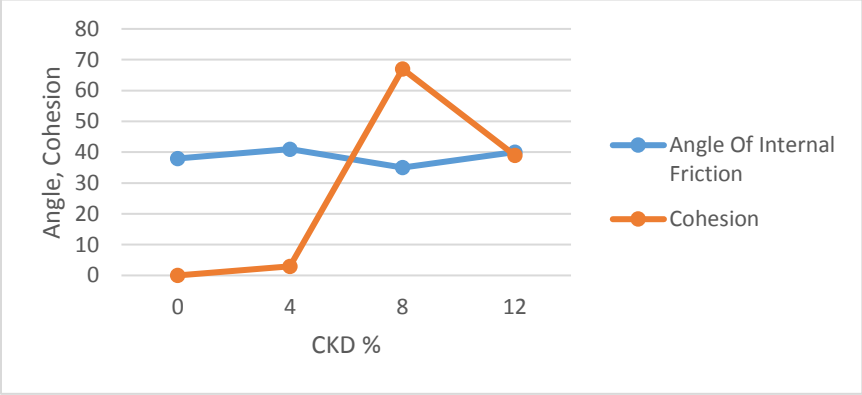

Figure 4.26 Angle of friction and Cohesion vs CKD%

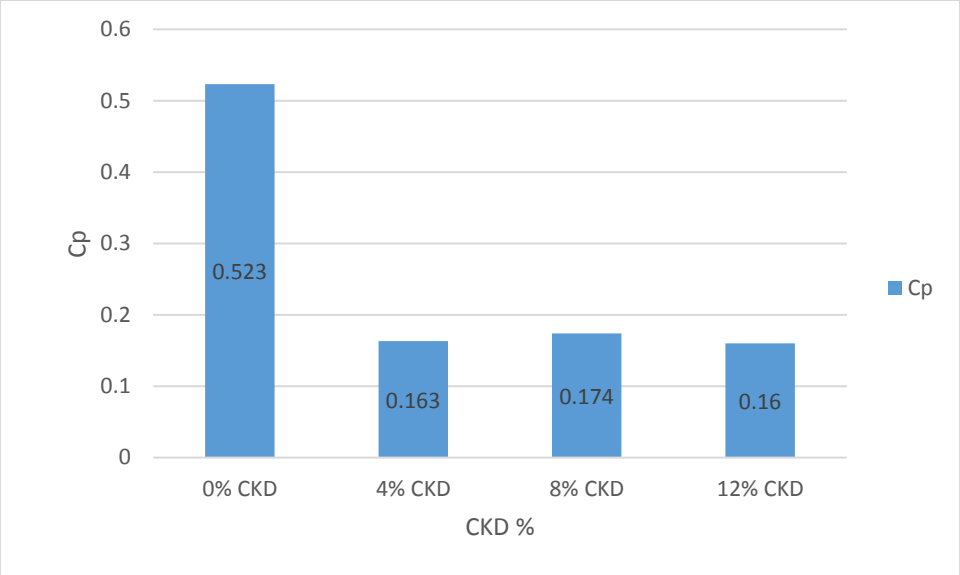

Figure 4.27 Collapse Potential vs CKD%

Soil was SP-SM. The Angle of friction remains constant with CKD. Thus the cohesion remains same. For 8% CKD highest strength was achieved. The collapse potential Cp dropped to half for stabilized soil. When water content was added specimen gain more strength. For the 7 days curing period highest cohesion and less change in angle of friction was observed(Albusoda et al., 2012).

- In this paper the soil was stabilized with CKD of 0 to 25% and results are:-

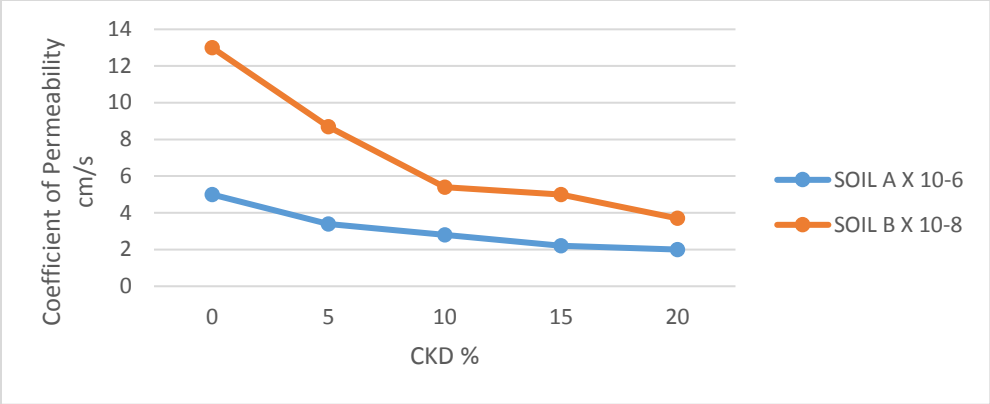

Figure 4.28 Coefficient of Permeability vs CKD%

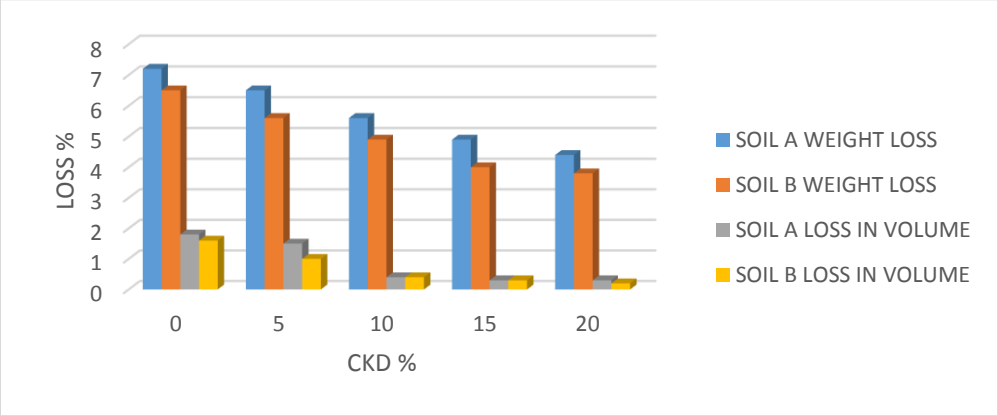

Figure 4.29 Loss vs CKD% for two soils

CL soil was treated. MDD decreases with CKD. The OMC first decreases and then increases. The UCS showed improvement with CKD. Permeability decreases. Loss in weight and volume decreases with in CKD(Al-hassani et al., 2015).

- In this research paper the CKD percentage of 0 to 25% was used to stabilize it. The results are:-

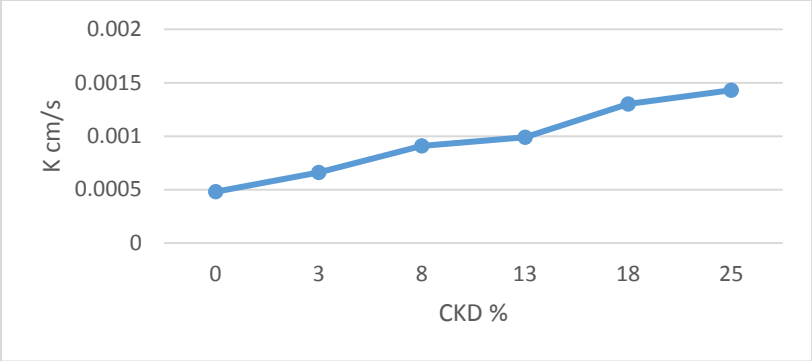

Figure 4.30 Coefficient of BCS with CKD%

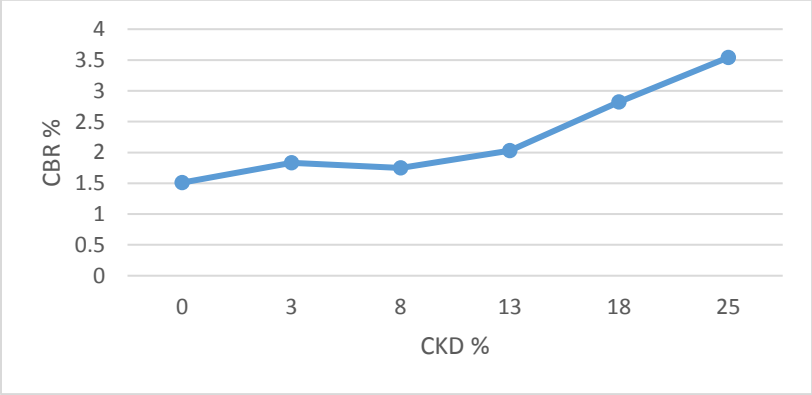

Figure 4.31 CBR vs CKD%

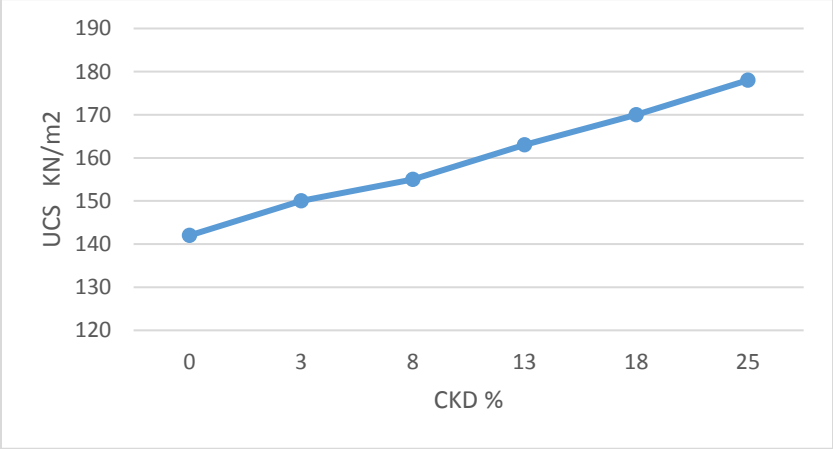

Figure 4.32 UCS vs CKD%

CL soil was classified according to USCS. OMC disproves and MDD improves with CKD. Thus compaction increases and soil stability increases. CBR decreases as CKD increases. DFS decreases and UCS increases with CKD(Singh et al., 2015).

- In this paper three soils were stabilized with CKD 2.5, 5 and 7.5%. The results are:-

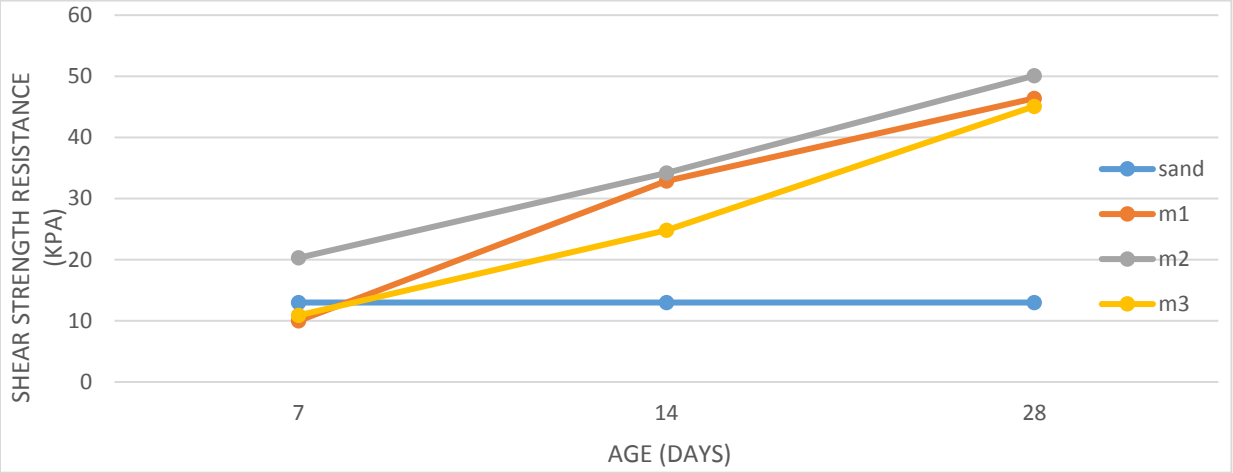

Figure 4.33 Shear Strength Resistance vs Curing days for soils

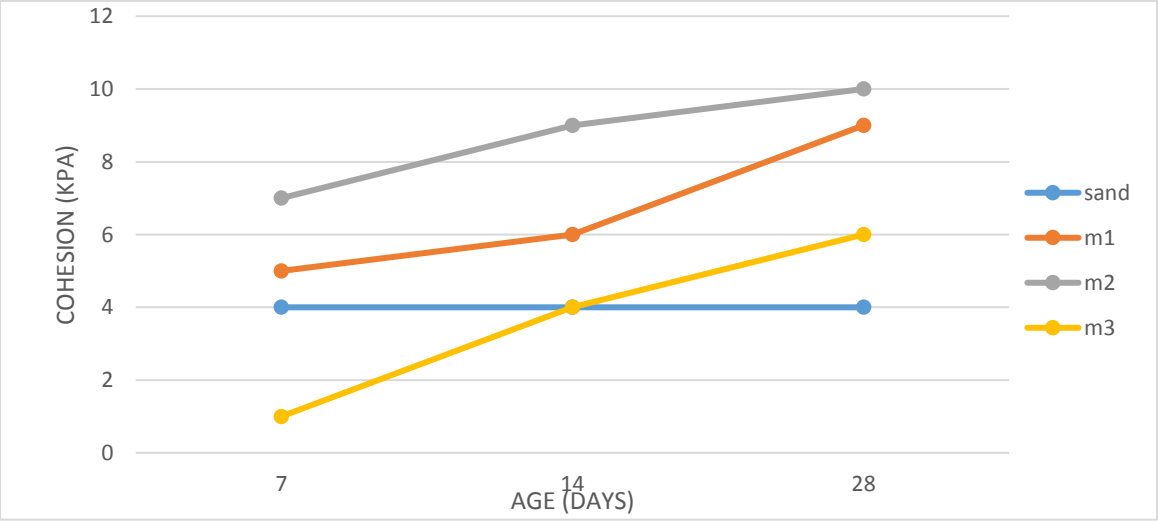

Figure 4.34 Cohesion vs Curing days for soils

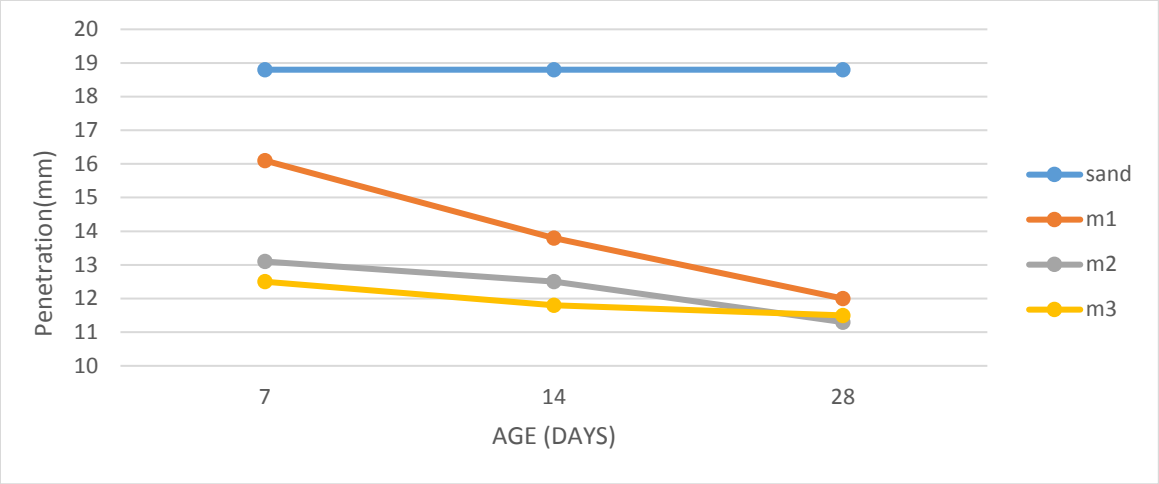

Figure 4.35 Penetration vs Curing days for soils

Shear strength and Cohesion increases for the soils as the curing day increases. The penetration decreases as the curing days increases(Rammal & Jubair, 2015).

- In this paper the soil was stabilized with CKD for 0.15B - 0.5B. The results are:-

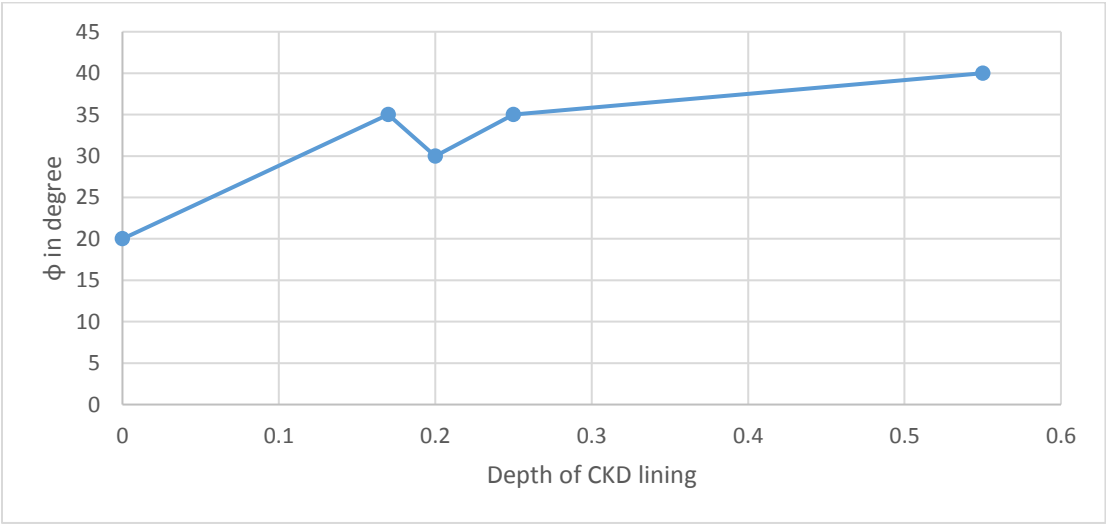

Figure 4.36 Angle of friction vs Depth of CKD lining

The friction angle increases with CKD lining. Thus ability to withstand shear stress increases. The angle in soil increased with lining was 1.7 times for 0.15B and 0.25B. The bearing capacity increases as the depth of lining increases(Abdulabbas, 2017).

- In this paper the soil was stabilized with CKD content of 5%, 10% and 20%. The results are:-

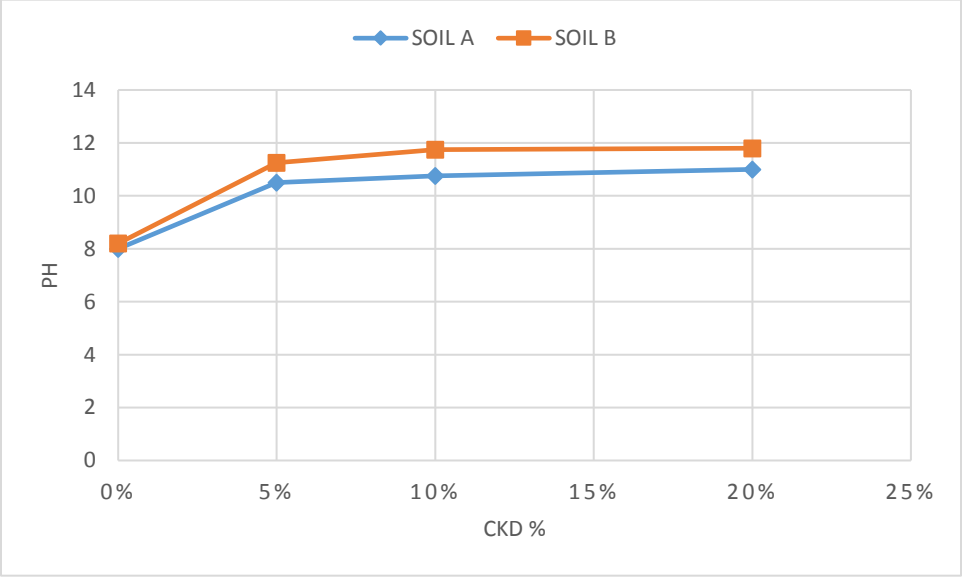

Figure 4.37 pH vs CKD value for soil A and soil B

CL soil was stabilized. In Atterbergs limit, the LL, PL and PI first increases till 10% CKD and then decreases. The pH value increases with the CKD content. Thus less acidic and less reaction with soil particles with CKD. The MDD decreases till 10% CKD and then increases for soil A and B(Ismail & Belal, 2016).

- In this paper soil was stabilized with CKD for 0 to 30%. The results are:-

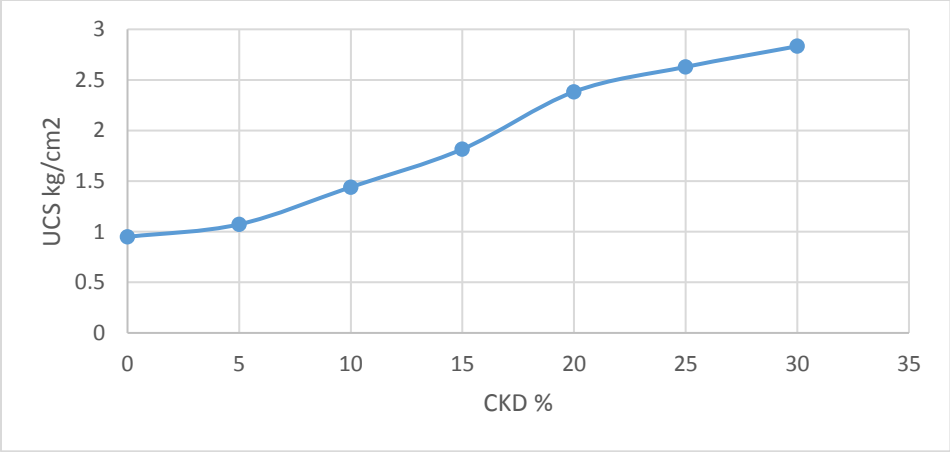

Figure 4.38 UCS vs CKD%

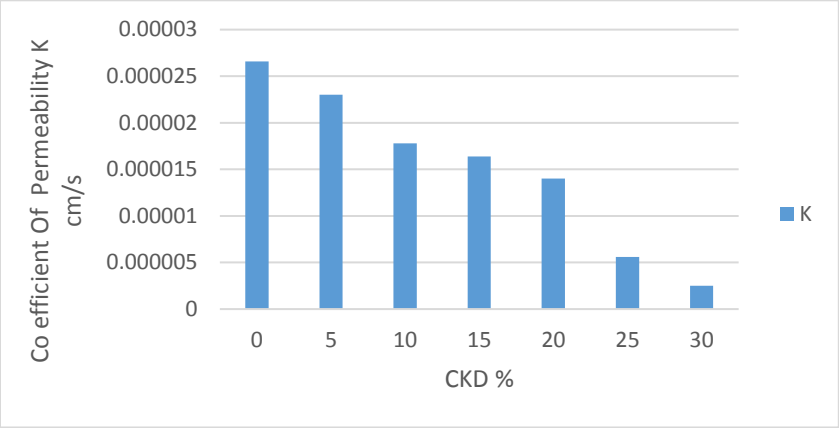

Figure 4.39 Coefficient of Permeability vs CKD%

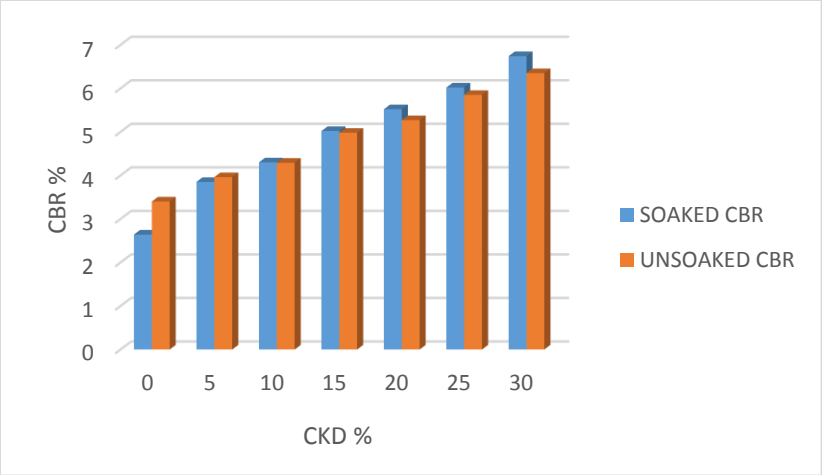

Figure 4.40 CBR vs CKD%

Soil was classified as CL. The OMC increases and MDD decreases. Thus stability decreases. Unconfined Compressive strength increases with CKD percentage. The value of CBR soaked and unsoaked also increases with CKD content. Soaked CBR is greater to unsoaked. Permeability decreases as CBR percentage increases(A. Kumar & Singh, 2017).

- In this paper the soil was stabilized with CKD of 4, 8, 12 and 16%. The results were:-

  The MDD increases as the OMC decreases for BSL and WAS compactive effort. Thus effect on stability and compaction. Hydraulic conductivity increases for every 2% OMC. For 8% and 12% CKD hydraulic conductivity gives best result. Volumetric shrinkage increases with CKD content. The UCS value decreases bur for 12% CKD value increases(Oriola & Moses, 2011).

4.3 Results for Stabilization of soils for slope stability

- In this paper the soil was stabilized with CKD for 10%, 15% and 30% CKD. The results for the soil stability are:-

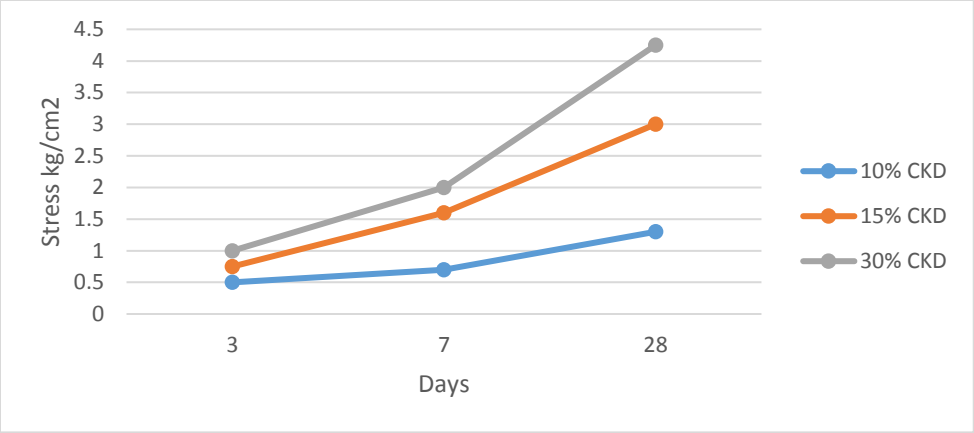

Figure 4.41 Stress vs Curing days for CKD %

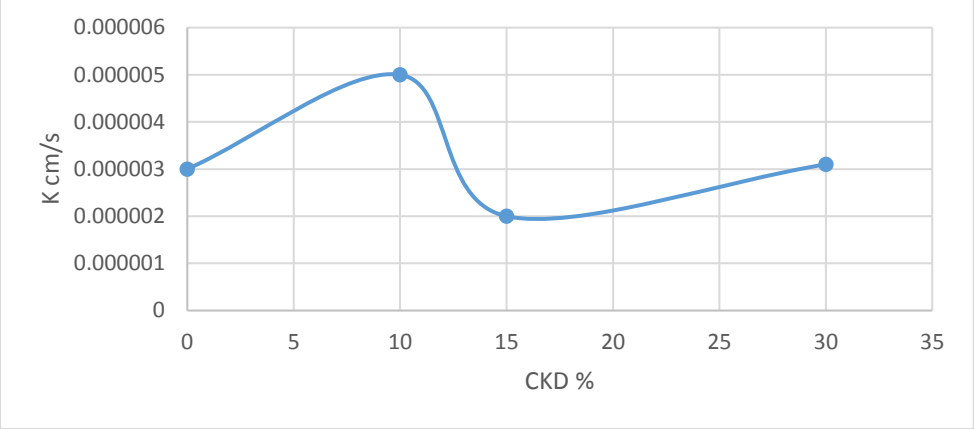

Figure 4.42 Coefficient of Permeability vs CKD %

SP soil was classified according to USCS. The MDD of natural soil was 1.8g/cm3 at 18% OMC. For 10% CKD mix the MDD increases with decreasing OMC. MDD shows that the stability increase. The CBR value increases with CKD ratio. The highest value of CBR was for 30% CKD. The CKD increases and the compressive strength increases. The strength also increases with curing time. The CKD mix of 15% was having min permeability coefficient(ElMashad & Hashad, 2013).

The numerical analysis was done to check the slope stability.

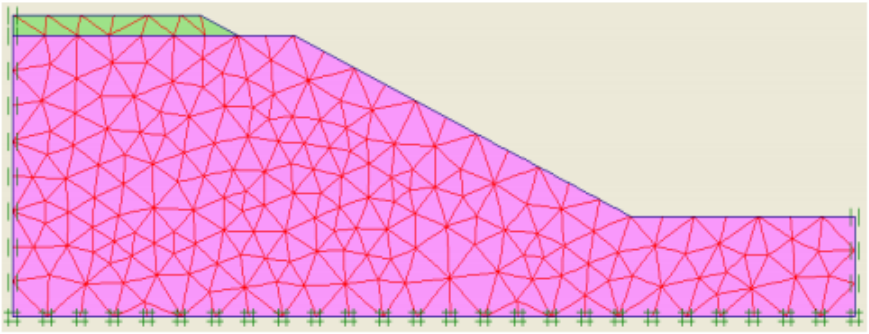

Figure 4.43 Finite Element model for natural soil

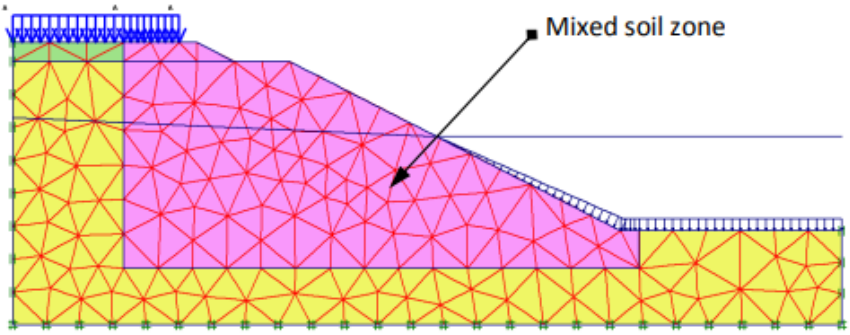

Figure 4.44 Finite Element Model for improved soil

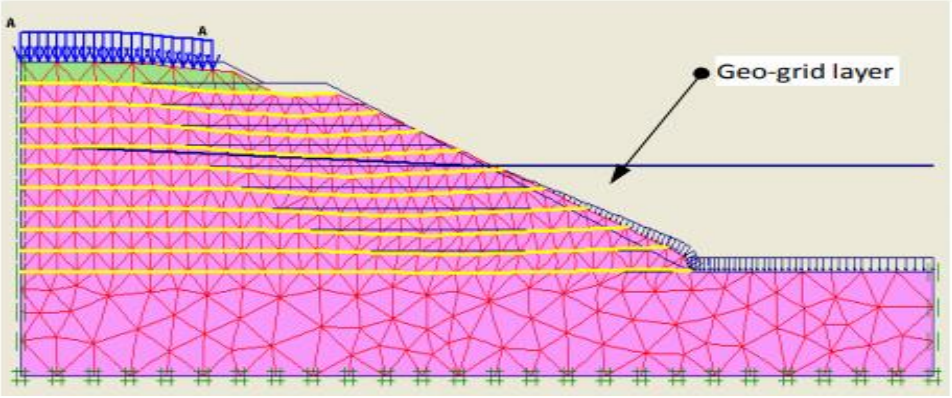

Figure 4.45 Geo grid layer Finite Model Element

The finite element model results for slope stability show that safety factor was doubled many times and the slope was safer. Soil reinforcement technique for

soils the no of geo-grid layers were used have little impact for the increase in safety factor(ElMashad & Hashad, 2013).

- In this project the soil was stabilized with CKD content of 0 to 2.5%. The soil was stabilized for highway embankments and culverts slopes. The results are:-

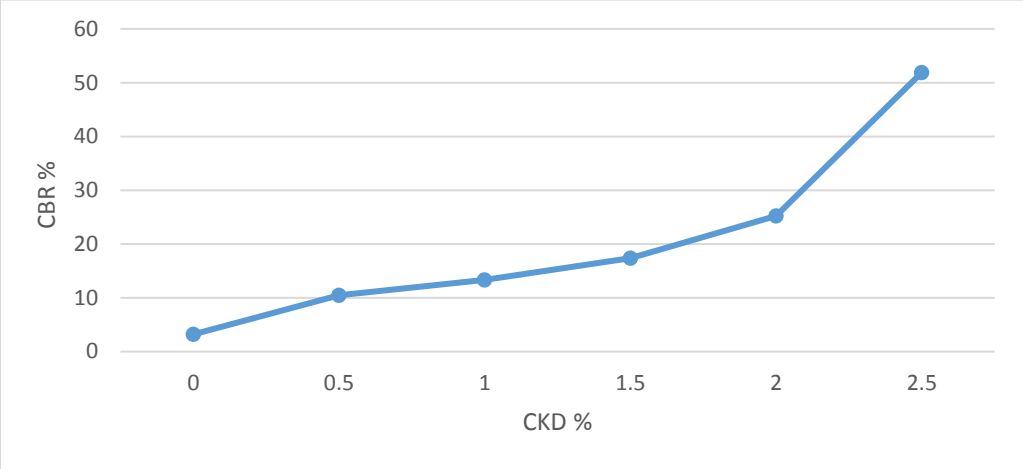

Figure 4.46 CBR vs CKD% for poor soil

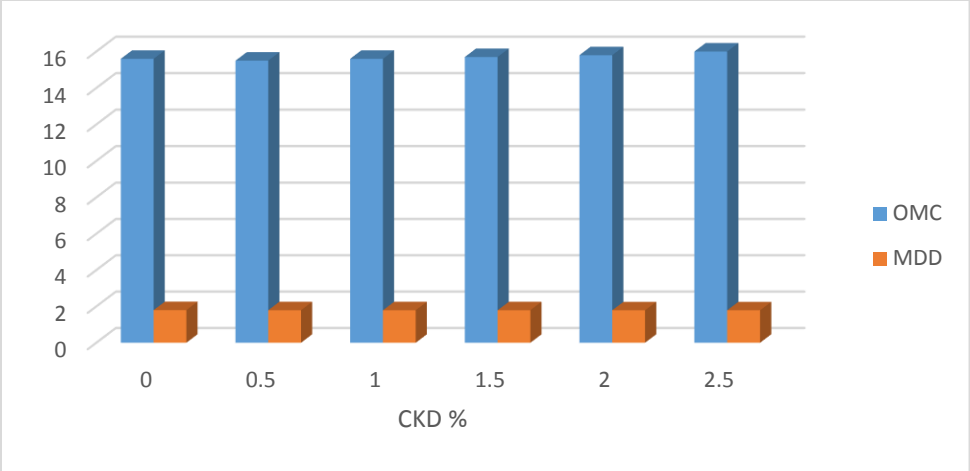

Figure 4.47 OMC and MDD vs CKD percentage

The soil classification was CL. The CBR increases with CKD. CBR value 25% which was the benchmark achieved between 1.5 to 2.5% CKD. 2% CKD mixture was selected for best results. The MDD decreases with increasing CKD. CKD content increases the OMC. LL, PL and PI decreases with CKD(Jasim & Mohammed, 2019).

4.4 Results for Stabilization of soil for constructing dams

In this paper the stability was improved of an upstream tailing. The laboratory tests were done to characterize mine tailing and properties that were changed upon stabilization. Soil was CL-ML. CKD percentage of 5%, 10% and 20% were used. The soil treated with CKD and gypsum achieves max strength in 14 days. The CKD proportion decreases the strength also decreases. UCS increases 100% times when CKD and plaster ratio changed from 1:1 to 1:4. The cohesion increases of the treated material by 11kPa. There was decrease in volumetric strain from 17% to 2.21%. The void ratio and water content reduces and increases dry unit weight. The void ratio was decreased and stress was decreased. The hydraulic conductivity was also lowered(Alsharedah, 2015).

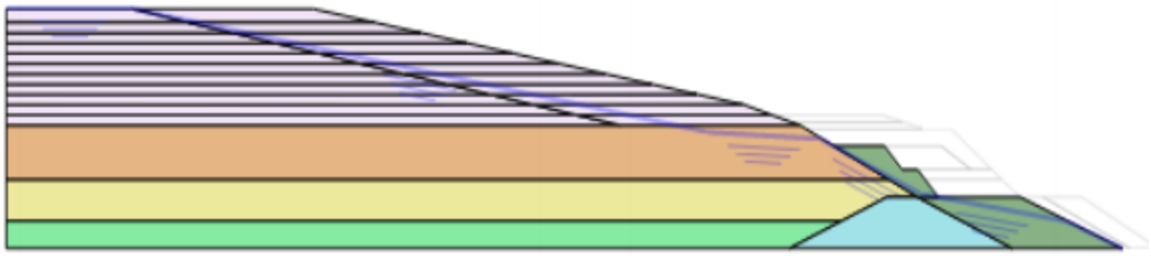

Figure 4.48 simplified version of Dam model

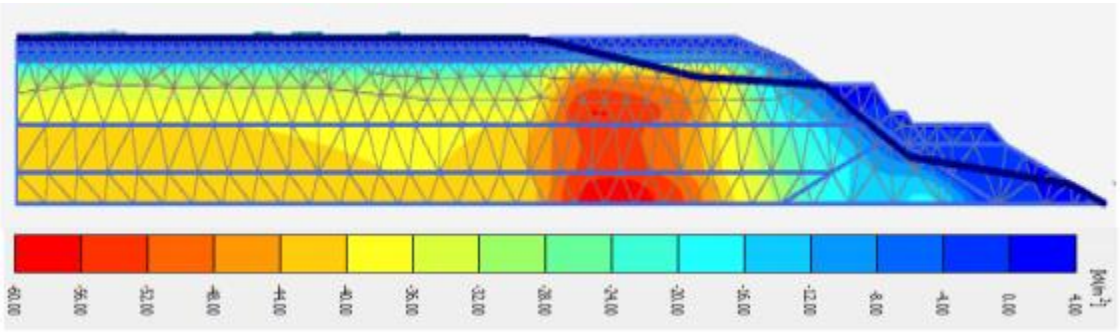

Figure 4.49 Pore pressure after constructing 2 layers

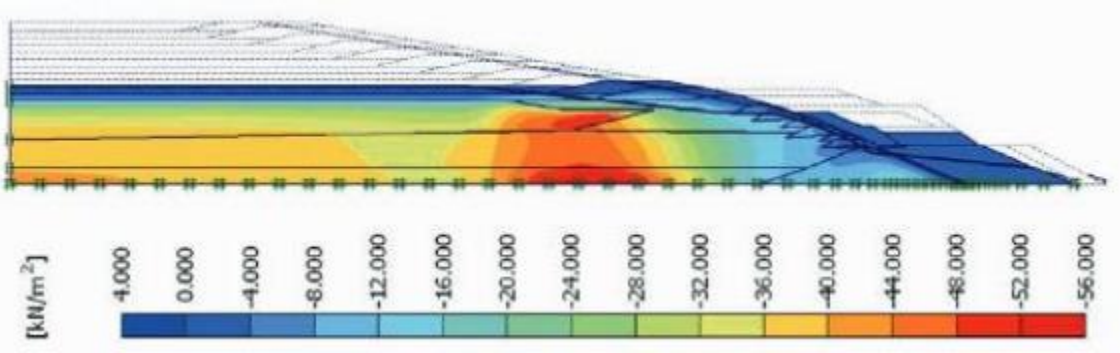

Figure 4.50 Excessive Pore pressure for second layer for model

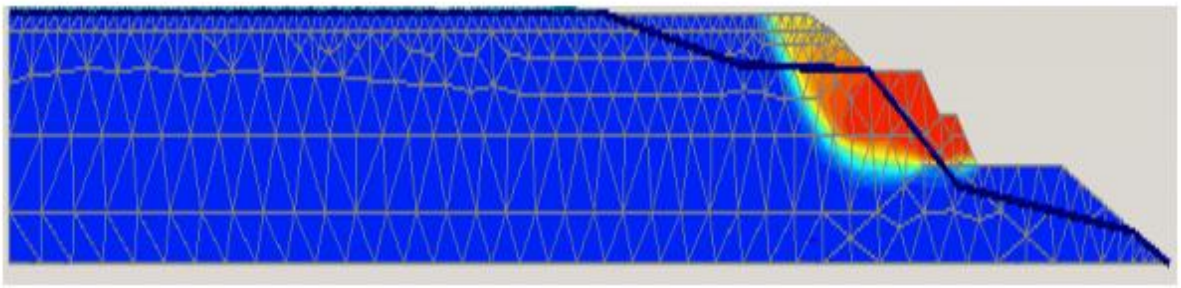

Figure 4.51 Slip surface for the dam

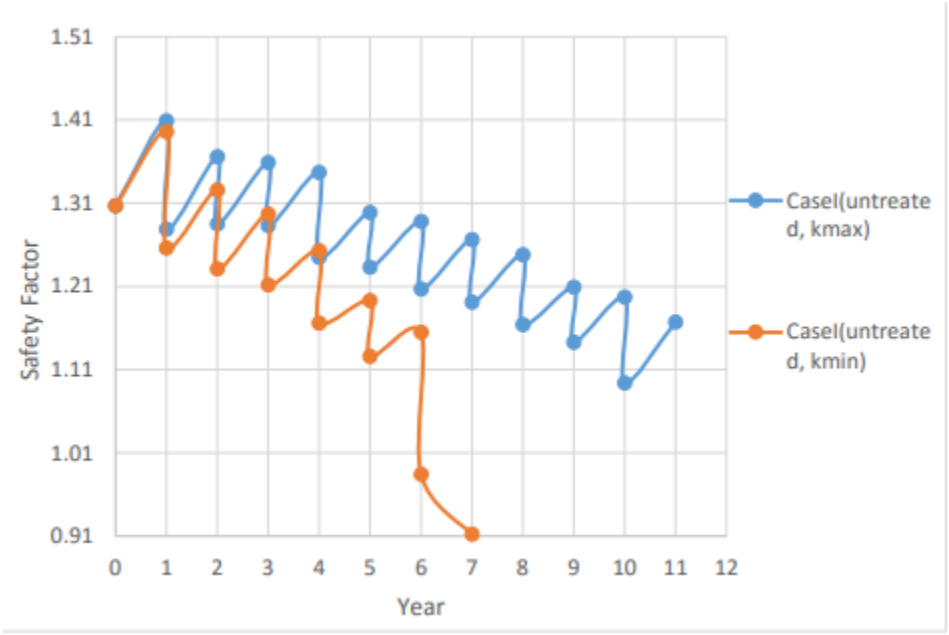

Figure 4.52 Safety factor vs No of years for Dam

CHAPTER 5

Conclusions and Recommendations

5.1 Conclusions

Basing on BE Civil Engineering knowledge inculcated through the courses under taken. Applying that knowledge we conclude that:-

5.1.1 Soil stabilization for pavement construction

- The use of CKD is beneficial for improving the soil properties. Using waste materials like CKD could help in protecting environment(Elbaz et al., 2019).
- The binding properties of sandy soils with CKD due to stabilization is same as OPC. The UCS was improved due to high lime and low alkalis present in CKD. CKD with less alkali and low LOI reduces the Plastic index and compressive strength(Rahman et al., 2011).
- OMC decreases and increase in MDD as CKD content increases. Strength of the clay increases till 20% CKD. CBR also increases with CKD(B. Kumar & Puri, 2013).
- In this study the benefit of use of additives for soil stabilization was studied and its results obtained showed great improvement(Michael et al., 2016).
- The OMC increases with CKD percentage. The UCS of mixture increases with CKD and curing days. The cohesion was improved about 2%(Abdel Aziz et al., 2010).
- The Black cotton soil was classified as CL. CKD with high LOI Atterberg limit modified after 10% CKD. Properties of CKD should be analyzed on the basis of plants it comes from. High LOI and alkali CKD should be avoided because it gives low CBR values(A Salahudeen & Akiije, 2014).

- The conclusion is that the virgin soil in nature is expansive. There Atterbergs limit decreases with CKD content. With increase in CKD content stabilization increases. At 8% CKD of virgin soil maximum stabilization was obtained(Gupta et al., 2015).
- Cement Kiln Dust show improved results for soil stabilization. Plasticity and MDD decreases while pH and OMC increases with CKD. CKD on adding with A-4 soil increases CBR(Al-Refeai & Al-Suhaibani, 2009).
- Increase in CKD,UCS also increases. The UCS increases with the curing days. The strength was increased 1.5% as the curing day increased(Manisha Meena, 2018).
- The addition of CKD stabilized soil increases CBR, resistance to the loss in strength and UCS for 10% CKD. The results showed that CKD improves the properties of subgrade for light traffic. CKD with high LOI should not be used(AB Salahudeen et al., 2014).
- By the addition of CKD, UCS and CBR was increased. Maximum results were at 24% CKD. CKD also reduces plasticity. Due to less value of lime and LOI increase in soil strength(Andrew, 2012).
- The CBR values increases with CKD content. Increase in CBR also increases M_r results in less thickness of pavements. The swelling ratio decreases and optimum at 20%. As the curing time increases the values of CBR increases. 14 days curing time gives more improved results(Mosa et al., 2017).
- The OMC and MDD increases. UCS increased about 10 times for 10% CKD after cured for 28 days(Rimal et al., 2019)
- The UCS and CBR value increased with CKD addition. The best results were for 24% CKD. The plasticity was also improved. The MDD and OMC increases with CKD percentage. The CKD has low lime and LOI. Low LOI of CKD results in strength improvement(Okafor & Egbe, 2013).
- Clay soil with addition of CKD improves compaction behavior, shear strength parameters, consistency limits and UCS. The permeability of soil is also improved by the addition of CKD(Alawi, 2016).

- Black cotton soil treated with CKD give UCS peak value at 7 days. BSL and WAS peak value for CBR was attained at 12% CKD. The durability test of CKD was unable to meet the desired limit(GK Moses & Saminu, 2012).
- The soil stabilization with CKD for hydraulic barrier shows immense improvement. The MDD increases and OMC decreases with increasing CKD percentages. The Unconfined compressive strength also increases(G Moses & Afolayan, 2011).

5.1.2 Soil stabilization for foundation construction

- CKD and silica gel could be used to stabilize dune sand. The UCS and cohesion increases and penetration decreases by mixing silica in dune sand(Rammal & Jubair, 2015).
- The mix of the soil were non plastic. The MDD of the mix was low with high OMC. CKD causes increase in angle of friction and cohesion. There are many advantages of soil stabilization with CKD, the bearing capacity increases 250% at 8% CKD(Albusoda et al., 2012).
- The lab test showed increase in MDD, UCS and shear strength. 28 days curing produced UCS that was much greater than hard clays(Mohamed Y Al-Aghbari & Dutta, 2009).
- In both the samples the pH value was increased with CKD content. With the increasing CKD percentage MDD and OMC increases. CKD decreases the plastic index of the soil and showed improvement in properties(Ismail & Belal, 2016).
- The CKD which is a waste material enhance the shear strength of soil for all cases. The best results were for CKD lining of 0.5B depth. The angle of friction also increases and is 2.14 times (Abdulabbas, 2017).
- The OMC increases and MDD decreases with CKD. As the CKD increases the LL decreases and PL increases. Soaked and unsoaked CBR increases with CKD content. Hydraulic conductivity reduces and then the soil was stabilized(A. Kumar & Singh, 2017).

- The soil when stabilized with CKD reduces the plasticity. OMC also increased. Durability of soil as showed improvement. The unconfined compressive strength also increased(Al-hassani et al., 2015).
- The stabilization of soil with CKD increases MDD and decreases OMC of the BCS. Swelling ratio was also reduced. The values of soaked CBR also increases. The UCS also increased with CKD content. (Singh et al., 2015).

5.1.3 Soil stabilization for slope stability

- The CKD soil mix improved the UCS, tri-axial and bearing stress. The results of numerical analysis showed increase in safety factor. The project was economical as well(ElMashad & Hashad, 2013).
- Soil mixed with CKD results the most improved results. MDD increases and OMC decreases with increasing CKD. WAS and BSL compactive efforts gave improved results of hydraulic conductivity(Oriola & Moses, 2011).
- The study shows the increase in CBR of soil which is 25%. It is the value that is mandatory to be attained. At 2% CKD the soil mix gives 25% CBR improvement(Jasim & Mohammed, 2019).

5.1.4 Soil stabilization for dam construction

- Soil stabilization with CKD increased MDD and cohesion. The compressive strength increases as the mixture increases. The 7.5% cement, CKD and B mixture was giving improved results DS and Odometer tests. There was increases of 300% in stiffness of dam. The permeability also decreased and SF increased 25%. The settlement also reduced to 40%(Alsharedah, 2015).

5.2 Recommendations

The recommendations based on the literature, tests results and analysis are:-

5.2.1 Soil stabilization for pavement construction

The recommendations for pavement construction are:-

- Industrial waste such as CKD is economical and when mixed less harmful. Results could be used to construct pavements over clay beds stabilized with CKD(B. Kumar & Puri, 2013).

- Recommendation from the paper is that cost analysis and economic consideration review should be done between natural soil and stabilized road(Michael et al., 2016).
- In future it is recommended to test at high CKD contents and long curing time. Data that would be obtained would be used for full pavement design(Manisha Meena, 2018).
- CKD could be used to improve soil properties to use it for subgrade and sub-base for pavement construction. The other soils of Nigeria could also be treated(Andrew, 2012).
- It is recommended for the Black cotton soil that CKD should not be used as a single additive for stabilizing. Some other additive must be added with it(GK Moses & Saminu, 2012).

5.2.2 Soil stabilization for foundation construction

- Study should be carried out to check improvement in sand dunes using additives. Study the long term effect of time on sand dunes(Rammal & Jubair, 2015).
- From the study it is recommended that comparison should be there between natural soils and stabilizes roads for cost analysis and economic consideration(Albusoda et al., 2012).
- CKD is a very cheap and effective material for stabilization. So it is recommended to be used as the soil stabilizer(A. Kumar & Singh, 2017).
- On the basis of test results it is recommended to use CKD as a most feasible additive for soil stabilization. The mix design should be made before so that their performance could be checked(Al-hassani et al., 2015).

5.2.3 Soil stabilization for slope stability

- The study tells that soil properties were improved by adding CKD. The numerical analysis results also showed great increase in safety factor. It is recommended that further studies should be carried out studying mix durability(ElMashad & Hashad, 2013).
- It is recommended to engineers to used CKD as stabilizer for increasing CBR of the layers and enhancing other properties. CKD is very cost effective and gives more strength(Jasim & Mohammed, 2019).

5.2.4 Soil stabilization for dam construction

- In cold region there is effect of freeze and thaw. That could also be studied. pH and salinity study could also be done. In mine tailing dams creep behavior could also be studied. SPT and CPT tests could be done to check the liquefaction of the tailings dams. Cyclic mobility should also be tested in seismic areas. Effect of high stresses should be tested on the strength of the dam(Alsharedah, 2015).

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CHAPTER 6

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