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Use of Lime- Stabilized Fly Ash and GBS in Pavements Laid over Expansive Clay Sub-Grades

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ABSTRACT

Infrastructure projects such as highways, railways, buildings etc. require huge quantities of good quality soil or aggregates. In urban areas, borrow earth is not easily available which has to be hauled from a long distance. Quite often, large areas are covered with highly plastic and expansive soil, which is not suitable for such purpose. Pavements founded in expansive soils undergo distress because of alternate swelling and shrinkage with respect to the changes in the moisture content. While variation in soil moisture content is inevitable over the life of a pavement, the performance of expansive sub-grades can be improved by adopting suitable measures. Cohesive non-swelling soil cushion is among the several techniques available to mitigate the problems associated with expansive clays. Since this technique has a few limitations, an alternative has been tried by providing a cushion of industrial waste, stabilized with lime. Granulated blast furnace slag and fly ash are the by-products of steel plants and thermal power plants respectively; whose disposal poses a problem. They can be used effectively as cushioning materials in place of sand or CNS. Detailed laboratory studies have been carried out, using these materials for cushioning over expansive clay beds. Lime-stabilized ground granulated blast furnace slag or fly ash, in the form of a cushion, has been placed over an expansive soil bed and the resulting heave measured. In both cases considerable reduction in heave was noticed in the expansive clay beds. CBR tests were also conducted on the cushion-soil system. Their results indicate a significant increase in the soaked CBR value. This investigation points to the utility of these two waste materials for use in sub-bases of flexible pavements.

Keywords: Expansive soil, Lime, Granulated Blast Furnace Slag, Heave, CBR, Industrial waste

INTRODUCTION

Growing industrialization and urbanization are posing problems of waste management. Industries produce millions of tons of waste as by-products. The most beneficial aspect of these materials is that some of them contain substantial amounts of silica and alumina, which exhibit pozollanic reactivity with lime in the presence of water. In India, industries like thermal power plants and steel plants produce considerable amounts of waste. Around 110 million tons of fly ash gets accumulated every year in thermal power stations. But, only about 35% of it finds its way for use in civil engineering applications such as manufacture of mass concrete and bricks, stabilization of road bases, soil modification and construction of embankments and pavements. The remainder is thrown as waste, requiring huge dumping yards, apart from causing environmental problems. Fly ash is a light weight material. Its pozollanic property makes it a potential material for use in the construction industry [1-3]. Fly ash has been used as a pozzolana to enhance the strength of composites, as a potential material for waste liner [4], as a backfill and embankment material, and as a material for the stabilization of road base courses [5-7].

Blast furnace slag is another waste material, which is obtained as a byproduct in the manufacture of pig iron. The main constituents of slag are lime, alumina, silica and magnesia. In India, about 15 million tons of slag is produced annually from steel plants [8]. About one-fifth of the surface deposits in India are covered by expansive soils. They are present worldwide and have been a major source of concern to the civil engineers because of the distress caused to the structures founded in them. Alternate swelling and shrinkage result in cracks in civil engineering structures, particularly, the lightly loaded ones [9]. There are many techniques of stabilizing soil to gain required engineering specifications. These methods range from mechanical to chemical stabilization and inclusions. Most of these methods are relatively expensive to be implemented and the better way is to use locally available inexpensive materials. Techniques such as sand cushion [10-11], which have been adopted to overcome these problems, have significant drawbacks [12]. So, in the present study, two industrial waste products, namely, fly ash and granulated blast furnace slag (GBS) are used as cushioning materials to improve the geotechnical properties of the expansive soils underlying them.

OBJECTIVES OF THE STUDY

Stabilizing expansive soils with admixtures like lime, cement, chemicals etc. has been found to be effective in improving their properties. But, uniform blending of large quantities of soil with admixtures is difficult. Among the several methods adopted for improving the performance of expansive soils, provision of a stabilized cushion of fly ash was found to yield satisfactory results [13]. In the present paper, results of model studies carried out using Fly ash/GBS, treated with lime, in the form of a cushion, are presented. The cushion was placed over the expansive clay bed, which simulates the sub-grade in a flexible pavement. The resulting swelling behavior of the soil was studied. Besides, after the expansive soil and the cushion were compacted in the CBR mould, the soaked CBR of the cushion-expansive soil system was determined.

MATERIALS and METHODOLOGY

Soil: The soil used in the study was collected from Chuttugunta, Guntur district in the state of Andhra Pradesh, India. While collecting the soil, care was taken to see that the material did not contain any organic matter. The properties of the soil are given in Table 1. Liquid limit of 73% and plasticity index of 45%, which are very high, show that the soil has a high potential for volume changes. A free swell index [14] of 150% shows that the soil has a high degree of expansiveness.

Fly Ash: Fly ash used in this study was collected from the electrostatic precipitator hoppers of the Vijayawada Thermal Power Station (VTPS), Vijayawada, India. The chemical composition of the fly ash is given in Table 2. Its high silica and alumina contents enable it to react with lime to produce cementitious products that help arrest heave.

Granulated Blast Furnace Slag: The material was procured from the Visakhapatnam Steel Plant, Visakhapatnam, India. The chemical properties of the ground granulated blast furnace slag are given in Table 3.

Lime: Commercial lime, manufactured by Birla Cements and available in the local market, was used.

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 (%)	18
IS Classification	CH
Specific Gravity	2.68
OMC (%)	25
Maximum Dry Density(Mg/cum)	1.56
Free Swell Index (%)	150
CBR (%) (soaked)	0.99

Table 2 Chemical Composition of Fly Ash

Name of the chemical	Symbol	% by weight
Silica	SiO_2	61 to 64.29
Alumina	Al_2O_3	21.60 to 27.04
Ferric Oxide	Fe_2O_3	3.09 to 3.86
Titanium Dioxide	TiO_2	1.25 to 1.69
Manganese Oxide	MnO	up to 0.05
Calcium Oxide	CaO	1.02 to 3.39
Magnesium Oxide	MgO	0.5 to 1.58
Phosphorous	P	0.02 to 0.14
Sulphur Trioxide	SO_3	up to 0.07
Potassium Oxide	K_2O	0.08 to 1.83
Sodium Oxide	Na_2O	0.20 to 0.48
Loss on ignition		0.20 to 0.85

(Courtesy VTPS, Vijayawada)

Table 3 Chemical Composition of Granulated Blast Furnace Slag

Name of the chemical	Symbol	% by weight
Silica	SiO_2	27 -38
Alumina	Al_2O_3	7 – 15
Ferric Oxide	Fe_2O_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_2O	0.08 to 1.83
Sodium Oxide	Na_2O	0.20 to 0.48
Loss on ignition		0.20 to 0.85

Data source: National Slag Association data 1985 a

HEAVE STUDIES

Experimental studies for determining the heave were carried out in cylindrical test moulds, 280 mm in diameter and 600 mm in height. A 10 mm thick sand layer, compacted to its Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), was laid at the bottom of the mould [15]. A cylindrical casing, 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 MDD and OMC, in order to serve as the draining face while saturating the sample. The expansive soil was compacted to its MDD and OMC. A hollow PVC pipe was placed at the top of the soil bed before the fly ash cushion (FAC) was compacted. Mixes of the cushioning material were prepared in different proportions, using lime contents varying from 2% to 10% by weight, at intervals of 2%. Lime, corresponding to the lime content used, was added to the fly ash/GBS in its dry state, and thoroughly mixed. Then, water, corresponding to the OMC of the cushioning material was added and mixed. The mix was compacted to its MDD by dynamic compaction, using the standard Proctor hammer, to form the cushion. After the lime-stabilized FAC was compacted, heave stake was placed through the PVC pipe on the top of the clay bed. A dial gauge was mounted atop the heave stake (Fig.1). After noting the initial reading of the dial gauge, water was admitted into the test tank, in order to saturate the sample, and the resulting heave of the soil recorded. The process was continued until no further heave was observed. Tests were conducted, keeping the clay bed thickness constant and varying the lime content and the cushion thickness. Experiments were conducted for different thickness ratios of soil (*ts*) and lime-treated fly ash (*tc*) given by *tc / ts* = 0.25, 0.5, 0.75. Similar studies were conducted using GBS cushion with the same variables as above.

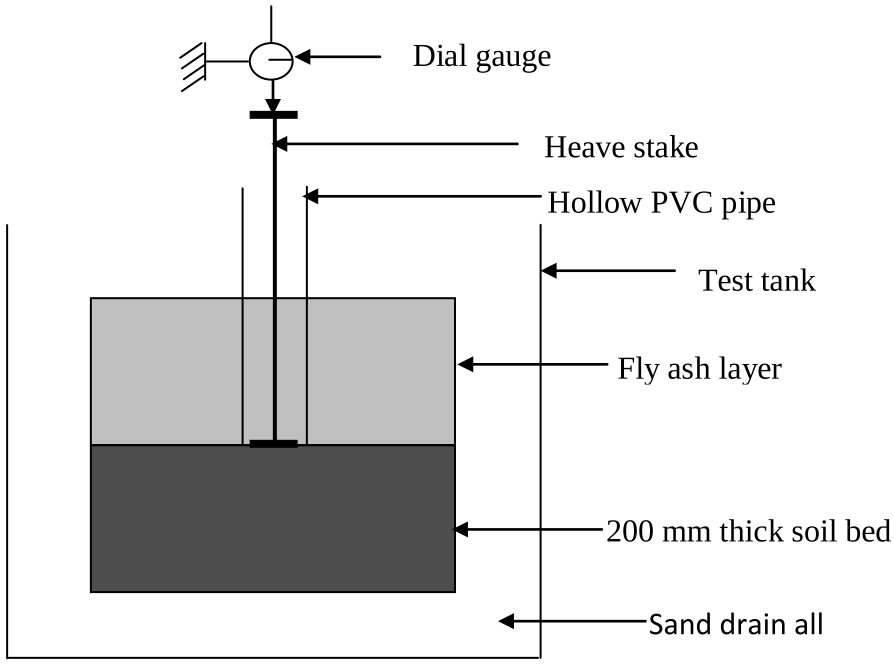

Fig.1 Experimental set–up for Swelling Studies

CBR STUDIES

California Bearing Ratio (CBR) tests were performed on the soil samples as per the Bureau of Indian Standard specifications [16] in soaked condition. In the experimental study, CBR samples were prepared for different thickness ratios of the stabilized fly ash/GBS cushion (tc) and the expansive soil bed (ts). Both the soil bed and lime-treated FAC/GBSC were compacted to their respective MDD and OMC values in the same manner as in the case of heave studies. Lime content of the cushioning material was varied from 2% to 10%, with increments of 2%. After compaction, a surcharge weight of 5 kg, sufficient to produce intensity equal to the weight of the base material and the pavement was placed 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. Three CBR tests were conducted on each specimen and the average of the three was reported. Both heave and CBR studies were conducted for different thickness ratios of the soil (ts) and the lime-treated cushion (tc), given by tc/ts=0.25,0.5. 0.75, corresponding to the different lime contents used in the cushion.

RESULTS AND DISCUSSION

Effect of FAC on Swelling Potential of Expansive Soils

Experiments were conducted to study the effect of the lime-stabilized Fly Ash Cushion (FAC) on the swilling potential of the expansive soil sub-grade, when cushions of different thickness ratios (tc/ts) were placed on the soil bed. Swelling Potential is the ratio of the heave or the increase in the thickness of the expansive clay bed, to its initial thickness. This is expressed as a percentage. Fig.2 shows the variation of the swelling potential of the expansive clay bed as a function of the lime content, for different thicknesses of the lime-stabilized FAC. The swelling potential of the expansive soil bed without stabilized FAC was found to be 19%. It can be seen from Fig.2 that the swelling potential decreases with an increase in the cushion thickness. Further, it also decreases with an increase in the lime content, for any cushion thickness, up to 6% lime and, thereafter, a slight increase in the swelling potential takes place. Pozollanic reaction between the lime and the silica present in the fly ash, in the presence of water, leads to the development of cementitious bonds in the FAC. This results in a reduction of heave of the underlying expansive clay significantly. At low lime contents, the lime reacts with the reactive silica present in the fly ash. But, beyond 6% lime, there may not be any reactive silica left in the fly ash for the reaction to take place and thus, some free lime is left unutilized. This free lime expands slightly which is indicated by a slight increase in the swelling potential. For the pozollanic reaction to take place, lime can be supplemented externally where as reactive silica cannot be. For all the cushion thicknesses, the minimum swelling potential was observed at 6% lime. A significant reduction in the swelling potential was observed for all the cushion thicknesses. For tc/ts = 0.75, the reduction was 80.6% at a lime content of 6%. It can be seen from the results that the lime-stabilized FAC performs effectively in arresting the swelling of expansive soils.

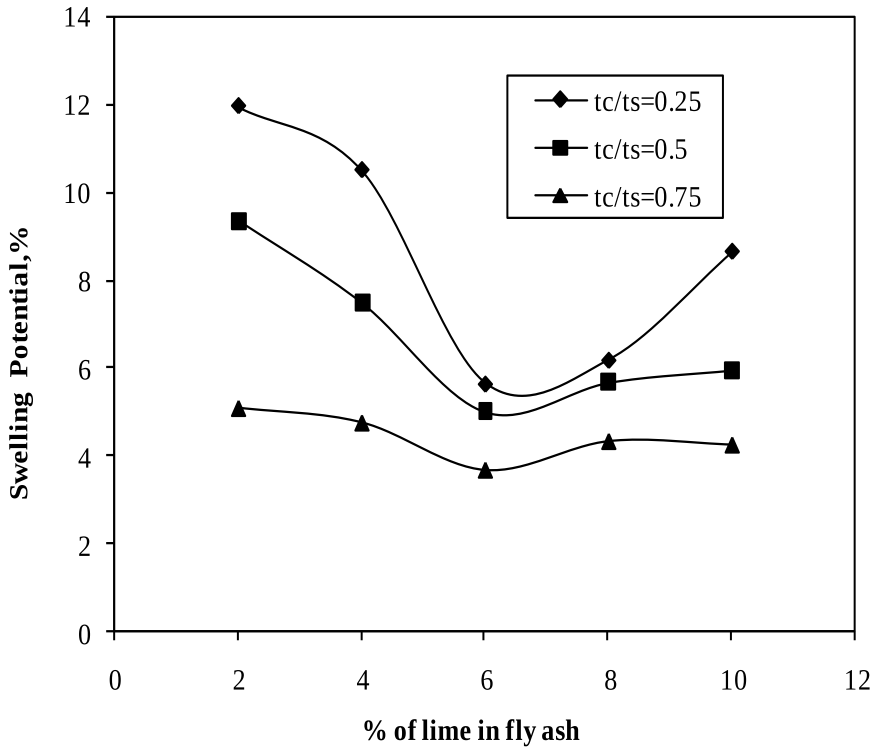

Fig. 2 Variation of Swelling Potential with Lime Content in Fly ash

Effect of GBSC on Swelling Potential of Expansive Soils

Fig. 3 shows the variation of the swelling potential with the lime content, for different thickness of the of lime-stabilized GBS cushion. It can be seen from the figure that the swelling potential decreases with an increase in the lime content, for all the cushion thicknesses. GBS is in the form of granules. Therefore, the reaction between the lime and the silica and the alumina present in the GBS takes place. As a result, cementitious bonds develop, which are responsible for arresting the heave of the expansive clay bed. However, upon increasing the lime content, the reduction in the swelling potential is not as much. From Fig.3, it can also be seen that the swelling potential decreases considerably when the thickness of the lime-stabilized GBS Cushion (GBSC) is increased. For tc/ts = 0.75, at a lime content of 6%, the reduction in the swelling potential of the expansive clay bed was observed to be 73% with respect to that of an uncushioned expansive clay bed. The addition of lime to GBS-clay system modifies the clay-lime reaction products. GGBS (Ground Granulated Blast Furnace Slag) provides additional alumina, calcium, silica and magnesia to the mixtures depending on the type and amount of GGBS replacement [17]. 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 [18].

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 [19]. Therefore, GGBS used on its own shows little hydration. Caijun and Day [20] found only a small amount of C-S-H was formed after 150 days of moist curing. The relative performance of different cushions is shown in Table 4.

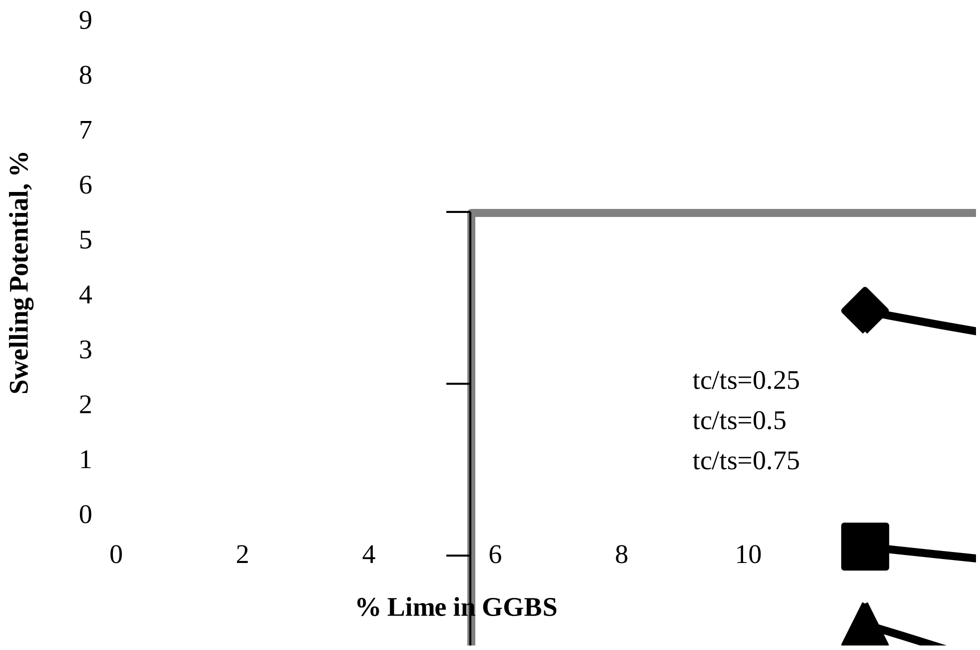

Fig. 3 Variation of Swelling Potential with Lime content in GBS

Table 4 Relative Performance of Different Cushions

Type of cushion	Swelling Potential (%)	% Reduction with respect to uncushioned soil bed
No cushion	**19**	
Lime-stabilized Fly ash cushion	**3.68**	**80.6**
Lime-stabilized GBS cushion	**5.62**	**73**

Effect of FAC on Soaked CBR of Expansive Soils

Fig.4 shows the variation of the soaked CBR of the stabilized FAC expansive soil system, as a function of the lime content added to the fly ash, for different tc/ts values. From the figure, it is seen that, for any thickness ratio, the soaked CBR increases with an increase in the lime content up to 6%, beyond which it begins to fall slightly. Thus, 6% may be considered as the optimum lime content from the point of view of increase in CBR also. This is because, any amount of lime added beyond 6% would remain unutilized and leaves soft pockets, which are the sources of weakness in the fly ash matrix. From the figure, it can be also inferred that the soaked CBR increases with an increase in the thickness of the stabilized fly ash cushion. The soaked CBR of the expansive soil bed without any cushion (tc/ts = 0) was as low as 0.99%. It has increased to a value of 14.2% corresponding to 6% lime for a tc/ts =0.75. It may be noted that the curing period adopted in the CBR test is only four days.

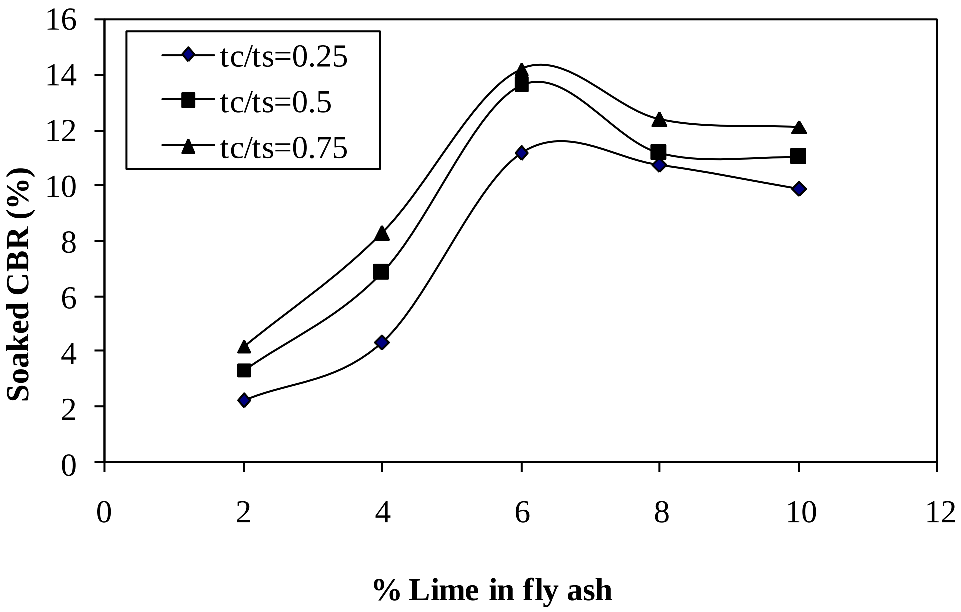

Fig. 4 Variation of Soaked CBR with the Lime content in the fly ash

Fig.5 shows the variation of the CBR of the stabilized FAC expansive soil system, as a function of the lime content added to the fly ash, for tc/ts = 0.75. For the same thickness ratio, samples were tested in unsoaked condition, soaked samples for 4 days and samples cured for 28 days. From the figure, it is seen that, for any lime content, the CBR increases with an increase in the curing period. Marked improvement in CBR is observed when the samples are cured for 28 days.

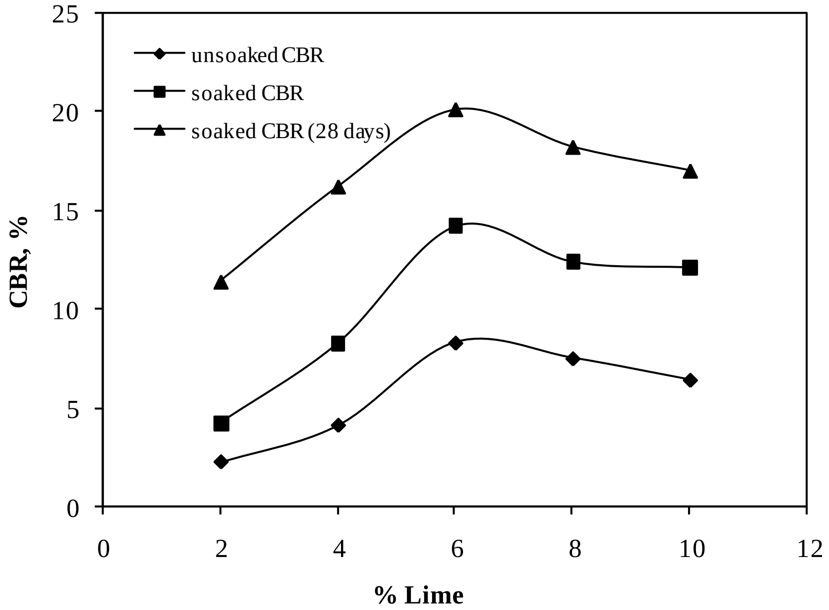

Fig. 5 Variation of Soaked CBR with the Lime content in the Fly ash

Effect of GBSC on Soaked CBR of Expansive Soils

Fig.6 shows the variation of the soaked CBR with the different thickness ratios of lime – stabilized GBS cushion and the expansive clay bed. From Fig.6, it is evident that the soaked CBR increases with an increase in the thickness of the cushion. It can also be seen that, as the lime content increases, an increase in the soaked CBR occurs, which is due to the pozollanic reaction between the lime and the silica present in the GBS. GBS has both cementitious and pozzolanic properties. When mixed with water, slag develops its hydraulic reaction [21]. However, at room temperature, GGBS is normally not a hydraulic material. Activators are required to initiate hydration. If GGBS is placed in water alone, it dissolves to a small extent but a protective film deficient in Ca^{2+} is quickly formed, and inhibits further reaction. Reaction continues if the pH is kept sufficiently high. The pore solution of a lime, which is essentially one of alkali hydroxide, is a suitable medium. The presence of solid $Ca(OH)_2$ ensures that the supply of OH^- is maintained [22]. The final products of the GGBS reaction are similar to the products of cement hydration the rate and intensity of reaction differs. Slag also exhibits pozzolanic reactivity in the presence of calcium hydroxide [23]. The pozzolanic reaction takes place in which calcium hydroxide is consumed to form secondary calcium silicate hydrates [24]. The primary factors of slag those influence hydration are Chemical composition of the GGBS, alkali concentration of the reacting system, glass content of the GGBS, fineness of the GGBS and temperature during the early phases of the hydration process. Upon soaking, the lime reacts with the reactive silica present in the GBS, which is responsible for the formation of cementitious bonds, Further; internal friction between the particles of GBS also contributes to the increase in the value of CBR. Hence, it can be inferred that lime-stabilized GBSC is also effective, in fact more effective than FAC, in improving the soaked CBR of the cushion-expansive soil system.

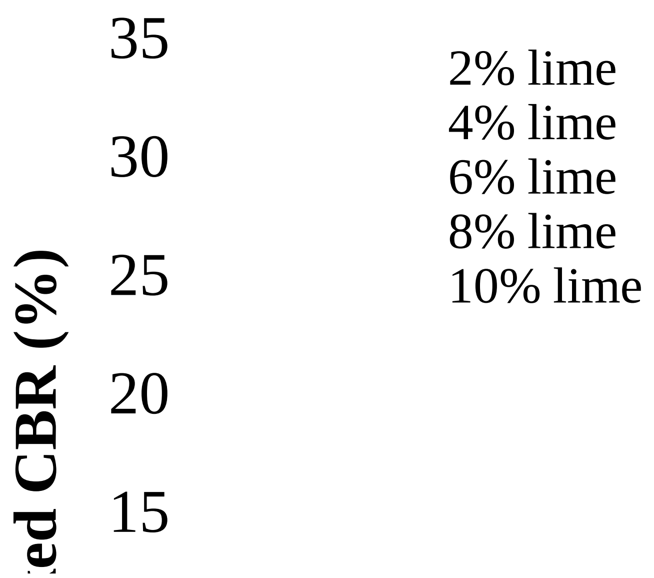

Fig. 6 Variation of Soaked CBR with tc/ts for different lime contents in GBS

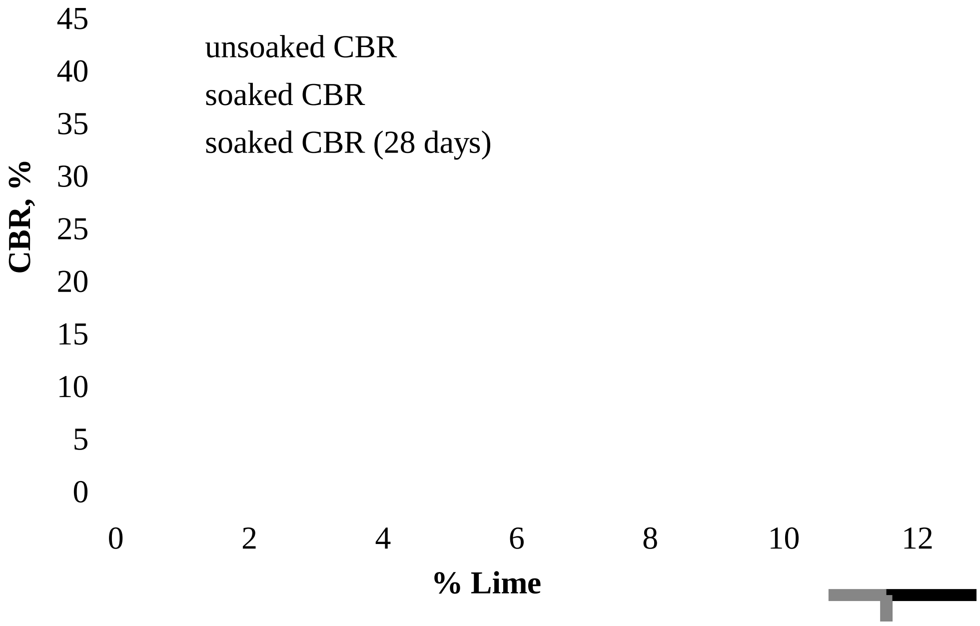

Fig. 7 Variation of Soaked CBR with different lime contents in GBS

MICROSTRUCTURAL INVESTIGATION OF FLY ASH AND LIME-STABILIZED FLY ASH MIXES

The Scanning Electron Microscopy (SEM) technique was employed for a qualitative identification of the microstructure of the fly ash and lime-stabilized fly ash. SEM tests were performed to observe the microstructure of the fly ash, and the changes in the microstructure when fly ash was stabilized with different contents of lime and cement. Fig. 8 is the Scanning Electron Micrograph showing the characteristic morphology of the fly ash. This ash consists of spherical particles of different sizes and there is no evidence of hydration of the fly ash. Fig. 9 shows the SEM of fly ash stabilized with 6% lime. Coarsening of the particles can be observed from the matrix. From the SEM, it can also be observed that the addition of lime resulted in agglomeration, which is indicated by the smaller particles being attached to the bigger particles closely reducing the void spaces.

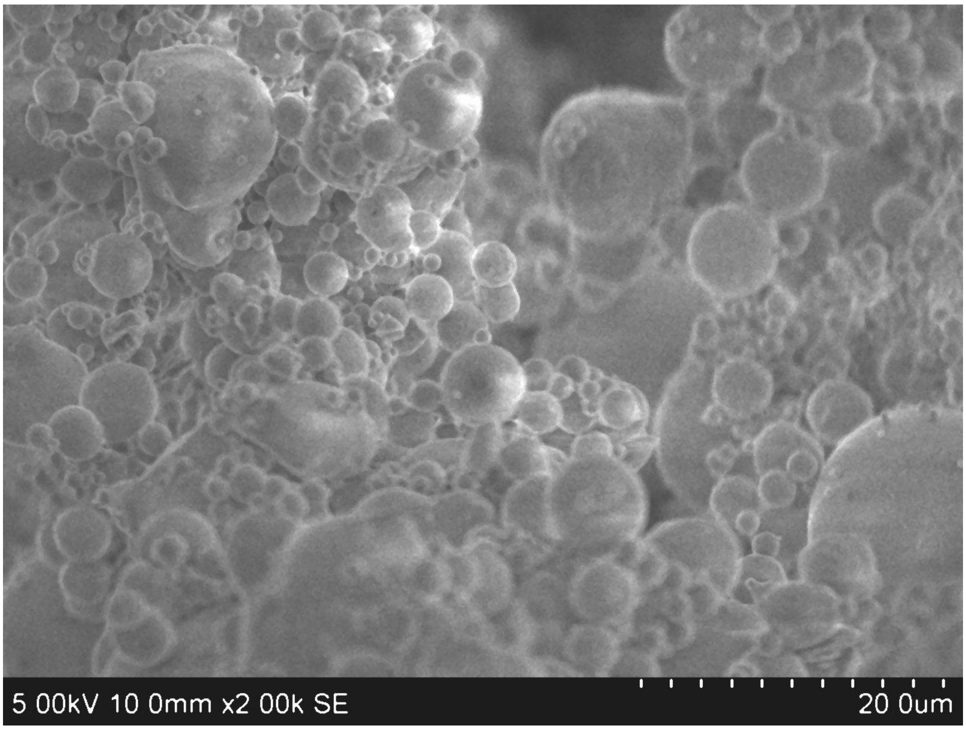

Fig. 8 Scanning Electron Micrograph of the fly ash

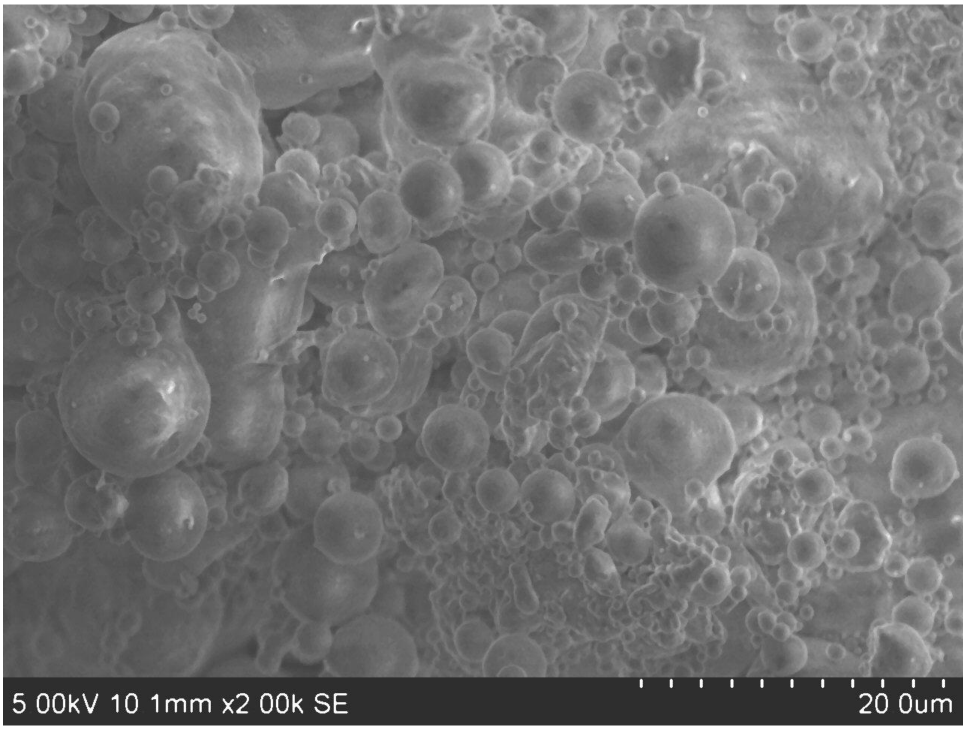

Fig. 9 SEM of fly ash stabilized with 6% lime

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CONCLUSIONS

The following conclusions are drawn from the investigations carried out on the use of lime –stabilized cushions of fly ash and granulated blast furnace slag cushions (FAC & GBSC):

1. Both cushions help in minimizing the heave of the underlying expansive clay bed. However, FAC performs a little better than GBSC in this regard.
2. With an increase in the thickness of GBS cushion, for any lime content, the swelling potential of the expansive clay decreases.
3. While in respect of fly ash, 6% lime was found to be the optimum for minimizing heave, no such optimum lime content was found in respect of GBS.
4. The soaked CBR of the cushion – soil system was found to increase under both cushions. It increased with an increase in the thickness of the cushion in both cases. The increase in soaked CBR value in respect of GBSC – expansive clay bed system was, however, much higher than that of the FAC – clay system.
5. In both the lime-stabilized fly ash as well as lime-stabilized GBS cushion – soil system, the CBR is found to be remarkably high when samples are cured for 28 days because of pozollanic reaction between lime and cushion material.
6. In respect of the FAC – soil bed system, 6% lime was found to be the optimum lime content from the point of view of the CBR value. However, no

such optimum lime content could be found in respect of the GBSC – soil system.

7. 6% lime in the case of fly ash cushion and 4% lime in the case of GBS cushion yield a CBR of more than 20%, so these contents of lime can be recommended for the use in sub base layer.
8. From the SEM, it can be observed that the addition of lime to fly ash resulted in agglomeration, which is indicated by the smaller particles being attached to the bigger particles closely reducing the void spaces.
9. In the light of the above observations, both FAC and GBSC can be recommended for use as sub – base materials.

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