Experimental investigation on the stabilization of soft clay using granulated blast furnace slag

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Abstract: Soft clay is associated with a soft consistency and poor shear strength. High percentage fines lead to higher liquid limit and lower plasticity index. Low bearing capacity and excessive settlement lead to uneconomic engineering structure constructed over it. There is a serious need to mitigate this problem and hence soil stabilization is the need of the hour. In the present study, Granulated Blast Furnace Slag (GBFS) which is an industrial waste/byproduction of steel industry is used as a stabilizer to improve the geotechnical property of the soft clay. Soft clay is replaced by granulated blast furnace slag in various percentages by weight (10%, 20%, 30%, 40% and 50%) and examined for its plasticity, compaction and strength properties of the mix. From the experimental investigation, it is shown that the plasticity index decreases and unconfined compressive strength (UCS) increases upon addition of slag to the soil. With the curing age, UCS value increased indicating the chemical reaction between free lime and soil. 40% slag replacing the soft clay is recommended as stabilizer as it gave the maximum increase in UCS value compared to the rest mix. Based on the laboratory work, it can be concluded that granulated blast furnace slag can be used as a potential stabilizer for soft clay and also largely solves the problem of disposal of slag.

Keywords: Soft clay, Granulated blast furnace slag, Unconfined Compressive strength.

1. Introduction
Soil/Site Possessing poor engineering properties causing difficulties in construction operations have been discarded/replaced by our ancestors. In the present scenario, due to the rapid industrialization and urbanization especially in a developing country like India, these lands cannot be neglected and hence there is a scope for ground improvement [1]. Soft clays are less sluggish, high plastic, blackish problematic silty clay possessing low shear strength and high compressibility due to the high liquid limit, plastic limit and plasticity index [2]. Constructions over the soft clay may lead to structural instability and failure due to their poor bearing capacity and excessive settlement [3,9]. Physicochemical improvements enhance the strength and workability of claye soils. Also, chemical stabilization with binders such as cement, lime, asphalt, polymers and geopolymers, reinforcement with geosynthetics and short fibers improves the quality of soil but are proven to be costlier [4,12]. From the point of economy and environmental impacts alternative additives need to be used. By-products from industries as a stabilizer for soil, prove to be cheaper and also solve the disposal problem. Granulated blast furnace slag is a by-product generated in the iron and steel industry. This slag contains calcium, magnesium, manganese and aluminium silicates in various combinations [5]. When ground into powder are used in cement manufacturing industries, but the grinding operations are costlier. For the reason, slag is stacked near iron industries thus leading to massive consumption of area [1]. Hence the investigation was undertaken to check the potential usage of granulated blast furnace slag to improve the geotechnical properties of soft clay.
2. Literature review

Soft clays are generally dominated by finer (<75 microns) particles with high liquid limit and plasticity index. They are flocculent in structure with low permeability [10]. Soft soils usually are characterized by excessive settlement and instability of structure posing poor geotechnical properties which make them unsuitable to support any engineering structures [11]. Usage of ordinary Portland cement to marine clay as stabilizer showed a rapid gain in strength and also with age, due to the formation of dicalcium silicate and tricalcium silicate with a primary cementitious product as calcium silicate hydrate [6,8]. Addition of alkaline activated ground granulated blast furnace slag for soft clay has significantly increased the unconfined compressive strength (UCS) compared with the ordinary Portland (OPC) cement stabilized marine clay [2]. Claye soil with the treatment of 6% fine slag showed an improvement in plasticity character and increased in UCS strength of more than twice the strength of untreated soil [13]. Lithomargic clay was replaced by granulated blast furnace slag (GBFS) in various percentage (5% to 45%) which showed a decrease in plasticity index with the increase in slag percentage. With 25% replaced lithomargic clay by GBFS showed increased unconfined compressive strength of 206.9% of untreated soil when tested at 28 days of curing [1,7]. The compressed stabilized earth block using cement and GBFS as a stabilizer to lateritic soil was studied. From this experimental work, they concluded that the block prepared from the mixture of cement (6%), GBFS (20%) and soil (80%) could be used for load bearing wall [7].

3. Materials and methods

Soft clay was taken from Chitrapura, Mangalore, Dakshina Kannada, Karnataka, India located at 12.9581°N, 74.8009°E. By removing the topsoil, Soft clay was taken at a depth of 2m from the ground level. The same soil was transported to the laboratory. The soil was then dried, sieved and stored in the container. For the establishment of physical and geotechnical properties, the soil was subjected to various investigations. Granulated blast furnace slag (GBFS) was procured from Kirloskar Ferrous Industries Limited, Koppal, Karnataka, India, located at 15.335547° N, 76.278816° E. Soft clay was replaced by GBFS by weight in various percentages (10%, 20%, 30%, 40% and 50%). Soil and GBFS was examined for various geotechnical properties. The tests include liquid limit, plastic limit, shrinkage limit, compaction test and unconfined compression test. All the tests conducted are according to IS code.

4. Results and discussion

The initial characterization of soil and granulated blast furnace slag (GBFS) was done and the results are presented in table 1. Particle size distribution curve of soft clay and GBFS is shown in Figure 1.

| Sl. No | Property            | Results   |
|--------|---------------------|-----------|
| 1      | Specific gravity    | 2.6       |
| 2      | Sand size (%)       | 31        |
| 3      | Silt size (%)       | 33        |
| 4      | Clay size (%)       | 36        |
| 5      | Liquid limit (%)    | 91        |
| 6      | Plastic limit (%)   | 33        |
| 7      | Shrinkage limit (%) | 20        |
| 8      | Plasticity index (%)| 58        |
| 9      | IS soil classification | CH  |
Figure 1. Particle size distribution curve for soft clay and GBFS.

The summary of the laboratory results conducted on the stabilized soft clay and GBFS mix are tabulated and summarized in table 2.

**Table 2. Atterberg limits and specific gravity of soft clay and GGBS mixture.**

| % GBFS Replacing soft clay | liquid limit | plastic limit | Shrinkage limit | Plasticity index ($I_P$) | Specific gravity (G) |
|---------------------------|--------------|---------------|-----------------|-------------------------|---------------------|
| 0                         | 91           | 33            | 20              | 58                      | 2.6                 |
| 10                        | 79           | 34            | 21              | 45                      | 2.56                |
| 20                        | 72           | 36            | 23              | 36                      | 2.54                |
| 30                        | 67           | 39            | 25              | 28                      | 2.50                |
| 40                        | 63           | 39            | 28              | 24                      | 2.47                |
| 50                        | 61           | 41            | 32              | 20                      | 2.43                |

From table 2 it can be noticed that there is a decrease in both liquid limit and plastic limit with the increased percentage of GBFS replacing the soft clay. From Figure 3 it is noticed that plasticity index decreases with the addition of slag to soft clay which proves that the soil is improved after addition. The possible reason behind the reduction in plasticity index ($I_P$) is due to the incorporation of coarser material (GBFS) which decreases the specific surface area and thus decrease in $I_P$. The decrease in Specific gravity of mix is due to the addition of lower specific gravity of GBFS compared to the soft clay.

**Table 3. Compaction characteristics of soft clay and GBFS mixture.**

| % GBFS Replacing soft clay | MDD (kN/m$^3$) | OMC (%) |
|---------------------------|----------------|---------|
| 0                         | 13.6           | 27      |
| 10                        | 14.4           | 24.6    |
| 20                        | 14.7           | 24      |
| 30                        | 14.9           | 22.6    |
| 40                        | 15.0           | 22.2    |
| 50                        | 14.9           | 21.8    |

Compaction characteristics of soft clay with and without GBFS addition are shown in table 3. Figure 3 indicates that the maximum dry density increases till 40% replacement of soft clay by GBFS and beyond this maximum dry density decreases. Optimum moisture content decreases with the increased addition of GBFS which is due to the increased percentage of coarser particles in the mix.
From table 4 with the incorporation of GBFS a marginal improvement in unconfined compressive strength is observed when tested immediately after casting. With the higher curing age, the strength (UCS) considerably increased for all percentage addition when compared to the strength of untreated soil. This gain is due to the reaction between soil and free lime in slag and thus formation of CSH gel. However, 40% replacement gave maximum UCS strength with age of curing (7, 14, 28 days) compared to untreated soil and other stabilized mixture. Graphical representation of a variation of UCS value with curing period for various combinations of soft clay and GBFS is shown in figure 4. The higher percentage (50%) replacement gave lower UCS value compared with the previously replaced percentage (40%) at all age of curing. It is due to increased coarser particles thus decreased the percentage of fines which are responsible for binding the particles and also due to lack of confinement.

| % GBFS Replacing soft clay | UCS (kPa) with duration of Curing |
|---------------------------|---------------------------------|
|                           | 0 day  | 3 day  | 7 day  | 14 day | 28 day |
| 0                         | 98     | 98     | 98     | 98     | 98     |
| 10                        | 117    | 150    | 219    | 271    | 282    |
| 20                        | 125    | 167    | 267    | 422    | 470    |
| 30                        | 147    | 259    | 335    | 452    | 514    |
| 40                        | 132    | 197    | 377    | 529    | 585    |
| 50                        | 132    | 140    | 316    | 502    | 518    |

Figure 2. Variation of plasticity index with percentage GBFS replacing soft clay. Figure 3. Variation of MDD and OMC with percentage GBFS replacing soft clay.

Figure 4. Variation of UCS value of soft clay and GBFS mixture with curing period.
5. Conclusion
Investigation on stabilization of soft clay by granulated blast furnace slag (GBFS) addition was attempted. From the results obtained of the laboratory tests, the following conclusions are drawn.

- With the increased percentage of GBFS replacing, Plasticity index mixture decreases.
- OMC decreases with increasing addition of GBFS. MDD increases till 40% replacement, beyond which MDD declined.
- With the addition of GBFS to soft clay, significant improvement in unconfined compressive strength is observed. 40% GBFS replacing soft clay showed maximum UCS value compared to other stabilized mixture with higher curing age.

References

[1] Sekhar, D.C., Nayak, S. and Preetham, H.K., 2017. Influence of Granulated Blast Furnace Slag and Cement on the Strength Properties of Lithomargic Clay. Indian Geotechnical Journal. 47(3) 384-392.

[2] Yi, Y., Li, C. and Liu, S., 2014. Alkali-activated ground-granulated blast furnace slag for stabilization of marine soft clay. J. Mater. Civ. Eng. 27(4) 04014146.

[3] Mirzababaei, M., Arulrajah, A., Horpibulsuk, S., Soltani, A. and Khayat, N., 2018. Stabilization of soft clay using short fibers and poly vinyl alcohol. Geotext. Geomembr.46(5) 646-655.

[4] Kavak, A. and Tüylüce, F., 2012. Treatment of Marine Clay with Hydrated Lime and Quicklime. Lime: Building on the 100-Year Legacy of The ASTM Committee C07. ASTM International.

[5] C Sekhar, D. and Nayak, S., 2017. SEM and XRD investigations on lithomargic clay stabilized using granulated blast furnace slag and cement. Int. J. Geotech. Eng. 1-15.

[6] Xiao, H., Shen, W. and Lee, F.H., 2017. Engineering properties of marine clay admixed with Portland cement and blended cement with siliceous fly ash. J. Mater. Civ. Eng. 29(10) 04017177

[7] Sekhar, D.C. and Nayak, S., 2018. Utilization of granulated blast furnace slag and cement in the manufacture of compressed stabilized earth blocks. Constr. Build. Mater. 166 531-536.

[8] Nguyen, T.T.M., Rabbanifar, S., Brake, N.A., Qian, Q., Kibodeaux, K., Crochet, H.E., Oruji, S., Whitt, R., Farrow, J., Belaire, B. and Bernazzani, P., 2018. Stabilization of Silty Clayey Dredged Material. J. Mater. Civ. Eng. 30(9) 04018199.

[9] Shen, Z., Cao, Y. and Fang, L., 2017. Experimental Investigation of Rapid Stabilization of Soft Clay Soils Using Chemical Admixtures. Soil Mech. Found. Eng. 54(3) 202-210.

[10] Jose, B.T., Sridharan, A. and Abraham, B.M., 1988. A study of geotechnical properties of Cochin marine clays. Marine Georesources & Geotechnology. 7(3) 189-209.
[11] Al-Bared, M.A.M. and Marto, A., 2017. A review on the geotechnical and engineering characteristics of marine clay and the modern methods of improvements. Malaysian Journal of Fundamental and Applied Sciences. 13(4) 825-831.

[12] Shahin, M.A. and Hong, L.S., 2010. Utilization of shredded rubber tires for cement-stabilized soft clays. In Ground Improvement and Geosynthetics 181-186.

[13] Shukla, R.P. and Parihar, N.S., 2016. Stabilization of Black Cotton Soil Using Micro-fine Slag. J. Inst. Eng. (India) 97(3)299-306.