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

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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.

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^OC
Solubility	Soluble in acids and glycerol Insoluble in alcohol
Solubility in water	1.89 g/L (0^OC) 1.73 g/L (20^OC) 0.66 g/L (100^OC)
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

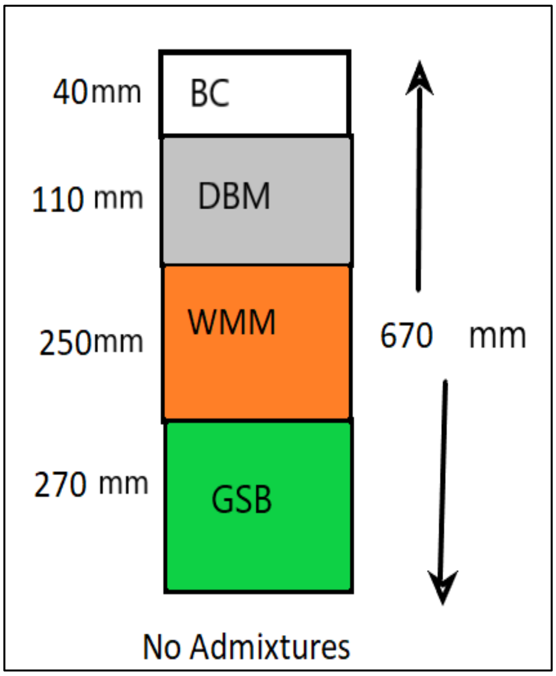
From the study there is a improvement in CBR of soil due to adding GGBS and Lime in to selected soil of sub grade due to cementicious properties in both the admixtures when properly mixed and in contact with moisture. By only adding GGBS to the soil, there was only slight improvement to the CBR and MDD. 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



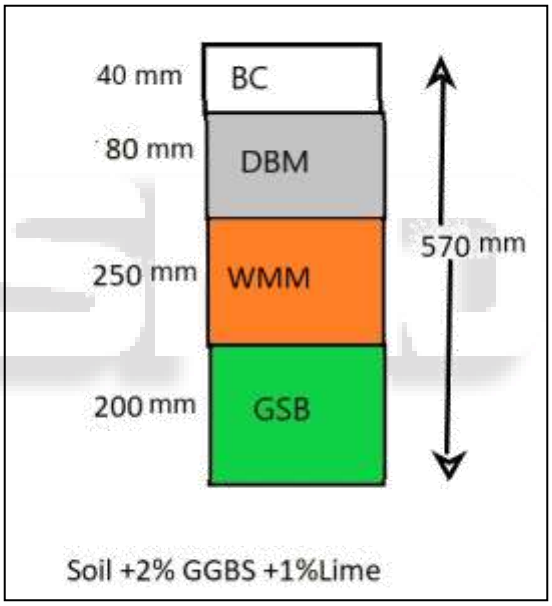


Fig. 1: Recommended crust thickness as IRC: 37 - 2018

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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