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Effects of Granulated Blast Furnace Slag in the Engineering Behaviour of Stabilized Soft Soil

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Abstract

The paper evaluated the potential of granulated blast furnace slag (GBS) to stabilize a soft soil. Soft soil samples were collected from Tatibandh-Atari, rural road of Raipur, Chhattisgarh. This soil was classified as CI-MI as per Indian standard classification system (ISCS). Different amounts of GBS, i.e., 3, 6, 9 and 12% were used to stabilize the soft soil. The performance of GBS stabilized soils was evaluated using physical and strength performance tests namely, plasticity index, specific gravity, free swelling index, compaction, swelling pressure, california bearing ratio (CBR) and unconfined compressive strength (UCS). Based on strength performance tests, optimum amount of GBS was determined as 9%. Moreover, results indicate that inclusion of GBS increases the strength of soft soils, for example, UCS of 9% GBS modified soil was found approximately 28% higher compared to raw soil. Similarly, significant improvement has been observed for unsoaked and soaked CBR value of soils.

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Keywords: Granulated blast burnace slag, soft soil, soil stabilization, UCS, CBR .

1. Introduction

Soft soils which contain montmorillonite clay mineral show major volume changes due to change in the moisture content. These soils create many construction and performance problems in the site due to swelling and shrinkage behaviour. To prevent these problems, stabilization of these soils is required. Apart from mechanical compaction and soil reinforcement methods, the different soil stabilizing materials are also available i.e. lime, cement, fly ash, blast furnace slag, rice husk ash etc to stabilize and improve the strength of the soil [10]. The stabilization of expansive soils with cement and lime is well documented [2, 12]. Soil stabilization with cement is not preferable because of the increasing cost and environmental concerns related to its production. Production process of cement release CO_2 in the environment. Approximately one tone of CO_2 is produced during the production of one tone of cement [10]. Production of lime also emits CO_2 in substantial amount to the environment. Moreover lime containing sulfates is not suitable for soils because the presence of sulfates may increase the swelling due to the formation of swelling minerals such as ettringite and thaumasite [9]. These facts forced to find alternatives to cement and lime. Now, it is important to focus on the use of the other industrial waste materials like fly ash, rice husk ash and GBS. At present, the use of various industrial waste products for stabilizing the soft soil have attained considerable attention in view of the increasing cost of waste disposal and environmental aspect.

Blast furnace slag is produced as a by-product during the manufacture of iron in a blast furnace. It results from the fusion of limestone flux with ash from coke and the siliceous and aluminous residue remaining after the reduction and separation of the iron from the ore. Iron blast furnace slag, consists essentially of silicates and alumino-silicates of lime and other bases [6].

Various researchers evaluated the potential of ground granulated blast furnace slag (GGBS) to stabilize the soils. Gupta

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and Seehra [3] 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 UCS and CBR in comparison to soil. They also concluded that partial replacement of GGBS with fly ash further increased the UCS. Akinmusuru [1] studied the effect of mixing of GGBS on the consistency, compaction characteristics and strength of lateritic soil. The GGBS content varied from 0% to 15% by dry soil weight. He observed a decrease in both the liquid and plastic limits and an increase in plasticity index with increasing GGBS. Further he observed that the compaction, cohesion and CBR increased with increasing the GGBS content up to 10% and then subsequently decreased. The angle of internal friction decreased with increasing GGBS percentage. Wong [12] studied the effect of GGBS, collected from different sources and with different gradings on the performance of pavement materials. He observed higher early strengths from finer GGBS. He also found that GGBS is preferred when longer working times are required and that GGBS can be as effective as portland cement in controlling erosion.

Wild et. al. [11] studied the use of GGBS to highway and other foundation layers by determining the beneficial effect in the reduction of expansion due to the presence of sulphates. From the study they concluded that small additions of GGBS to sulphate containing clays which are stabilized with lime reduce substantially their expansion when exposed to water and have no significant deleterious effect on strength development. They also observed that there is a decrease in plasticity index, significant increase in strength and slight increase in maximum dry density with a decrease in lime / GGBS ratio. Higgins et al. [4] investigated the effect of using GGBS and lime on the swelling characteristics of kaolinite and Kimmeridge clay in a site trial. This trial showed that GGBS was completely successful in reducing \ swelling caused by sulphate. They also observed that the optimum lime / GGBS ratio to achieve the maximum UCS is 1: 5 for kaolinite clay and that the optimum is about 2: 3 for Kimmeridge clay. Higgins and Kennedy [5] also carried out a site trial using GGBS and lime on a temporary diversion to carry the A421 Tingewick bypass traffic in UK. This site contained sulphate-containing boulder clay. They used GGBS activated by lime in particular sections and lime and cement in other sections. They found that the temporary diversion performed well over a year. They did not observe any swelling problems in the sections which were treated with GGBS activated by lime while observing indications of expansion at the section which was treated with lime and cement without using GGBS.

Neeraja and Rao [7] utilize industrial wastes like RHA, FA and GGBS as stabilizing agents for the construction of flexible pavements on expansive clayey subgrade. They found that there is a maximum change in the properties with addition of lime up to 5%, RHA and GGBS up to 15% and FA up to 20%. Yadu et. al. [14-15] investigated the potential of RHA and FA to stabilize the black cotton soil and determined their optimum content for the soil stabilization. Sharma and Shivapullaiah [10] studied the improvement of various engineering properties of the expansive soil by using waste material GGBS as an alternative to lime or cement, so as to make it capable of taking more loads from the foundation structures. They have observed that the strength improvement depends on the amount of GGBS used and the effect of curing period is less pronounced. Further they have concluded that the initial tangent modulus values generally increases with increase in GGBS content.

In context of above mentioned studies, it has been decided to perform the similar study on soft soil collected from Tathibandh-Atari road district Raipur, India to know the potential of non-grounded granulated blast furnace slag (GBS) alone as an additive and to evaluate the cost effective mixing proportion. Further to study the effect of GBS in cost-effective proportion, an experimental program was undertaken and the result of these tests is reported in this paper.

2. Materials and Methods

2.1 Location of study

The soil sample used for this study was collected from Tatibandh Atari rural road district Raipur, Chhattisgarh, India at a depth of 0.4 meter using the method of disturb sampling. GBS was obtained from Bhilai steel plant district Durg, Chhattisgarh, India.

2.2 Testing Methods

The laboratory tests carried out on the natural raw soil includes Atterberg’s limits, pH value, specific gravity, compaction, free swelling index, swelling pressure, CBR and UCS. The engineering properties of the soil were determined in accordance with Bureau of Indian standards (BIS). Specimens for swelling pressure, UCS and CBR tests were prepared at optimum moisture content and maximum dry densities. The swelling pressure, unsoaked and soaked CBR and UCS tests were conducted as specified by the Indian Standard Code IS: 2720 (Part 41) – 1977, IS: 2720 (Part 16) – 1987 and IS 2720

(Part 10) - 1991 respectively. Compacted specimens were cured for 96 hours for conducting the soaked CBR test.

2.3 Properties of Soft Soil and GBS

The soft soil and GBS properties were evaluated in accordance with the BIS in laboratory. The soft soil was identified as inorganic fine grained expansive soil with blackish gray in colour. The specific gravity and pH value of soft soil were evaluated as 2.56 and 7.62, respectively. The liquid limit, plastic limit, and plasticity index of the raw soil were found 46%, 29%, and 17%, respectively. The engineering properties of the soft soil are shown in Table 1. As referred to the Indian standard and AASHTO soil classification system, the soil was classified as CI-MI and A-7-5 with 4% group index (GI) respectively. This shows that, raw soil falls below the standards recommended for most of the geotechnical works and would therefore require stabilization. GBS was identified as non-plastic (NP) material and having high specific gravity and pH value as compared to soft soil. These properties are tabulated in Table 2.

Table 1. Properties of soft soil

Soil Characteristics	**Description**
Field Moisture Content	18.50%
Liquid limit	46%
Plastic limit	29%
Plasticity index	17%
Maximum dry density	17.6 kN/m^3
Optimum moisture content	11%
CBR value (soaked)	2.05%
CBR value (unsoaked)	8.14%
Free swelling index	83%
Swelling pressure	41.8 kN/m^2
Specific gravity	2.56
pH value	7.62
Indian Standard Soil Classification	CI-MI
AASTHO Classification	A-7-5 (4)

Table 2. Properties of GBS

GBS Characteristics	**Description**
Field moisture content	3.52%
Maximum dry density	19.8 kN/m^3
Optimum moisture content	9.30%
CBR value (soaked)	4.10%
CBR value (unsoaked)	11.14%
Plastic limit	NP
Specific gravity	2.89
pH value	8.4

2.4 Blended Mix Proportions

GBS used in this study was blended with soft soil in different proportions i.e. 3, 6, 9 and 12% by weight of the soft soil to obtain the optimum amount for stabilization. Physical and strength properties of the blended mix was evaluated in the laboratory and compared with the properties of the soft soil to obtain the optimum amount of GBS.

3. Results and Discussion

3.1 Atterberg's Limits

Atterberg's limits of the blended soil was determined as per IS: 2720 (Part 5) – 1985. Liquid limit and plastic limit both decreases with increasing percentage of GBS which is similar to observation reported by Akinmusuru [1] and Wild et. al. [11]. Variation of plasticity index with various percentage of GBS is shown in fig 1, it was inferred that plasticity index decreases with increasing percentage of GBS.

3.2 Compaction Properties

Compaction properties of the blended mixes were determined in accordance with IS: 2720 (Part 8) – 1983 and variation of MDD and OMC is shown in figs 2 and 3 respectively. From the figs 2 and 3, it is conferred that MDD increased and OMC decreased with increasing percentage of GBS which is consistent with observations reported by Akinmusuru [1]. The increase in the MDD can be attributed to the replacement of soil by the GBS in the mixture which have relatively, higher specific gravity (2.89) compared to that of the soil which is 2.56. The increase in the MDD may also be explained by considering the GBS as filler with higher specific gravity in the soil voids. There was decrease in OMC with increase GBS content. Addition of GBS, decreased the quantity of free silt and clay fraction, hence smaller surface area required less water. This implies less water is needed in order to compact the soil with GBS mixtures [10].

3.3 Swelling Behaviour

Free swelling index and swelling pressure test were conducted in accordance with IS: 2720 (Part 40) – 1977 and IS: 2720 (Part 41) – 1977 respectively on the sample prepared at optimum moisture content. Figs 4 and 5 shows the variation of swelling pressure and free swelling index respectively by addition of varying percentage of GBS, which is similar to observation reported by Higgins et al. (1998) [4] and Wild et al., (1996) [11]. Blended mix of 9% GBS reduces the free swelling index and swelling pressure at about 67 % and 21% respectively from its unstabilized counterpart.

3.4 Unconfined Compressive Strength

This is most useful and adaptable method of evaluating the strength of stabilized soil and effectiveness of stabilization [8]. The UCS tests were conducted on soft soil and blended material in accordance with IS: 2720 (Part 10) – 1991 in remoulded sample at length to diameter ratio 2.0. Variation of UCS with increase in GBS from 0 to 12 % is shown in fig 6, which is similar to observation reported by Neeraja and Rao [7] and Wild et.al [11].

There was a sharp increase in the UCS with addition of GBS when compared with the UCS value of natural soil. The UCS values further increases with addition of GBS to its maximum at between 6 – 9 % GBS, after which it dropped from 9 – 12% GBS. The subsequent increase in the UCS is attributed to the formation of cementitious compounds between the CaOH present in the soil and the pozzolana present in the GBS [10]. The decrease in the UCS values after addition of 9% GBS may be due to the excess GBS introduced to the soil and therefore forming weak bonds between the soil and the cementitious compounds formed [10].

3.5 California Bearing Ratio

CBR value is widely used in the design of base and sub-base material for the pavement as an indicator of compacted soil strength and bearing capacity [14]. It is one of important test to evaluate the optimum amount of stabilizer for stabilizing the soft soils. Soaked and unsoaked both CBR tests were conducted on the soft soil as well as on blended material with various GBS percentages for evaluating the optimum amount of GBS. The soaked CBR tests were conducted on samples compacted at OMC, and soaked for 96 hours in accordance with IS: 2720 (Part 16) – 1987. Variation of the soaked and unsoaked CBR value with GBS mixes is shown in fig 7, which shows similar behaviour as Akinmusuru [1]. It was observed that CBR value increases with addition of GBS up to a certain point, after that it starts decreasing.

For unsoaked samples, CBR value rises rapidly with addition of 3 to 6 % GBS and then decreases continuously upto 12 % GBS. The increment in the CBR can be attributed to the gradual formation of the cementious compounds between the GBS and CaOH contained in the soil [10]. The gradual decrease in the CBR after 6% GBS may be due to excess GBS that was not mobilized in the reaction, which consequently occupies spaces within the sample and therefore reducing bond in the soil-GBS mixes. The trend of the soaked CBR was similar to the unsoaked CBR, only that even after the addition of 6% GBS, CBR kept increasing and rises to peak at 9% GBS. It slightly dropped at 12 % GBS. This trend shows that the presence of water (moisture) helps to further formation of the cementitious compound between the soil's CaOH and the pozzolanic GBS [10].

3.6 Optimum *amount of GBS*

Strength properties i.e. CBR and UCS test results have been used in most of the previous studies [1, 4, and 11] to decide the optimum amount of additive of blended soil. In the present study soaked CBR, which simulates the actual field condition and UCS test results have been used to decide the optimum amount of GBS. It can be inferred from the figs 6 and 7, that soaked CBR value increased from 2.05% of its unstabilized counterpart to maximum value of 11.05% at 9% GBS. Similarly, UCS increased from unstabilized soft soil (116.7 kN/m^2) to 152.7 kN/m^2 and 149.4 kN/m^2 by 6% and 9% addition of GBS respectively. There is not significant decrease in the UCS value from 6% to 9% GBS. Hence, form both CBR and UCS consideration, 9% GBS considered as optimum value as an additive for the soft soil.

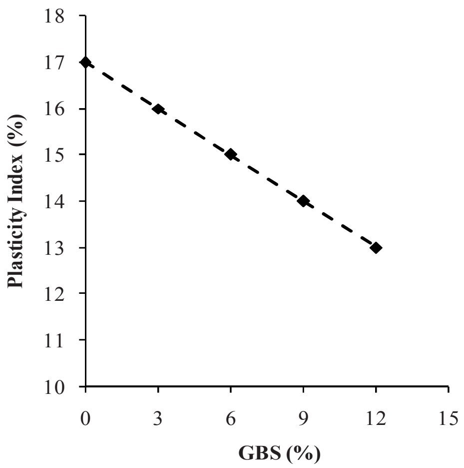

Fig. 1 Plasticity Index of GBS Mixes

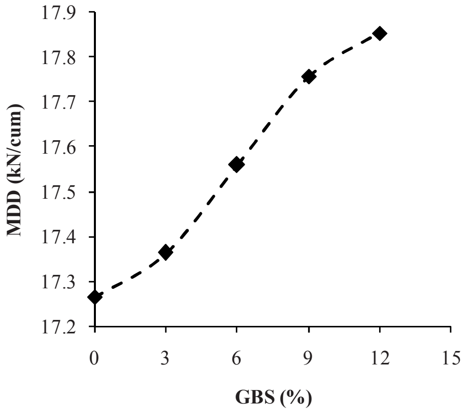

Fig. 2 MDD of GBS Mixes

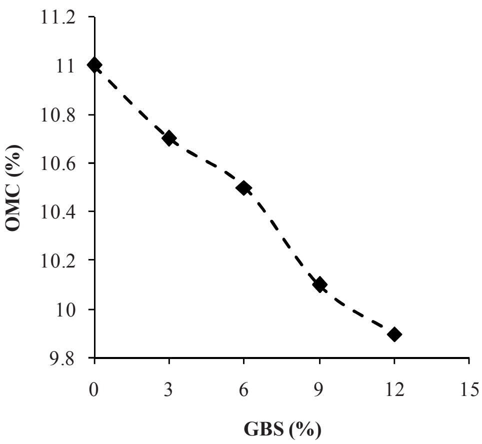

Fig. 3 OMC of GBS Mixes

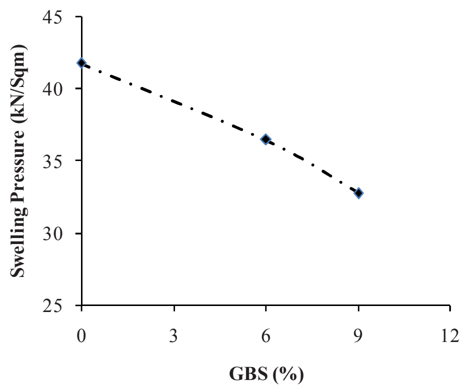

Fig. 4 Swelling Pressure of GBS Mixes

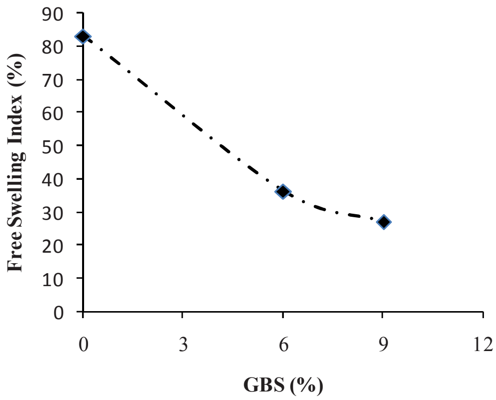

Fig. 5 FSI of GBS Mixes

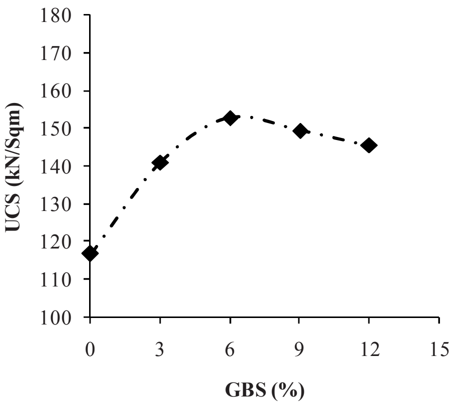

Fig. 6 UCSof GBS Mixes

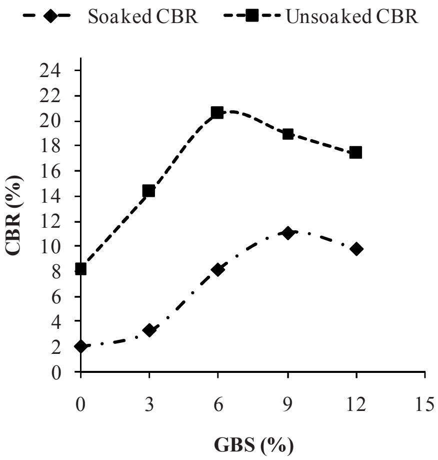

Fig. 7 CBR of GBS Mixes

4. Conclusion

The study has been conducted to assess the potential of GBS to stabilize the soft soil. Selected soft soil for study was identified as CI-MI as per Bureau of Indian Standard Classification System. The soft soil was mixed with various percentages of GBS (i.e., 3, 6, 9, and 12%). The physical and strength properties have been evaluated experimentally on raw and blended soil. The results indicate that the use of GBS significantly improves the physical and strength properties of soil. MDD increased while OMC decreased with addition of GBS to the soft soil. There is significant reduction in the swelling behaviour of the soil. Based on the strength tests, optimum amount of GBS was determined as 9%. Soaked CBR and UCS values increased about 400 % and 28 % respectively by the addition of optimum amount of GBS. Moreover blended mix of 9% GBS reduces the free swelling index and swelling pressure at about 67 % and 21% respectively from its unstabilized counterpart.

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