STABILIZATION OF SOIL USING LIME ACTIVATED GROUND GRANULATED BLAST FURNACE SLAG

A Thesis submitted in partial fulfilment of the requirement

for the degree of

MASTER OF TECHNOLOGY

in

TRANSPORTATION ENGINEERING

By

ABHRANEEL SENGUPTA

(University Roll No. - 1180465002)

Under the guidance of

Prof. D.S. RAY

PROFESSOR

Department of Civil Engineering

BBD UNIVERSITY

BABU BANARASI DAS UNIVERSITY

LUCKNOW

JULY-2020

CERTIFICATE

Certified that ABHRANEEL SENGUPTA (1180465002), has carried out the research work presented in this Thesis entitled, "**STABILIZATION OF SOIL USING LIME ACTIVATED GROUND GRANULATED BLAST FURNACE SLAG**" for the award of **Master of Technology**, from Babu Banarasi Das University, Lucknow under my supervision. The Thesis embodies result of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis of for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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Prof. D. S. Ray

Professor, CE Department

CANDIDATE'S DECLARATION

I hereby certify that the work presented in this thesis entitled "**STABILIZATION OF SOIL USING LIME ACTIVATED GROUND GRANULATED BLAST FURNACE SLAG**" submitted to the Department of Civil Engineering , Babu Banarasi Das University, Lucknow in partial Fulfillment for the award of degree of **Master Of Technology** in **Transportation Engineering** is an authentic record of my own work carried out during the period from August 2018 – July 2020 under the own guidance and supervision of Prof. D.S. Ray. I have not plagiarized or submitted the same work for the award of any other degree of this or any other university. All the tests were performed in the University campus.

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University Roll No - 1180465002

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ABSTRACT

Soil is used as a material for road construction in sub grade and sub base region of the pavement. If the strength of soil is poor due to it being soft, has a high swelling tendency or low shear strength than soil stabilization is required. Its main advantage over soil replacement is most of the time it is done to reduce the cost incurred. There are numerous stabilizers available in the market like lime, cement, flyash, granulated slag etc. In this paper we will use ground granulated blast furnace slag as stabilizer. Although the stabilizer is neutral, it requires a activator to start the reaction which is provided in form of lime. So the percentage of soil to admixture play a crucial role in soil stabilization as they have different specific density.

The objective of the study is to improve the locally available weak soil with stabilizers. The test involved are Modified proctor test to find the maximum dry density of the sample mixture and CBR test to check whether adding admixture improves the soil, as higher the CBR it helps to reduce the crust thickness and helps in increasing the bearing capacity of the soil. Thus overall may help in reduction of cost incurred in the project.

Lime and GGBS are primarily use for clay soil having high plasticity. For fine-grained soils, lime is an effective stabilizing agent, which has been used successfully to reduce plasticity, increase workability, and decrease the shrink-swell potential. Strength gain is important when the sub grade is to support the overlaying base course. The amount of strength a soil show depends on the puzzolanic reaction. Plasticity of soils is dramatically decreased with increase in lime; in fact, the soils may become non plastic. The addition of lime results in a decrease in the MDD and an increase in the OMC. Swell potential of fine-grained soils can also be controlled with the use of lime. The unconfined compressive strength is the best way to select the optimum lime content and is also a good measure of shear strength.

In this project we have tried to evaluate whether on addition of such materials will there be increase in the physical as well as chemical properties of the soil along with it we are expecting certain properties to improve such as CBR value, shear strength, liquidity index, plasticity index, unconfined compressive strength and bearing capacity of soil etc. Mainly we have focused on increasing the CBR of the soil because on increasing the CBR value it helps in reducing the thickness of the pavement and it is also beneficial to us economically.

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Abhraneel Sengupta

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Chapter 1

Soil Stabilization

1.1 Introduction

With the limited finances available, the biggest challenge in developing countries like India is to provide a complete network of road system, particularly in providing connectivity to remote villages. The cost of road construction and materials is increasing leaps and bound year after year. Therefore there is a need to resort to one suitably low cost road construction method by effectively utilizing local materials and adopting stabilizing techniques.

The object of soil stabilizing road constructions are

- To effect economy in initial construction cost of lower layer of pavement such as subgrade and sub base course.
- possibly to upgrade the pavement structure to higher specifications at a later stage such as construction of pavement to meet the growing needs of the road safety.

Application of soil stabilization techniques

- In Subgrade of Pavement

  If the locally available soil is found to be unsuitable as a subgrade material for the construction material of important road pavement.

  - To find suitable soil from nearby and other borrow areas that have acceptablesoil properties, transport the borrowed soil from the pits to the construction sites, compact the same in layers and construct the subgrade of specified 500mm thickness.
  - To resort to appropriatensoil stabilization techniques and improve the properties of soil itself to acceptable levels, compact in layers and construct the subgrade to required thickness.

- In Sub-base course

  Soil Stabilization have been successfully adopted to improve locally available soil and soil aggregates mixes for construction of lower layers of the pavement structures such as sub-base course thus saving cost of procurring high quality material at a reasonable price.

1.2 Mechanics of Soil Stabilization

The term soil Stabilization means improvement of the stability or bearing power of the soil by the use of controlled compaction, proportion and/or addition of suitable stabilizers and additives. Soil Stabilizers deal with physical, physiochemical and chemical method to ensure that the stabilized soil serves its intended purpose as the pavement component material. The basic principle are

- evaluating the properties of the given soil and assessing the deficient properties of the soil which are weak.
- deciding the appropriate method of supplementing the deficient properties by effective and economical method of soil stabilization.
- Designing the soil Stabilized mix for intended stability and durability values.
- Resorting to suitable construction procedure including addition of selected stabilizer, mixing spreading and by adequate compaction.

Soil stabilization may be one of the following changes

- Increase in strength characteristics
- Modification of some of the undesirable properties of soil such as high plasticity and swelling
- Change in chemical properties
- Retaining desired minimum strength even after subjecting the stabilized soil to soaked condition.

1.3 Soil Stabilization Techniques

- Proportioning and mixing different materials

  The strength property of a soil is achieved by the cohesion component 'C' per unit area and friction components represented by 'phi'. Granular soils contains no cohesion, therefore the stabiliation of fine grained soil can be increased by addition of course grained soil at an appropriate proportion

- Cementing Agent

  Strength of soil can be increased by adding binding agent like OPC, Lime or some bituminous binders.

- Modifying Agents

  If a stabilizer added can modify any undesirable properties such as plasticity or selling such as its reduction without adding to its strength it is called modifying agent. Lime is most common modifying agent used in clayey soil.

- Water Proofing Agents

  A Compacted Soil which is normally stable becomes weak if there is an ingress of water when subjected to soaking condition . If absorbtion can be stopped or retarded by any means of some water proofing agents it will be possible to make use of such an material with advantage, the most common method of water proofing is by use of bituminous binder

- Water Retaining Agents

  Some non cohesive soil have sufficient stability when compacted in layers possesses slight moisture content, by 'imparting apparent' to the soil. But the soil may become loose and unstable when completely dry In such cases use of deliquescent material is recommended like Calcium Chloride to retain some moisture or absorb moisture from the atmosphere and thus impart some apparent cohesion and retain the stability. This incidentally can also reduce the dust problems in un-surfaced roads.

- Heat Treatment

  Heat treatment of the soil or thermal stabilization results in some useful and desirable changes in clayey soil. The changes depend on temperature and duration of heating. Brick manufacturing is based on this principle. The desirable changes include reduction in swelling properties and heat treated soil may be used as soft aggregates in mechanical soil stabilization or as pozzolonic additives in soil lime stabilization.

- Chemical Stabiliation

  There are several chemicals when added as one chemical or in combination even in small proportion say .5% by weight of soil may impart useful changes in certain types of soil. However considerable investigation and care is needed before any costly chemical is added. India has successfully adopted chemicals under chemical stabilization. A few have been found successful in curbing the undesirable properties of soil components and improving strength and durability to stabilized mixes of certain type of soil.

1.4 Soil - Lime Stabilization

Soil Lime works in both ways as a binder and as well as modifier for high plasticity soil. Lime can be used in both coarse and fine grained soil. The basic principle attached with soil lime stabilizer is puzzolonic action. The puzzolonic reaction takes place due to addition of hydrated lime with moist soil and is defined as hydrated lime (Ca(OH) + Water + Soil (SiO_2, Al_2O_3 and others). Cementitious material with stable silicate hydrates and calcium aluminate hydrates. The effect due to the addition of lime are improvement in workability by increasing OMC wrt soil without lime, increase in all type of strength related properties by decreasing plasticity index, swell reduction and soil becoming hydrophobic. With suitable addition of granular blast furnace slag it can be added to the gravel, sand and silt.

Figure 1.1 Lime Stabilization

Chapter-2

Literature Review

2.1 General

(Cokca, 2001) studied effect of flyash on expansive nature of soil. Flyash is often hollow spheres of Silicon, Aluminum and Iron oxides. Both classes of flyash class C and class F are puzzolans, which means siliceous and aluminous materials. Thus Flyash can provide an array of divalent and trivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+} etc) under ionized conditions that can promote flocculation of dispersed clay particles. Thus expansive soils can be potentially stabilized effectively by cation exchange using flyash. He investigated the Soma and Tuncbilek flyash and added it in (0-25%) to expansive soil. The specimen was cured for 3 and 28 days and were subjected to oedometer free swell test. This confirmed that Plasticity index, activity and swelling potential of soil sample decreased with addition of flyash, and optimum flyash content was found to be 20%. The changes in physical properties and swelling potential is a result of additional silt particles and chemical reaction that causes flocculation of clay particles and the time dependent pozzolanic and cementitious properties of flyash. It is concluded that both high and low CaO flyash can be used as a stabilizing agent in expansive soil.

(Al Rawas, 2002) worked out that additives such as copper slag containing higher amounts of Na^{+} but lower amount of Ca^{2+} and CaO, and was less effective than GGBS, which had low amounts of Na^{+} but relatively higher amount of CaO. Calcium ions help in reducing the intensity of swell potential of the soil containing smectite and illite clay minerals by forming aggregations of different sizes. He concluded that the chemical composition of stabilizing agents provides a good indication about their effectiveness in soil stabilization and should essentially be determined.

(Pandian et.al., 2002) had studied two type of Flyash, Class F (Raichur Ash) and Class C (Neyvalli Flyash) on CBR of Black Cotton Soil. Since CBR is linked with cohesion and friction. CBR of fine soil is attributed to cohesion while for flyash which is coarse it is with friction. With fine clayey soil, it has low CBR and flyash increases CBR. Adding Flyash to black cotton soil enhances its CBR. But when flyash exceeds its optimum concentration, it starts to reduce CBR and here the reduction is up to 60% and then increases to second optimum level. It also concludes that variation of CBR on Flyash - BC soil is due to frictional and cohesive resistance of soil and stabilizer. In class C flyash with increase in flyash strength increases due to additional pozzolonic reaction forming cementitious compound resulting in a good binding between BC soil and Flyash.

(PhaniKumar and Sharma, 2004) carried out study on expansive soil and its engineering properties when Flyash is added to it on experimental basis. The effect on Free Swell Index (FSI), Plasticity index, swelling pressure and potential, hydraulic conductivity, compaction and strength were studied. The ash blended soil was made by adding Flyash at 0, 5, 10,20 % on dry weight basis and was concluded that additive reduces plasticity properties and FSI by 50% by adding 20% flyash. Hydraulic conductivity of expansive soils mixed with flyash decreases with an increase of flyash due to increase in maximum dry unit weight. When Flyash content increases, OMC decreases and unconfined compressive strength increases. Thus addition of flyash makes the soil more stable.

(Bhubneswari et.al., 2005) had studied on engineering properties of soil through experimental programme. The experiment was regarding construction of an ash dyke at Ennore, North of Chennai were the city is covered with clay with liquid limit between 33-50%. During summer the shrinkage cracks exceed 10mm. The soil had poor workability for compaction, was highly compressible and had a very low shear strength. So instead of hauling soil from long distance, it was decided to use the locally available plastic clay stabilized using flyash. Flyash is freely available in locality of a thermal power plant. Flyash was added at varying percentage of 10, 20, 25, 30, 40, 50 and a major problem was to mix the soil and flyash to form a uniform mass. The adopted method was placing these material in layers and operating a “Disc Harrow”. Field trials were carried out by building an embankment of 3 to 4 meter wide, 30 meter long and 600mm high. Each layer of 200mm thickness was placed with flyash of varying content. For each mix the required thickness of soil was spread and above which flyash collected from ESP of thermal plant was spread. After this disc harrow was used to form a uniform mix of soil and flyash. The equipment is a circular disc which penetrate through loosely placed soil and pulled horizontally by a tractor. To uniformly mix the soil 8 passes of disc harrow was required. Though a sheep foot roller is used in clayey soil, but after 12 passes of the harrow, compaction was easily carried out using a 12 ton smooth roller. It was inferred that since the local soil was highly plastic therefore flyash was used to stabilize the soil and at 25% flyash content maximum dry density was observed at 1.25times the original. The local soil before mixing with flyash needed to be dry with moisture content below 7%, and presence of dry lumps in the soil increases the no. of passes required by the disc harrow.

(**Amu et al., 2005**) used Class F flyash to stabilize expansive soil and found out that 3% Flyash with 9% cement is a better stabilizer than 12% cement. Both Cement and Flyash were increased at increment of 1%.

(Cokra et. al., 2009) used GGBS and grounded GGBS-cement to stabilize an artificially prepared expansive soil. These stabilizers decreased the amount of swell whereas increased the rate of swelling. After leachates analysis it was concluded that that if expansive soil existed near drinking water wells, these stabilizer should not be used.

(Sharma and Sivapullaiah, 2012) studied effect of ground GGBS on UCS of expansive soil at 7, 14 and 28 days of curing and found that strength development depends more on ground GGBS content and effect of curing is less pronounced. There was also an increase in tangent modulus values with increase in ground GGBS content. The main objective was to substitute lime or cement with GGBS and to alter it to take more load from foundations. BC soil was obtained from Belgaun in Karnataka and GGBS obtained from cement industry and were dry-mixed. The strength of specimen increased by 20% at 7 and 14 days of curing, at 40% for 28 days. Also there was an increase in Tangent Modulus.

(Osinubi et.al., 2012) studied effect of stabilization delay in strength characteristic of BC soil stabilized with blast furnace slag and cement and concluded that compaction delay reduces the strength of stabilized soil.

(Ankit Singh Negi, 2013) Lime is used as an excellent soil stabilizing materials for highly active soils which undergo through frequent expansion and shrinkage. Lime acts immediately and improves various property of soil such as carrying capacity of soil, resistance to shrinkage during moist conditions, reduction in plasticity index, and increase in CBR value and subsequent increase in the compression resistance with the increase in time. The reaction is very quick and stabilization of soil starts within few hours.

(**Celik and Nalbantoglu, 2013**) studied effect of grounded GGBS on plasticity index, linear shrinkage, swelling potential of lime stabilized sulphate-bearing expansive soil. Ettringite is an expansive mineral which develops in presence of sulphate, calcium and aluminum compounds of clay. Lab test were performed on lime treated expansive soil with varying concentration of added sulphate and then same test was repeated on lime treated soil with same amount of sulphate but with 6% Slag, and three different concentration (2000, 5000 and 10000 ppm) were used in the study and atterberg limit, linear shrinkage and swelling were investigated. Test result showed that presence of sulphate in soil resulted in abnormal increase in plasticity as well as shrinkage and swelling of the soil at 5000 and 10000 ppm of sulphate. At 10000 ppm of sulphate the rate of swelling becomes nearly three times to the virgin soil. On scanning it was found that there was a growth of Ettringite minerals. It was found that adding grounded GGBS to the lime stabilized expansive soil prevents growth of ettringite mineral. These minerals leads to increase in plasticity index, linear shrinkage, swelling potential of the specific soil.

(**Sharma and Sivapuliah, 2015)** attempted to utilize mixture of fly ash (class F) and GGBS as binder to stabilize expansive soil. The objective of this research was to assess the effect of flyash-GGBS based binder on the physical properties and UCS of the soil. The influence of different percentages of binder on the Atterberg limits, compaction characteristics and unconfined compressive strength of an artificially-mixed soil were examined. The addition of binder was shown to bring about a significant improvement in these soil properties. It was found that the liquid limit and plasticity index of the expansive soil decreased considerably with the addition of binder, while the strength improved. The addition of lime–binder to the soil decreased liquid limit and plasticity index while increasing the shrinkage limit. Since both the materials require alkali activation, addition of small amount of lime (1%) in the binder is also considered and it further improved the soil properties by enhancing the pozzolanic reactivity of the binder It is found that the addition of binder causes flocculation of clay particles and increases the number of coarser particles which help in reducing the Atterberg limits. UCS was found to increase with an increase in binders and curing period and confirms that Flyash mixed with GGBS and has potential to improve properties of expansive soil with the help of minimum chemical additives. Based on the results of the UCS test, the addition of 20% binder is recommended as optimum content. Test results indicate that the use of GGBS mixed flyash as binder to stabilize expansive is well suited for sustainable construction besides economic benefits.

(Singh and Ray, 2019) studied the CBR of locally available soil in lucknow region with various stabilizers locally found. Stabilizers included Emulsions, Cement and Lime. Based on CBR value they calculated crust thickness and reduction in crust thickness based on CBR. Then they calculated the net savings in cost per km for a standard carraigeway based on reduction in crust thickness. They found that Emulsions are the most costliest of the batch. Although the results were positives but the cost of admixtures were high. Therefore the overall savings were drastically reduced. In case of Cement (1%) showed the highest CBR and highest reduction in crust thickness.

2.2 Summary of Literature

A thorough work has been done in field of soil stabilization, and mainly it emphasized on necessity of on field improvement of soil stabilization like CBR, MDD, OMC, UCS and Atterberg limits. The fundamentals of soil stabilization with respect to lime and GGBS is studied. Overall the integrity of pavement is improved due to soil stabilization, and economy in construction is analysed and if possible reduced with help of lower cost of admixture, or lowering the crust thickness. Further in this project we are going to study the effects of soil stabilization with lime and GGBS and its effect on MDD, CBR, Crust thickness and would check if overall cost of 1km road using stabilized soil has positive or negative effect on the economy of the project.

Chapter 3

Materials

3.1 Soil

The soil is obtained from Kalagaon Area in lucknow. There soil is mildly expansive due to some clay content in it. The soil is sieved through 4.75mm sieve followed by 2.36mm, 1.18mm, .600mm, .425mm, .075mm, finally .002mm and retained on pan) weighed and air dried. Once the soil is naturally air dried, it is tested for natural moisture content in a muffle furnace. The various geotechnical properties of the soil are listed below.

3.2 Lime

When quick lime is finely crushed, slaked with a minimum amount of water and screened or ground to form a fine homogenous powder the product is called hydrated lime. Quick lime obtained by burning limestone or $CaCl_2$ obtained from lime quarry, when sprinkled with water slakes within 10 minutes and become powder. The slaked lime so produced is sieved through IS: sieve 3.5 mm. It is then used for various purposes such as white washing, plastering making mortars and lime putty and when mixed with soil, helps to reduce its swelling and helps to gain strength. The process is also known as hydration of lime.

$$\mathbf{Cao + H_2O \rightarrow Ca\,(OH)_2 + 15.6\ Kcal}$$

In the above reaction high heat of hydration is produced at a temperature of about 350^{o}C which is an exothermic reaction. The energy liberated during this reaction causes the lumps of quicklime to split and fall to lime to powder the heat causes excess water to evaporate. In hydration of lime the heat of hydration generated is not sufficient to break the lime to powder and therefore, the lime is broken mechanically to a suitable size and pulverized before hydration and thus fine powder is produced by mechanical grounding. Limes from coarse grained stone, lump limes and pulverized usually slake rapidly; limes from fine grained stones, and dense lumpy lime usually slakes slowly. Over burning or under burning of the lime stone causes the lime to slake more slowly.

Lime for lime – soil stabilization work shall be commercial dry lime slaked at site or pre – slaked lime delivered to the site in suitable packing. Unless otherwise permitted by the engineer, the lime shall have purity of not less than 70 percent by weight of Quick Lime (CaO) when tested in accordance with IS:1514. Lime shall be properly stored to avoid prolonged exposure to the atmosphere and consequent carbonation which would reduce its binding properties. When soils are treated with lime, either modification in soil properties or binding or both actions may take place. In the case of clayey soils with high plasticity the predominant action is generally modification resulting benefits such as reduction in plasticity and volume changes due to variation in moisture content. Other benefits are soil – lime mixes become friable and easy to be pulverized having less affinity with water, also there could be puzzolanic action resulting in slow rate of increase in strength with curing period. All these modifications are considered desirable in construction of soil stabilized roads. Lime also imparts a little binding action in soils. The maximum dry density of soil – lime mix is decreased by 2 to 3% in terms of untreated soils; however this decrease in dry density with addition of small proportion of lime does not cause reduction in strength. When clay is treated with lime, the various possible reactions are bas exchange, coagulation or flocculation, reduction in thickness of water film around clay particles, cementing action and carbonation. The fine clay particles react with lime and get flocculated or aggregated into larger particles groups which are fairly stable even under subsequent soaking. Plastic clay soils tend to agglomerate more than silty and sandy soils. Due to this flocculation the lime – treated clays indicate a different grain size distribution, indicating substantial reduction in proportion of fines the changes in plasticity, characteristics of soil – lime mixture also take place simultaneously; the total time required for the changes depends on several factors including the soil type.

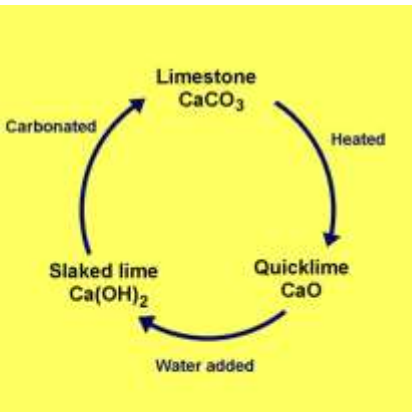

Figure 3.1 Lime Cycle

Figure 3.2 Lime Stone

Figure 3.3 Quick Lime **Figure 3.4 Slaked Lime**

Table 3.1 Properties of Lime

Chemical Formula	$Ca(OH)_2$
Molar Mass	74.093 g/mol
Appearance	White Powder
Odour	Odourless
Density	2.211 g/cm^3
Melting Point	$580^{O}C$
Solubility	• Soluble in acids and glycerol • Insoluble in alcohol
Solubility in water	• 1.89 g/L ($0^{O}C$) • 1.73 g/L ($20^{O}C$) • 0.66 g/L ($100^{O}C$)
Refractive Index	1.574
Magnetic Susceptibility	$-22*10^{-6}$ cm^3/g

3.3 Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBS), more commonly known to as slag and It is a by product from steel industry. It is majorly a waste product formed from steel industry and about 40-42% of annual generated GGBS is only used. The slag is majorly used as a landfill material as large quantity can be dumped at a particular site. Slag is chemically neutral and over time in alkaline nature is slowly activates its cementations properties and gain strength. Cement industry has very high demand of Blast Furnace Slag as it helps to manufacture slag cement. It gains 7 day strength slowly, but the 28 day strength remains the same as other cement. Cement plants near Steel plant are large consumer of slags.

Production

The chemical composition of a slag is different considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore and coke (C) are combined in the blast furnace with a flux which lowers the viscosity of the slag which in fact helps to separate the slag from molten ore. In the case of pig iron production the flux consists mostly of a mixture of limestone ($CaCl_2$) and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation as in form of a froth. Slow cooling of slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates ranging from off white to grey depending on metal oxide specially amount of CaO. To obtain a good slag reactivity or hydraulicity, the slag melt needs to be rapidly cooled or quenched below 800 °C in order to prevent the crystallization of merwinite and melilite else the slag becomes glassy. To cool and fragment the slag a granulation process can be applied in which molten slag is subjected to jet streams of water or air under pressure as water helps to dissolve the granules and float some impurities. Alternatively, in the pelletization process the liquid slag is partially cooled with water and subsequently projected into the air by a rotating drum and small droplets are dropped in water taking form of pellets. In order to obtain a suitable reactivity, the obtained fragments are ground to reach the same fineness as Portland cement to get an uniformity with coarse and fine aggregate.

Figure 3.5 Process of Manufacturing GGBS

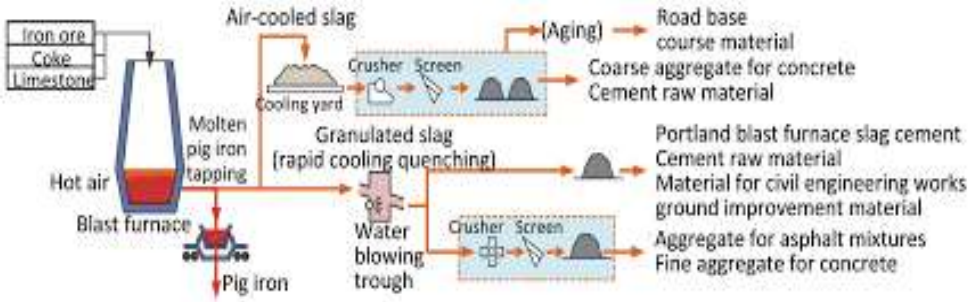

Figure 3.6 Various Uses of Slag

Figure 3.7 GGBS

Forms of Blast Furnace Slags

- Air Cooled Blast Furnace Slag

  A type of blast furnace slag, formed when the liquid slag is poured over the sand bed and is cooled at room temperature. The product is hard, lumpy and crystalline in nature which can be crushed, screen and used in cement industry as an raw material, hot mixed asphalt aggregate, pipe filling, septic drain fills.

- Foamed Blast Furnace Slag

  The process of cooling and solidification can be accelerated if the molten slag is cooled and solidified by adding controlled quantities of water, air, or steam. It enhances the cellular nature of the BFS and produces a lightweight expanded or foamed product. Its has a high porosity and low bulk density helps us to distinguish foamed slag from air cooled blast furnace.

- Granulated Blast Furnace Slag

  In this case the molten slag is cooled and solidified by rapid water quenching to a glassy state. Crystallization can be avoided resulting in the formation of sand size (or frit-like) fragments, usually with some friable clinker-like material. According to chemical composition of the slag, its temp at the time of water quenching, and the method of production are the three factors responsible for the physical structure and gradation of granulated slag. Ground granulated blast furnace slag shows binding properties, when it is crushed or milled to very fine cement sized particles.

- Pelletized Blast Furnace Slag

  Pelletized blast furnace slag is cooled rapidly using water or steam to produce a lightweight aggregate which can be used for high fire rated concrete masonry and lightweight fill application over marginal soil . The pellet can be made more brittle by controlling the process . This vitrified pelletized BFS used for the production of cement.

Table 3.2 Properties of GGBS

S.NO	CHARACTERISTICS	REQUIREMENT AS PER BS: 6699	TEST RESULT
1	Fineness (M / Kg)	275 (MIN)	390
2	Specific Gravity		2.85
3	Particle Size (Cumulative %)	45 MICRON	97.10
4	Insoluble Residue (%)	1.5 (Max)	0.49
5	Magnesia. Content (%)	14.0 (Max)	7.73

6	Sulphide Sulphur (%)	2.00 (Max)	0.50
7	Sulphite Content (%)	2.50 (Max)	0.38
8	Loss On Ignition (%)	3.00 (Max)	0.26
9	Manganese Content (%)	2.00 (Max)	0.12
10	Chloride content (%)	0.10 (Max)	0.009
11	Glass Content (%)	67 (Min)	91
12	Moisture Content (%)	1.00 (Max)	0.10
13	Chemical Moduli		
A	CaO + MgO + SiO2	66.66 (Min)	76.03
B	(CaO + MgO) / SiO2	> 1.0	1.30
C	CaO / SiO2	< 1.40	1.07

3.4 Slag Activation

GGBS without an activator does react with water and the rate of hydration is very slow. Its hydraulic reactivity depends on various factors like glass phase content, particle size distribution, chemical composition etc.

When the slag is exposed to the water , an impermeable coating of alumino-silicate is formed on the surfaces of slag grains and this inhibits further reaction with water. Hence a chemical activator or chemical medium is essential for further hydration . Many activators have been suggested to activate GGBS and among them the most commonly used activators are calcium hydroxide, gypsum, ordinary Portland cement, sodium hydroxide, sodium carbonate and sodium sulphate etc.

Rate of hydration becomes high with increasing alkali contents as they help in breaking the Si-O and Al-O bonds. Portland cement is one of the most commonly used activators and the reaction with GGBS with and water is a complex process. Calcium hydroxide [$Ca(OH)_2$] and C-S-H gel and other minor alkalis produced during hydration of Portland Cement. Among them Slag is mainly activated by the hydration product Ca{OH)$_2$ (**Hakkinen, 1993; Bijen, 1996).**

Thus lime in the form of $Ca(OH)_2$, may be added either as an additive or released from Portland cement hydration. GGBS, due to its high alumina and silica content, produces slightly different hydrates from those formed when using ordinary Portland cement.

The main reactants of GGBS hydration are C-S-H, calcium aluminates hydrate and a small amount of calcium hydroxide **(Higgins et al., 1998).**

Lime as an activator has studied by many investigators and found to be the most efficient activator. It quicken the hydration reaction of GGBS. Due to its high alumina and silica content, the main reaction products of GGBS activated by lime are C-A-S-H gel and hydroxide type phases containing magnesium.

Requirement of lime for activation of slag is also less and it varies from 2% to 4%. Calcium sulphate is also a successful Activator as it increases the rate of hydration of slag further and contributes in gaining higher strength

Chapter 4
Methodology

4.1 Modified Proctor Test (IS 2720 Part 8- 1983, Reaffirmed May 2015)

Modified proctor test is used to determine the compaction of different types of soil and change in properties of soil with the change in moisture content. It gives us a relationship between Moisture Content and dried density. Compaction is densification of unsaturated soil by the reduction in the volume of voids filled with air, while the volume of solids & water content remains the same.

The major aim of compaction of soil is to increase shear strength, decrease compressibility, reduce permeability, & to control swelling & shrinkage of soil. The degree of compaction of soil is measured in terms of its dry density. The maximum dry density of soil occurs at optimum moisture content (OMC).

The Modified Proctor Test is of great importance and is widely used in the construction of roads, highways, earth fill dams, earth filling, Airports, etc.

In modified Proctor test, the soil is compacted in the given mould in Five (05) layers with a rammer of 10 lbs (4.5 kg) with a fall of 18 inches (45 cm).

Apparatus Required

- Proctor Mould (Metal Mould 2250 cc, 150mm diameter)
- Metal Rammer 4.9kg (as per IS 9189- 1979)
- Electronic Balance (200g to 10kg with sensitivity up to 1grams)
- Sieves (37.5mm 19mm and 4.75mm)
- Oven (Temperature 105-110 ^{0}C)
- Steel Straight Edge
- Airtight Container

Procedure

1. 5-6 kg of soil is taken and passed through sieves 37.5mm 19mm 4.75mm.
2. Then the soil sample is mixed with water at various percentage increments (0, 3, 6, 9, 12, 15 %) (Sample 1)
3. Mix the soil sample with water and Admixtures (GGBS and Lime) at various percentage increments of 0, 1, 2, 3, 4 % GGBS and 0, 0.5 and 1% Lime.
4. Then Weigh the empty mould without base plate and collar.
5. Placing the mould With the collar attached on a solid base and compact the soil mass into the mould using standard compaction in five layers with 25 blows per layer; and with a 4.5 kg rammer dropping from a height of 45 cm
6. Then take care to distribute the blows uniformly over the surface of each layer, and to let the rammer fall freely.
7. Remove the collar carefully strike off the projected part of the compacted soil by steel straight edge.
8. Then weigh the mould + soil.
9. Extrude the compacted soil specimen from the mould and split it on a large tray
10. Take a sample for moisture content determination.
11. Break-up the specimen to No.4 sieve size, and mix it with the remainder of the original sample.
12. Add suitable increments of water, and mix thoroughly for at least 5 trials.
13. Then repeat 3 to 5 steps for each trial. (Step 2)
14. Draw compaction curve on a graph with dry density on ordinate and moisture contents on the x-axis.

Maximum dry density shall be at the apex of the curve and optimum moisture content (OMC) at which maximum dry density is obtained.

4.2 Sample Description

Table 4.1 Sample Description and Numbering

Sample No	Description
1	Soil + 0% Slag + 0% Lime
2	Soil + 1% Slag + 0.% Lime
3	Soil + 2% Slag + 0.% Lime
4	Soil + 3% Slag + 0.% Lime
5	Soil + 4% Slag + 0% Lime
6	Soil + 0% Slag + 0.5% Lime
7	Soil + 1% Slag + 0.5% Lime
8	Soil + 2% Slag + 0.5% Lime
9	Soil + 3% Slag + 0.5% Lime
10	Soil + 4% Slag + 0.5% Lime
11	Soil + 0% Slag + 1.0% Lime
12	Soil + 1% Slag + 1.0% Lime
13	Soil + 2% Slag + 1.0% Lime
14	Soil + 3% Slag + 1.0% Lime
15	Soil + 4% Slag + 1.0% Lime

Table 4.2 Tabulation Sheet for MPT for Sample 1

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	3.93	1.746	8.2	1.61
2250	4.90	4.02	1.788	10.4	1.62
2250	4.90	4.17	1.852	12.9	1.64
2250	4.90	4.35	1.935	15.8	1.67
2250	4.90	4.49	1.995	19.6	1.66
2250	4.90	4.52	2.010	23.3	1.63

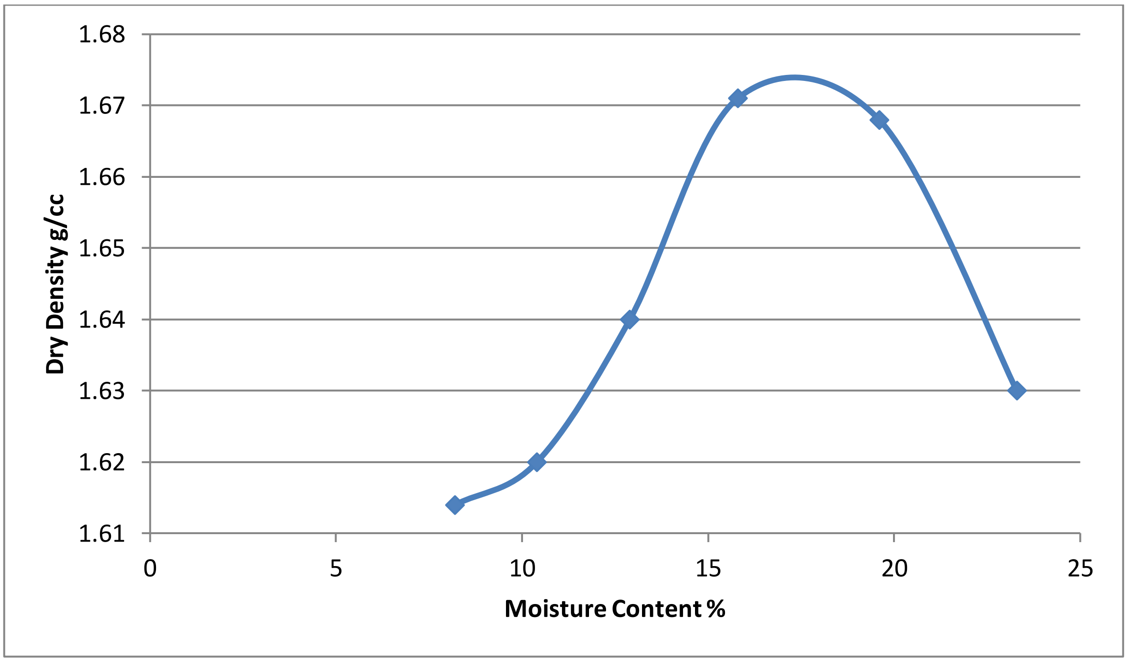

Figure4.1 Compaction Curve for Sample 1

Table 4.3 Tabulation Sheet for MPT for Sample 2

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	3.90	1.74	7.1	1.62
2250	4.90	4.00	1.78	9.2	1.63
2250	4.90	4.14	1.84	11.5	1.65
2250	4.90	4.26	1.89	14.0	1.66
2250	4.90	4.35	1.93	17.9	1.64
2250	4.90	4.36	1.94	21.0	1.60

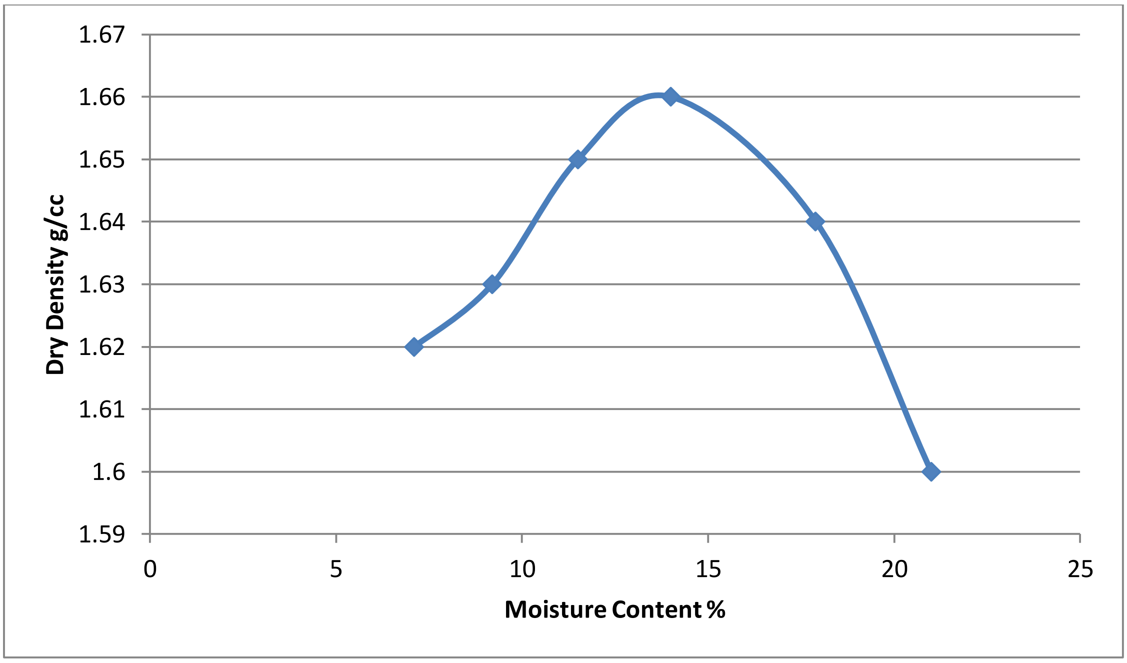

Figure 4.2 Compaction Curve for Sample 2

Table 4.4 Tabulation Sheet for MPT for Sample 3

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	3.99	1.77	7.4	1.65
2250	4.90	4.09	1.82	9.4	1.66
2250	4.90	4.23	1.88	11.8	1.68
2250	4.90	4.34	1.93	14.2	1.69
2250	4.90	4.41	1.96	18.1	1.66
2250	4.90	4.47	1.99	21.8	1.63

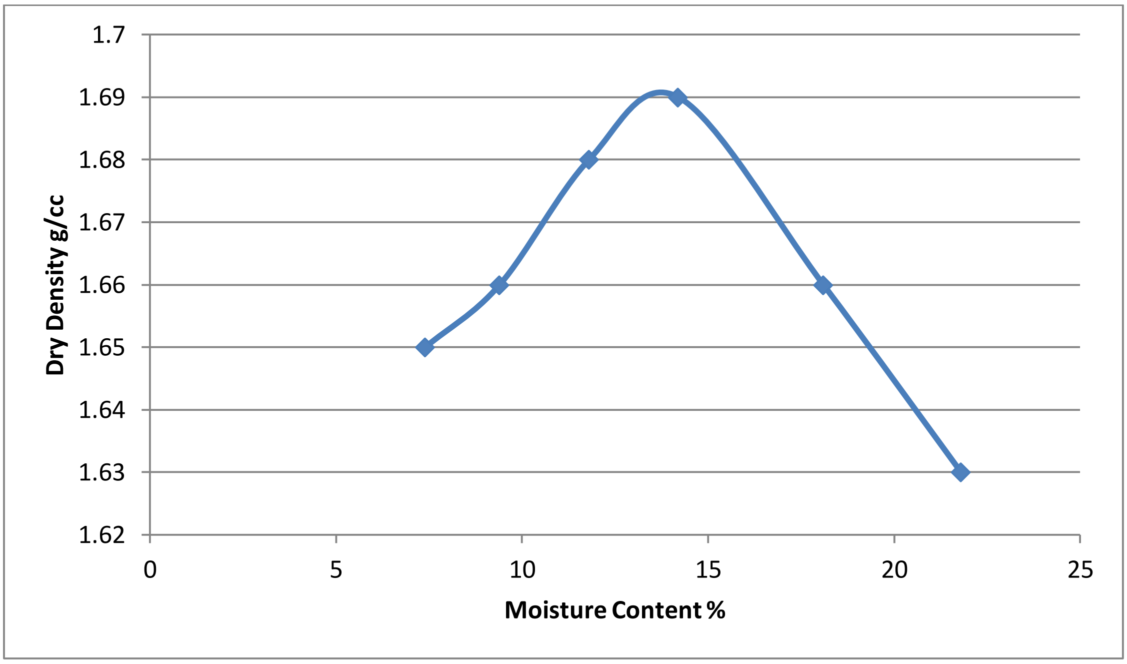

Figure 4.3 Compaction Curve for Sample 3

Table 4.5 Tabulation Sheet for MPT for Sample 4

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.04	1.80	7.5	1.67
2250	4.90	4.15	1.84	9.7	1.68
2250	4.90	4.27	1.90	11.6	1.70
2250	4.90	4.39	1.95	14.1	1.71
2250	4.90	4.48	1.99	17.8	1.69
2250	4.90	4.54	2.02	21.5	1.66

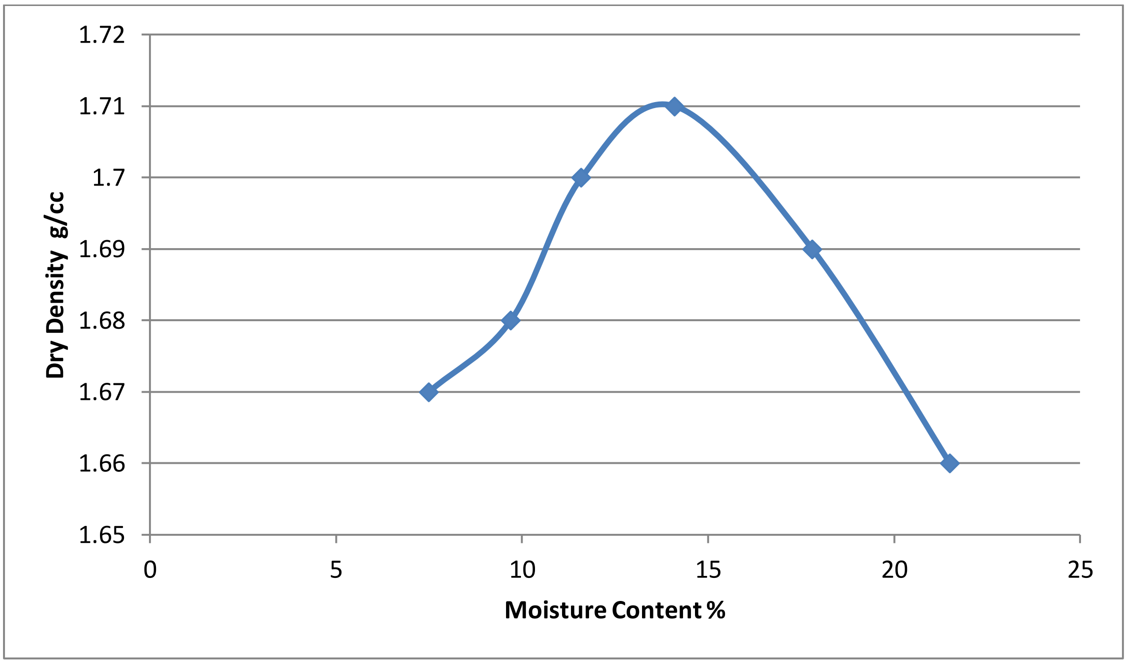

Figure 4.4 Compaction Curve for Sample 4

Table 4.6 Tabulation Sheet for MPT for Sample 5

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.03	1.79	7.9	1.66
2250	4.90	4.13	1.83	9.8	1.67
2250	4.90	4.25	1.89	11.9	1.69
2250	4.90	4.35	1.93	13.6	1.70
2250	4.90	4.36	1.94	16.0	1.67
2250	4.90	4.42	1.96	19.8	1.64

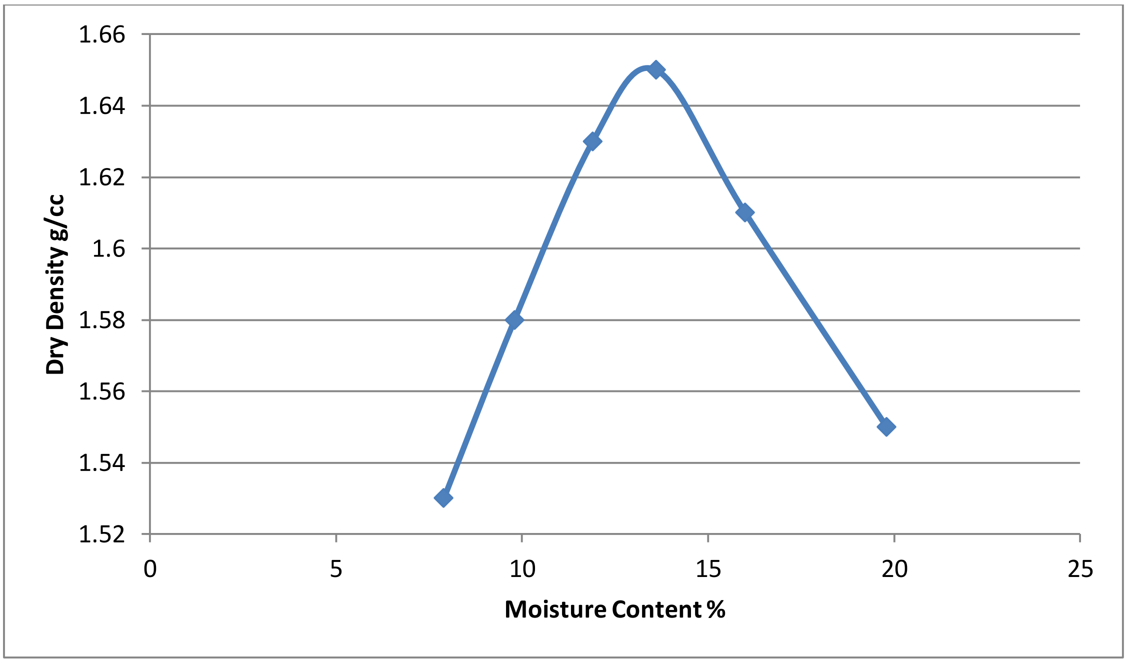

Figure 4.5 Compaction Curve for Sample 5

Table 4.7 Tabulation Sheet for MPT for Sample 6

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.08	1.81	8.0	1.68
2250	4.90	4.22	1.87	10.2	1.70
2250	4.90	4.32	1.92	12.4	1.71
2250	4.90	4.44	1.97	14.8	1.72
2250	4.90	4.47	1.99	16.9	1.70
2250	4.90	4.51	2.00	20.7	1.66

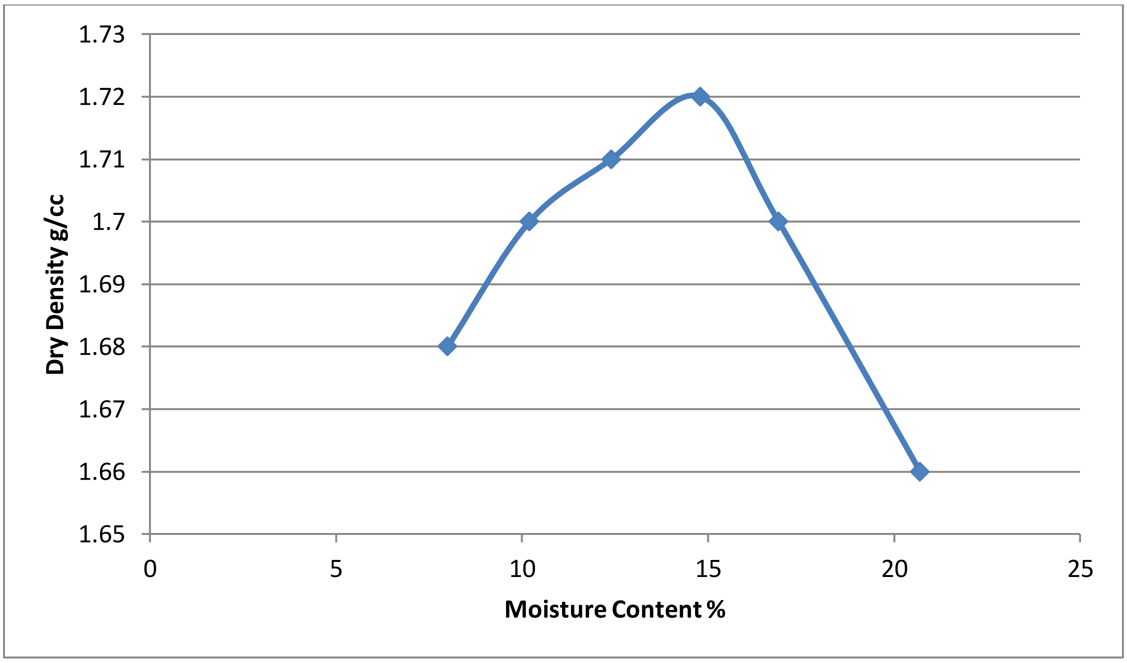

Figure 4.6 Compaction Curve for Sample 6

Table 4.8 Tabulation Sheet for MPT for Sample 7

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.13	1.84	8.10	1.70
2250	4.90	4.25	1.89	10.40	1.71
2250	4.90	4.36	1.94	12.70	1.72
2250	4.90	4.50	2.00	14.90	1.74
2250	4.90	4.50	2.00	17.00	1.71
2250	4.90	4.55	2.02	21.00	1.67

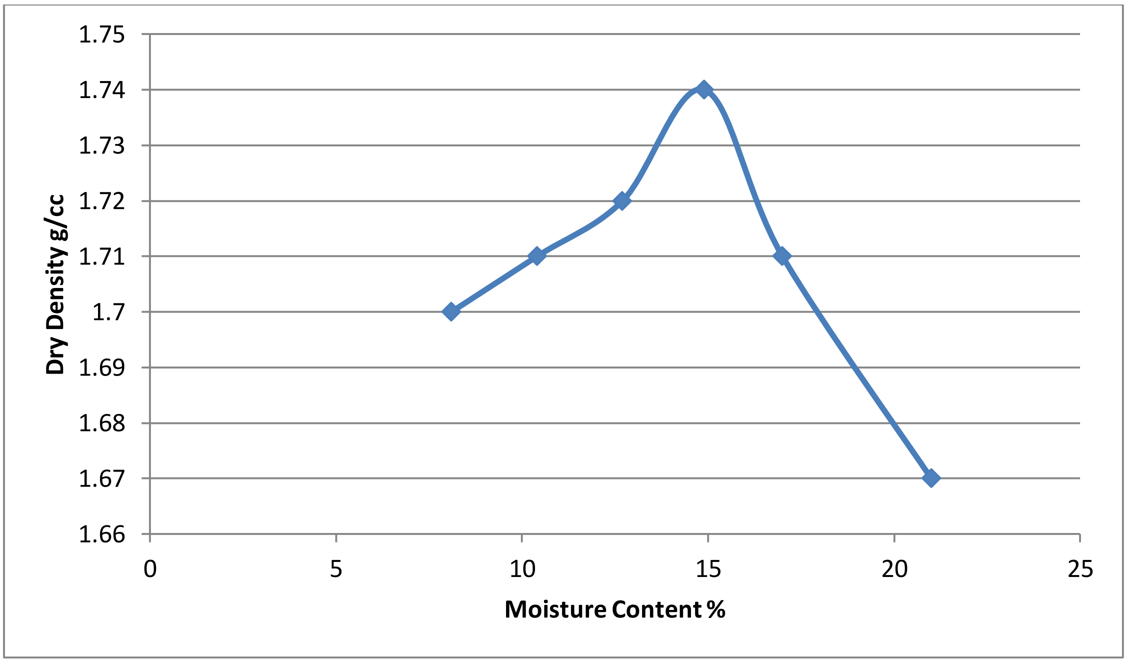

Figure 4.7 Compaction Curve for Sample 7

Table 4.9 Tabulation Sheet for MPT for Sample 8

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.19	1.86	8.3	1.72
2250	4.90	4.29	1.91	10.2	1.73
2250	4.90	4.43	1.97	12.4	1.75
2250	4.90	4.51	2.01	15.3	1.74
2250	4.90	4.55	2.02	17.7	1.72
2250	4.90	4.65	2.07	22.4	1.69

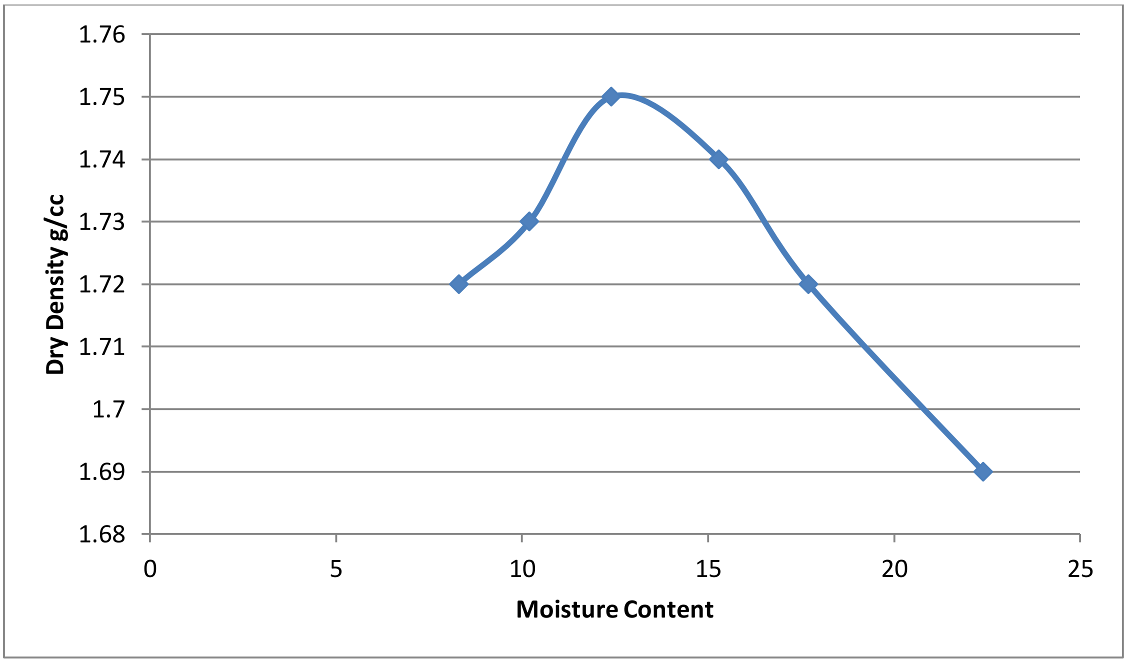

Figure 4.8 Compaction Curve for Sample 8

Table 4.10 Tabulation Sheet for MPT for Sample 9

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.21	1.87	7.6	1.74
2250	4.90	4.28	1.90	10.0	1.73
2250	4.90	4.50	2.00	12.9	1.77
2250	4.90	4.67	2.08	15.4	1.80
2250	4.90	4.66	2.07	17.7	1.76
2250	4.90	4.62	2.05	20.7	1.70

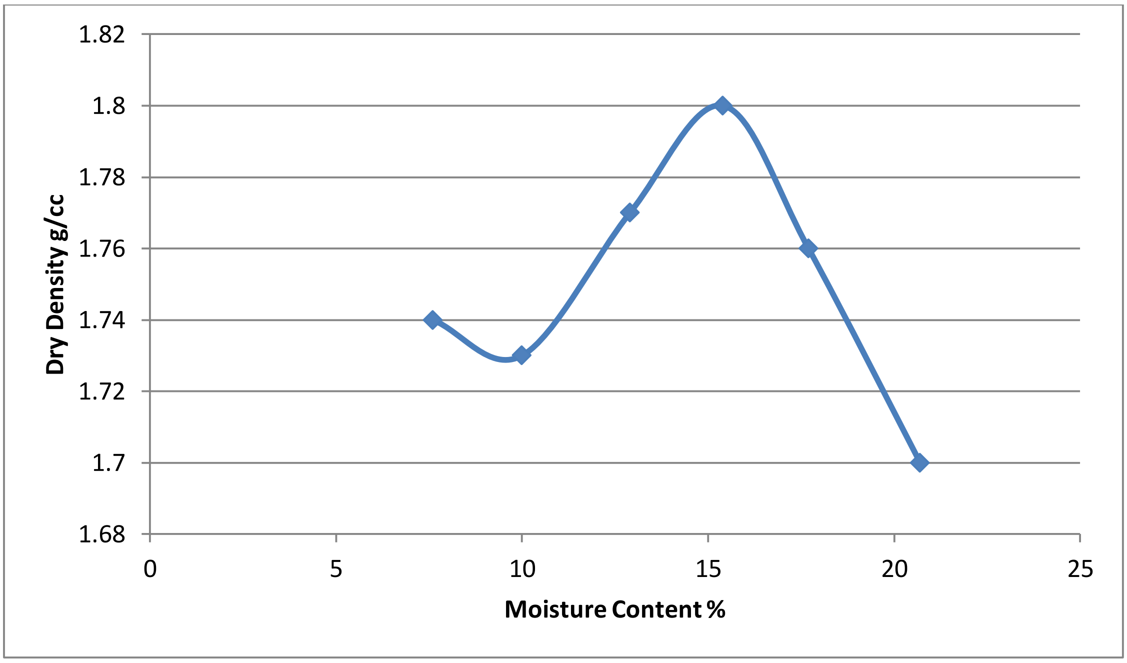

Figure 4.9 Compaction Curve for Sample 9

Table 4.11 Tabulation Sheet for MPT for Sample 10

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.17	1.85	7.8	1.72
2250	4.90	4.27	1.90	9.6	1.73
2250	4.90	4.40	1.95	11.7	1.75
2250	4.90	4.54	2.02	14.0	1.77
2250	4.90	4.53	2.01	16.3	1.73
2250	4.90	4.58	2.03	20.4	1.69

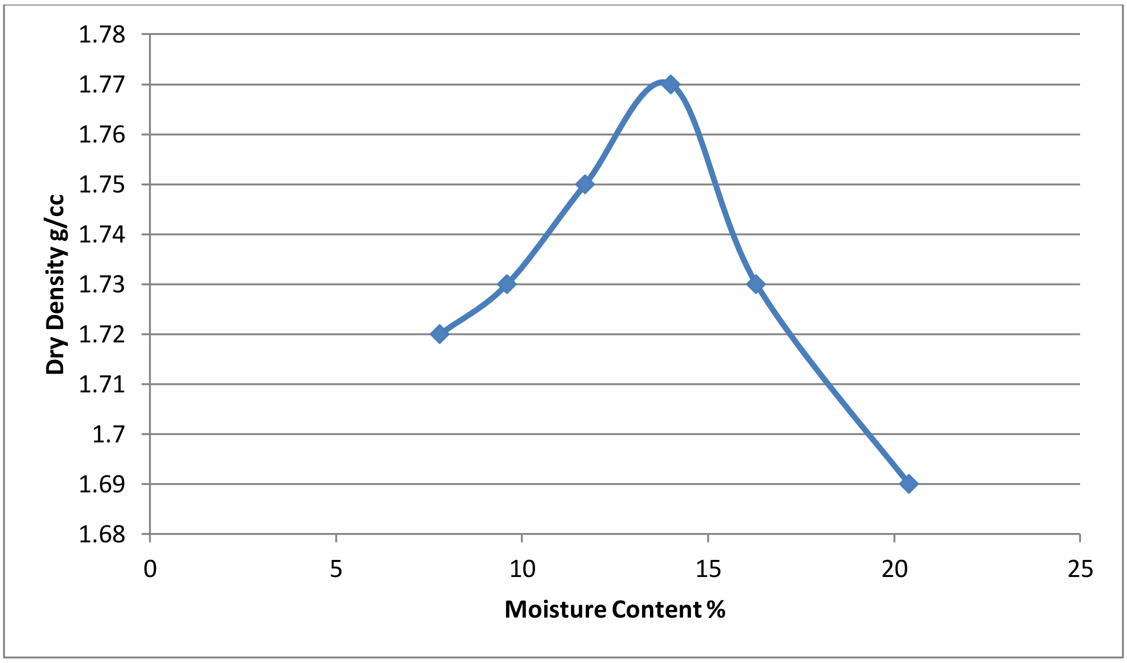

Figure 4.10 Compaction Curve for Sample 10

Table 4.12 Tabulation Sheet for MPT for Sample 11

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	3.83	1.70	10.4	1.76
2250	4.90	3.96	1.76	12.0	1.78
2250	4.90	4.13	1.84	13.8	1.81
2250	4.90	4.24	1.88	16.7	1.83
2250	4.90	4.31	1.92	19.0	1.83
2250	4.90	4.27	1.90	21.4	1.79

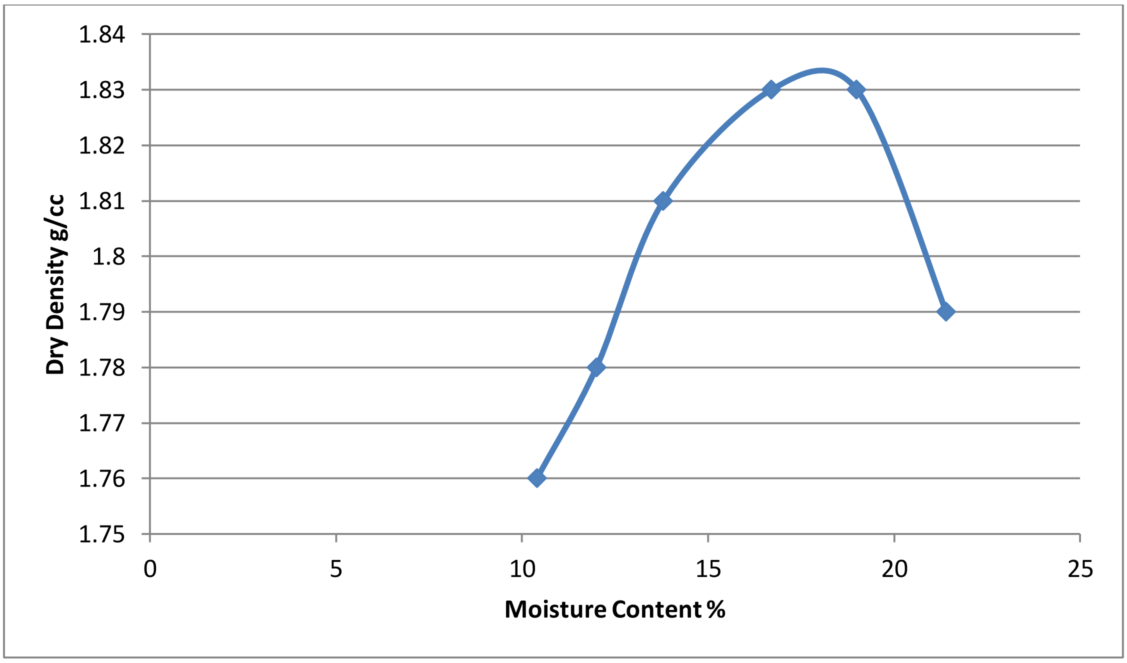

Figure 4.11 Compaction Curve for Sample 11

Table 4.13 Tabulation Sheet for MPT for Sample 12

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.42	1.97	10.5	1.78
2250	4.90	4.54	2.02	12.0	1.80
2250	4.90	4.74	2.10	14.4	1.84
2250	4.90	4.88	2.17	16.6	1.86
2250	4.90	4.87	2.17	19.0	1.82
2250	4.90	4.92	2.19	22.1	1.79

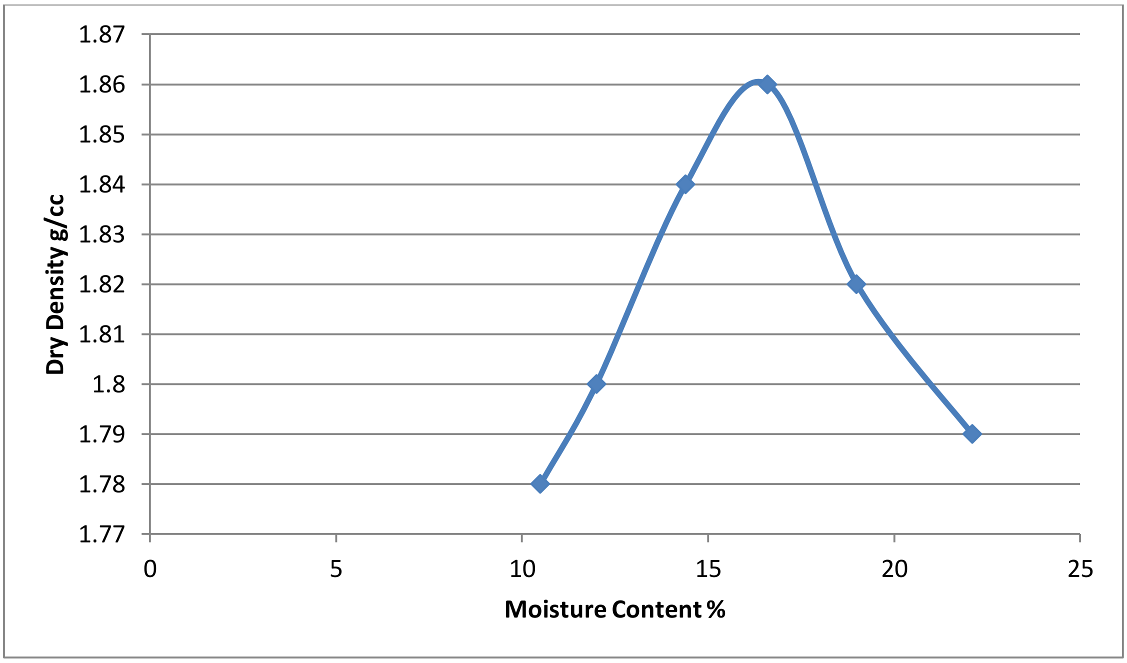

Figure 4.12 Compaction Curve for Sample 12

Table 4.14 Tabulation Sheet for MPT for Sample 13

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.50	2.00	9.9	1.82
2250	4.90	4.62	2.06	11.1	1.85
2250	4.90	4.83	2.15	13.5	1.89
2250	4.90	5.02	2.23	16.2	1.92
2250	4.90	4.97	2.21	18.8	1.86
2250	4.90	4.97	2.21	20.7	1.83

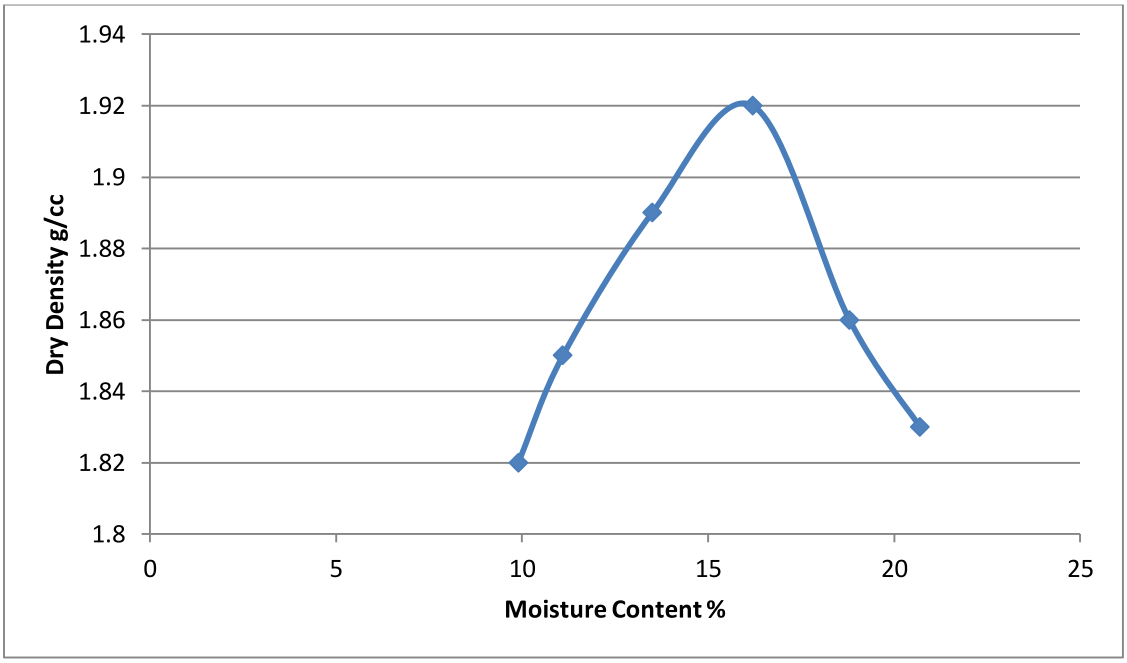

Figure 4.13 Compaction Curve for Sample 13

Table 4.15 Tabulation Sheet for MPT for Sample 14

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.44	1.97	9.6	1.80
2250	4.90	4.62	2.05	12.90	1.82
2250	4.90	4.75	2.11	14.1	1.85
2250	4.90	4.94	2.19	16.7	1.88
2250	4.90	4.95	2.20	19.5	1.84
2250	4.90	4.89	2.17	21.4	1.79

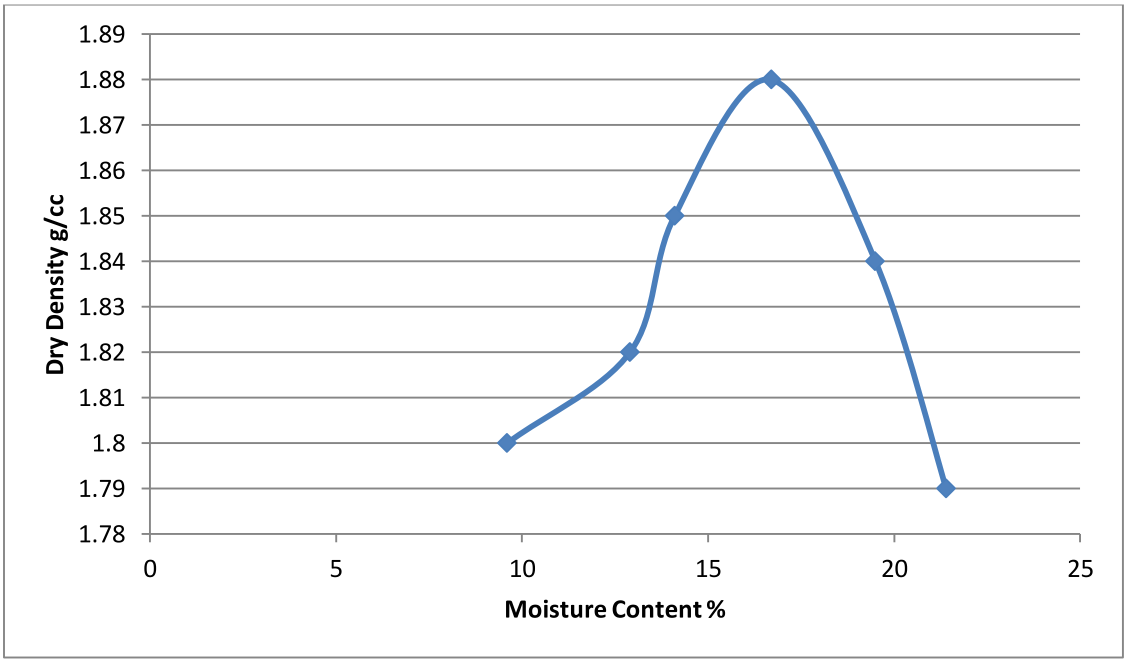

Figure 4.14 Compaction Curve for Sample 14

Table 4.16 Tabulation Sheet for MPT for Sample 15

Volume of Mould (kg)	Weight of Mould (kg)	Weight of Soil in Mould in Kg	Bulk Density in g/cc	Moisture Content	Dry unit Weight in g/cc
2250	4.90	4.31	1.91	8.1	1.77
2250	4.90	4.44	1.97	10.9	1.78
2250	4.90	4.60	2.04	13.6	1.80
2250	4.90	4.77	2.12	15.9	1.83
2250	4.90	4.76	2.11	18.1	1.79
2250	4.90	4.74	2.11	21.0	1.74

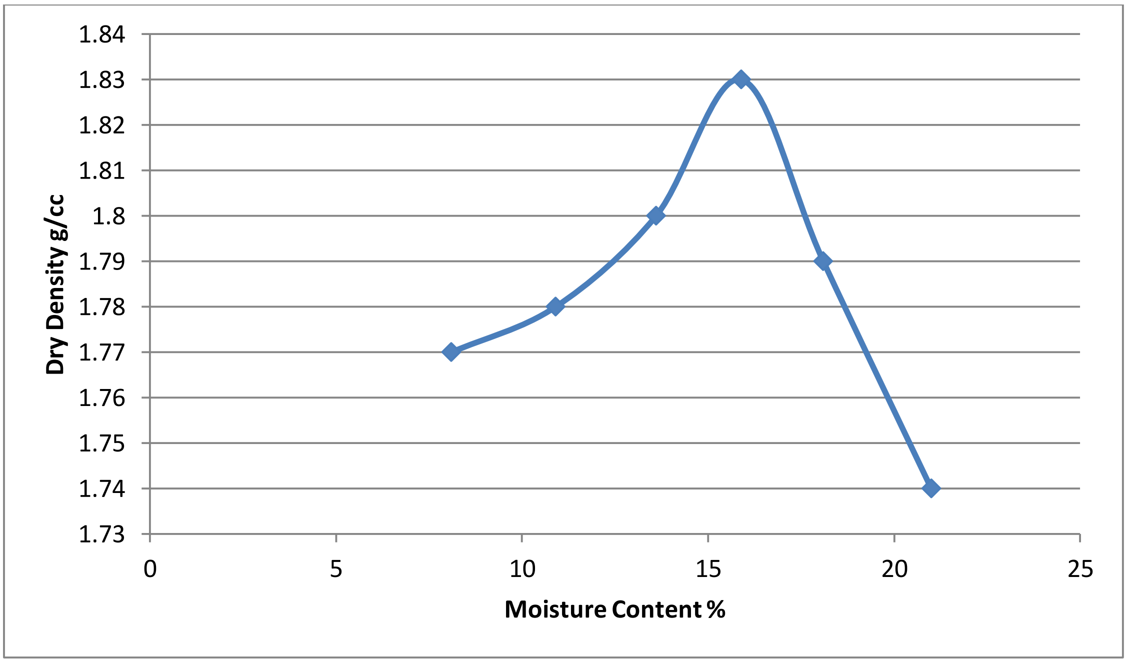

Figure 4.15 Compaction Curve for Sample 15

Table 4.17 Sample Description with the respective MDD

Sample No.	**Description**	**Max. Dry Density g/cc**
1	Soil + 0% Slag + 0% Lime	1.67
2	Soil + 1% Slag + 0.% Lime	1.66
3	Soil + 2% Slag + 0.% Lime	1.69
4	Soil + 3% Slag + 0.% Lime	1.71
5	Soil + 4% Slag + 0% Lime	1.70
6	Soil + 0% Slag + 0.5% Lime	1.72
7	Soil + 1% Slag + 0.5% Lime	1.74
8	Soil + 2% Slag + 0.5% Lime	1.75
9	Soil + 3% Slag + 0.5% Lime	1.80
10	Soil + 4% Slag + 0.5% Lime	1.77
11	Soil + 0% Slag + 1.0% Lime	1.83
12	Soil + 1% Slag + 1.0% Lime	1.86
13	**Soil + 2% Slag + 1.0% Lime**	**1.92**
14	Soil + 3% Slag + 1.0% Lime	1.88
15	Soil + 4% Slag + 1.0% Lime	1.83

4.3 California bearing Ratio

CBR test was developed by California state highway department for evaluating the strength of subgrade soil and other pavement materials for the designs and construction of felxible pavements. The CBR results have been correlated with flexible pavement thickness requirements for highway and airfields. Being emperical test method, CBR test result cannot be related accurately with any fundamental property of soil or pavement material to be tested. CBR method is also standardized by Bureau of Indian Standards (BIS).

CBR test denotes a measure of resistance to penetration of a soil or flexible pavement material of standard plunger under controlled test condition. The test also conducted on both undisturbed and remoulded soil specimens. Lab test procedure should be strictly adhered if high degree of reproducibility is required.

The basic principle of CBR test is by causing a cylindrical plunger of 50mm diameter to penetrate into the soil sample or pavement component material at an rate of 1.25mm per minute. The load required for 2.5mm and 5mm penetration of plunger in soil or pavement material to be tested is recorded. The CBR value of the material tested is expressed as a percentage of standard load value in a material. The standard load value have been established based on a large number of test standard crushed stone aggregates at penetration value of 2.5 and 5mm. These standard load value may directly. These standard load value given below maybe directly used to compute the CBR value of the test material.

Penetration mm	**Standard Load kg**	**Unit Standard Load kg**
2.5	**1370**	**70**
5.0	**2055**	**105**

Determination of CBR value in the Laboratory

The Laboratory CBR apparatus consists of a mould 150mm diameter with a base plate and collar and a loading frame with the cylindrical plunger at 50mm diameter and dial gauge for measuring the expansion on the soaking and the penetration curve values.

The specimen in the mould is compacted to a dry density corresponding to the minimum state of compaction likely to be achieved in practice. In absence of the information the specimen may be compacted to maximum dry density at the optimum moisture content.

IS:2720 Part VIII is preferred for high traffic roads like expressway and national highway and state highway however for light compaction roads IS 2720 Part VII is used. The specimen is subjected to 4 day water absorbtion for soaking, swelling and water absorption. The surcharge weight on top of the specimen in the mould and the assembly is placed under the plunger of the loading frame. The load value are noted corresponding to penetration value at 0.0, 0.5, 1.0. 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, 12.5mm. The load vs penetration graph is plotted or the values may be converted to pressure values and plotted against the penetration values

Two Typical types of load - penetration curves may be obtained. Normal curve with high convexity upwards and load and penetration values are noted. Sometimes a curve with initial concavity upwards indicating the necessity corrections, In that case corrected origins is established by drawing a tangent from the steepest point on the curve to obtain the corrected origin . The load values corresponding to 2.5mm and 5mm penetration values from the corrected origins are noted.

A - Load or pressure sustained by the specimen at 2.5 or 5mm penetration level

B - Load or pressure obtained by standard aggregates at 2.5 or 5mm penetration level

CBR% = (A / B)*100

The causes of initial concavity of load penetration curve calling for the correction in origin are due to

- top layer of the soil is too soft or slushy after soaking water
- top layer of the soil is uneven
- the penetration plunger is not vertical therefore bottom surface of the plunger is not horizontal and not fully in contact with the top surface of the specimen

Normally CBR value of 2.5mm is higher than 5mm and higher value is reported as CBR. However if the CBR value of mm is higher than 2.5mm than the test is repeated for checking. If the test value is similar again than CBR 5mm is reported.

The CBR test is essentially an arbitrary strength test and hence cannot be used to evaluate the soil properties like cohesion or angle of internal friction or shearing resistance. Presence of coarse grained soil would result in poor reproducibility of the CBR results. Material passing 20mm sieve are only used for the test.

Application of CBR test in flexible pavement designs

Several agencies in different countries have a standardized CBR test method and have developed charts for the designs of flexible pavement for the roads and runway based on CBR values of sub-grade soil and other pavement material. CBR test as well as CBR method of flexible pavement design are simple and the performance studies of these pavement have been extensively investigated and found to be generally satisfactory. The Indian Road Congress IRC has standardized the guildlines for the design of flexible pavement based on CBR test (vide IRC 37- 2001) and this method is being followed for the design of flexible pavement for all category of the road in India

Test Methodology

Features of the CBR machine on which we are going to

- conduct the Test
- Plunger(diameter) = 50mm
- Mould Height = 126mm
- Mould Height with collar = 167.6mm
- Inner diameter of Mould = 100mm
- Weight of Hammer = 2.6kg
- Height of Fall = 310mm
- Number of blows = 56 per Layer
- Number of layer = 3

Sieve set used for sieving the soil sample for CBR.

- 4.75mm
- 2.36mm
- 1.18mm
- 425micron
- 300micron
- 150micron
- 75micron

In this project we have tried to perform a comparative study between all the mentioned admixtures used for soil stabilization and in this we mainly focused on increasing the CBR of the soil and compare which of the following admixture is giving the maximum CBR as compared to the CBR of the soil without any admixture. And we will also check which admixture is best suited to us chemically and economically, economically because increase in CBR helps us in reducing the overall crust thickness of the pavement and for this we followed the following procedure

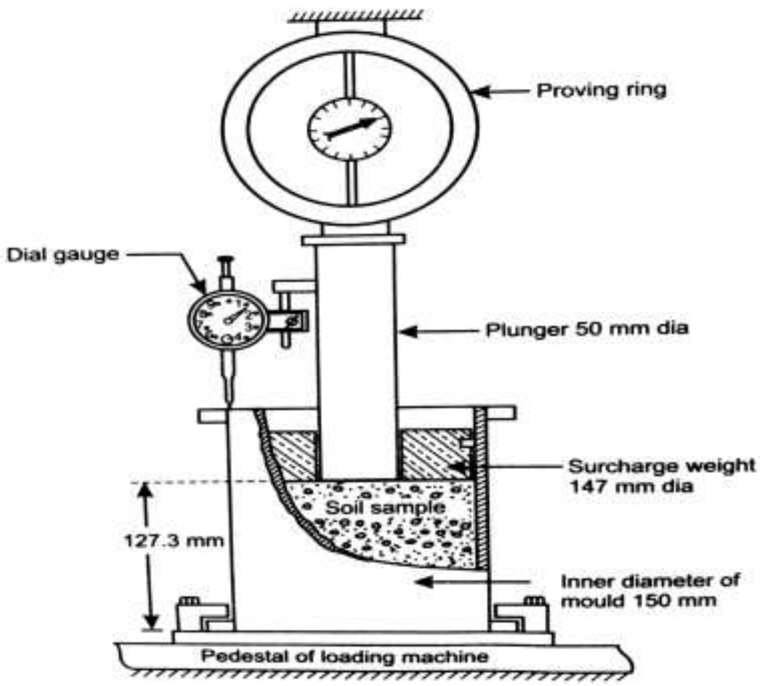

Figure 4.16 Diagram and Parts of CBR machine

Figure 4.17 CBR Machine

Procedure

1. Firstly, the sample was made without adding any admixture (for sample 1)
2. We make a sample of 4.5 kg each without adding any admixture in it.
3. Then sample is placed in a mould along with a base plate and displacer disc.
4. Then each soil sample was compacted in 3 equal layers, each layer given 56 blows by 2.6 kg hammer.
5. Remove the collar and trim off soil.
6. Turn the mould upside down and remove the base plate and the displacer disc.
7. Base plate along with mould under loading system is fixed.
8. Sample was checked for 0.0, 0.5, 1.0. 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, 12.5mm penetration values of load were noted from proving ring and on the basis of the reading from proving ring graph was plotted and with help of which CBR was calculated
9. Secondly, the sample was made by adding any admixture such as GGBS and Lime (Sample 2-15)
10. We make a sample of 4.5 kg each by adding admixture in it.
11. Repeat Step 3 to 8 for each sample.

Table 4.18 CBR Tabulation sheet for Sample 1

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	2.1	8.68		
3	1.0	4.5	18.6		
4	1.5	9.4	38.44		
5	2.0	13.3	54.56		
6	2.5	19.7	80.6	1370	5.88
7	3.0	21.5	88.04		
8	4.0	25.1	102.92		
9	5.0	27.8	114.08	2055	5.56
10	7.5	35.1	143.84		
11	10.0	39.6	162.44		
12	12.5	43.6	178.56		

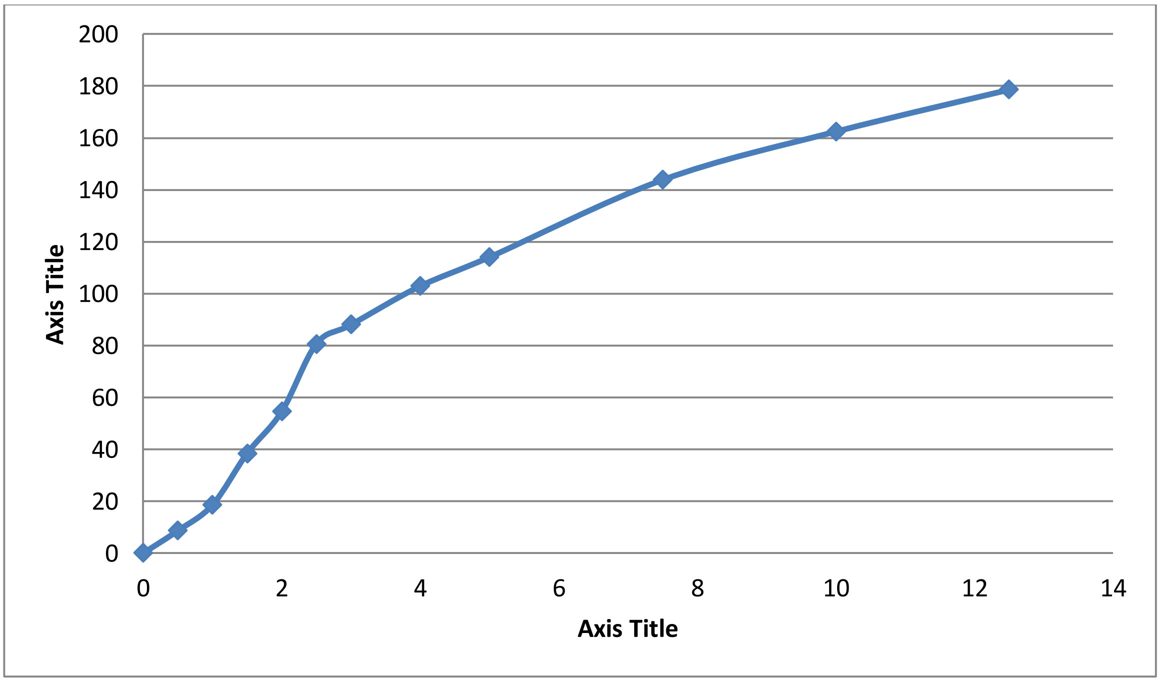

Figure 4.18 CBR Curve for Sample 1

Table 4.19 CBR Tabulation sheet for Sample 2

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	3.4	13.9		
3	1.0	7.0	28.9		
4	1.5	11.6	47.4		
5	2.0	15.0	61.4		
6	2.5	19.7	81.0	1370	5.91
7	3.0	23.0	94.5		
8	4.0	26.9	110.4		
9	5.0	29.3	120.0	2055	5.84
10	7.5	37.3	152.8		
11	10.0	42.6	174.7		
12	12.5	47.2	193.6		

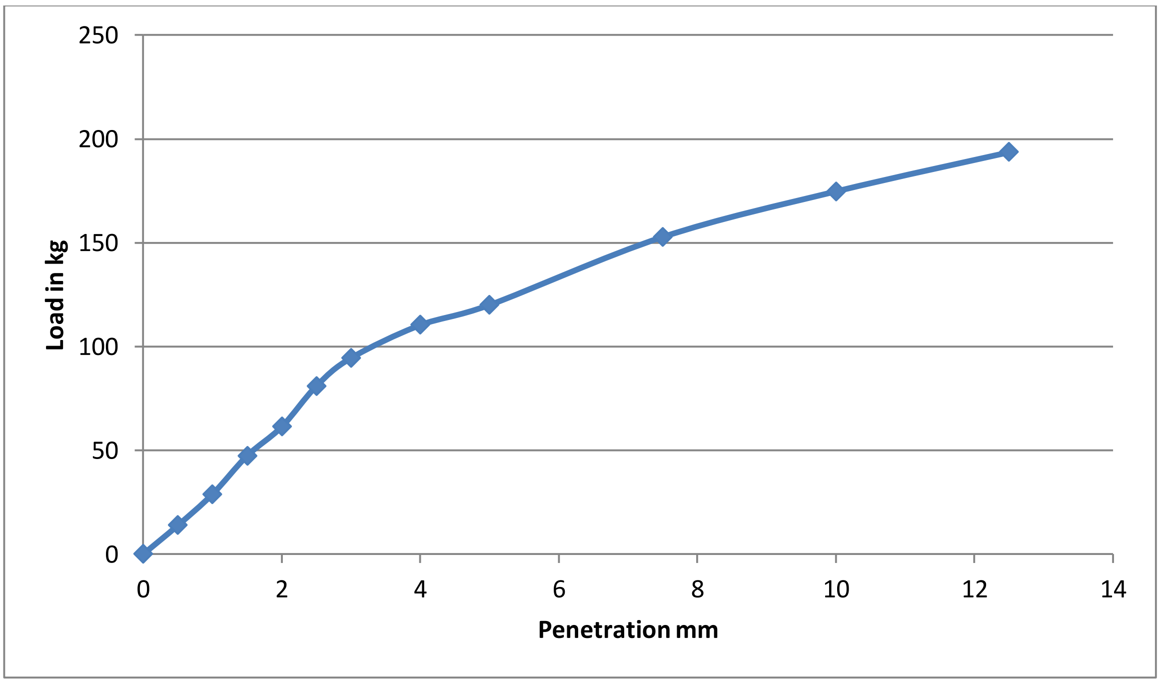

Figure 4.19 CBR Curve for Sample 2

Table 4.20 CBR Tabulation sheet for Sample 3

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	4.3	17.6		
3	1.0	6.9	28.3		
4	1.5	11.4	46.6		
5	2.0	14.3	58.5		
6	2.5	19.2	78.7	1370	5.75
7	3.0	22.4	92.0		
8	4.0	25.0	102.4		
9	5.0	28.3	115.9	2055	5.64
10	7.5	37.3	153.0		
11	10.0	43.3	177.6		
12	12.5	48.4	198.5		

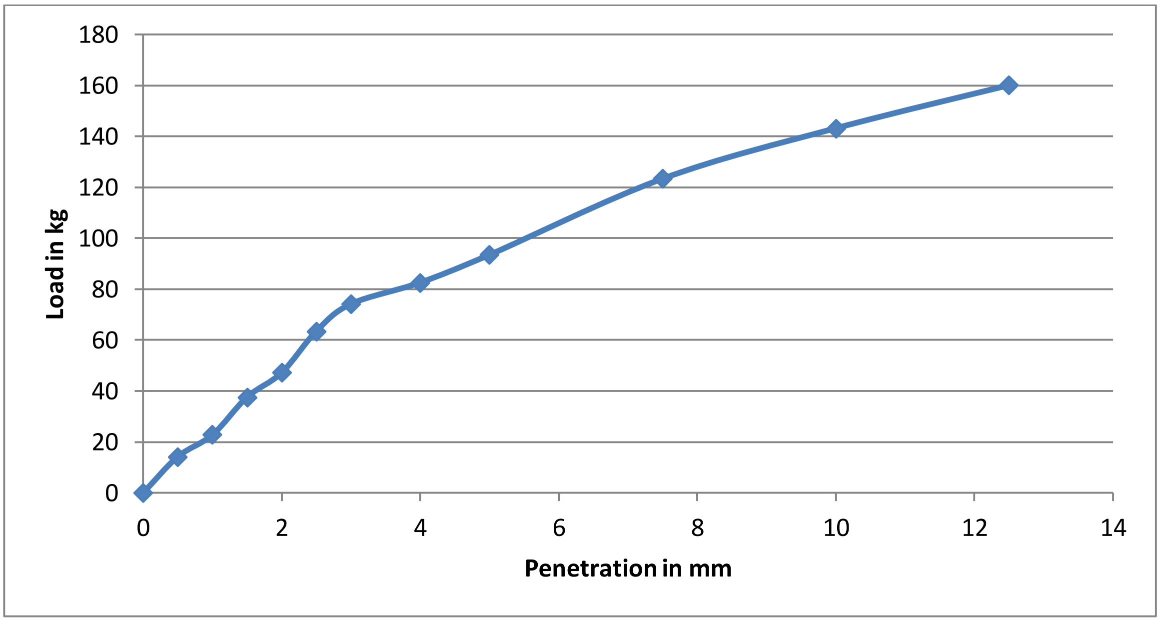

Figure 4.20 CBR Curve for Sample 3

Table 4.21 CBR Tabulation sheet for Sample 4

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	5.2	21.2		
3	1.0	7.6	31.1		
4	1.5	12.3	50.3		
5	2.0	16.4	67.2		
6	2.5	21.1	86.7	1370	6.33
7	3.0	24.6	100.8		
8	4.0	27.4	112.2		
9	5.0	31.2	127.8	2055	6.22
10	7.5	40.6	166.4		
11	10.0	43.9	180.0		
12	12.5	47.5	194.6		

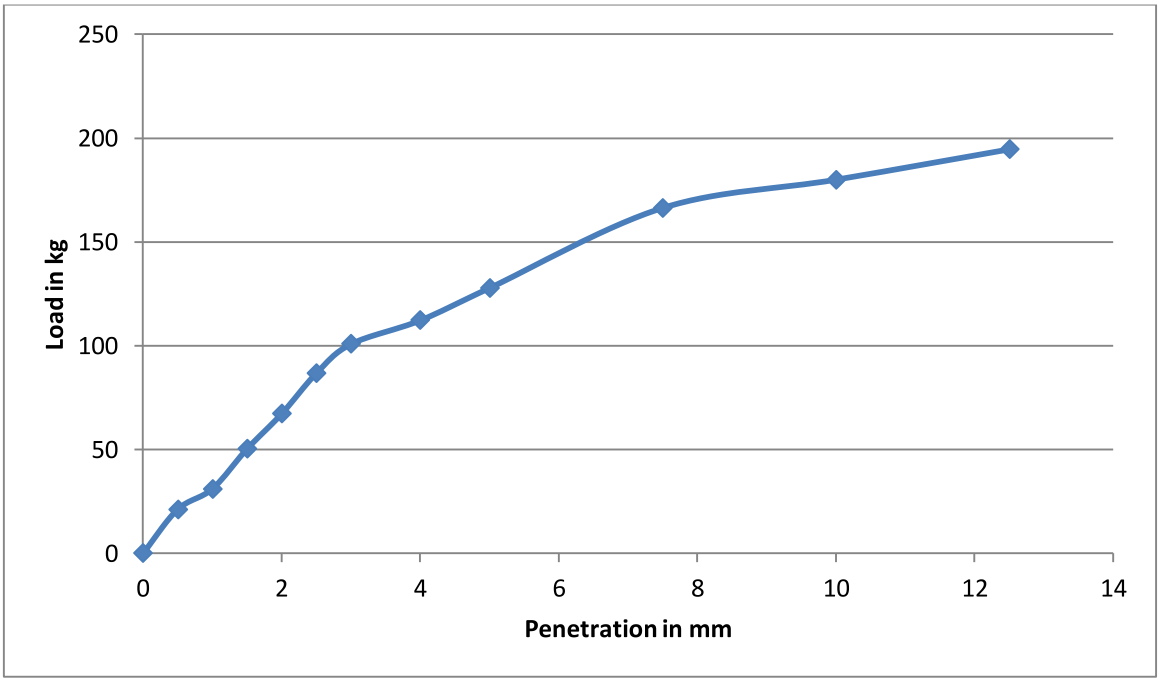

Figure 4.21 CBR Curve for Sample 4

Table 4.22 CBR Tabulation sheet for Sample 5

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	6.1	25.2		
3	1.0	7.8	32.1		
4	1.5	12.9	52.8		
5	2.0	16.3	66.7		
6	2.5	21.5	88.3	1370	6.44
7	3.0	26.3	107.6		
8	4.0	28.8	118.2		
9	5.0	31.5	129.3	2055	6.29
10	7.5	40.1	164.3		
11	10.0	43.8	179.7		
12	12.5	48.8	200.0		

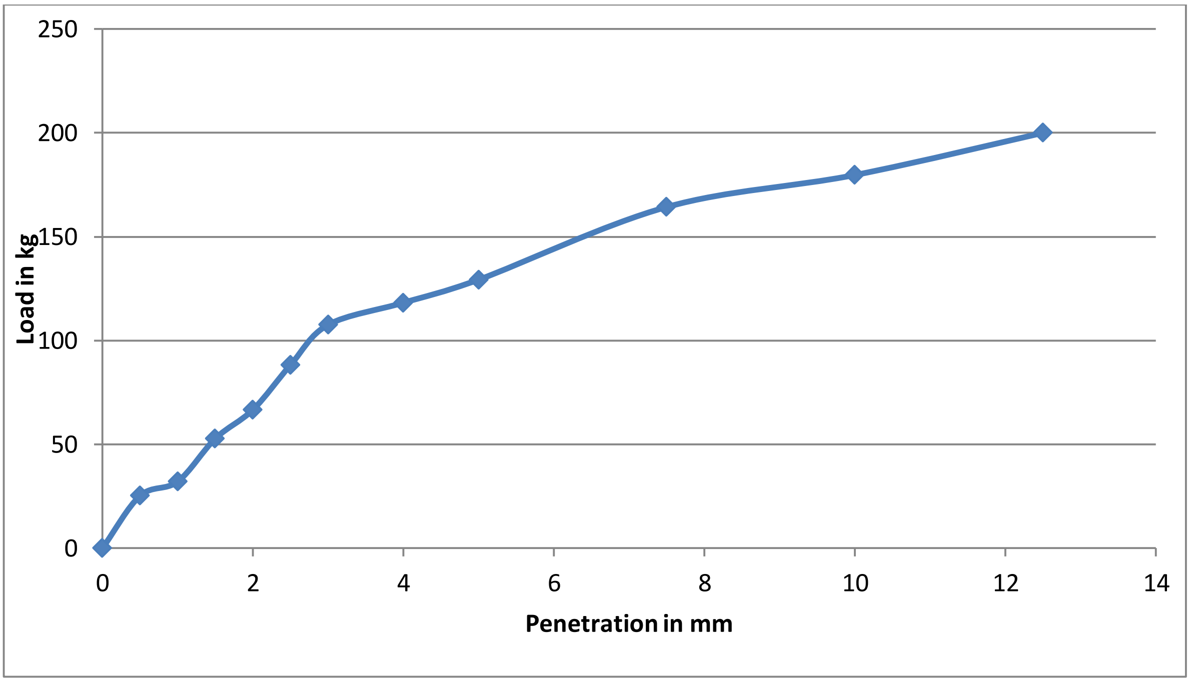

Figure 4.22 CBR Curve for Sample 5

Table 4.23 CBR Tabulation sheet for Sample 6

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	7.6	31.3		
3	1.0	9.7	39.6		
4	1.5	15.4	63.0		
5	2.0	19.4	79.7		
6	2.5	25.1	102.8	1370	7.50
7	3.0	27.7	113.4		
8	4.0	32.1	131.7		
9	5.0	35.8	146.8	2055	7.15
10	7.5	42.3	173.3		
11	10.0	50.7	207.9		
12	12.5	53.6	219.6		

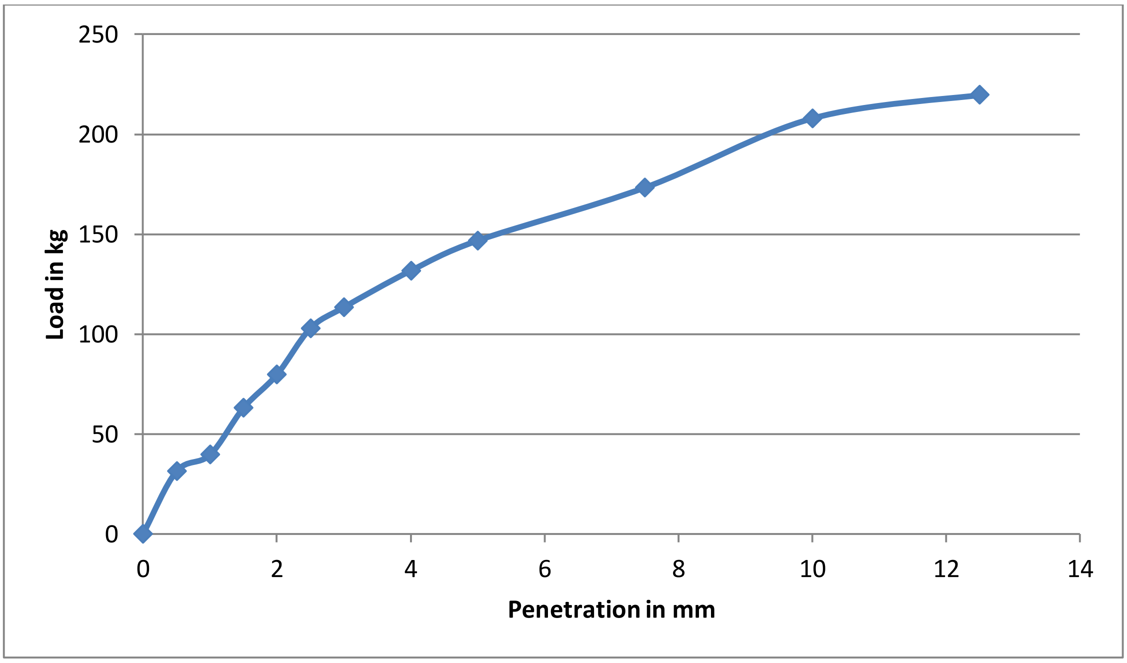

Figure 4.23 CBR Curve for Sample 6

Table 4.24 CBR Tabulation sheet for Sample 7

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	10.8	44.2		
3	1.0	13.2	54.3		
4	1.5	17.9	73.5		
5	2.0	22.6	92.8		
6	2.5	26.2	107.6	1370	7.85
7	3.0	29.0	118.8		
8	4.0	32.5	133.4		
9	5.0	37.4	153.2	2055	7.46
10	7.5	45.7	187.4		
11	10.0	50.5	207.1		
12	12.5	52.9	217.1		

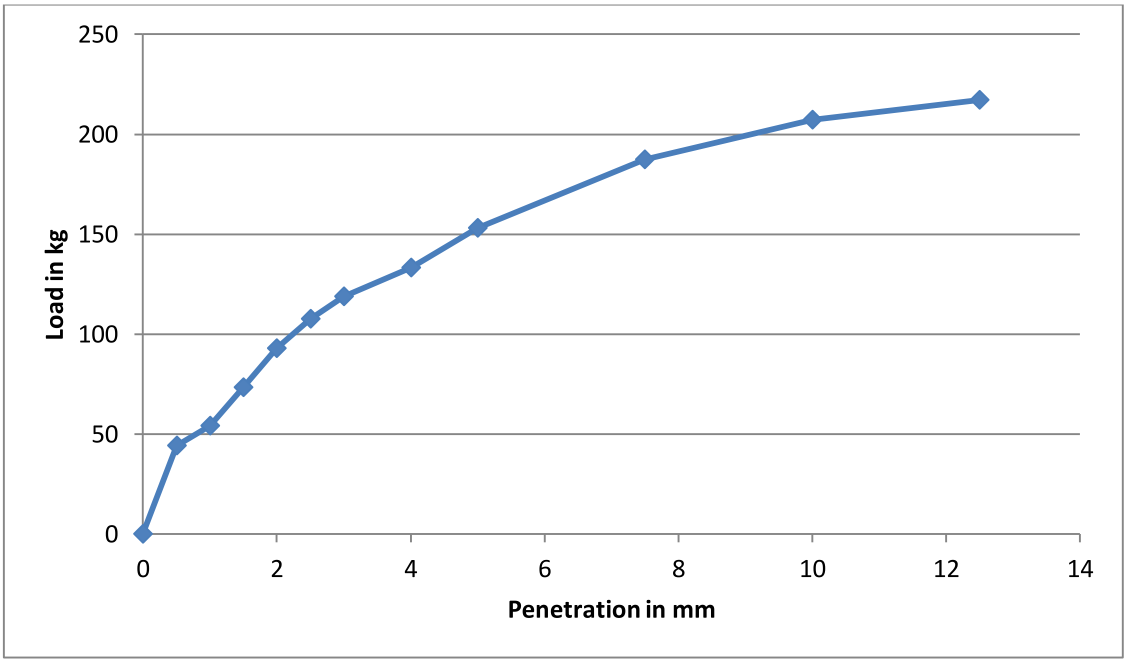

Figure 4.24 CBR Curve for Sample 7

Table 4.25 CBR Tabulation sheet for Sample 8

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	12.4	50.9		
3	1.0	15.3	62.8		
4	1.5	17.5	71.7		
5	2.0	21.8	89.4		
6	2.5	26.6	109.1	1370	7.96
7	3.0	29.5	120.8		
8	4.0	34.9	143.0		
9	5.0	37.9	155.3	2055	7.56
10	7.5	45.6	187.1		
11	10.0	50.5	207.2		
12	12.5	55.6	227.8		

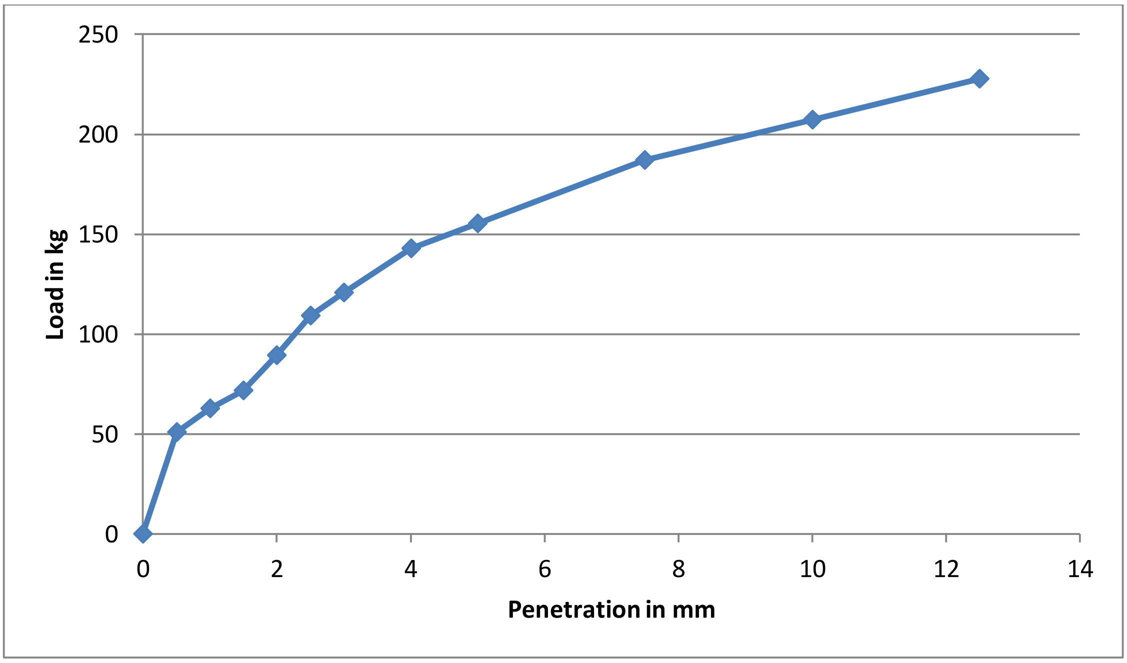

Figure 4.25 CBR Curve for Sample 8

Table 4.26 CBR Tabulation sheet for Sample 9

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	13.8	56.7		
3	1.0	16.1	66.15		
4	1.5	18.7	76.734		
5	2.0	23.8	97.524		
6	2.5	27.3	112.014	1370	8.18
7	3.0	30.9	126.504		
8	4.0	36.9	151.452		
9	5.0	39.9	163.6488	2055	7.96
10	7.5	45.5	186.732		
11	10.0	54.5	223.272		
12	12.5	60.6	248.346		

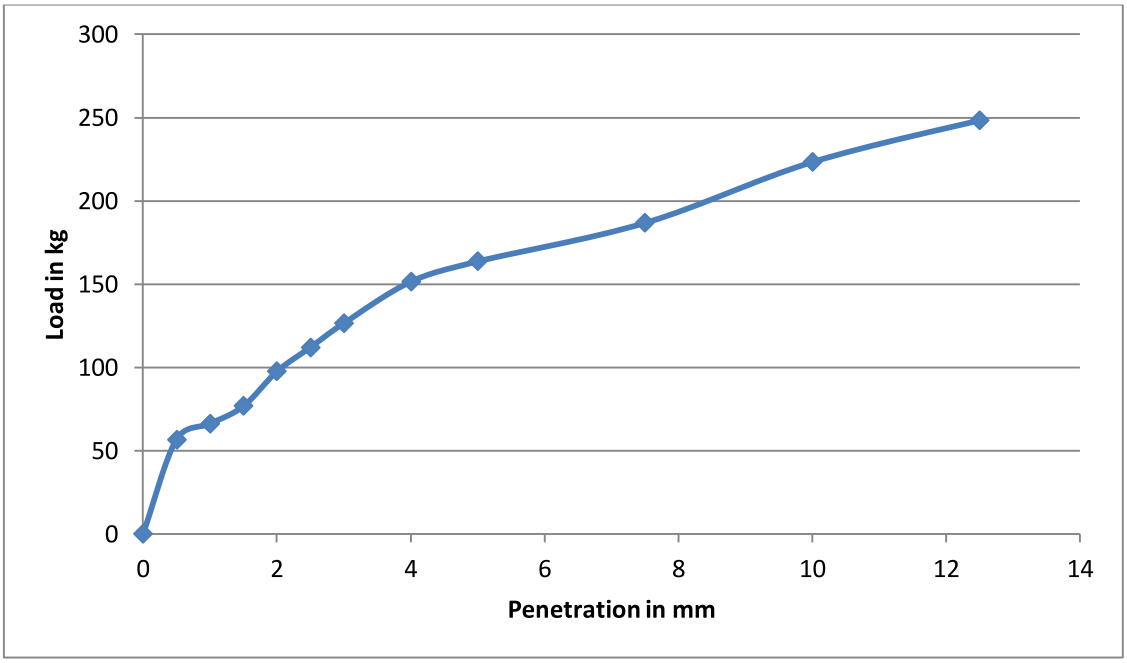

Figure 4.26 CBR Curve for Sample 9

Table4.27 CBR Tabulation sheet for Sample 10

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	12.6	51.48		
3	1.0	19.7	80.64		
4	1.5	22.9	93.84		
5	2.0	25.1	102.84		
6	2.5	27.5	112.92	1370	8.24
7	3.0	31.1	127.44		
8	4.0	35.4	144.96		
9	5.0	39.4	161.4	2055	7.85
10	7.5	46.9	192.12		
11	10.0	56.2	230.28		
12	12.5	62.4	255.96		

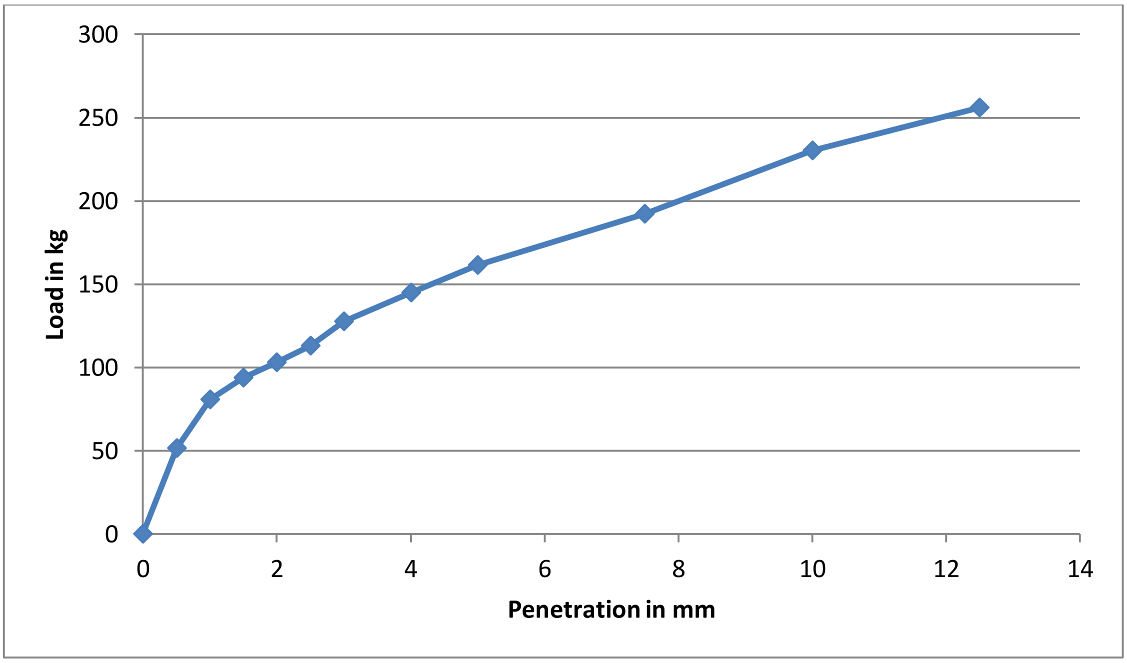

Figure 4.27 CBR Curve for Sample 10

Table 4.28 CBR Tabulation sheet for Sample 11

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	11.3	46.44		
3	1.0	14.7	60.24		
4	1.5	19.8	81.36		
5	2.0	23.4	96		
6	2.5	28.2	115.44	1370	8.43
7	3.0	31.8	130.44		
8	4.0	36.0	147.48		
9	5.0	41.1	168.48	2055	8.20
10	7.5	52.5	215.16		
11	10.0	62.5	256.44		
12	12.5	68.3	280.2		

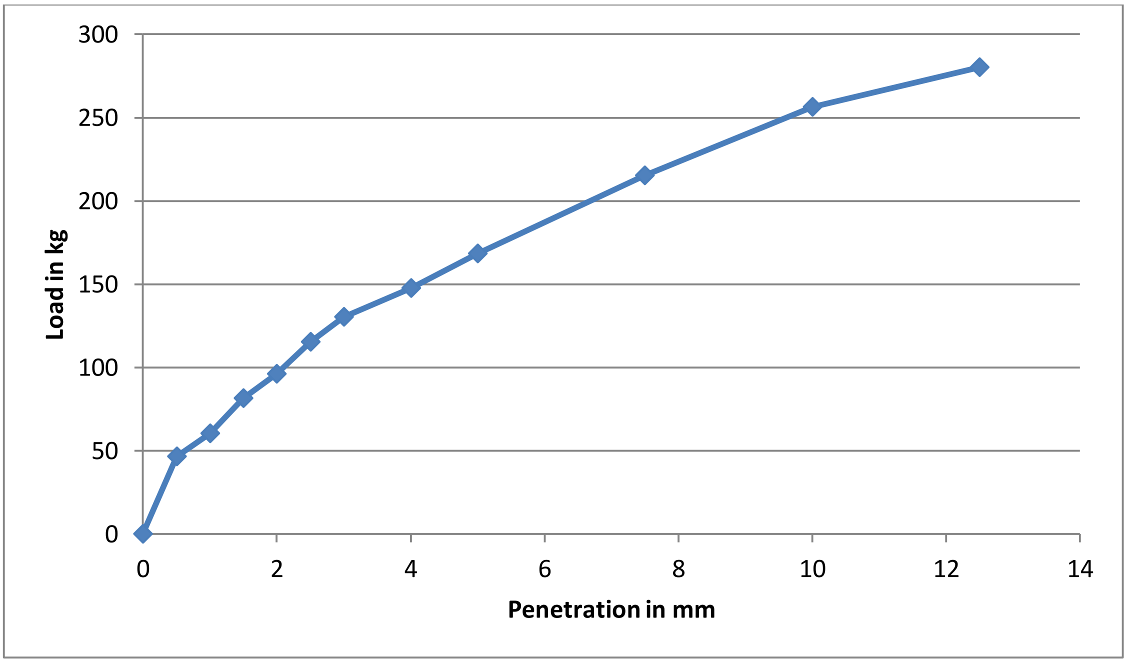

Figure 4.28 CBR Curve for Sample 11

Table 4.29 CBR Tabulation sheet for Sample 12

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	12.1	49.476		
3	1.0	16.0	65.702		
4	1.5	22.4	91.903		
5	2.0	27.3	111.986		
6	2.5	32.1	131.803	1370	9.62
7	3.0	36.9	151.221		
8	4.0	42.6	174.496		
9	5.0	47.6	194.978	2055	9.49
10	7.5	60.5	248.045		
11	10.0	67.9	278.236		
12	12.5	78.1	320.131		

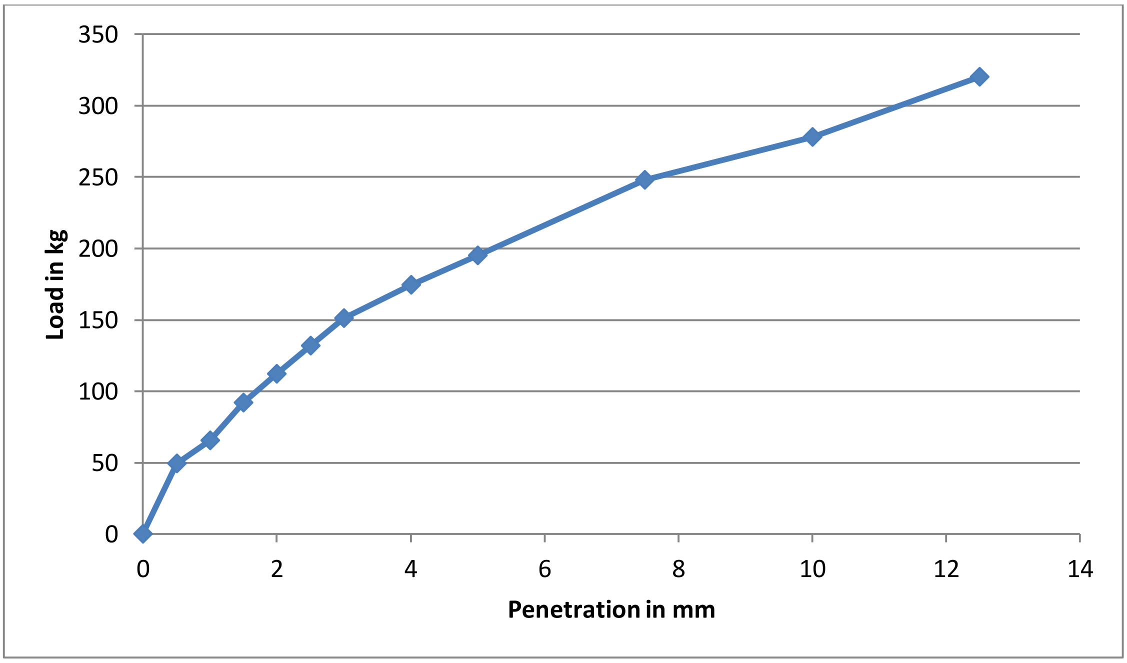

Figure 4.29 CBR Curve for Sample 12

Table 4.30 CBR Tabulation sheet for Sample 13

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	12.7	52.08		
3	1.0	16.9	69.16		
4	1.5	23.6	96.74		
5	2.0	28.8	117.88		
6	2.5	33.8	138.74	1370	10.13
7	3.0	38.8	159.18		
8	4.0	44.8	183.68		
9	5.0	50.1	205.24	2055	9.99
10	7.5	63.7	261.1		
11	10.0	71.4	292.88		
12	12.5	82.2	336.98		

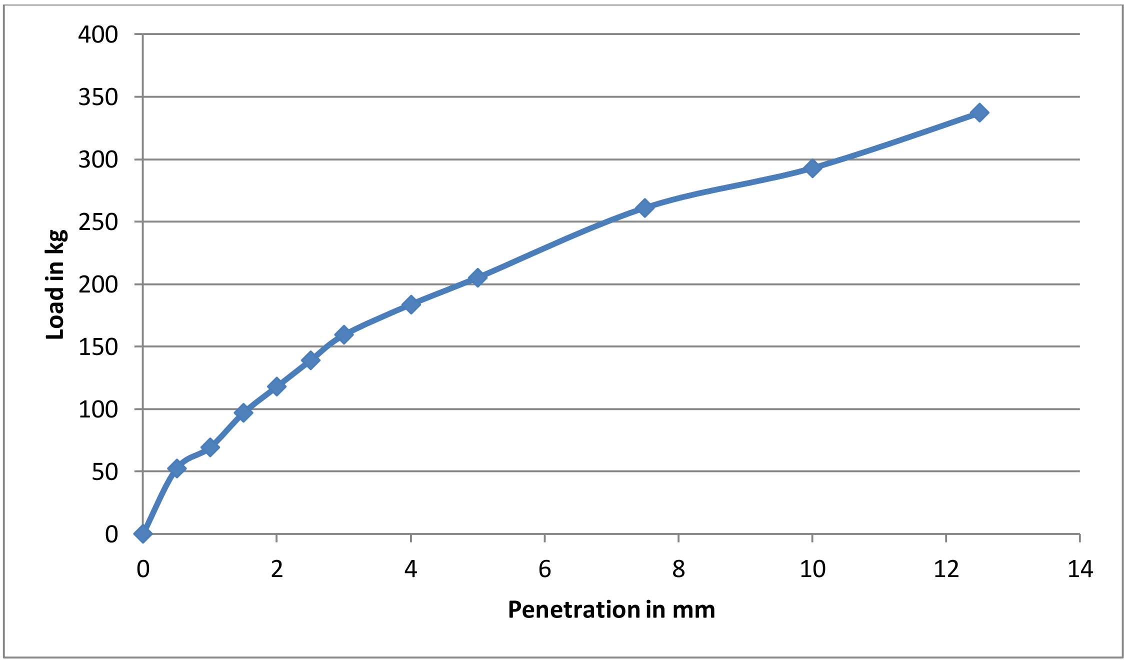

Figure 4.30 CBR Curve for Sample 13

Table 4.31 CBR Tabulation sheet for Sample 14

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	11.6	47.74		
3	1.0	15.4	63.28		
4	1.5	22.9	93.94		
5	2.0	27.4	112.14		
6	2.5	33.6	137.76	1370	10.06
7	3.0	36.6	150.22		
8	4.0	42.9	175.84		
9	5.0	49.8	203.98	2055	9.90
10	7.5	60.0	246.12		
11	10.0	65.1	266.84		
12	12.5	68.3	280.14		

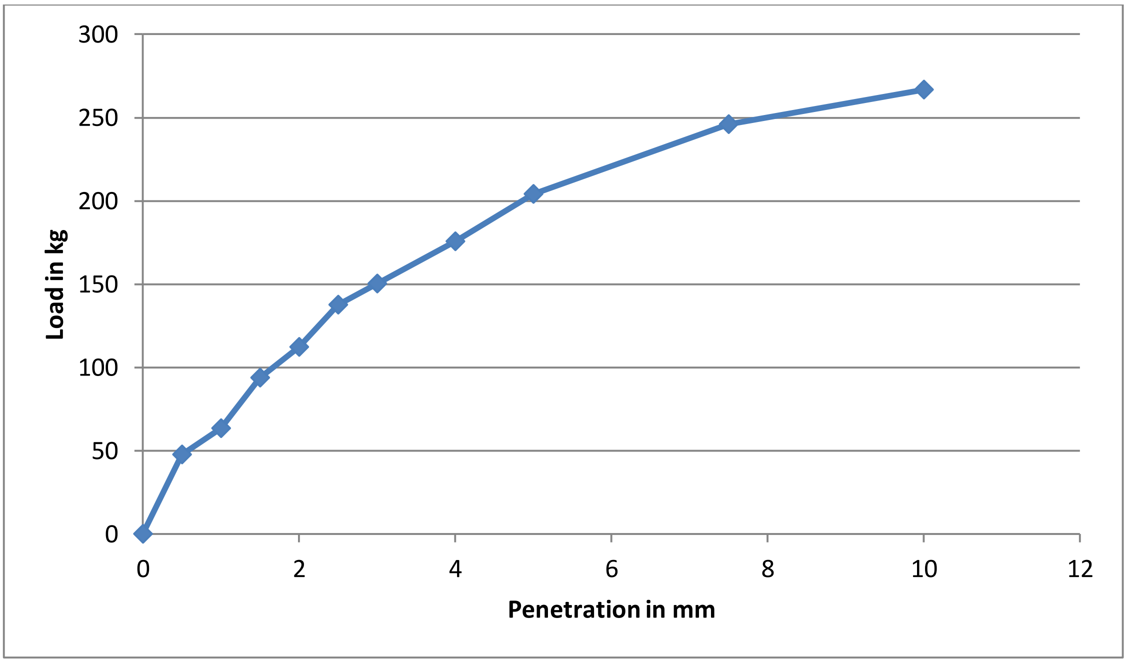

Figure 4.31 CBR Curve for Sample 14

Table 4.32 CBR Tabulation sheet for Sample 15

S.No	Plunger Penetration, mm	Load Dial Readings, division	Load in kg	Standard Load in kg	CBR in %
1	0.0	0.0	0		
2	0.5	11.2	46.04		
3	1.0	14.9	61.02		
4	1.5	22.1	90.59		
5	2.0	26.4	108.14		
6	2.5	32.4	132.84	1370	9.70
7	3.0	35.3	144.86		
8	4.0	41.4	169.56		
9	5.0	48.0	196.70	2055	9.57
10	7.5	57.9	237.33		
11	10.0	62.8	257.31		
12	12.5	65.9	270.14		

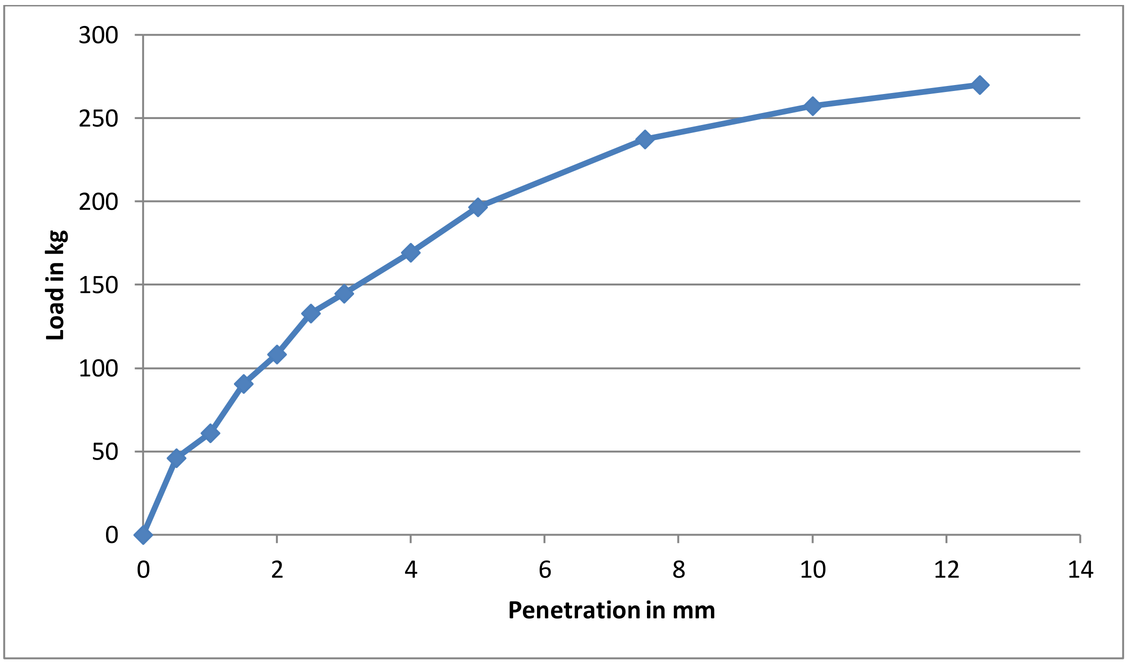

Figure 4.32 CBR Curve for Sample 15

Table 4.33 List of Sample Description with the CBR

Sample No.	Description	CBR
1	Soil + 0% Slag + 0% Lime	5.88
2	Soil + 1% Slag + 0.% Lime	5.91
3	Soil + 2% Slag + 0.% Lime	5.75
4	Soil + 3% Slag + 0.% Lime	6.33
5	Soil + 4% Slag + 0% Lime	6.44
6	Soil + 0% Slag + 0.5% Lime	7.50
7	Soil + 1% Slag + 0.5% Lime	7.85
8	Soil + 2% Slag + 0.5% Lime	7.96
9	Soil + 3% Slag + 0.5% Lime	8.18
10	Soil + 4% Slag + 0.5% Lime	8.24
11	Soil + 0% Slag + 1.0% Lime	8.43
12	Soil + 1% Slag + 1.0% Lime	9.62
13	**Soil + 2% Slag + 1.0% Lime**	**10.13**
14	Soil + 3% Slag + 1.0% Lime	10.06
15	Soil + 4% Slag + 1.0% Lime	9.70

Chapter 5
Result analysis and Discussions

From the study there is a improvement in CBR of soil due to adding GGBS and Lime in to selected soil of sub grade due to cementicious properties in both the admixtures when properly mixed and in contact with moisture. By only adding GGBS to the soil, there was only slight improvement to the CBR and MDD. It is due to the fact that GGBS is fairly neutral compound and does not react unless a activator is added, in this case it is lime. Slight reaction between soil and GGBS has taken place, also the specific gravity of GGBS is higher than soil, so there is an increase in MDD. MDD increased from 1.67g/cc in case of Sample 1 (Soil 100%) to 1.71g/cc when 3% GGBS is added.

CBR value also increases from 5.88 in case of sample 1 to 6.44% in case of sample 5 (4% GGBS. But when activator is not added than significant increase in CBR does not take place.

When lime is added to the mix, than lime acts as a cementitious compound and also act as an activator which helps in significant gain in MDD and CBR. Also the specific gravity of the soil has slight increase.

The most increase in CBR and MDD takes place in case of sample 13 (Soil +2% GGBS+ 2% Lime) when CBR increases upto 10.13%, and MDD increases upto 1.92g/cc

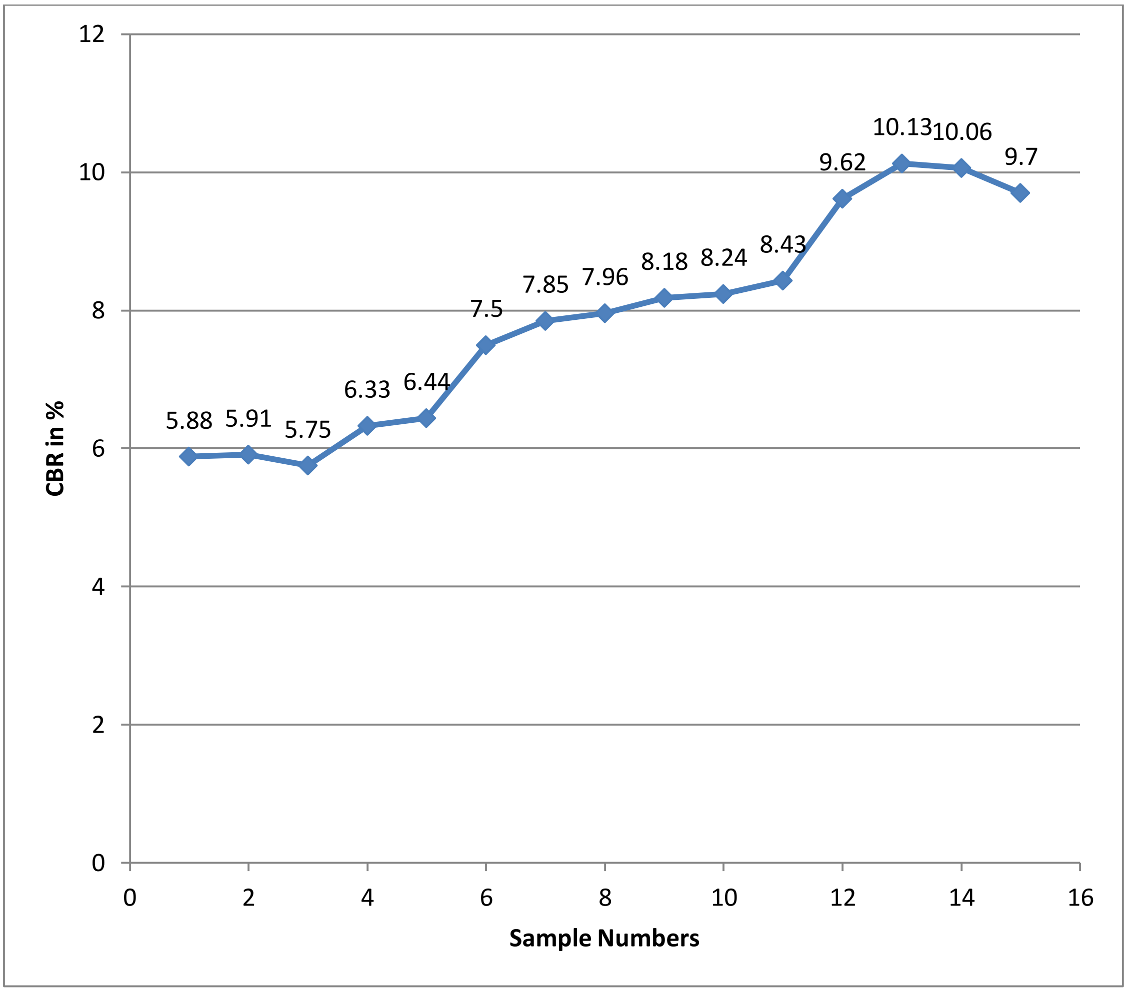

Fig 5.1 CBR value of Samples

5.1 Crust Thickness

Calculation of Crust Thickness: All the calculations are done as per the guidelines of IRC: 37 - 2018

Traffic	1130Cvd (An assumed road)
Standard Axle (Ns)	[(365 * (1+r) n – 1/r) * D * F *A]
Traffic	Ns / 10^6
Design Period (n)	15 years for SH, NH
Growth Rate (r)	5%
Lane Distribution Factor (D)	0.75
Vehicle Damage Factor (F)	3.5
A	1130 CVD
Standard Axles (Ns)	[({365x (1+0.05)15–1}/0.05)x0.75x3.5x1130]
	= 23169378.75 CVD
Design Traffic	Ns / 10^6
	= 23.16 MSA

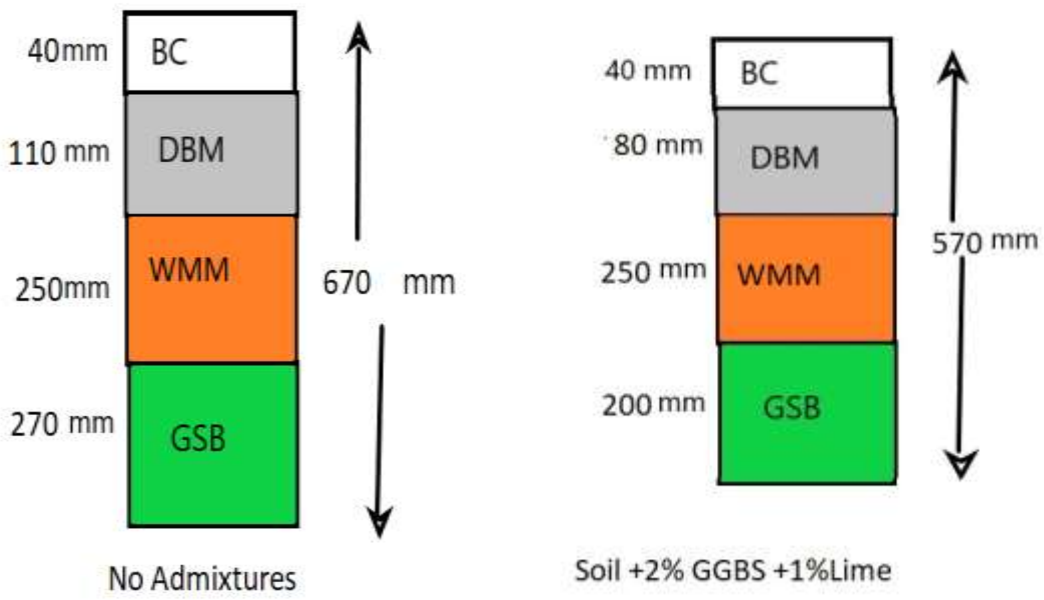

Fig 5.2 Recommended crust thickness as IRC: 37 - 2018

Table 5.1 Crust Thickness

S.No	Admixture	CBR	Sub grade Thickness in mm (Earth Work)	Crust Thickness				
				Total crust in mm	GSB in mm	WMM in mm	DBM in mm	BC in mm
1	No Admixture	5.88	500	670	270	250	110	40
2	Soil +2% GGBS + 1% Lime (Sample 13)	10.13	500	570	200	250	80	40
3	Reduction in Crust Thickness	-	-	100	70	-	30	-

5.2 Rates

- Item Rates are calculated as per Data Book of Roads and Bridges, MORTH .
- Admixture Rates are taken from Local Vendors and are Market Rates
- Admixtures are added to top 500mm of the sub grade as per IRC 37 2018 and the procedures are taken in accordance with Specification for Roads and Bridges Work IRC - MORTH

5.3 Quantity, Cost of Admixture and Net Savings

Cost of Admixtures

For Sample 13, The maximum CBR and MDD was observed

Density of Stabilized Soil = 1.92g/cc (Modified Proctor Test Sample 13)

MDD = 1.92g/cc = 1920 kg/m^3

For 1 m^3 soil,

Weight of Stabilized Soil= 1920kg for 1m^3 mix.

Quantity of Admixture Added in soil = 2% GGBS + 1% Lime

Weight of 2% GGBS = 1920*2/100 = 38.40kg in 1m^3 of sample.

Weight of GGBS in 6000 m^3 = 2,30,400 kg or 230.4 tonnes

Cost of GGBS = Rs 5 per kg or Rs 5000 per tonne.

Weight of 1% Lime in $1m^3$ Sample = 1920*1/100= 19.20kg

Weight of Lime in 6000 m^3 = 1,15,200 kg or 115.2 tonnes

Cost of Lime = Rs 10.5 per kg or Rs 10500 per tonne

Table 5.2 Rate Analysis for preparation of sub grade using admixtures by mechanical means

S.No	Description	Unit	Quantity	Rate	Amount
1	**Labour**				
	Mate	day	0.360	351.00	126.36
	Skilled mazdoor for alignment and geometrics	day	1.000	351.00	351.00
	Mazdoor for spraying lime	day	8.000	338.00	2704.00
2	**Machinery**				
	Tractor with ripper and rotavator attachments @ 60 cum per hour for ripping and 25 cum per hour for mixing	hour	12.000	486.00	5832.00
	Motor Grader 110 HP @ 50 cum per hour	hour	6.000	2858.25	17149.50
	Vibratory roller 8 - 10 tonne capacity	hour	6.00x0.65*	1838.90	7171.71
	Water tanker 6 KL capacity	hour	12.000	28.86	346.32
3	**Material**				
	Lime at site	tonne	115.2	10500	1209600
	Slag at Site	tonne	230.4	5000	1152000
	Cost of water	KL	72.000	250.00	18000.00
4	**Overhead Charges (1+2+3) @ 10%**				241327.97
5	**Contractor's Profit (1+2+3+4) @10%**				265461.75
6	**Cost of 6000 m^3**				2920068.41
7	**Rate per m^3 (1+2+3+4+5)/6000**				**486.68**

Rate of Sub grade Preparation with admixtures = Rs 486.68 /m^3

Table 5.3 Bill of Quantity for Sub grade with No Admixtures for 1km road of 7m wide

S.No	Description	Quantity (m^3)	Rate (Rs)	Amount (Rs)
1	Earth Work for Sub grade Preparation	1000*12*0.50 = 6000	120	7,20,000
2	GSB	1000*7.3*0.27 = 1971	3687	72,67,077
3	WMM	1000*7*0.25 = 1750	4124	72,17,000
4	DBM	1000*7*0.11 = 770	8805	67,79,850
5	BC	1000*7*.04 = 280	9664	27,05,920
-	**Total**	**-**	**-**	**2,46,89,847**

Table 5.4 Bill of Quantity for Sub grade with Admixtures for a 1km road of 7m wide

S.No	Description	Quantity (m^3)	Rate (Rs)	Amount (Rs)
1	Earth Work for Sub grade Preparation	1000*12*0.50 = 6000	486.68	29,20,068.41
2	GSB	1000*7.3*0.20 = 1460	3687	53,83,020
3	WMM	1000*7*0.25 = 1750	4124	72,17,700
4	DBM	1000*7*0.08 = 560	8805	49,30,800
5	BC	1000*7*.04 = 280	9664	27,05,920
-	**Total**	**-**	**-**	**2,31,57,508**

Net Savings = Cost of Road without Admixture - Cost of Road With admixtures

= 2,46,89,847 - 2,31,57,508 = 15,32,339

Net Savings % = (Net Saving / Cost of Road without Admixtures)*100

= (15,32,339 / 2,46,89,847)*100 = 6.21%

Table 5.5 Net Saving due to stabilization

Cost of Road without Admixture (Rs)	Cost of Road with Admixture (Rs)	Change in Amount	Net Savings (Rs)	Net Savings %
2,46,89,847	**2,31,57,508**	15,32,339	**15,32,339**	**6.21 %**

Now as per my results, we had an maximum CBR was found to be 10.13% at Sample 13 (Soil + 2% GGBS +1% Lime). At the particular CBR, the Crust thickness was calculated as 570 mm. If no stabilization was done, then the crust thickness was found to be 670mm. Therefore by doing stabilization we are saving 100mm of crust.

Based on that per km cost saving was Rs 15,32,339 which was the difference between Cost of the Pavement without admixture and Cost of the pavement with admixtures. Based on this savings we find out that we have a net saving % of 6.21%.

Chapter 6
Conclusion

6.1 Cost Conclusion

Table 6.1 Net Saving Cost w.r.t. Normal Soil Subgrade (per km)

Total Cost of Flexible Pavement (No Admixture)	**2,46,89,847**
Total Cost of Flexible Pavement (With Admixture)	**2,31,57,508**
Cost saving in construction due to stabilization	**15,32,339**
Net Saving including cost of admixture	**6.21 %**

The critical study of admixtures for stabilization indicates that the stabilization is getting more and more popularity due to its cost efficiency, innovations, waste disposal problems. however in the present state the knowledge does not leads to rational design for stabilization and thus various studies are being carried out to find the efficiency of the stabilizer in terms of strength, cost, and its effect to surrounding areas and difficulty to incorporate into the mix.

Now a days the cost of construction of a flexible pavement highway are much higher, which in turn affect the construction of infrastructure of the country. The bitumen and stone ballast and grit are main constituents of flexible pavement in highway industry. Also a flexible pavement has a design life of 15 years whereas rigid pavement has 30 years design life. Our country needs huge financial resources to meet out international standard based road infrastructure. To meet out these financial resources, it is now our duty to proceed technological innovation to reduce quantity of material resources and enhance construction quality to ensure this objective with different type of admixtures.

A very important parameter, CBR, California Bearing Ratio, is used as tool for determining the improvement of strength of soil in Highway Construction CBR determined with the help of CBR apparatus by adding admixture. While performing the CBR test, it is clear that GGBS alone cannot be used as an soil stabilizer because when we added GGBS from 0 to 4% at an increment of 1%, increment in CBR value is negligible from 5.88% to 6.44%. It means that although the Calcium is present in GGBS, it is not participating in the reaction process to strengthen the soil. But after adding only 0.5% Lime to GGBS at 0 to 4%, CBR value increases to 8.24. Which means that lime is actively taking part in reaction and forcing the GGBS to take part in reaction. When lime is added to the mix, it helps to activate the Slag, thus the Calcium in slag becomes active. When 1% Lime is added to mixture of soil +GGBS, the CBR value increase to 10.13% in case of maximum value.

It means that by adding more lime to the mix we are getting a better CBR value. Now in case of Soil + 1% Lime, the CBR was found to be 8.43, in case of soil+ 0.5% Lime CBR was 7.50%. Although by adding more Lime we are getting a better CBR, still the maximum value is obtained in both cases by adding slag to the mix.

To achieve ultimate objective of study, the crust thickness was evaluated with the help of IRC code "Design of flexible pavement: IRC 37-2012" and traffic (MSA) Million Standard Axles. It was investigated further construction cost difference of each admixture with respect to soil with no admixture with Data Book of Standard Highway – MORTH. Because, admixture were added in whole process, the cost involved in procuring different admixture and construction were also considered while comparing the cost of different admixture.

Now as per my results, we had an maximum CBR was found to be 10.13% at Sample 13 (Soil + 2% GGBS +1% Lime). At the particular CBR, the Crust thickness was calculated as 570 mm. If no stabilization was done, then the crust thickness was found to be 670mm. Therefore by doing stabilization we are saving 100mm of crust.

Based on that per km cost saving was Rs 15,32,339 which was the difference between Cost of the Pavement without admixture and Cost of the pavement with admixtures. Based on this savings we find out that we have a net saving % of 6.21%.

Chapter 7

Future Scope and Investigations

Based on the present findings, it is felt that further work should be pursued in the following area:

- Evaluation could be done with other admixtures like geo synthetics, crumb rubber, and waste materials like PET bottles, fly ash and debris.
- Evaluation should be carried out for the types of activators for Ground granulated blast furnace slag like calcium hydroxide, gypsum, ordinary Portland cement, sodium hydroxide, sodium carbonate and sodium sulphate
- Evaluation should be carried out with locally available soil which will be more useful for practical purpose.
- Mixture of admixture used for stabilization should be carried out better result.
- Findings of this investigation should be carried tested in field for actual result. While we have only involved lab work, these test should also be carried out in field. Generally a difference in result is observed since in lab we can control the environment.
- Environmental condition should also considered in evaluation of the findings for further actual results like the results obtained on soil will be different in summer, monsoon and winter.

Chapter 8
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Stabilization of Soil using Flyash and Granulated Blast Furnace Slag: A Review

Abhraneel Sengupta
M.Tech Student,
Department of Civil Engineering, BBDU,
Lucknow, India

D S Ray
Professor
Department of Civil Engineering, BBDU,,
Lucknow, India

Abstract
n India about 160 million tons of flyash is produced mainly produced in coal-fired electric and steam generating plants, of which only 100million tons are used annually. The rest of which is used as fills in dumps, while grounded granulated blast furnace slag (GGBS) is a solid waste generated by iron and steel plants in about 40 million tons annually and in future, recycling will inevitably become an important measure for the environmental protection and therefore will be of great social and economic significance. Flyash is rich in silica and alumina while has less than 20% lime (CaO) which is well complemented by GGBS with 40-50% lime. Lime needs to be added in very small quantity as a chemical activator (cementing agent) to create a basic environment and produce cementitious compound. The expansive nature of Black Cotton soil is very poor and undependable as a subgrade material. The joint use of these two materials to form a binder provides new opportunities to enhance pozzolanic activities that may reduce the swell potential and increase the unconfined compressive strength of expansive clays. Hence the main objective is to treat and stabilize the soil such that undesirable characteristics are modified by a suitable stabilization material and technique

Keywords
Expansive soil, Flyash, Ground Granulated Blast Furnace Slag (GGBS), Subgrade, Joint Activation

Introduction
Black Cotton (BC) soils are high in clay content and varies from grey to black in color and is found in many states throughout India. In BC soil areas, suitable road aggregates needs to be hauled from distant places and thus increasing the cost of conventional road aggregates and pavement layers. Behavior of these soil under climatic condition made both construction costly and difficult. In pavement made on expansive soil suffers from early failures. In case of flexible pavements with heavy traffic, excessive unevenness, ruts, waves, cracks and corrugation are formed every monsoon season which results in high maintenance demand every year. BC soil contains “montmorillonite” clay minerals which are responsible for the highly expansive nature (Khanna and Justo, 1971)

Lime and cement are very well known additives for stabilization of expansive soil (Al-Mukhtar et. al., 2010; Bell, 1996; Prusinski and Bhattacharja, 1999; Yong and Ouhadi, 2007). These additives are a by-product of industrial activities and are associated with the emission of greenhouse gases such as Carbon di-oxide (CO_2), Methane (CH_4) and nitrous oxide (NO_2). Industrial by-products such as flyash (Cokca, 2001; Ferguson, 1993; Phanikumar and Sharma 2004), blast furnace slag (Cokca et.al., 2009; Higgins, 2005), Cement kiln dust (Miller and Azad, 2000; Zaman et.al., 1992) and limestone dust (Brooks et.al., 2010) becoming more popular due to low cost compared to lime and cement. Also CO_2 emissions can be comparatively reduced using such supplementary cementitious compound which are wasted in dumps and lagoons. The most important feature of stabilizer seen in clayey soil is its ability to provide sufficient calcium (Wang, 2002). Industrial wastes such as flyash and blast furnace slag can act as a good stabilizing agent because of their siliceous and calcareous nature.

The aim of this study is to investigate the joint activation of flyash and grounded granulated blast furnace slag (grounded GGBS) in the stabilization of expansive soils. In India, the two types of industrial Waste produced in the greatest volumes are fly ash and granulated blast furnace slag, with an approximate annual production of 170 and 15 million tons, respectively (Chatterjee, 2011; Singh et.al., 2008). The majority of flyash is used in cement industry to manufacture PPC by partially replacing cement with flyash cement which helps to reduce the amount of cement required and helps to reduce the CO_2 and in brick industry while GGBS is used in partial replacement of cement. These industrial waste have a great potential to be used as a stabilizing agents. However, the utilization rate is as low as 58%for flyash and 55% for blast furnace slag (CEA, 2014; Singhetal, 2008). The main reason for their Underutilization of these byproducts is the lack of pozzolanic reactivity. Indian fly ash (Class F), which is obtained by burning bituminous coal has a low lime content of less than 10% (Sunku, 2006). Hence, a chemical activator like lime or cement is added to improve its pozzolanic reactivity. While GGBS (obtained after granulated slag is ground into fine powder) is a latent hydraulic cement (rich in lime content) which only needs to be activated (Bijen, 1996).

Chemical composition of flyash and GGBS (Sharma and Sivapuliah, 2015)

Oxides	Flyash	GGBS
SiO_2 (%)	54.4	29.2
Al_2O_3 (%)	28.6	13.8
CaO (%)	1.6	44.9
MgO (%)	1.4	6.2
Fe_2O_3 (%)	3.2	5.5
Na_2O (%)	0.3	0.3
K_2O (%)	1.7	1.0
TiO_2 (%)	1.8	2.1
LOI (%)	5.0	-
CaO/SiO_2 (Ratio)	.03	1.54

Flyash is divided into two class, Class C and Class F. Class C is obtained from sub- bituminous coals and contains primarily calcium alumino-sulfate glass, as well as quartz, tricalcium aluminate, and free lime (CaO). Class C ash is also referred to as high calcium fly ash because it typically contains more than 20 percent CaO. On the other hand Class F is obtained from from bituminous and anthracite coals and consist primarily of an alumino-silicate glass, with quartz, mullite, and magnetite also present. Class F, or low calcium fly ash has less than 10 percent CaO.

There is a wide variation in the chemical properties of flyash and GGBS. Flyash is low in calcium oxide content but rich in silica and alumina while GGBS is relatively high in calcium oxide. When used together, these two materials can be more beneficial when used as a stabilizing agent than using them individually. Both can provide sufficient lime or silica to support pozzolanic reaction, thereby requiring lower amounts of chemical activators. Generally, pozzolanic reactions are quicker if more calcium is present in the oxides of the stabilizing material (Lin et al., 2007)

Literature Review

(Cokca, 2001) studied effect of flyash on expansive nature of soil. Flyash is often hollow spheres of Silicon, Aluminum and Iron oxides. Both classes of flyash class C and class F are puzzolans, which means siliceous and aluminous materials. Thus Flyash can provide an array of divalent and trivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+} etc) under ionized conditions that can promote flocculation of dispersed clay particles. Thus expansive soils can be potentially stabilized effectively by cation exchange using flyash. He investigated the Soma and Tuncbilek flyash and added it in (0-25%) to expansive soil. The specimen was cured for 3 and 28 days and were subjected to oedometer free swell test. This confirmed that Plasticity index, activity and swelling potential of soil sample decreased with addition of flyash, and optimum flyash content was found to be 20%. The changes in physical properties and swelling potential is a result of additional silt particles and chemical reaction that causes flocculation of clay particles and the time dependent pozzolanic and cementitious properties of flyash. It is concluded that both high and low CaO flyash can be used as a stabilizing agent in expansive soil.

(Al Rawas, 2002) worked out that additives such as copper slag containing higher amounts of Na^+ but lower amount of Ca^{2+} and CaO, and was less effective than GGBS, which had low amounts of Na^+ but relatively higher amount of CaO. Calcium ions help in reducing the intensity of swell potential of the soil containing smectite and illite clay minerals by forming aggregations of different sizes. He concluded that the chemical composition of stabilizing agents provides a good indication about their effectiveness in soil stabilization and should essentially be determined.

(Pandian et.al., 2002) had studied two type of Flyash, Class F (Raichur Ash) and Class C (Neyvalli Flyash) on CBR of Black Cotton Soil. Since CBR is linked with cohesion and friction. CBR of fine soil is attributed to cohesion while for flyash which is coarse it is with friction. With fine clayey soil, it has low CBR and flyash increases CBR. Adding Flyash to black cotton soil enhances its CBR. But when flyash exceeds its optimum concentration, it starts to reduce CBR and here the reduction is up to 60% and then increases to second optimum level. It also concludes that variation of CBR on Flyash - BC soil is due to frictional and cohesive resistance of soil and stabilizer. In class C flyash with increase in flyash strength increases due to additional pozzolonic reaction forming cementitious compound resulting in a good binding between BC soil and Flyash.

(Jiru and Xing, 2002; Rao and Sabat, 2005; Zha et. al., 2008; Bose, 2012) had investigated the effect of flyash (class-F) and lime on geotechnical properties of expansive soil and the investigation had yielded positive effects

(PhaniKumar and Sharma, 2004) carried out study on expansive soil and its engineering properties when Flyash is added to it on experimental basis. The effect on Free Swell Index (FSI), Plasticity index, swelling pressure and potential, hydraulic conductivity, compaction and strength were studied. The ash blended soil was made by adding Flyash at 0, 5, 10,20 % on dry weight basis and was concluded that additive reduces plasticity properties and FSI by 50% by adding 20% flyash. Hydraulic conductivity of expansive soils mixed with flyash decreases with an increase of flyash due to increase in maximum dry unit weight. When Flyash content increases, OMC decreases and unconfined compressive strength increases. Thus addition of flyash makes the soil more stable.

(**Bhubneswari et.al., 2005**) had studied on engineering properties of soil through experimental programme. The experiment was regarding construction of an ash dyke at Ennore, North of Chennai were the city is covered with clay with liquid limit between 33-50%. During summer the shrinkage cracks exceed 10mm. The soil had poor workability for compaction, was highly compressible and had a very low shear strength. So instead of hauling soil from long distance, it was decided to use the locally available plastic clay stabilized using flyash. Flyash is freely available in locality of a thermal power plant. Flyash was added at varying percentage of 10, 20, 25, 30, 40, 50 and a major problem was to mix the soil and flyash to form a uniform mass. The adopted method was placing these material in layers and operating a "Disc Harrow". Field trials were carried out by building an embankment of 3 to 4 meter wide, 30 meter long and 600mm high. Each layer of 200mm thickness was placed with flyash of varying content. For each mix the required thickness of soil was spread and above which flyash collected from ESP of thermal plant was spread. After this disc harrow was used to form a uniform mix of soil and flyash. The equipment is a circular disc which penetrate through loosely placed soil and pulled horizontally by a tractor. To uniformly mix the soil 8 passes of disc harrow was required. Though a sheep foot roller is used in clayey soil, but after 12 passes of the harrow, compaction was easily carried out using a 12 ton smooth roller. It was inferred that since the local soil was highly plastic therefore flyash was used to stabilize the soil and at 25% flyash content maximum dry density was observed at 1.25times the original. The local soil before mixing with flyash needed to be dry with moisture content below 7%, and presence of dry lumps in the soil increases the no. of passes required by the disc harrow.

(**Amu et al., 2005**) used Class F flyash to stabilize expansive soil and found out that 3% Flyash with 9% cement is a better stabilizer than 12% cement. Both Cement and Flyash were increased at increment of 1%.

(Cokra et. al., 2009**)** used GGBS and grounded GGBS-cement to stabilize an artificially prepared expansive soil. These stabilizers decreased the amount of swell whereas increased the rate of swelling. After leachates analysis it was concluded that that if expansive soil existed near drinking water wells, these stabilizer should not be used.

(Sharma and Sivapullaiah, 2012) studied effect of ground GGBS on UCS of expansive soil at 7, 14 and 28 days of curing and found that strength development depends more on ground GGBS content and effect of curing is less pronounced. There was also an increase in tangent modulus values with increase in ground GGBS content. The main objective was to substitute lime or cement with GGBS and to alter it to take more load from foundations. BC soil was obtained from Belgaun in Karnataka and GGBS obtained from cement industry and were dry-mixed. The strength of specimen increased by 20% at 7 and 14 days of curing, at 40% for 28 days. Also there was an increase in Tangent Modulus.

(Osinubi et.al., 2012) studied effect of stabilization delay in strength characteristic of BC soil stabilized with blast furnace slag and cement and concluded that compaction delay reduces the strength of stabilized soil.

(Celik and Nalbantoglu, 2013) studied effect of grounded GGBS on plasticity index, linear shrinkage, swelling potential of lime stabilized sulphate-bearing expansive soil. Ettringite is an expansive mineral which develops in presence of sulphate, calcium and aluminum compounds of clay. Lab test were performed on lime treated expansive soil with varying concentration of added sulphate and then same test was repeated on lime treated soil with same amount of sulphate but with 6% Slag, and three different concentration (2000, 5000 and 10000 ppm) were used in the study and atterberg limit, linear shrinkage and swelling were investigated. Test result showed that presence of sulphate in soil resulted in abnormal increase in plasticity as well as shrinkage and swelling of the soil at 5000 and 10000 ppm of sulphate. At 10000 ppm of sulphate the rate of swelling becomes nearly three times to the virgin soil. On scanning it was found that there was a growth of Ettringite minerals. It was found that adding grounded GGBS to the lime stabilized expansive soil prevents growth of ettringite mineral. These minerals leads to increase in plasticity index, linear shrinkage, swelling potential of the specific soil.

(Sharma and Sivapuliah, 2015) attempted to utilize mixture of fly ash (class F) and GGBS as binder to stabilize expansive soil. The objective of this research was to assess the effect of flyash-GGBS based binder on the physical properties and UCS of the soil. The influence of different percentages of binder on the Atterberg limits, compaction characteristics and unconfined compressive strength of an artificially-mixed soil were examined. The addition of binder was shown to bring about a significant improvement in these soil properties. It was found that the liquid limit and plasticity index of the expansive soil decreased considerably with the addition of binder, while the strength improved. The addition of lime–binder to the soil decreased liquid limit and plasticity index while increasing the shrinkage limit. Since both the materials require alkali activation, addition of small amount of lime (1%) in the binder is also considered and it further improved the soil properties by enhancing the pozzolanic reactivity of the binder It is found that the addition of binder causes flocculation of clay particles and increases the number of coarser particles which help in reducing the Atterberg limits. UCS was found to increase with an increase in binders and curing period and confirms that Flyash mixed with GGBS and has potential to improve properties of expansive soil with the help of minimum chemical additives. Based on the results of the UCS test, the addition of 20% binder is recommended as optimum content. Test results indicate that the use of GGBS mixed flyash as binder to stabilize expansive is well suited for sustainable construction besides economic benefits.

Conclusion

From the review of literature on stabilization of expansive soil using solid waste, the following conclusion can be drawn

1. From stabilization point of view the major problem of expansive BC soil in field is
    a. It is difficult to pulverize the soil as dry lumps and break due to high dry strength and wet soil is sticky and unmanageable
    b. Excessive variation in volume and stability with variation in moisture content.
    c. Considerable shrinkage on drying which results in extensive cracks. BC soil when compacted at OMC will shrink further as shrinkage limit lower than OMC.
    d. BC soil exerts a high swelling pressure from below on being soaked.
2. Stabilization of expansive soil improves the geotechnical properties of the expansive soil.
3. Majority of researchers have discussed the effects of stabilization on index properties, compaction properties, UCS, CBR and swelling properties of expansive soil.
4. The effect of stabilization on mechanical properties (shear strength, splitting tensile strength, stiffness, compressive strength), hydraulic conductivity, consolidation properties of expansive soil have not been studied by most researchers.
5. Investigation of contaminants on geotechnical properties of stabilized soil, mineralogical studies, durability, feasibility and viability aspect of stabilization are limited in literature.
6. Behavior of stabilized soil subjected to cyclic loading is hardly covered in the literature.
7. Methods of construction utilizing these stabilizers are hardly found in literature.
8. Results of field studies are hardly touched in the literature.
9. Very limited research regarding Sulphur rich expansive soil.
10. Studies regarding use of solid waste as stabilizer have been mostly confined to subgrade of pavement. Studies regarding its use as liner material in landfills, canal, backfill material in retaining wall and as a sub-base material in pavement is negligible in the literature.
11. Future research on stabilization of expansive soil using industrial waste should take into consideration the above mentioned issues.

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Stabilization of Soil Using Lime Activated Ground Granulated Blast Furnace Slag for Soil Subgrade

Abhraneel Sengupta[1] D. S. Ray[2]
[1]M. Tech Scholar [2]Professor
[1,2]Department of Civil Engineering
[1,2]BBD University, Lucknow, India

Abstract— Soil is used as a material for road construction in sub grade and sub base region of the pavement. If the strength of soil is poor due to it being soft, has a high swelling tendency or low shear strength than soil stabilization is required. Its main advantage over soil replacement is most of the time it is done to reduce the cost incurred. There are numerous stabilizers available in the market like lime, cement, flyash, granulated slag etc. In this paper we will use ground granulated blast furnace slag as stabilizer. Although the stabilizer is neutral, it requires a activator to start the reaction which is provided in form of lime. So the percentage of soil to admixture play a crucial role in soil stabilization as they have different specific density. The objective of the study is to improve the locally available weak soil with stabilizers. The test involved are Modified proctor test to find the maximum dry density of the sample mixture and CBR test to check whether adding admixture improves the soil, as higher the CBR it helps to reduce the crust thickness and helps in increasing the bearing capacity of the soil. Thus overall may help in reduction of cost incurred in the project.

Keywords: Soil, Lime

I. INTRODUCTION

With the limited finances available, the biggest challenge in developing countries like India is to provide a complete network of road system, particularly in providing connectivity to remote villages. The cost of road construction and materials is increasing leaps and bound year after year. Therefore there is a need to resort to one suitably low cost road construction method by effectively utilizing local materials and adopting stabilizing techniques. The term soil Stabilization means improvement of the stability or bearing power of the soil by the use of controlled compaction, proportion and/or addition of suitable stabilizers and additives. Soil Stabilizers deal with physical, physiochemical and chemical method to ensure that the stabilized soil serves its intended purpose as the pavement component material.

The object of soil stabilizing road constructions are

- To effect economy in initial construction cost of lower layer of pavement such as subgrade and sub base course.
- possibly to upgrade the pavement structure to higher specifications at a later stage such as construction of pavement to meet the growing needs of the road safety.
- If the locally available soil is found to be unsuitable as a sub grade material for the construction material of important road pavement.
- To find suitable soil from nearby and other borrow areas that have acceptable soil properties, transport the borrowed soil from the pits to the construction sites, compact the same in layers and construct the sub grade of specified 500mm thickness.
- To resort to appropriate soil stabilization techniques and improve the properties of soil itself to acceptable levels, compact in layers and construct the sub grade to required thickness.

II. LITERATURE REVIEW

(Al Rawas, 2002)[12] worked out that additives such as copper slag containing higher amounts of Na^+ but lower amount of Ca^{2+} and CaO, and was less effective than GGBS, which had low amounts of Na^+ but relatively higher amount of CaO. Calcium ions help in reducing the intensity of swell potential of the soil containing smectite and illite clay minerals by forming aggregations of different sizes. He concluded that the chemical composition of stabilizing agents provides a good indication about their effectiveness in soil stabilization and should essentially be determined.

(Bhubneswari et.al., 2005)[2] had studied on engineering properties of soil through experimental programme. The experiment was regarding construction of an ash dyke at Ennore, North of Chennai were the city is covered with clay with liquid limit between 33-50%. During summer the shrinkage cracks exceed 10mm. The soil had poor workability for compaction, was highly compressible and had a very low shear strength. So instead of hauling soil from long distance, it was decided to use the locally available plastic clay stabilized using flyash. Flyash is freely available in locality of a thermal power plant. Flyash was added at varying percentage of 10, 20, 25, 30, 40, 50 and a major problem was to mix the soil and flyash to form a uniform mass. The adopted method was placing these material in layers and operating a “Disc Harrow”. Field trials were carried out by building an embankment of 3 to 4 meter wide, 30 meter long and 600mm high. Each layer of 200mm thickness was placed with flyash of varying content. For each mix the required thickness of soil was spread and above which flyash collected from ESP of thermal plant was spread. After this disc harrow was used to form a uniform mix of soil and flyash. The equipment is a circular disc which penetrate through loosely placed soil and pulled horizontally by a tractor. To uniformly mix the soil 8 passes of disc harrow was required. Though a sheep foot roller is used in clayey soil, but after 12 passes of the harrow, compaction was easily carried out using a 12 ton smooth roller. It was inferred that since the local soil was highly plastic therefore flyash was used to stabilize the soil and at 25% flyash content maximum dry density was observed at 1.25times the original. The local soil before mixing with flyash needed to be dry with moisture content below 7%, and presence of dry lumps in the soil increases the no. of passes required by the disc harrow.

(Cokra et. al., 2009)[7] used GGBS and grounded GGBS-cement to stabilize an artificially prepared expansive soil. These stabilizers decreased the amount of swell whereas increased the rate of swelling. After leachates analysis it was concluded that that if expansive soil existed near drinking water wells, these stabilizer should not be used.

(Sharma and Sivapullaiah, 2012)[13] studied effect of ground GGBS on UCS of expansive soil at 7, 14 and 28 days of curing and found that strength development depends more on ground GGBS content and effect of curing is less pronounced. There was also an increase in tangent modulus values with increase in ground GGBS content. The main objective was to substitute lime or cement with GGBS and to alter it to take more load from foundations. BC soil was obtained from Belgaun in Karnataka and GGBS obtained from cement industry and were dry-mixed. The strength of specimen increased by 20% at 7 and 14 days of curing, at 40% for 28 days. Also there was an increase in Tangent Modulus.

(Osinubi et.al., 2012)[10] studied effect of stabilization delay in strength characteristic of BC soil stabilized with blast furnace slag and cement and concluded that compaction delay reduces the strength of stabilized soil.

(Ankit Singh Negi, 2013)[9] Lime is used as an excellent soil stabilizing materials for highly active soils which undergo through frequent expansion and shrinkage. Lime acts immediately and improves various property of soil such as carrying capacity of soil, resistance to shrinkage during moist conditions, reduction in plasticity index, and increase in CBR value and subsequent increase in the compression resistance with the increase in time. The reaction is very quick and stabilization of soil starts within few hours.

(Celik and Nalbantoglu, 2013)[5] studied effect of grounded GGBS on plasticity index, linear shrinkage, swelling potential of lime stabilized sulphate-bearing expansive soil. Ettringite is an expansive mineral which develops in presence of sulphate, calcium and aluminum compounds of clay. Lab test were performed on lime treated expansive soil with varying concentration of added sulphate and then same test was repeated on lime treated soil with same amount of sulphate but with 6% Slag, and three different concentration (2000, 5000 and 10000 ppm) were used in the study and atterberg limit, linear shrinkage and swelling were investigated. Test result showed that presence of sulphate in soil resulted in abnormal increase in plasticity as well as shrinkage and swelling of the soil at 5000 and 10000 ppm of sulphate. At 10000 ppm of sulphate the rate of swelling becomes nearly three times to the virgin soil. On scanning it was found that there was a growth of Ettringite minerals. It was found that adding grounded GGBS to the lime stabilized expansive soil prevents growth of ettringite mineral. These minerals leads to increase in plasticity index, linear shrinkage, swelling potential of the specific soil.

(Sharma and Sivapuliah, 2015)[14] attempted to utilize mixture of fly ash (class F) and GGBS as binder to stabilize expansive soil. The objective of this research was to assess the effect of flyash-GGBS based binder on the physical properties and UCS of the soil. The influence of different percentages of binder on the Atterberg limits, compaction characteristics and unconfined compressive strength of an artificially-mixed soil were examined. The addition of binder was shown to bring about a significant improvement in these soil properties. It was found that the liquid limit and plasticity index of the expansive soil decreased considerably with the addition of binder, while the strength improved. The addition of lime–binder to the soil decreased liquid limit and plasticity index while increasing the shrinkage limit. Since both the materials require alkali activation, addition of small amount of lime (1%) in the binder is also considered and it further improved the soil properties by enhancing the pozzolanic reactivity of the binder It is found that the addition of binder causes flocculation of clay particles and increases the number of coarser particles which help in reducing the Atterberg limits. UCS was found to increase with an increase in binders and curing period and confirms that Flyash mixed with GGBS and has potential to improve properties of expansive soil with the help of minimum chemical additives. Based on the results of the UCS test, the addition of 20% binder is recommended as optimum content. Test results indicate that the use of GGBS mixed flyash as binder to stabilize expansive is well suited for sustainable construction besides economic benefits.

(Singh and Ray, 2019)[15] studied the CBR of locally available soil in lucknow region with various stabilizers locally found. Stabilizers included Emulsions, Cement and Lime. Based on CBR value they calculated crust thickness and reduction in crust thickness based on CBR. Then they calculated the net savings in cost per km for a standard carraigeway based on reduction in crust thickness. They found that Emulsions are the most costliest of the batch. Although the results were positives but the cost of admixtures were high. Therefore the overall savings were drastically reduced. In case of Cement (1%) showed the highest CBR and highest reduction in crust thickness

A. *Summary of Literature*

A thorough work has been done in field of soil stabilization, and mainly it emphasized on necessity of on field improvement of soil stabilization like CBR, MDD, OMC, UCS and Atterberg limits. The fundamentals of soil stabilization with respect to lime and GGBS is studied. Overall the integrity of pavement is improved due to soil stabilization, and economy in construction is analysed and if possible reduced with help of lower cost of admixture, or lowering the crust thickness. Further in this project we are going to study the effects of soil stabilization with lime and GGBS and its effect on MDD, CBR, Crust thickness and would check if overall cost of 1km road using stabilized soil has positive or negative effect on the economy of the project.

III. MATERIALS

A. *Soil*

The soil is obtained from Kalagaon Area in lucknow. There soil is mildly expansive due to some clay content in it. The soil is sieved through 4.75mm sieve followed by 2.36mm, 1.18mm, .600mm, .425mm, .075mm, finally .002mm and retained on pan) weighed and air dried. Once the soil is naturally air dried, it is tested for natural moisture content in a muffle furnace. The various geotechnical properties of the soil are listed below.

B. Lime

When quick lime is finely crushed, slaked with a minimum amount of water and screened or ground to form a fine homogenous powder the product is called hydrated lime. Quick lime obtained by burning limestone or $CaCl_2$ obtained from lime quarry, when sprinkled with water slakes within 10 minutes and become powder. The slaked lime so produced is sieved through IS: sieve 3.5 mm. It is then used for various purposes such as white washing, plastering making mortars and lime putty and when mixed with soil, helps to reduce its swelling and helps to gain strength. The process is also known as hydration of lime.

$$Cao + H2O \rightarrow Ca\,(OH)_2 + 15.6\ Kcal$$

In the above reaction high heat of hydration is produced at a temperature of about 350oC which is an exothermic reaction. The energy liberated during this reaction causes the lumps of quicklime to split and fall to lime to powder the heat causes excess water to evaporate. In hydration of lime the heat of hydration generated is not sufficient to break the lime to powder and therefore, the lime is broken mechanically to a suitable size and pulverized before hydration and thus fine powder is produced by mechanical grounding. Limes from coarse grained stone, lump limes and pulverized usually slake rapidly; limes from fine grained stones, and dense lumpy lime usually slakes slowly. Over burning or under burning of the lime stone causes the lime to slake more slowly.

Chemical Formula	$Ca(OH)_2$
Molar Mass	74.093 g/mol
Appearance	White Powder
Odour	Odourless
Density	2.211 g/cm^3
Melting Point	580^{O}C
Solubility	Soluble in acids and glycerol Insoluble in alcohol
Solubility in water	1.89 g/L (0^{O}C) 1.73 g/L (20^{O}C) 0.66 g/L (100^{O}C)
Refractive Index	1.574
Magnetic Susceptibility	$-22*10^{-6}$ cm^3/g

Table 1: Properties of Lime

C. Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBS), more commonly known to as slag and It is a by product from steel industry. It is majorly a waste product formed from steel industry and about 40-42% of annual generated GGBS is only used. The slag is majorly used as a landfill material as large quantity can be dumped at a particular site. Slag is chemically neutral and over time in alkaline nature is slowly activates its cementations properties and gain strength. Cement industry has very high demand of Blast Furnace Slag as it helps to manufacture slag cement. It gains 7 day strength slowly, but the 28 day strength remains the same as other cement. Cement plants near Steel plant are large consumer of slags. Along with flyash GGBS is one of the largest industrial waste product produced with an annual production of nearly 25 Million MT. The Majority of GGBS is used in partial replacement of lime with GGBS. But the utilization rate is low, about 55% (Singh et. al., 2008)[16]

Hence, a chemical activator like lime or cement is added to improve its pozzolanic reactivity. While GGBS (obtained after granulated slag is ground into fine powder) is a latent hydraulic cement (rich in lime content) which only needs to be activated (Bijen, 1996)[3]. The main reason for their Underutilization of these by-products is the lack of pozzolanic reactivity.

S.NO	CHARACTERISTICS	REQUIREMENT AS PER BS: 6699	TEST RESULT
1	Fineness (M / Kg)	275 (MIN)	390
2	Specific Gravity		2.85
3	Particle Size (Cumulative %)	45 MICRON	97.10
4	Insoluble Residue (%)	1.5 (Max)	0.49
5	Magnesia. Content (%)	14.0 (Max)	7.73
6	Sulphide Sulphur (%)	2.00 (Max)	0.50
7	Sulphite Content (%)	2.50 (Max)	0.38
8	Loss On Ignition (%)	3.00 (Max)	0.26
9	Manganese Content (%)	2.00 (Max)	0.12
10	Chloride content (%)	0.10 (Max)	0.009
11	Glass Content (%)	67 (Min)	91
12	Moisture Content (%)	1.00 (Max)	0.10
13 A B C	Chemical Moduli CaO + MgO + SiO2 (CaO + MgO) / SiO2 CaO / SiO2	66.66 (Min) > 1.0 < 1.40	76.03 1.30 1.07

Table 2: Properties of GGBS

IV. METHODOLOGY

A. Soil - Lime Stabilization

Soil Lime works in both ways as a binder and as well as modifier for high plasticity soil. Lime can be used in both coarse and fine grained soil. The basic principle attached with soil lime stabilizer is puzzolonic action. The puzzolonic reaction takes place due to addition of hydrated lime with moist soil and is defined as hydrated lime (Ca(OH) + Water + Soil (SiO_2, Al_2O_3 and others). Cementitious material with stable silicate hydrates and calcium aluminate hydrates. The effect due to the addition of lime are improvement in workability by increasing OMC wrt soil without lime, increase in all type of strength related properties by decreasing plasticity index, swell reduction and soil becoming hydrophobic. With suitable addition of granular blast furnace slag it can be added to the gravel, sand and silt.

B. Slag Activation

GGBS without an activator does react with water and the rate of hydration is very slow. Its hydraulic reactivity depends on various factors like glass phase content, particle size distribution, chemical composition etc. When the slag is exposed to the water, an impermeable coating of alumino-silicate is formed on the surfaces of slag grains and this inhibits further reaction with water. Hence a chemical activator or chemical medium is essential for further hydration. Many activators have been suggested to activate GGBS and among them the most commonly used activators are calcium hydroxide, gypsum, ordinary Portland cement, sodium hydroxide, sodium carbonate and sodium sulphate etc. Rate of hydration becomes high with increasing alkali contents as they help in breaking the Si-O and Al-O bonds. Lime is one of the most commonly used activators and the reaction with GGBS with and water is a complex process. Calcium hydroxide [$Ca(OH)_2$] and C-S-H gel and other minor alkalis produced during hydration of Lime. Among them Slag is mainly activated by the hydration product $Ca\{OH)_2$ (Hakkinen, 1993; Bijen, 1996)[5].

GGBS, due to its high alumina and silica content, produces slightly different hydrates from those formed when using ordinary Portland cement. The main reactants of GGBS hydration are C-S-H, calcium aluminates hydrate and a small amount of calcium hydroxide (Higgins et al., 1998)[13]. Lime as an activator has studied by many investigators and found to be the most efficient activator. It quicken the hydration reaction of GGBS. Due to its high alumina and silica content, the main reaction products of GGBS activated by lime are C-A-S-H gel and hydroxide type phases containing magnesium. Requirement of lime for activation of slag is also less and it varies from 2% to 4%. Calcium sulphate is also a successful Activator as it increases the rate of hydration of slag further and contributes in gaining higher strength

C. Test Performed

1) Modified Proctor Test (IS 2720 Part 8- 1983, Reaffirmed May 2015)

Modified proctor test is used to determine the compaction of different types of soil and change in properties of soil with the change in moisture content. It gives us a relationship between Moisture Content and dried density. Compaction is densification of unsaturated soil by the reduction in the volume of voids filled with air, while the volume of solids & water content remains the same.

The major aim of compaction of soil is to increase shear strength, decrease compressibility, reduce permeability, & to control swelling & shrinkage of soil. The degree of compaction of soil is measured in terms of its dry density. The maximum dry density of soil occurs at optimum moisture content (OMC).

2) California Bearing Ratio Test

CBR test was developed by California state highway department for evaluating the strength of subgrade soil and other pavement materials for the designs and construction of flexible pavements. The CBR results have been correlated with flexible pavement thickness requirements for highway and airfields. Being emperical test method, CBR test result cannot be related accurately with any fundamental property of soil or pavement material to be tested. CBR method is also standardized by Bureau of Indian Standards (BIS).

CBR test denotes a measure of resistance to penetration of a soil or flexible pavement material of standard plunger under controlled test condition. The test also conducted on both undisturbed and remoulded soil specimens. Lab test procedure should be strictly adhered if high degree of reproducibility is required.

The basic principle of CBR test is by causing a cylindrical plunger of 50mm diameter to penetrate into the soil sample or pavement component material at an rate of 1.25mm per minute. The load required for 2.5mm and 5mm penetration of plunger in soil or pavement material to be tested is recorded. The CBR value of the material tested is expressed as a percentage of standard load value in a material. The standard load value have been established based on a large number of test standard crushed stone aggregates at penetration value of 2.5 and 5mm. These standard load value may directly. These standard load value given below maybe directly used to compute the CBR value of the test material. The penetration points in mm for CBR test was 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, 12.5 mm

Sample No	Sample Mix Description (by weight)	Maximum Dry Density g/cc	CBR Value %
1	Soil + 0% Slag + 0% Lime	1.67	5.88
2	Soil + 1% Slag + 0.% Lime	1.66	5.91
3	Soil + 2% Slag + 0.% Lime	1.69	5.75
4	Soil + 3% Slag + 0.% Lime	1.71	6.33
5	Soil + 4% Slag + 0% Lime	1.70	6.44
6	Soil + 0% Slag + 0.5% Lime	1.72	7.50
7	Soil + 1% Slag + 0.5% Lime	1.74	7.85
8	Soil + 2% Slag + 0.5% Lime	1.75	7.96
9	Soil + 3% Slag + 0.5% Lime	1.80	8.18
10	Soil + 4% Slag + 0.5% Lime	1.77	8.24
11	Soil + 0% Slag + 1.0% Lime	1.83	8.43
12	Soil + 1% Slag + 1.0% Lime	1.86	9.62
13	Soil + 2% Slag + 1.0% Lime	1.92	10.13
14	Soil + 3% Slag + 1.0% Lime	1.88	10.06
15	Soil + 4% Slag + 1.0% Lime	1.83	9.70

Table 3: Sample Description and Test Results for MPT and CBR

V. RATE AND CRUST THICKNESS ANALYSIS

From the study there is a improvement in CBR of soil due to adding GGBS and Lime in to selected soil of sub grade due to cementicious properties in both the admixtures when properly mixed and in contact with moisture. By only adding GGBS to the soil, there was only slight improvement to the CBR and MDD. It is due to the fact that GGBS is fairly neutral compound and does not react unless a activator is added, in this case it is lime. Slight reaction between soil and GGBS has taken place, also the specific gravity of GGBS is higher than soil, so there is an increase in MDD. MDD increased from 1.67g/cc in case of Sample 1 (Soil 100%) to 1.71g/cc when 3% GGBS is added.

CBR value also increases from 5.88 in case of sample 1 to 6.44% in case of sample 5 (4% GGBS. But when activator is not added than significant increase in CBR does not take place. When lime is added to the mix, than lime acts as a cementitious compound and also act as an activator which helps in significant gain in MDD and CBR. Also the specific gravity of the soil has slight increase. The most increase in CBR and MDD takes place in case of sample 13 (Soil +2% GGBS+ 2% Lime) when CBR increases upto 10.13%, and MDD increases upto 1.92g/cc

A. Crust Thickness

Calculation of Crust Thickness: All the calculations are done as per the guidelines of
IRC: 37 - 2018

Traffic	1130Cvd (An assumed road)
Standard Axle (Ns)	[(365 * (1+r) n – 1/r) * D * F *A]
Traffic	Ns / 10^6
Design Period (n)	15 years for SH, NH
Growth Rate (r)	5%
Lane Distribution Factor (D)	0.75
Vehicle Damage Factor (F)	3.5
A	1130 CVD
Standard Axles (Ns)	[({365x (1+0.05)15–1}/0.05)x0.75x3.5x1130] = 23169378.75 CVD
Design Traffic	Ns / 10^6 = 23.16 MSA

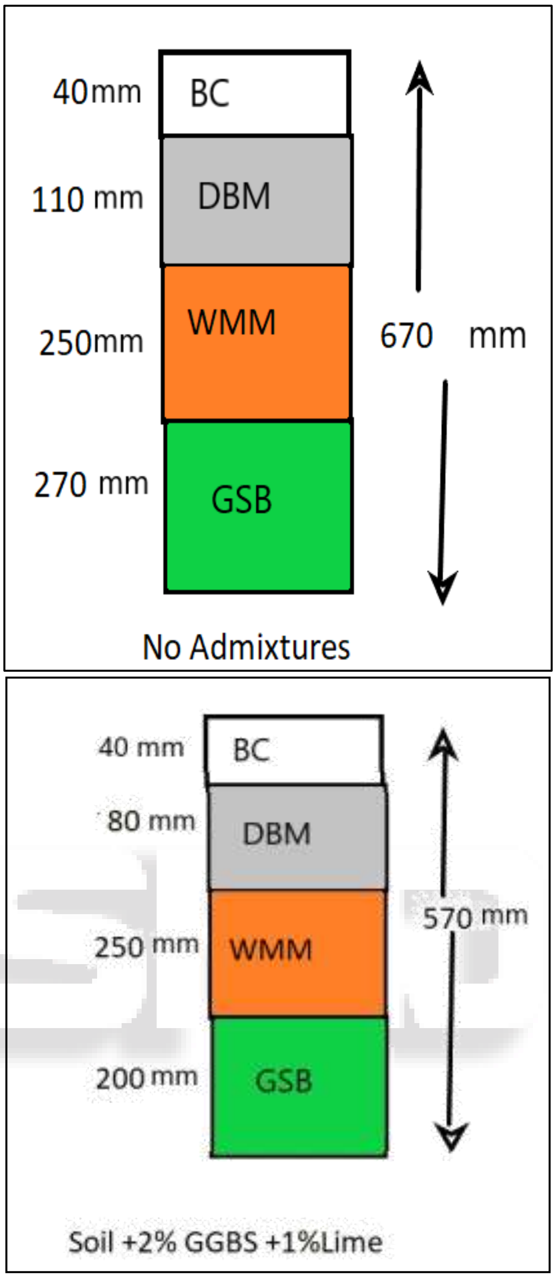

Fig. 1: Recommended crust thickness as IRC: 37 - 2018

S.No	Admixture	CBR	Sub grade Thickness in mm (Earth Work)	Crust Thickness				
				Total crust in mm	GSB in mm	WMM in mm	DBM in mm	BC in mm
1	No Admixture	5.88	500	670	270	250	110	40
2	Soil +2% GGBS + 1% Lime (Sample 13)	10.13	500	570	200	250	80	40
3	Reduction in Crust Thickness	-	-	100	70	-	30	-

Table 4: Crust Thickness

B. Rates

- Item Rates are calculated as per Data Book of Roads and Bridges, MORTH.
- Admixture Rates are taken from Local Vendors and are Market Rates
- Admixtures are added to top 500mm of the sub grade as per IRC 37 2018 and the procedures are taken in accordance with Specification for Roads and Bridges Work IRC - MORTH

C. Quantity, Cost of Admixture and Net Savings

1) Cost of Admixtures

For Sample 13, the maximum CBR and MDD was observed
Density of Stabilized Soil = 1.92g/cc (Modified Proctor Test Sample 13)

MDD = 1.92g/cc = 1920 kg/m^3

2) *For 1 m^3 soil,*

Weight of Stabilized Soil= 1920kg for 1m^3 mix.

Quantity of Admixture Added in soil = 2% GGBS + 1% Lime

Weight of 2% GGBS = 1920*2/100 = 38.40kg in 1m^3 of sample.

Weight of GGBS in 6000 m^3 = 2,30,400 kg or 230.4 tonnes

Cost of GGBS = Rs 5 per kg or Rs 5000 per tonne.

Weight of 1% Lime in 1m^3 Sample = 1920*1/100= 19.20kg

Weight of Lime in 6000 m^3 = 1,15,200 kg or 115.2 tonnes

Cost of Lime = Rs 10.5 per kg or Rs 10500 per tonne

S.No	Description	Unit	Quantity	Rate	Amount
1	Labour				
	Mate	day	0.360	351.00	126.36
	Skilled mazdoor for alignment and geometrics	day	1.000	351.00	351.00
	Mazdoor for spraying lime	day	8.000	338.00	2704.00
2	Machinery				
	Tractor with ripper and rotavator attachments @ 60 cum per hour for ripping and 25 cum per hour for mixing	hour	12.000	486.00	5832.00
	Motor Grader 110 HP @ 50 cum per hour	hour	6.000	2858.25	17149.50
	Vibratory roller 8 - 10 tonne capacity	hour	6.00x0.65*	1838.90	7171.71
	Water tanker 6 KL capacity	hour	12.000	28.86	346.32
3	Material				
	Lime at site	tonne	115.2	10500	1209600
	Slag at Site	tonne	230.4	5000	1152000
	Cost of water	KL	72.000	250.00	18000.00
4	Overhead Charges (1+2+3) @ 10%				241327.97
5	Contractor's Profit (1+2+3+4) @10%				265461.75
6	Cost of 6000 m^3				2920068.41
7	Rate per m^3 (1+2+3+4+5)/6000				486.68

Table 5: Rate Analysis for preparation of sub grade using admixtures by mechanical means

3) *Rate of Sub grade Preparation with admixtures = Rs 486.68 /m^3*

S.No	Description	Quantity (m^3)	Rate (Rs)	Amount (Rs)
1	Earth Work for Sub grade Preparation	1000*12*0.50 = 6000	120	7,20,000
2	GSB	1000*7.3*0.27 = 1971	3687	72,67,077
3	WMM	1000*7*0.25 = 1750	4124	72,17,000
4	DBM	1000*7*0.11 = 770	8805	67,79,850
5	BC	1000*7*.04 = 280	9664	27,05,920
-	Total	-	-	2,46,89,847

Table 6: Bill of Quantity for Sub grade with No Admixtures for 1km road of 12m (2.5 + 7.0+ 2.5)

S.No	Description	Quantity (m^3)	Rate (Rs)	Amount (Rs)
1	Earth Work for Sub grade Preparation	1000*12*0.50 = 6000	486.68	29,20,068.41
2	GSB	1000*7.3*0.20 = 1460	3687	53,83,020
3	WMM	1000*7*0.25 = 1750	4124	72,17,700
4	DBM	1000*7*0.08 = 560	8805	49,30,800
5	BC	1000*7*.04 = 280	9664	27,05,920
-	Total	-	-	2,31,57,508

Table 7: Bill of Quantity for Sub grade with Admixtures for a 1km road of 12m (2.5 + 7.0+ 2.5)

Net Savings = Cost of Road without Admixture - Cost of Road With admixtures

= 2,46,89,847 - 2,31,57,508 = 15,32,339

Net Savings % = (Net Saving / Cost of Road without Admixtures)*100

= (15,32,339 / 2,46,89,847)*100 = 6.21%

Cost of Road without Admixture (Rs)	Cost of Road with Admixture (Rs)	Change in Amount	Net Savings (Rs)	Net Savings %
2,46,89,847	2,31,57,508	15,32,339	15,32,339	6.21 %

Table 8: Net Saving due to stabilization

Now as per my results, we had an maximum CBR was found to be 10.13% at Sample 13 (Soil + 2% GGBS +1% Lime). At the particular CBR, the Crust thickness was calculated as 570 mm. If no stabilization was done, then the crust thickness was found to be 670mm. Therefore by doing stabilization we are saving 100mm of crust.

Based on that per km cost saving was Rs 15,32,339 which was the difference between Cost of the Pavement without admixture and Cost of the pavement with admixtures. Based on this savings we find out that we have a net saving % of 6.21%.

VI. CONCLUSION

From the research paper on stabilization of expansive soil using Lime activated ground granulated blast furnace slag following conclusion can be drawn.

– Lime and GGBS can work together as an admixture in stabilization of soil, it is due to the fact that although slag is neutral, slag contains about 35-45% CaO in it, and when lime and water are added to it, due to exothermic reaction between lime and water, the overall alkalinity of the mixture increases, therefore it helps slag to activate which in turn additionally helps in increasing strength of soil.
– Stabilization of expansive soil improves the geotechnical properties of the expansive soil like Maximum dry density, reducing swelling Optimum moisture content of the soil and index properties of the soil etc
– The maximum dry density of original soil was found to be 1.67 g/cc, whereas sample 13 (Soil + 2% GGBS + 1% Lime) was found to be 1.92 g/cc, which indicates strength of soil has increased due to admixture and compaction.
– The CBR value increased from 5.88 in case of Sample 1 to 10.13% in case of Sample 13. Which resulted in decrease in crust thickness of the pavement by 100mm
– Due to a decrease of 100 mm in crust thickness (70mm in GSB and 30mm in DBM), significant reduction in cost has taken place. The Net saving amount is found to be Rs 15,32,339.
– The Net Saving % is found to be 6.21%
– The rates have been taken from Data Book of Standard Highway MORTH, and the design of flexible pavement is done as per IRC 37: 2018.
– It is found that both in case of CBR and MPT, when in soil only GGBS is added, negligible increase in density and CBR value is observed from Sample 1 to Sample 5. But when lime is added, the values show a significant increase.
– The effect of stabilization on mechanical properties (shear strength, splitting tensile strength, stiffness, compressive strength), hydraulic conductivity, consolidation properties of expansive soil have not been studied in this paper.
– Behavior of stabilized soil subjected to cyclic loading is hardly covered in the paper. Also these test are performed in the lab, and if performed in the field results may show variations.

VII. FUTURE SCOPE AND DISCUSSIONS

Based on the present findings, it is felt that further work should be pursued in the following area:

– Evaluation could be done with other admixtures like geo synthetics, crumb rubber, and waste materials like PET bottles, fly ash and debris.
– Evaluation should be carried out for the types of activators for Ground granulated blast furnace slag like calcium hydroxide, gypsum, ordinary Portland cement, sodium hydroxide, sodium carbonate and sodium sulphate
– Evaluation should be carried out with locally available soil which will be more useful for practical purpose.
– Mixture of admixture used for stabilization should be carried out better result.
– Findings of this investigation should be carried tested in field for actual result. While we have only involved lab work, these test should also be carried out in field. Generally a difference in result is observed since in lab we can control the environment.
– Environmental condition should also considered in evaluation of the findings for further actual results like the results obtained on soil will be different in summer, monsoon and winter.

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