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Role of Ground Granulated Blast Furnace Slag Cushion on the Volume Change Behaviour of Expansive Soil

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***Abstract*— The cushion techniques to mitigate the heave of expansive soil by using sand and cohesive non-swelling soil (CNS) are found to be uneconomical and inefficient for various projects due to availability of suitable materials and seasonal variations. An attempt has been made in the present study to investigate the potential of Ground Granulated Blast Furnace Slag (GGBS) cushion to combat with undesirable volume change of expansive soil upon seasonal variation. Detailed swell strain tests have been performed on the different thickness ratios (0.25, 0.50, 0.75 and 1.0) of cushion layer to soil layer (Tc/Ts). Further, durability of cushion layer subjected to wetting-drying cycles is also assured. The results revealed that increase in the thickness of lime treated GGBS cushion has a great impact on the swelling of expansive soil. The swelling of expansive soil reduces continuously by 7.9, 3.7, 1.0 and 0.4% with increase in the thickness of cushion layer by 25, 50, 75 and 100% over soil layer, respectively. Further, results of several wetting-drying cycles shows that lime treated GGBS cushion can withstand the adverse impact caused by seasonal variation. Hence, it is recommended that lime treated GGBS can be utilized effectively, efficiently and economically as a cushion materials for various civil engineering structures constructed on expansive soil.**

***Keywords*— Cushion, GGBS, Lime, Swell-Shrink, Volume change behaviour.**

I. INTRODUCTION

Due to rapid economic growth and Industrialization, huge quantities of waste materials are produced every year, creating a tremendous threat to environment and ecology. Recently, some waste materials such as fly ash and GGBS are observed to be effective and economical for the stabilization of soils in the various construction projects. Further, GGBS has great advantages over fly ash in terms of stability of raw material, stability of chemical compositions, fineness and self hardening capacity. The chemical composition of GGBS is very similar chemical compositions to Ordinary Portland Cement (OPC) such as 30-42% of CaO, 35-38% of SiO_2, 10-18% of Al_2O_3, 5-14% of MgO etc.

Hence, bulk amount of GGBS are utilized as a good quality cement replacement materials which provide improved resistance to sulphate attack of concrete or, mortar in seawater or other aggressive environments. GGBS is manufactured from blast furnace slag, a by-product from the manufacture of iron and obtained by quenching molten iron blast furnace slag immediately in water or stream, to produce a glassy granular product that is then dried and ground into a fine powder [1]. India produces annually 15 million tonnes of slag as a by-product from steel industries. The possibility of being use of GGBS, to use as a partial replacement for cement in mortar or concrete, or to stabilise soils, has great potential economic benefits in all areas of the construction industry [2].

However, rapid growth in the transportation sector worldwide particularly in India poses great challenge among the researchers to deal with the different types of soil for the quality pavement construction. In India, major portions of country (i.e. 20% area) are covered with expansive soils, which are not favourable for the construction of roads due to its undesirable volume change behaviour upon temporal variation. Expansive soils are found generally in the arid and semi-arid regions of the world where the annual evaporation exceeds the precipitation [3]. It is reported that the damages caused by the expansive soils have received the universal attention in view of the serious economic losses at many countries of worldwide [4, 5]. The volume change can be either in the form of swell or in the form of shrinkage and often called as swell–shrink soil. Moisture fluctuation and the amount and type of clay minerals control significantly the expansion behaviour of the soil. Further, the state of soil in term of dry density, moisture content and confining pressure also influence considerably to expansion behaviour [6]. Swelling and shrinkage in the expansive soil due to the moisture variation is due to the presence of montmorillonite minerals.

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Montmorillonite is a three-layer mineral having a single octahedral sheet sandwiched between two tetrahedral sheets to give a 2:1 lattice structure. In the clay-water-air system, the water within the clay is called adsorbed water, the water and ions with clay lattice constitute the Diffused Double Layer (DDL). The particles are plate shaped with an average diameter of approximately 1 micrometer. When water gets in these particles, they tend to absorb water into their molecular layers causing swelling, and expansion of the interlayer spacing due to the mineral variety. The damages caused by the expansive soils have received the universal attention in view of the serious economic losses at many countries of worldwide [3, 4]. The several remedial techniques are developed previously to overcome the problem caused by expansive soils which include as replacement of existing soil with suitable one, controlling the moisture, alteration and modification using chemical stabilizers, application of the adequate surcharge pressure, using various geosynthetic materials, provision of suitable cushion materials, construction of suitable substructure (underreamed piles, belled pier foundation, mat foundation, recently piled footings, anchored granular piles) and stiffening superstructure [4, 7-14]. However, stabilization of soils by chemical and waste stabilizers is considered as an effective and economical technique.

Hence, the use of cushion materials in the construction of lightly loaded structures are considered as a distinction in view of its effectiveness and adoptability, particularly economically while compared to other methods of treatment [15-17]. It was believed previously to use non expansive materials as cushion materials. Hence, the uses of sand and cohesive non expansive soil (CNS) are frequent to alleviate the undesirable damage of structures resting on expansive soils. However, sand cushion was found to be inconsistent under varied site conditions in compared to CNS cushion. Katti [18] also reported that cohesive non-swelling soil (CNS) could be used as a good cushion material for reducing swelling and counteracting swelling pressure. On the contrary, the cohesive non-swelling soil (CNS) cushion is not observed effective under wetting-drying cycle. It is reported that increase in the number of cycle reduces the effectiveness of cushion with time periods. Also, accessibility of CNS materials at several construction sites is very difficult [19, 20]. Hence, the CNS cushion technique has not adopted at many cases due to scarcity of materials and ineffectiveness under wetting-drying cycles.

Several researches have performed to develop the artificially prepared CNS materials and to utilize waste materials as cushion to sort out the disadvantage of natural CNS materials.

Expansive soils are prepared artificially for cushion materials by using chemical stabilizers (lime, calcium chloride ($CaCl_2$)) alone or in combination of waste binders (fly ash, rice husk ash (RHA)) [15, 17, 21-23]. It has been reported that lime or cement treated RHA causes significant reduction in the heave of expansive and withstands the adverse effect of wetting-drying cycle due to seasonal variation [15]. Further, Sahoo et al. [20] revealed that the soil cushion stabilized with lime and cement subjected to all the wetting and drying cycles performs successfully to control swell-shrink behaviour. However, calcium chloride ($CaCl_2$) is also generally used as chemical stabilizer to modify the properties of expansive soil [24]. It is reported that the combination of $CaCl_2$ and RHA abolishes the swell properties of expansive soil [25]. Katti and Katti [17] have recommended preparing an artificial CNS material by mixing lime/gypsum or sand with the native expansive soil. Rao et al. [26] reported that the fly ash cushion stabilized with 10% cement with thickness equal to that of the expansive soil can be used effectively as a cushion to reduce the heave of the expansive soil. However, the thickness of CNS cushion depends on the allowable value of swell and for a given value of swell; an increase in cohesion value of CNS cushion causes a reduction in the thickness of cushion [18].

Researchers have reported the various beneficial effects of GBBS to improve the strength and volume change behaviour of different soils [1, 27]. Further, Shao et al. [28] reported that GGBS has the superiority of social benefit, economic benefit and environmental benefit in soft soil treatment. Very less research has been carried out to utilize GBBS as a cushion material. Rao et al. [26] reported after using the fly ash, granulated blast furnace slag (GBS) and ground granulated blast furnace slag (GGBS) cushions that cement-stabilized GGBS is the most effective of all in reducing heave. However, further detail investigation needs to be performed for effective and economical utilization of GGBS as a cushion material to control the heave and damage caused by wetting-drying cycles.

The present study explores the role of GGBS cushion to control the heave of expansive soil and their potential to counteract the damage caused by wetting-drying cycles. The various swell and cyclic swell–shrink tests have been performed on the expansive soil by using lime treated GGBS cushion. Tests have been carried out on the specimens prepared at different thickness ratios of cushion layer to soil layer. Further, proper thickness of cushion materials has been proposed.

II. Materials And Methodology Followed

A. *Material Used*

The geotechnical properties of soil are presented in Table 1. The soil was collected from Kanuru Village, Vijayawada, Andhra Pradesh, India. The soil was obtained by open excavation from a depth of 2 m from the existing ground level. The soil was oven dried at a constant temperature and pulverized. The soil passed through 425 micron Indian Standard (IS) sieve was used for experimental purpose. The soil is predominated with clayey sized particles having liquid limit and plasticity index of 72 and 40%, respectively. The optimum water content and maximum dry density of expansive soil are obtained to be 24% and 1.92 gm/cc. Based on IS classification, the soil is classified as highly expansive soil and highly plastic clayey soil.

The GGBS was obtained from the Vizag steels, Vishkhapatnam, Andhra Pradesh. The physical and chemical properties of GGBS are presented in Table 2 and 3, respectively. It is observed that GGBS is observed as non-plastic materials. Further, the optimum water content and maximum dry density reduces and increases than that of soil. Further, specific gravity of GGBS is observed to be higher than the specific gravity of soil. The chemical composition of GGBS (Table 3) showed the presence of silica and alumina with minor amount of iron compounds in the GGBS. However, it is interesting to note that GGBS contains a predominant amount of calcium of 40%.

B. *Methodologies Followed*

Sample Preparations

The schematic representation of experimental setup is illustrated in Fig. 1. Mild steel cylindrical mould of size (20 cm × 20 cm) was used for the preparation of specimens containing both soil and cushion layer. Maximum dry density (MDD) and Optimum Water Content (OWC) are used to prepare layer of expansive soil in the mould. Also, cushion layer of 3% lime treated GGBS was also compacted at MDD and OWC of mixes at different thickness ratios (Tc/Ts) of 0.25, 0.50, 0.75 and 1.0. The compacted soil sample was transferred to another mould of size 25 cm diameter and 40 cm height which is represented as a test mould. Then coarse sand was used to fill the remaining gap between test mould and sample mould. Thereafter, the compacted soil layer overlaid with the compacted cushion layer of lime treated GGBS of varying thickness ratios. The cover plate placed on the top of entire sample having soil and cushion layer. The measurement of the vertical deformation was captured by placing dial gauge on the cover plate.

The entire setup was submerged in a water tank and started to take the dial gauge reading. The reading was taken continuously till no further movement in dial gauge reading.

Cyclic Swell–Shrink Test

The entire setup was removed from the water tank after reaching the constant dial gauge reading, and kept outside for a day to drain out the excess water. The same was dried in the oven for four days in the oven maintaining a constant temperature of 50º C. The readings are taken after removing from the oven to know the amount of shrink in the samples. The setup of soil and cushion materials are again kept to the tank and submerged with water and continued to take the readings day after day. The similar procedure was repeated for a minimum of five cycles.

TABLE 1
GEOTECHNICAL PROPERTIES OF EXPANSIVE SOIL

Description	Value
Soil classification	CH
Specific gravity	2.65
Clay content, %	100
Liquid Limit, %	72
Plastic Limit, %	32
Plasticity Index, %	40
Shrinkage Limit, %	18
Optimum Water Content, %	24
Maximum Dry Density, gm/cc	1.48
Unconfined Compressive Strength, Kg/cm^2	1.92
Differential Free Swell, %	120
Swell Pressure, Kg/cm^2	0.75

TABLE 2
PHYSICAL PROPERTIES OF GGBS

Description	Value
Specific gravity	2.87
Liquid limit, %	28
Plastic limit, %	NP
Plasticity index, %	NP
Optimum water content, %	16
Maximum dry density, Kg/cm^3	1.51

TABLE 3
CHEMICAL PROPERTIES OF GGBS

Properties	Value
Al_2O_3, %	15-22
SiO_2, %	30-40
Fe_2O_3, %	5
CaO, %	30-38
MgO, %	8-11
MnO, %	2

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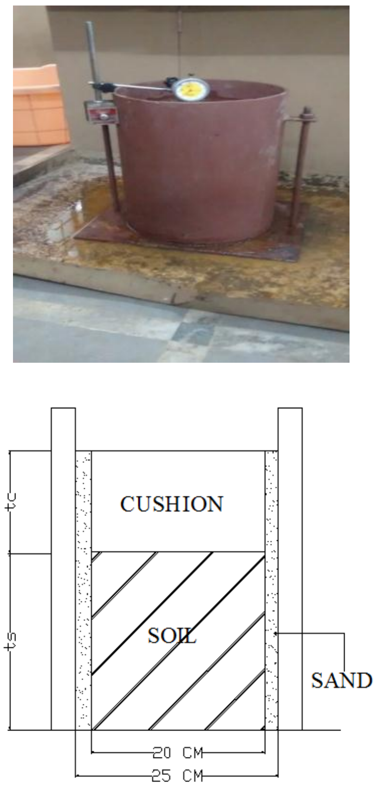

Figure 1. Schematic representation of sample preparation of soil-cushion layers for test

III. Results And Discussions

A. Swell Behaviour

The swell percentage of expansive soil overlaid by different thickness ratios (0.25, 0.5, 0.75 and 1.0) of lime treated GGBS cushion is shown in Fig. 2. The swell of expansive soil is continued up to 14 days for each thickness of cushion layer. However, it is interesting to observe that increase in the thickness of cushion (Tc) drastically reduces the swell strain of expansive soil. The swell percentage reduces by 7.8, 3.7, 1.0 and 0.4 % with increase in the thickness ratios of 0.25, 0.5, 0.75 and 1.0 of lime treated GGBS cushion layer, respectively. Hence, it is observed that ratio of Tc/Ts for one showed beneficial to control the swell of expansive soil by using lime treated GGBS cushion. The drastic reduction in the swell percentage of expansive soil with increase in the thickness of cushion layer of lime treated GGBS is due to the increase in the surcharge pressure to the expansive soil.

Further, the presence of free lime in the GGBS and addition of 3% lime forms the silicate and aluminates hydrated cementitious compounds (CSH, CAH and CASH). This causes the formation of compacted and stronger cushion layer which is adequate enough to withstand the vertical pressure exerted by the expansion soil. Hence, the increase in the surcharge pressure and formation of stronger cushion layer cause the reduction in swell percentage of expansive soil.

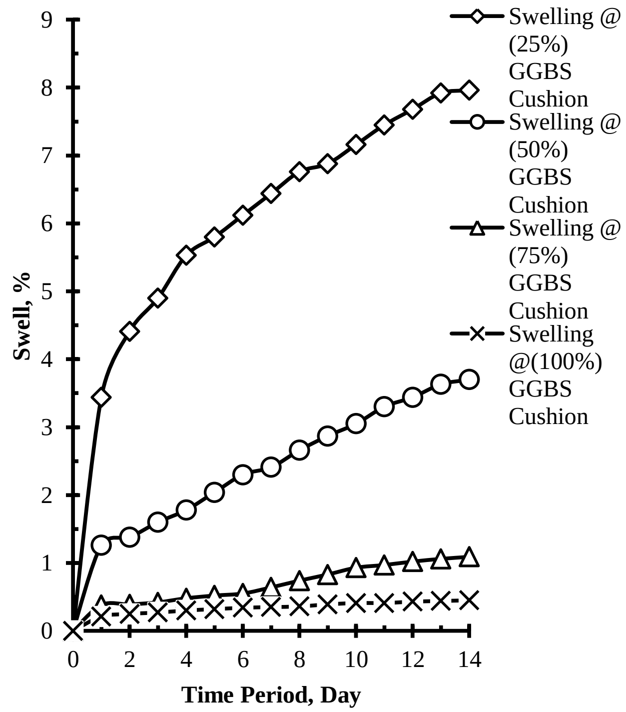

Figure 2. Swell behaviour of expansive soil with different thickness of lime treated GGBS cushion

B. Cyclic Swell-Shrinkage Behaviour

Cyclic swell-shrinkage behaviour of expansive soil by using different thickness ratios of lime treated GGBS cushion layer is shown in Fig. 3. It is observed that percentage of swell increases than that of shrinkage of expansive soil at any particular cycle. Further, percentage of swell and shrink for any cycle of wetting and drying at any Tc/Ts ratios are almost same. It is revealed that the number of wetting-drying cycle does not influence the swell-shrinkage of expansive soil. However, it is interesting to observe that increase in the thickness of cushion layer reduces drastically the percentage of swell-shrinkage and almost verge to eliminate after using the thickness of cushion layer equal to that of the soil layer (i.e. Tc/Ts = 1).

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This shows the increase in the durability of lime treated GGBS cushion. The increase in the durability is due to the formation of stronger cushion layer by the binding and filling of GGBS particles with cementitious compounds.

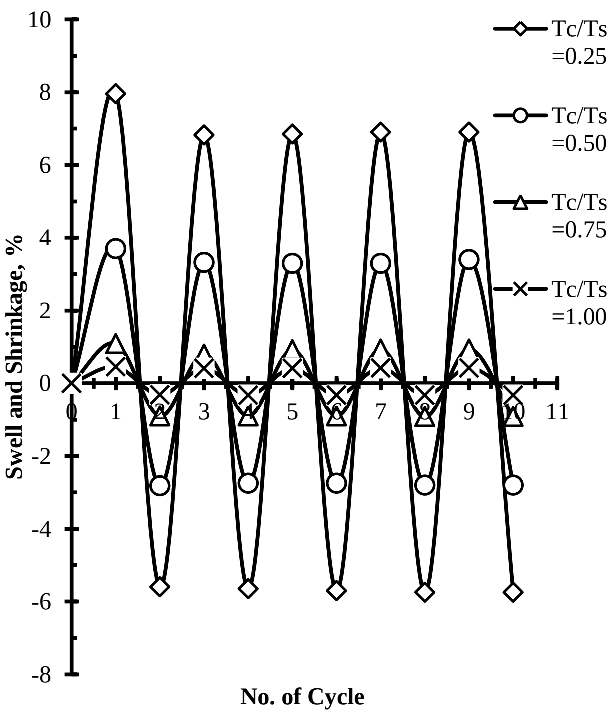

Figure 3. Cyclic swell-shrinkage behaviour of expansive soil with different thickness of lime treated GGBS cushion

IV. Conclusions

The present study clearly brought out the role of lime treated GGBS cushion to control the heave of expansive soil. Also, effect of wetting-drying upon the durability of cushion is also investigated. The following important conclusions are withdrawn from the present work:

- The heave of expansive soil reduces drastically with increase in the thickness of lime treated cushion layer. This is due to the increase in the surcharge pressure with increase in thickness of cushion on the expansive layer and formation of stronger and compacted cushion by the binding and filling of GGBS particles with cementitious compounds.
- The durability of lime treated GGBS cushion also increases significantly with increase in the thickness of cushion layer.
- Cushion layer having thickness ratio (Tc/Ts) of one can be adopted for the effective utilization in different construction activities to combat with heave induced by expansive soil.

Formation of cementitious compounds and thereby binding and filling of GGBS matrix with lime leads to form the stronger and compacted matrix is the cause of improvement in the volume change behaviour and durability of expansive soil overlaying by the cushion materials of lime treated GGBS

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