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Efficacy of GGBS Stabilized Soil Cushions With and Without Lime in Pavements

Sridevi G^a and Sreerama Rao A^b

^aDepartment of Civil Engineering, C.V. Raman College of Engg. Bhubaneswar, Odisha, India.

^bFormerly Principal, JNTU College of Engg., Kakinada, A.P., India

Abstract: Expansive clays suffer volume change due to changes in moisture content which causes heaving, cracking and the breakup of the road pavement. The main properties of the expansive soil that are to be improved are strength, volume stability and durability. Stabilization of a clayey sub-grade is necessary to improve its volume stability, increase its unconfined compressive strength and its soaked California Bearing Ratio (CBR), in order to improve the overall pavement performance. The use of industrial by-products for stabilizing expansive soils is gaining importance, because of the ecological and economic benefits derived there from. In the present study, expansive soil, stabilized with Ground Granulated Blast furnace Slag (GGBS), with and without lime was used as cushioning material above an expansive clay sub-grade to study its performance in improving the properties of the sub-grade. The investigations show that the GGBS-stabilized expansive soil, with and without lime, as a cushioning material is effective in reducing the heave of the underlying clay bed apart from improving the soaked CBR and increasing the unconfined compressive strength of the soil, GGBS mix system. The studies also indicate that the cushioning material possesses all the properties needed for use as sub-base material. So, the cushion also serves as a sub-base layer in the pavement structure. The use of GGBS-stabilized soil alone, or in combination with lime, has significant effect in improving the properties of potentially swelling clays.

Keywords: Expansive soil, Lime, Ground Granulated Blast Furnace Slag, Heave, CBR.

I. Introduction

A well connected road network is essential for the development of agriculture, commerce and industry. Expansive clay soils undergo heave and shrinkage due to seasonal moisture changes. It is established that the major problems on account of expansive sub-grades to the pavements are detrimental heave and severe cracking [1]. Roads constructed on expansive clay sub-grades are adversely affected by the behaviour of the clay leading to cracking and buckling of the infrastructure built on them and results in billions of dollars of damage annually [2-3]. Pavements may crack due to uneven heave during wetting and shrinkage of the sub-grade during drying. The swell-shrink and engineering behaviour of clay depends on the principal minerals in the clay deposit. The volume changing is highest for the montmorillonite group which is formed as a result of the weathering of ferromagnesium minerals, calcic feldspars, and volcanic materials. They are most likely to form in an alkaline environment with a supply of magnesium ions and absence of leaching. Expansive clays are extensively present all over the world and are responsible for the most costly natural hazards.

Different methods are employed to improve the geotechnical properties such as strength and the stiffness of expansive soils, by treating them in situ. The methods that are commonly employed to improve problematic soils include densification such as compaction, preloading, pore water pressure reduction techniques such as dewatering and electro-osmosis, bonding of soil particles by ground freezing, grouting, chemical stabilization and use of reinforcing elements such as geotextiles and stone columns [4]. Chemical stabilization [5-7] of fine-grained and expansive soils has been proved to be effective in many of the geotechnical engineering applications such as pavement structures, building foundations to avoid damage due to settlement or the swelling of expansive soils. The improvement of the geotechnical properties of expansive soil using lime takes place through two basic chemical reactions *Short-term reactions* include cation exchange and flocculation, where lime is a strong alkaline base which reacts chemically with clays causing a base exchange. Calcium ions (divalent) displace sodium, potassium, and hydrogen (monovalent) cations and change the electrical charge density around the clay particles. This results in an increase in the interparticle attraction causing flocculation and aggregation with a subsequent decrease in the plasticity of the soils. *Long-term reaction* include pozzolanic reaction, where calcium from the lime reacts with the soluble alumina and silica from the clay in the presence of water to produce stable calcium silicate hydrates (CSH), calcium aluminate hydrates (CAH), and calcium aluminosilicate hydrates (CASH) which induce long-term strength gain and improve the geotechnical properties of the soil [8-10]. The clay-lime-GGBS reaction was different from the clay-lime reaction. In fact there are two competing reactions rather than one. The first reaction was the hydration of GGBS activated by lime to produce C-A-S-H gel and hydrotalcite type phases containing magnesium [11]. This reaction was also known to consume lime. The second reaction was the clay-lime reaction to produce C-A-S-H and calcium aluminates and

alumino- silicates. In contrast to the pozzolanic reaction of clay with lime, which was slow, the slag hydration, activated by lime, was much quicker [12]. The strength of clay-lime-GGBS mixtures was governed by the same factors observed in GGBS-OPC blend hydration, such as properties of the C-S-H gel in terms of its amount, porosity, permeability and structure. The lime in the lime-clay mix supplies the required alkaline environment for GGBS activation and hydration. Wild *et al.* [13] reported that lime replacement by GGBS enhances strength and using a GGBS-lime system instead of lime only leads to a reduction in total binder content. They also recommended that the lime content should be partially replaced with 60 to 80% GGBS to reduce sulphate expansion. However, the degree of replacement should not exceed to maintain a minimum lime content sufficient to fully activate the GGBS. Therefore, preliminary strength and swelling tests must first be conducted in order to establish appropriate lime-GGBS content. However, some of these techniques suffer from a few limitations such as high cost for hauling suitable refill material in the case of soil replacement [1, 14] requirement of longer time periods for prewetting the highly plastic clays [15], complexity in constructing the ideal moisture barriers [1, 14], pulverization and mixing problems in case of lime stabilization [16-17]. In CNS technique, developed by Katti [18], about 1m of the expansive soil is removed and replaced with a cohesive non-swelling soil (CNS) layer beneath the foundations in order to prevent heave and the subsequent cracking of canal beds and linings and foundations of residential buildings placed or built over it. But, the specifications for the soil to be considered for use as CNS material [18] are hard to meet. CNS cushion provided over expansive soil has been found to be effective only during the first cycle and becomes less and less effective subsequently, as was observed from the studies carried out by [19]. In the present study, expansive soil, blended with GGBS-stabilized with lime and without lime is placed as a cushion above the expansive clay bed in order to overcome the drawbacks of CNS technique to study its efficacy in arresting swelling, improving the CBR and the unconfined compressive strength.

II. Materials and methods

A. Soil

The soil used in the study was collected from Chuttugunta, Guntur Dist., in Andhra Pradesh. While collecting the soil, it was ensured that it did not contain any organic matter. The various properties of the soil are presented in Table-1. The liquid limit is 73 % and plasticity Index is 45 %, which are high and show that the soil has a high swelling potential. A free swell index [20] of 150 % indicates that the soil has a high degree of expansiveness [21].

Table 1 Physical properties of black cotton soils

Grain-Size Distribution	
Sand (%)	27.2
Silt (%) & Clay (%)	72.8
Liquid Limit (%)	73
Plastic Limit (%)	28
Plasticity Index (%)	45
Shrinkage Limit (%)	13
IS Classification	CH
Specific Gravity	2.68
OMC (%)	25
Maximum Dry Density(Mg/cum)	1.62
Free Swell Index (%)	150
CBR (%) (soaked)	0.99

B. Ground Granulated Blast Furnace slag

The Ground granulated blast furnace slag was procured from the Visakhapatnam Steel plant, Visakhapatnam. The chemical composition of GGBS is given in Table 2.

C. Lime

The lime in the present study is procured from Birla cements. The use of lime for soil stabilization is either in the form of quicklime (CaO) or hydrated lime Ca(OH)₂.

D. Compaction Characteristics

The unit weight of GGBS-soil mixture is an important parameter because it controls the strength, compressibility, and permeability. Compaction studies were performed on the GGBS-stabilized soil sample with and without lime as per the Bureau of Indian Standard (BIS) specifications [22]. GGBS was added to the soil in different proportions, namely, 5%, 10%, 15% and 20% by weight and their respective OMC and MDD were determined. Similarly, lime content of 2% was added to the GGBS first and mixed thoroughly and then mixed with the soil in dry, in order to determine their MDDs and OMCs.

Table 2 Chemical composition of GGBS

Name of the chemical	Symbol	% by weight
Silica	SiO ₂	27 -38
Alumina	Al ₂ O ₃	7 – 15
Ferric Oxide	Fe ₂ O ₃	0.2 – 1.6
Manganese Oxide	MnO	0.15 – 0.76

Calcium Oxide	CaO	34 – 43
Sulphur Trioxide	SO ₃	up to 0.07
Potassium Oxide	K ₂ O	0.08 to 1.83
Sodium Oxide	Na ₂ O	0.20 to 0.48
Loss on ignition		0.20 to 0.85

* Data source: Source: Turner-Fairbank Highway Research Center, National Slag Association data

E. Heave Studies

A schematic diagram of the experimental set up for the conduct of heave studies is shown in Fig.1. The experimental study was carried out in Galvanized Iron (G.I) cylindrical test moulds 280 mm in diameter and 600 mm in height. A sand layer, compacted to its maximum dry density (MDD), was laid at the bottom of the mould. A cylindrical casing made of G.I, 190 mm in diameter and 300 mm in height was placed centrally in the test tank. The gap between the casing and test mould was filled with coarse sand compacted to its maximum dry density in order to serve as a draining face while saturating the sample. The expansive soil was compacted at its MDD and OMC in 4 layers, each 50 mm thick. A hollow PVC pipe was placed on the top of the soil layer before the GGBS-stabilized soil with and without lime cushion was compacted. GGBS content, varying from 5% to 20%, with increments of 5% by weight, was added to expansive soil in dry condition and mixed thoroughly. Then, water corresponding to OMC was added and the cushion placed above expansive soil bed and compacted to its maximum dry density. After the cushion was compacted, heave stake was placed through PVC pipe on the top of the clay bed. A dial gauge was mounted on the top of the heave stake.

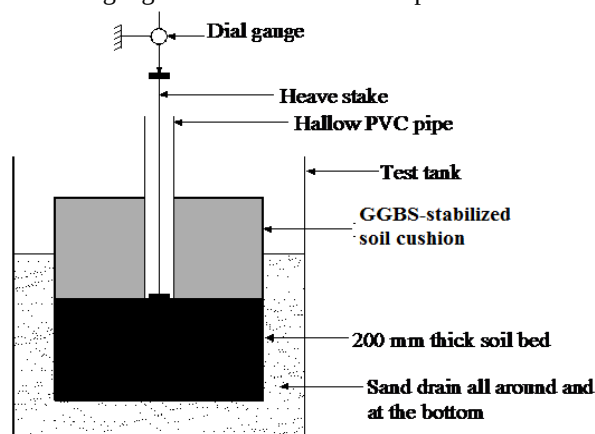


Fig. 1 Schematic diagram for heave studies

Water was then admitted into the test tank in order to saturate the sample and the heave of the soil recorded. The process was continued till there was no change in the dial gauge reading. After the soil specimen has completely swollen, the moisture content was found to ensure whether the sample was fully saturated or not. Experiments were conducted for different thickness ratios of soil (t_s) and GGBS treated soil (t_c) given by $t_c/t_s = 0.25, 0.5, 0.75, 1.0$. In the case of GGBS-stabilized soil with lime, lime content of 2% was added to GGBS in dry and mixed thoroughly and then mixed with expansive soil in dry thoroughly and moisture content corresponding to MDD was added and compacted to corresponding MDD and similar tests were conducted.

F. Soaked CBR

California Bearing Ratio (CBR) test was performed on the soil sample as per the Bureau of Indian Standard (BIS) specifications [23], in soaked condition. In the experimental study, CBR samples were prepared for different contents of GGBS ranging from 5% to 20% in increments of 5% with and without lime, to the expansive clay. The soil and GGBS with and without lime were compacted to their respective MDDs at OMC values. While placing the GGBS-stabilized soil with lime, lime was added to GGBS in dry and was thoroughly mixed and then mixed with the soil in dry. Then water corresponding to the optimum moisture content was added and compacted to its MDD. After compaction, a surcharge weight of 5 kg, sufficient to produce an intensity of load equal to the weight of base material and pavement was placed as per IS specifications during soaking and penetration. A metal penetration plunger of diameter 50 mm was used to penetrate the samples at a rate of 1.25 mm/min. The samples were soaked for 4 days and three CBR tests were conducted on each specimen and the average of the three was reported. The CBR tests were also conducted on GGBS-stabilized soil with and without lime after moist curing for 24 days and soaking them for 4 days.

G. Unconfined Compressive Strength

Unconfined compressive strength (UCS) was performed on the soil sample as per BIS specifications [24]. Test specimens were prepared in a static compaction mould of length 76.2 mm and diameter 38.1 mm to MDD by adding moisture content corresponding to its OMC. The compacted samples were cured in desiccators at 100% humidity. Unconfined compressive strength tests were conducted for the GGBS-stabilized expansive soil mixes by varying the GGBS content from 5% to 20% in increments of 5% after curing them for one day in desiccators

at 100% humidity. Similarly, unconfined compressive strength tests were conducted on lime-GGBS-stabilized expansive soil mixes with 2% lime content, by varying the GGBS content from 5% to 20% in increments of 5%, after curing them for one day and 28 days in desiccators at 100% humidity.

III. Results and discussion

A. Compaction characteristics of GGBS-stabilized expansive soil and lime-GGBS-stabilized expansive soil

The compaction characteristics of GGBS-stabilized expansive soil with and without lime were shown in Fig. 2 and Fig. 3. It is found that there is a slight decrease in MDD of the mix on increasing the GGBS content. Small increase in the OMC is observed which may be due to the increase in the specific surface that is to be lubricated. Soil-GGBS mixtures require more moisture to achieve their maximum dry density than untreated soils. The small decreases in the MDD corresponding to additions of GGBS is likely to be associated with the replacement of soil particles by the glassy angular shaped GGBS particles in a given volume; they partially fill the voids between these particles, prevent them from coming into a closer state of packing and leave larger volume of voids. The OMC of the GGBS-stabilized expansive soil was increased from 25.5% to 28.7% and MDD was decreased from 15.6 kN/m³ to 15.3 kN/m³.

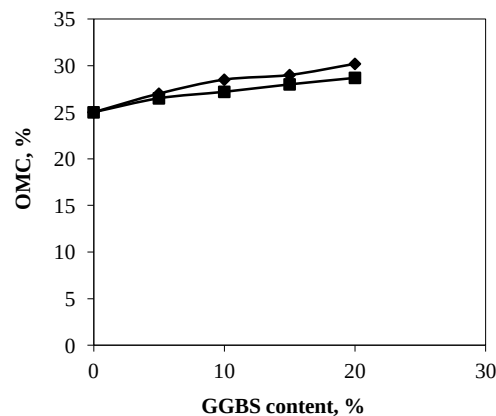


Fig.2 Variation of OMC with the GGBS content

In the case of lime-GGBS-soil mixtures, the increase of GGBS content causes a slight reduction in the MDD. The OMC of the GGBS-stabilized expansive soil was increased from 25.5% to 30.2% and the MDD was decreased from 15.6 kN/m³ to 15.1 kN/m³. Addition of lime improves the workability and also causes flocculation of soil particles. The bigger clay particles form more voids, thus a slight reduction in the dry density is caused. The formation of cementitious products immediately after mixing clay with lime can also cause resistance to compaction and reduced the density [13].

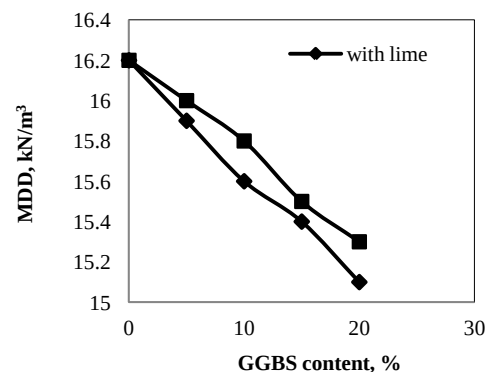


Fig.3 Variation of MDD with the GGBS content

B. Effect of GGBS-stabilized expansive soil cushion (with and without lime) on heave of expansive soil

Heave studies were conducted on expansive soils by placing GGBS-stabilized expansive soil as cushioning material above the expansive soil bed. The expansive soil and GGBS were mixed dry and moisture content corresponding to OMC was added. The material was wrapped in polyethylene cover for 15 min. for moisture homogenization. Then, the cushioning material was compacted to MDD at its OMC and was placed over the expansive clay bed compacted to corresponding the MDD and OMC of soil bed. The expansive soil without any cushion undergoes heave of 25 mm when saturated. Providing a cushion made of expansive soil and GGBS reduces the heave of expansive soil to some extent. At $t_c/t_s=0.25$, for a GGBS content of 5%, the observed heave was 24.0 mm and for the same thickness ratio, upon increasing the GGBS content to 20%, the resulting heave was 22.8 mm. Further improvement in heave was observed when the ratio of cushion to expansive clay

bed was increased. At $t_c/t_s=1.0$, and for a GGBS content in the expansive soil of 5%, the observed heave was 20.6 mm. For the same thickness ratio, upon increasing the GGBS content to 20%, a considerable reduction of 17.8mm in heave was observed. For low GGBS contents and lower thickness ratios, significant reduction in heave was not observed. In the case of lime-GGBS-stabilized expansive soil cushion, first, the Lime and the GGBS were mixed dry, and then it was mixed thoroughly with the expansive soil in dry. After mixing thoroughly in dry, then OMC was added and the material was wrapped in a polyethylene cover for moisture homogenization. To study the resulting heave, the cushioning material was compacted to its corresponding MDD and OMC and was placed on the expansive clay bed compacted to its MDD at OMC. Considerable reduction in the heave was observed when compared with the GGBS stabilized soil cushion without lime. At $t_c/t_s=0.25$, for a GGBS content of 5%, the observed heave was 23.1 mm and for the same thickness ratio, upon increasing the GGBS content to 20%, the resulting heave was 20.5 mm. Further improvement in heave was observed when the ratio of cushion to expansive clay bed was increased. At $t_c/t_s=1.0$, and for a GGBS content in the expansive soil of 5%, the observed heave was 18.6 mm. For the same thickness ratio, upon increasing the GGBS content to 20%, a considerable reduction of 14.8mm was observed. For low GGBS contents and lower thickness ratios, significant reduction in heave was not observed. The addition of lime to GGBS-clay system modifies the clay-lime reaction products. GGBS provides additional alumina, calcium, silica and magnesia to the mixtures depending on the type and amount of GGBS replacement. Since the principal reactants introduced by GGBS are also present in the clay-lime system, the reaction products of clay-lime-GGBS system are relatively similar to those of clay-lime system. The effectiveness of GGBS hydration depends primarily the factors like the chemical composition of the GGBS, alkali concentration of the reacting system, fineness of the GGBS, glass content of the GGBS, and temperature [25]. The initial reaction during GGBS hydration produces coatings of aluminosilicate on the surface of GGBS grains within a few minutes of exposure to water and these layers are impermeable to water, inhibiting further hydration reactions [26]. Therefore, GGBS used on its own shows little hydration. Caijun et al. [27] found only a small amount of C-S-H was formed after 150 days of moist curing.

C. Effect of GGBS-stabilized expansive soil cushion (with and without lime) on soaked CBR of cushion-expansive soil system

GGBS was mixed with expansive soil in various percentages ranging from 5% to 20% in increments of 5% and the soaked CBR of the GGBS-stabilized expansive soil was determined. Strength gain using GGBS activated by lime has been investigated by many investigators. The variation of soaked CBR with the GGBS content in the expansive soil is presented in Fig. 4. From the figure it can be seen that, the increase in the soaked CBR was more pronounced when the GGBS content in the soil was between 10% to 15%. Upon increasing the GGBS content further in the soil, there was little increase in the soaked CBR. For a GGBS content of 5%, the soaked CBR was 2.3% and was increased to 7.6% on increasing the GGBS content to 20%. The increase can be because of characteristics of natural soil. Wild et al. [13] suggested that GGBS could be activated in some cases by some components in natural soils. They observed an increase in the UCS of the Kimmeridge clay with addition of GGBS only. When GGBS was exposed to water a Si-Al-O rich layer forms on the GGBS particle surfaces. This layer may absorb H^+ from water, resulting in an increase in OH^- concentration and then the pH of the solution also increases to values close to the pH of a saturated lime solution [27]. At these high values of pH, Si-O and Al-O bonds are broken and then semi-crystalline C-A-S-H, crystalline calcium aluminate hydrate and C-A-S-H (Calcium aluminosilicate hydrate) are formed.

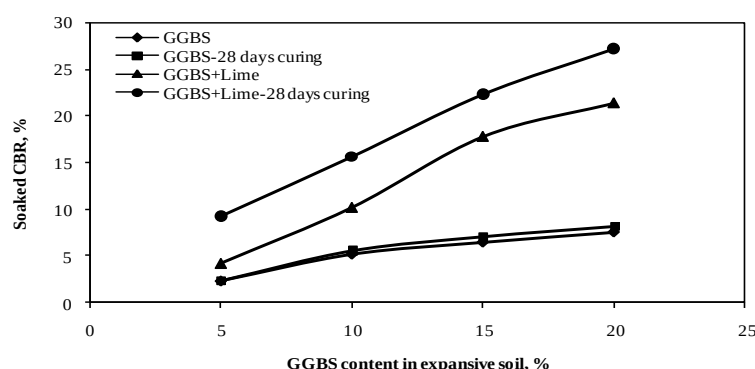


Fig.4 Variation of soaked CBR with the GGBS content in expansive soil GGBS-stabilized soil & lime-GGBS-stabilized expansive soil

The addition of 2% lime to the GGBS-stabilized expansive clay resulted in a remarkable improvement in the soaked CBR of Lime-GGBS-Stabilized expansive soil cushion-expansive soil system. In clay-GGBS-lime systems, the primary cementing agent was C-A-S-H gel. Due to the high alumina content of GGBS, some alumina was expected to replace silica and C-S-A-H gel was also formed. In chemical soil stabilisation

processes, using lime or GGBS activated by lime, it was established that new cementitious materials are formed and alter the particle-to-particle forces through the cementitious effects of the reaction products. Due to the formation of these cementitious materials, the pore fluid and pore pressure, will then be decreased, thus reducing the swelling pressure and the swelling potential and leading to volume stability [25]. Significant improvement in the soaked CBR was observed in lime-GGBS-stabilized soil mixes. It can be seen that as the GGBS content was increased, an increase in the soaked CBR was observed which was due to pozzolanic reaction between the silica present in the GGBS and the lime. As the GGBS content was increased, very high soaked CBR values were reported because of the higher content of lime-GGBS and soil which leads to more cementitious bonds. From Fig. 4., it can be seen that for a lime content of 2%, at a GGBS content of 5%, the soaked CBR was found to be 4.2%, which was further increased to 21.4% when GGBS content was increased to 20%. Curing of the samples have resulted in further increase in soaked CBR. All the lime-GGBS-stabilized soil samples were cured for 28 days and the soaked CBR values were determined. For a GGBS content of 20%, the soaked CBR increased from 21.4% to 27.2% and for a GGBS content of 5%, the soaked CBR increased from 4.2% to 9.2% with an increase in the curing period to 28 days, keeping all the others conditions constant.

D. Effect of GGBS-stabilized expansive soil (with and without lime) on UCS

The effect of GGBS with and without lime on the strength characteristics of the expansive soil was studied. Two series of UCS tests were performed to assess the strength development of the expansive soil with varying GGBS content. The first series was meant to investigate the effect of the addition of GGBS alone on the UCS of the expansive soil on samples which were cured for 1 day and 28 days. The second series was meant to study the effect of GGBS activated by lime on the UCS of the expansive soil. Two curing periods were employed 1 day and 28 days. The UCS increases gradually with an increase in GGBS and also with an increase in curing period of 28 days. A slight increase in the UCS was observed when GGBS-stabilized soil mix was cured for 28 days. At a GGBS content of 5%, the UCS was found to be 124.5 kN/m² and upon increasing the GGBS content to 20%, the UCS has increased to 207.5 kN/m². Upon curing the sample for 28 days, for a GGBS content of 20%, the UCS has increased to 219 kN/m². Significant increase in the UCS was observed for lime-GGBS-soil mixes. The rate of increase in the UCS increases with an increase in the GGBS content. Curing has considerable effect on GGBS activated by lime on the UCS of the expansive soil. The variation of UCS with GGBS content is given in Fig. 5. At a GGBS content of 5% the UCS of lime-GGBS-soil was found to be 194 kN/m² and upon increasing the GGBS content to 20%, the UCS has increased to 306 kN/m². Upon curing the sample for 28 days, for a GGBS content of 20%, the UCS has increased to 427 kN/m².

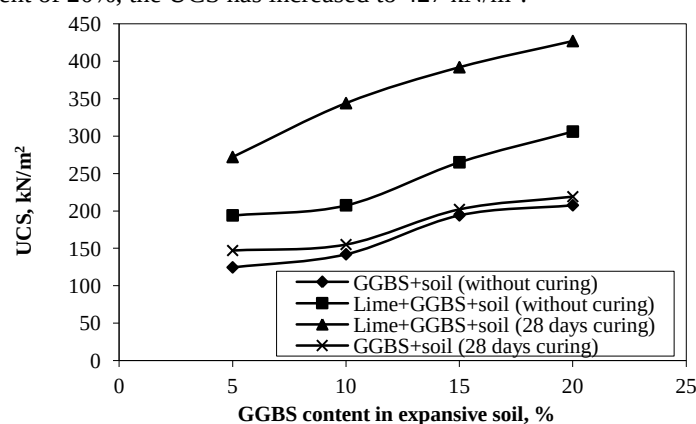


Fig. 5 Variation of UCS with GGBS content in expansive soil of GGBS - stabilized expansive soil

The strength gain using GGBS activated by lime has been investigated by many authors. Gupta and Seehra [28] studied the effect of lime-GGBS on the strength of soil. They found that lime- GGBS soil stabilised mixes with and without addition of gypsum, or containing partial replacement of GGBS by fly ash produced high unconfined compressive strength (UCS) and California Bearing Ratio (CBR) in comparison to plain soil. GGBS is a hydraulic material and therefore requires no additives for hydration and hardening to take place other than water if hydrated at an elevated temperature and for a long time [29]. Higgins [30] observed that GGBS on its own has only mild cementitious properties and in conventional concrete it is used in combination with Portland cement whose alkalinity provides the catalyst to activate the cementitious properties of the GGBS.

IV. Conclusions

Based on the results, it appears that expansive soil can effectively be stabilized with the addition of GGBS. Soil-GGBS mixtures are suitable for use in highway embankments and it can provide fill materials of comparable strength to most soils. In the case of GGBS soil mixes there was a slight increase in the OMC and a small decrease in MDD of the mix upon increasing the GGBS content. In the case of lime-GGBS-soil mixtures, the increase of lime content causes slight reduction in the MDD. The OMC of the GGBS-stabilized expansive soil was increased from 25.5% to 30.2% and MDD was decreased from 1.56 g/cc to 1.51 g/cc. Providing GGBS-

stabilized soil as a cushion above the expansive soil bed reduced the heave of the underlying expansive soil bed considerably. Relatively higher reduction was observed when lime-GGBS-stabilized expansive soil cushion was provided on the expansive clay bed. Significant improvement in the soaked CBR was observed in lime-GGBS-stabilized soil mixes. It can be seen that as the GGBS content was increased, an increase in the soaked CBR was observed which was due to pozzolanic reaction between the silica present in the GGBS and the lime. It can be seen that considerable improvement in soaked CBR when lime content of 2% was added. Curing of the samples have resulted in further increase in soaked CBR. Addition of GGBS to expansive soil makes the mix well graded which in turn increases the compacted density and hence the mechanical strength of the compacted mix. Apart from that, the formation of compounds (C-S-H gel) possessing cementing properties in the presence of highly reactive siliceous and aluminous materials and water help improvement in soaked CBR. The UCS increases gradually with an increase in GGBS and also with an increase in curing period of 28 days. A slight increase in the UCS was observed when GGBS-stabilized soil mix was cured for 28 days. Significant increase in the UCS was observed for lime-GGBS-soil mixes. Curing has considerable effect on GGBS activated by lime on the UCS of the expansive soil.

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