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A REVIEW OF ANALYSIS OF DURABILITY AND STRENGTH OF CEMENT TREATED SOILS FOR SUB-BASE AND BASE LAYERS OF PAVEMENT

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Abstract

Soil stabilization is defined as the modification of soil properties through chemical or physical means in order to improve the engineering quality of the soil. The primary goal of soil stabilization is to increase the soil's bearing capacity, resistance to weathering, and permeability. The stability of the underlying soils is critical to the long-term performance of any construction project. Unstable soils can cause major issues for pavements and structures. As a result, soil stabilization techniques are required to ensure that the soil is stable enough to support the load of the superstructure, particularly in the case of highly active soil. Clayey soil, a common type of expansive soil, has an unusual property of swelling and shrinking in the presence and absence of water or moisture. The best way to stabilize this type of soil is to physically add an additive to the soil sample. The additive used should be inexpensive, effective, environmentally friendly, and widely available.

Keywords: *Soil Stabilization, Stabilization, Cement.*

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1. INTRODUCTION

The sustainable development of infrastructure can be accredited to conservation of natural resources which are limited in occurrence and simultaneously encouraging the reuse, recycling and reprocessing of available material. Widely accepted method to deal with this problem is to strengthen the weak constituents of pavement like soil and/or aggregates by using stabilizers so they can be effectually and satisfactorily used to replace the granular layer in pavement construction. It is very common and eco-friendly practice which is presently used by many countries to save natural resources and reduce carbon footprint owing to pavement construction. The stabilizers significantly improve the properties of soil and thus, stabilized soil/ aggregate are significantly used for base underlying the asphalt or concrete pavement and there has been immense growth in its use during last half century.

Soil stabilization is defined as the process of modification of virgin or natural soil or aggregate with the intention of improving soils engineering properties and characteristics. Some other advantages of stabilization include use of borderline base material which saves the cost and time for transportation of expensive good quality fill material. The popularity of stabilization has increased lately because almost all types of soils can be stabilized. Although, there are some exceptions include organic soils, highly plastic clays, and poorly reacting sandy soils. Generally soils having size IS 75 micron sieve passing between 5% and 35% produce the most economical stabilized soil. Need of Stabilization can possibly be justified by many factors like high transportation cost and lack of good quality aggregates.

The subgrade found generally in most places is very soft and thus stabilization allow use of marginal aggregates which are nearby and certainly available in abundance. IRC 37-2012 allows the engineers to use his sound engineering judgement consistent with the local environment using semi mechanistic approach for design of pavements. As stabilization can easily improve high water table, sites with drainage problem can also be used. Soil stabilization increase durability and strength of soil which is retained even under saturated condition which result as reduced surface deflections and increased erosion resistance, also the stabilized material does not offer any problem of contamination from the underlying layer.

Many researchers have reported that construction of granular layers above stabilized layer increase its Elastic Moduli. The use of cement treated base (CTB) as a replacement of granular-base pavement reduces the cost of construction. The utilization of in-place or neighbouring borrow materials helps in preservation of energy, time and cost as the need for hauling of costly, granular-base is eliminated.

Following advantages of cementitious treatment of granular layers are summarized based on the literature review.

Use of cement treated bases result in better Load Distribution: Due to higher stiffness of cement treated bases, it will distribute loads over a larger area thus stresses on the subgrade is reduced compared to the granular bases.

Deflection: The higher stiffness of cement-treated bases lead to lower pavement deflections and lower asphalt strains which results in longer fatigue life for the asphalt surface.

Rutting in Base: With increased strength cement-treated base prevents the occurrence of rutting in deep depth of pavement where repairing is extremely difficult.

Moisture Problems: Treatment of base with cement reduces permeability and thus helps prevent the percolation of water to underlying water susceptible layers. Due to reduced permeability the water could not enter base and so even under frost conditions the problem of ice lenses is not encountered in base layer. To complete the pavement structure top course of bitumen or Portland cement concrete is placed on the CTB.

Use of CTB as a pavement base material is done extensively for highways, roads, airports, parking areas, materials handling and storage areas. Old roads with granular-base can also be recycled to form excellent cementitious base either including or excluding their asphalt surfaces. The use of stabilized bases may be advantageous in lightly trafficked roads, moderately to heavily-trafficked roads on low strength subgrade, and in improving the ability to carry load especially in areas that are subjected to frequent flooding thus reducing design life cost by recycling of inadequate existing pavements.

2. SUBJECT OBJECTIVE

The primary objective of this study is to assess the laboratory performance in terms of durability and residual strength characteristics of Soil-Cement treated mix as a full replacement of granular aggregate layer in LVRs.

In order to fulfill the above mentioned primary objective the following sub objectives have been defined as follows:

To study various test and analysis methods for assessing the durability and strength characteristics of moderately cement treated soils to be used as sub-base and base layers of LVRs.

To carryout detailed laboratory investigations such as Conventional physical, volumetric and strength properties of virgin soil, moderately cement treated soils at different proportions.

To assess the laboratory performance by performing various laboratory investigations such as durability tests and residual strength tests for cement treated soil samples.

To analyze the test results of virgin soil and moderately cement treated soils at different proportions for estimating variations in percentage mass loss at different cycles.

To develop and validate empirical models for predicting performance of moderately cement treated soil by considering UCS (7 days strength), Percentage mass loss, Cement content, and Water cement ratio as explanatory variables.

3. LITERATURE REVIEW

Several researchers have previously studied the effects of stabilization of different soil types using various stabilizing agents in varying concentrations and their effects on behavioural and characteristic properties of soil based on many aspects. Here in this section an overview on the previous research work done on this regard has been presented.

1. Xin Kang et.al, 2015, “Chemically Stabilized Soft Clays for Road-Base Construction.”

The researcher in this paper tested soft clay having very low initial strength & high volume change making it unstable subgrade material. Researchers tested lime kiln dust and Class C fly ash as stabilizer. Static compaction method was used to mould the test samples. Tests used were Scanning electron microscopic (SEM) analysis for testing the micro-structural change of treated soil, proctor compaction tests, Unconfined Compression Tests (UCS), and resilient modulus (MR) test on samples prepared at OMC and were tested at various curing periods to develop a relation to calculate resilient modulus from basic soil properties. The results indicate that adding Class C FA causes an increase in dry unit weight and strength (UCS) of treated soil with improved resilient modulus. A power law equation is developed for interrelating the MR and curing time and for correlation between UCS and MR.

2. Korakod Nusit et.al, 2017, “Advanced Characteristics of Cement-Treated Materials with respect to Strength Performance and Damage Evolution.”

In this research cement-stabilized base CSB was tested with respect to its strength and damage evolution behaviour in case of static and dynamic loading conditions. Standard crushed rock was used as parent material and a novel mix design concept was developed for CSB which is based primarily on rational mix design parameters which replace the tedious process of trial and error and instantly provide the quantity of water and cement required for target strength. Characteristics of CSB for monotonic and dynamic (compressive) loading conditions were examined. By testing varying loading rates and assessing the responses of material and evolutions of damage they concluded that the strength of CSB is based on the moisture content at time of compaction, maximum dry density achieved and degree of compaction used. Specimens compacted at OMC resulted the maximum value for UCS of CSB whereas increase in moisture content resulted in increased UCS of CRB and thus the strength estimation for CSB should be done from curing period and water cement ratio form CSB prepared at OMC and higher moisture content. Effective CSB was obtained using cement content in range of 3 to 7%. Research also concluded that the responses of CSB test specimens under different rates of loading are explicitly different.

3. Nilo Cesar Consoli et.al. 2017, "Influence of Moulding Moisture Content and Porosity/Cement Index on Stiffness, Strength, and Failure Envelopes of Artificially Cemented Fine-Grained Soils".

Researchers tested the outcome of varying the moulding moisture content (ω) at time of specimen preparation with aim to produce more stable binder for fine grained soil and to assess initial shear stiffness, compressive (qu) and tensile (qt) strength and to analyze and compare the properties of fine-grained soils stabilised with different dosage of cement and having different dry densities and different ω .Other tests performed were ultrasonic pulse velocity test, UCS test, splitting tensile strength test and triaxial (drained) test. They found that porosity/cement index (η=Civ) had a crucial role in affecting the values of initial shear stiffness (G0), compressive (qu) and tensile (qt) strengths, and parameters for determination of triaxial failure envelope. They found as binder content was increased there was increased values of G0, qt and qu and decreased porosity of the compacted mixture. Researchers used power functions to represent interaction diagrams to represent the relationship between G0, qt, or qu with cement content or porosity by cement index. They stated that the index of porosity/cement is suitable parameter to assess G0, qu, and qt for studied fine-grained soil blended with stabiliser. Researcher suggested that the properties of fine grained cement soil mix are affected by both moisture content at time of moulding and the porosity/cement index. Equations were develop for crucial parameters between soil and cement used for analysis in paper.

4. Sabry A. Shihata and Zaki A. Baghdadi, 2001 "Long-term Strength and Durability of Soil Cement".

The researchers tested the change in durability and compressive strength characteristics of soil cement mixture when subjected to saline ground water for prolonged period of time. Three soils classified as A-2-4 as per AASHTO were used for testing. It was found that strength gain continues at early ages for about 90 days despite being exposed to saline water after which the strength starts deteriorating. They detected that with passage of time the residual compressive strength converges to a certain value after which the frequency of deterioration

become negligible. This time was found to be about 270 days for tested soil while the UCS of samples which were kept immersed in saline ground water continued to gain strength for a time period of about 6 month even though the rate of strength gain after 28 days was very small. The researcher concludes that severity of deterioration of soil cement mix can be analyzed by residual compressive strength of durability samples. They observed that the after about 270 days of exposure the percentage mass loss stabilizes and about the same time the residual strength tend to converge at about same time.

5. Dipti Ranjan Biswal et.al, 2018 “Durability and shrinkage studies of cement stabilised granular lateritic soils”.

The researchers performed various tests on granular lateritic soils (CLS) stabilised with cement for their durability and shrinkage characteristics through laboratory tests. The tests used were Wet–Dry (W–D) durability test and soaked UCS tests for evaluating the minimum binder content required and drying shrinkage test for Shrinkage properties of cement stabilised lateritic soil. Initial studies were done for assessing the water absorption properties of cement stabilised lateritic soil. The different cement content used with CLS sample are 3, 4, 6 and 8% for wetting– drying durability test. Researchers found that all samples except 4% pass the limiting criteria of minimum mass loss percent. The study of variation of mass loss with w-d cycle suggest that graph of mass loss with durability cycle is linear upto 6% cement content and as the amount of cement content decreased more mass loss was observed in initial cycles of w-d. Also when the hand brushing was used instead of mechanical brushing, the mass loss was found 2.7 times more. It is also found that with increase in curing period, the water absorption capacity of soil decreases for same cement content as water absorption for 28 day sample was less than 7 day cured sample of same cement content. As per drying shrinkage test, it was found that increase in cement content causes increase in drying shrinkage too for moulding moisture content equals to OMC, for higher moisture content increase in cement content causes decrease in drying shrinkage for CLS ranging between 2-8%.

6. Zhongjie Zhang and Mingjiang Tao, 2008 “Durability of Cement Stabilized Low Plasticity Soils”.

The researchers used low plastic silt clay in this test and performed tests were tube suction, 7day UCS, and W-D durability, apart from these major tests all other relevant tests for investigation of soil properties were also performed. The soil was stabilised with six different cement content of 2.5, 4.5, 6.5, 8.5, 10.5, and 12.5% by dry weight of soil and varying moisture

Contents at time of moulding as 15.5, 18.5, 21.5, and 24.5%. The researchers concluded that maximum dielectric value DV, 7-day UCS, and durability of stabilized sample is largely influenced by the water-cement ratio. They also found that the DV of treated soil also gives very promising result same as the 7 day UCS value and thus DV value can also be used effectively alternative test in predicting the durability of treated soil. In this paper only one CL soil sample has been tested and the author suggests that more number of different soil samples should also be tested.

7. N. Khoury and M. M. Zaman, 2006 “Durability of stabilized base courses subjected to wet –dry cycles”.

The researchers examined the effect of WD cycle on Resilient Modulus (MR) of soil samples stabilised with different stabilising agent. The stabilisers used were cement, cement kiln dust (CKD), class C fly ash, fluidized bed ash at varying content in cylindrical shaped specimen. Before WD cycle and MR the curing time for samples was taken 28 days. Results indicated that MR decrease with increase in W-D cycles up to 30 cycles except for one specimen of sawyer specimen which was stabilized with 15% CKD which showed an increase in Resilient Modulus value with W-D cycle upto 8 cycles beyond this a normal behaviour of reduction in Mr was observed. The author suggest that the behaviour of the stabilized specimens is governed by SAF (Silica, Alumina and Ferric

Oxide compounds) and amount of free lime in stabilizing agents also, the optimum moisture content (OMC) and maximum dry density (MDD), can be used as a good indicator for prediction of performance of stabilised material subjected to wet- dry cycles. A regression model with correlation between MR with W-D cycles, SAF, free lime, OMC and MDD was also presented.

8. Jeerapan Donrak et.al, al 2018 “Wetting-drying cycles durability of cement stabilised marginal lateritic soil/melamine debris blends for pavement applications”.

In this paper the change density, UCS and durability by using cement and Melanin Debris as stabilizer has been investigated. The MD is a waste product which is already being used to modify the swelling characteristics of soil prior to stabilizing the sample with cement. The tests used were density, unconfined compression strength (UCS) and durability with various blends of cement and MD at different ratios. The researchers found that the increase in MD replacement causes decrease in density and UCS of sample but its durability by WD cycle and CBR value increases. An exponential relation between density and UCS was found for 3%

cement stabilized sample while linear relation for 5% cement stabilized sample. This behaviour could be due to the high water absorption property of MD which causes an increase in OMC with increase in MD replacement. The use of MD not only helps in dealing with the disposal problem of MD but it also proves to be good stabilizing agent which can effectively be used with cement. The use of MD also helps in reducing he overburden pressure over the pavement while providing improved strength. The optimum MD replacement to be used corresponding to highest value of soaked CBR and WD cycle was 20%.

9. A. R. Estabragh et.al, 2012 “Stabilised expansive soil behaviour during wetting and drying”.

In this study lime, coal ash and cement were used with admixtures for stabilization of expansive soil. Modified Oedometer is used for analyzing the effect of WD on swelling behaviour of stabilized soil with varying amount of stabilizer. The author found that the change in physical and chemical properties of soil such as Atterberg limits, increase in OMC and decrease in MDD is because of chemical reaction between soil and stabilizing agent. The stabilization with cement and lime stabilizers result in reduction of properties with increase in WD cycle such as swell potential, swell pressure, free swell and increase in these properties when coal ash admixture were used. An admixture reduces the swelling, shrinkage and plasticity properties of soil. The axial deformation was reduced when Portland cement was used for stabilization. However the initial improvement reported due to stabilization with coal ash diminished and finally lost after initial cycles and subsequent cycle reported an increase in swelling potential.

10. Liangxing Jin et.al, 2017 “Use of water reducer to enhance the mechanical and durability properties of cement-treated soil”.

In this paper the author has investigated the effect of water reducers (WR) in improving mechanical and durability characteristics of soil. The soils used were classified as A-4, A-7-6 and A-2-6 as per AASHTO classification system and CL as per USCS classification. The stabilizer used in the study was Type I Portland cement by 9% of total dry weight of soil. The additive used was water reducer which is normally used in America for producing concrete classified as Type A according to ASTM C 494 in two varying content of 0.15% and 0.3% by the weight of cement as suggested by the ,manufacturer of WR. The author suggests that the improved mechanical and durability characteristics of soil were because of the property of WR to enhance the compaction behaviour of treated soil by reducing the OMC and increasing the

MDD. The effect of WR as additive shows a promising result and thus it can effective be used as admixture for preparation of stabilised soil.

11. Kamei et.al, 2013 "Durability of soft clay soil stabilized with recycled Bassanite and furnace cement mixtures".

In their research the authors has investigated the effect of recycled Bassanite which is by product produced from gypsum production and furnace cement mix as stabilising agent and the consequence of varying moisture content on strength and W-D durability of very soft clay soil. The samples were produced in cylindrical shape and cured for a period of 28 days prior to testing for durability and UCS. The authors found that increase in amount of bassanite in stabilizer mix result as an increase in strength and maximum dry density and reduction in optimum moisture content of stabilized specimen. It was also observed that UCS decreases gradually with increase in number of WD cycle. Earlier WD cycle reported much adverse effect on mas loss and UCS than later cycles .The authors concluded that recycled Bassanite can be efficiently used for stabilizing soft clay soil because it helps soil to achieve acceptable durability, increase the strength and improves the engineering characteristics of soft clay soil even in a moist conditions.

12. Silvia Caro, Juan Pablo Agudelo et.al, 2018 "Advanced characterisation of cement-stabilised lateritic soils to be used as road materials".

In this paper the authors have used Laterites or lateritic soil to examine the effect of cement stabilization at three different amounts (i.e. 2, 4 and 6% by dry mass of soil. The study was comprised of the evaluation of the basic properties of laterite like gradation, Atterberg's limits, specific gravity and Los Angeles abrasion test, and the advanced characterisation of the cement- stabilised material through its resilient modulus at different partial saturation conditions, and its compressive and tensile strengths and evaluation of the mechanical properties and fatigue degradation under torsional conditions using a rheometer. The authors found that cement stabilization at varying doses of 2 and 6% by dry mass of soil effectively improves the mechanical characteristics of laterite, and thus can be used as part of low- and eventually medium-volume roads construction as pavement material.

13. Menglim Hoy et.al, 2017 "Effect of wetting–drying cycles on compressive strength and microstructure of recycled asphalt pavement – Fly ash geopolymer".

In this paper, the authors have investigated the strength and microstructural changes RAP- FA and RAP-FA geopolymer blend due to wetting–drying (w–d) cycles. The tests used were unconfined compression strength (UCS) for strength, and evaluation of microstructural changes through X-ray diffraction (XRD) and scanning electron microscope (SEM). The test results indicated an increase in UCS of RAP-FA blend with increase in number of wet–dry (w–d) cycles which was occurred due to stimulation of the chemical reactions occurred between the high amount of Calcium in RAP and the high amount of Silica and Alumina in FA during w–d cycles producing more Calcium (Aluminate) Silicate Hydrate [C–(A)-S-H]. The time taken for this reaction to its peak was observed to be 6 w–d cycles. Improved durability characteristics were observed when RAP-FA geopolymers were prepared using higher NaOH content. This research approved the feasibility of using RAP-FA blends and RAP-FA geopolymers as an alternative sustainable material for pavement construction.

14. Agostino Walter Bruno et.al, 2017 “Effect of stabilisation on mechanical properties, moisture buffering and water durability of hypercompacted earth”.

In their research the authors have used the technique of alkaline activation and silicon based admixture to evaluate their effect on mechanical characteristics, moisture content variation and durability when used as stabilizer with earthen material primarily for building construction. Authors assessed the strength and stiffness for both stabilized and virgin cylindrical soil samples at different humidity by the use of unconfined compression tests, durability against water erosion by performing immersion of samples followed by suction and liquid contact test. The tests were conducted on both stabilized and virgin soil samples as per the norms of DIN 18945. For evaluation of effect of stabilization on moisture buffering capacity experimental procedures were adopted suggested by ISO 24353. The authors concluded that stabilization improved the durability of material and maintained a comparatively good mechanical performance while moisture buffering capacity was reported as good to excellent.

15. Emmanuel Mengue et.al, 2017 “Mechanical Improvement of a Fine-Grained Lateritic Soil Treated with Cement for Use in Road Construction”.

In their research the authors used fine-grained lateritic soil and stabilized it with CEMII/BM 32.5 N cement in proportion upto 9% of dry mass of soil. The samples were prepared at three different moisture contents. The test used were California bearing ratio (CBR) test, unconfined compressive strength (UCS), indirect tensile strength (TS), and triaxial shear tests. For assessing the change in microstructure of lateritic soil due to stabilisation scanning electron microscopy (SEM) and Raman spectroscopy were used. The authors concluded that stabilisation with cement improves the properties of soil especially when optimum moisture content is used for or the sample are stabilised at dry side of OMC. The triaxial shear tests revealed that stabilization changes the behaviour of soil with untreated soil behaving in ductile nature and treated soil in brittle nature. This change in behaviour was caused by formation of substances such as ettringite, calcite, portlandite, and calcium silicate hydrates due to cement addition.

4. CONCLUSION

Following key research gaps have been identified based on the detailed literature review:

- Numerous studies were reported on assessing the durability characteristics of cement concrete/ Cement-aggregate mixes. However, limited studies were reported on the assessing the durability characteristics of soil-cement mix in Indian context.
- Laboratory performance of soil-cementitious material mix is being assessed only in terms of percentage mass loss globally.
- Need for rapid and robust techniques for assessing the trade-off between laboratory performance related parameters.

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